The Woods Hole
Research Center

Final Report to
The William and Flora Hewlett Foundation
From The Woods Hole Research Center

Phase I of a Project on

"Linking Climate Policy with Development Strategy in Brazil, China, and India"

November 15, 2007

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OVERVIEW AND FINDINGS

Introduction

In late October 2005, The William and Flora Hewlett Foundation awarded the Woods Hole Research Center a grant to identify, analyze, and promote technical options and associated policies to reduce greenhouse-gas emissions in major emerging economies (hence contribute to mitigating global climate change) while simultaneously advancing other dimensions of sustainable development (such as improving access to basis services while lowering costs, reducing conventional pollution, improving health, and increasing rural employment). An initial focus on four countries -- Brazil, China, India, and Mexico -- was reduced to a focus on the first three of these after it was agreed, early in the effort, that other organizations being funded for this purpose by the Hewlett Foundation would take on the case of Mexico.

The overarching aims of the project, of which the work of the Center and its collaborators over the period from October 2005 to the present has constituted Phase I, are:

1. To work with experts and decision makers in each study country to identify and analyze the greenhouse-gas-reduction measures available to the country that would advance important development interests in addition to climate-change mitigation.

2. To explore and discuss, with experts and decision makers in each country, approaches for generating the country's deeper engagement in discussions of the options for making commitments to address climate change during international negotiations in ways that promote the country's wider development interests.

3. To assist experts and decision makers in each country in understanding and conveying to the international community what their country has already been doing and will be able to do in the future to address its greenhouse-gas emissions.

4. To promote, through progress on aims 1-3, thinking by the political leaders of each country about how their country could advance its broad national interests by exercising leadership in the next round of international climate negotiations.

5. To deepen understanding among political leaders and experts about the differences and similarities in the situations and perspectives -- and the common challenges and interests – among the three study countries.

The role of the Center in pursuit of these aims has been to serve as a facilitator, coordinator, prime contractor, and synthesizer of work performed by teams largely based in the three study countries, to foster communication among all of the participants in pursuit of cross-cutting insights, and to work with the country teams in communicating their findings to decision makers and the wider interested communities in the three countries and internationally, including particularly at the annual Conferences of the Parties of the UN Framework Convention on Climate Change. Long the beneficiary of wide and deep ties with relevant experts and decision makers in Brazil through an Amazon program led at the Center by Dan Nepstad, and benefiting as well from the extensive connections of WHRC Director John P. Holdren and Visiting Senior Scientist Kirk R. Smith in China and India, the Center also subcontracted with the Energy Technology Innovation Policy Project at Harvard's Kennedy School of Government, directed by Kelly Gallagher, to exploit the additional China and India expertise and connections of that group. Joan Diamond has served as Project Coordinator at the Woods Hole Research Center. Kilaparti Ramakrishna served as the Principal Investigator at the Woods Hole Research in the initial months of the project, before taking a leave of absence to serve as the Policy Advisor to the head of the UN Environment Programme in Nairobi.

The lead collaborating organization in Brazil has been the Institute for Amazonian Environmental Research (Instituto de Pesquisa Ambiental da Amazonia – IPAM), where the work has been led by Paulo Moutinho and the principal focus has been the costs, returns, and co- benefits of reducing greenhouse-gas emissions by reducing deforestation rates. In China the lead collaborating organization is the Institute of Environmental Economics at Renmin University; the work there has been led by the Institute's Director, ZOU Ji, and the primary focuses have been on the economics of "win-win" approaches to climate mitigation (with additional collaborators at Renmin University), advanced coal technologies (in collaboration with the Institute of Engineering Thermophysics of the Chinese Academy of Sciences), and clean and efficient vehicle technologies (in collaboration with the Chinese Automotive Technology and Research Center). In India the lead collaborating organization has been the Energy Systems Department of the Indian Institute of Technology - Bombay; that effort has been led by Prof Rangan Banerjee and the main focuses have been advanced coal technologies, improving efficiencies in electricity transmission and distribution and end use, and improved biomass technologies (supported by additional collaborators at The Energy and Resources Institute - Delhi, the Indian Institute of Management - Ahmedabad, and the Indian Institute of Science - Bangalore). Ambuj Sagar played a special role integrating the India efforts across the Woods Hole Research Center, Harvard, and the Indian institutions.

There is also a Focus-Country Steering Committee, consisting of ZOU Ji (who in addition to his roles at Renmin University is a member of the Chinese delegation to the Conferences of the Parties of the UN Framework Convention on Climate Change); Ajay Mathur (Director-General of the Bureau of Energy Efficiency in the Indian Ministry of Power and member of the Indian delegation to the UNFCCC COP), and Jose Goldemberg (former Environment Minister of the State of Sao Paulo, former Federal Minister of Science and Technology, and former Federal Minister of Education). A more complete list of advisors, authors, researchers, and workshop participants is provided as an Annex .

In the remainder of this Overview, we summarize the activities undertaken in Phase I of the project, highlight some key findings from the Country Synthesis Reports, and address some important cross-cutting questions relevant to an anticipated Phase II of the work. The rest of the package comprises those syntheses, additional topical reports from the country teams, and an extensive annotated bibliography. Because of the complexities of working with a total of ten subcontracts in three foreign countries for this project, we have not been able to complete a final financial report in time for this submission; it will follow shortly.

Synopsis of Phase I Activities

The first few months of the effort were devoted to meetings with leading analysts and decision makers in the focus countries in order to solicit their interest and ideas and to lay the groundwork for forming the country teams and Focus-Country Steering Committee. The departure of the original WHRC Principal Investigator for UNEP in February 2006 then precipitated the formation of a new leadership team at the Center and a process of review and refinement of the workplan for the effort, in consultation with the architects and overseers of the wider project on climate strategy and development at the Hewlett Foundation -- Environment Program Director Hal Harvey and Program Office Joseph Ryan -- and with the leaders of a parallel Hewlett-funded effort at the Center for Clean Air Policy that had started some months earlier.

In this period of spring into summer of 2006 the work was focused on the actual recruitment of collaborating institutions and lead researchers in the focus countries, the refinement of the list of research topics to be pursued in common across the country studies, and the negotiation of corresponding terms of reference and subcontracts for the collaborators. The template for the common workplan for the country teams worked out in this period was as follows:

a. compilation of the relevant demographic, economic, and emissions data for each country;

b. identification and characterization of the priority development objectives that have been defined for each country by its political and economic leadership;

c. development of an inventory of climate-change-mitigation initiatives already underway in or being planned by each country;

d. analysis of the interactions (positive and negative) of the measures identified in part c with the development objectives identified in part b;

e. screening of the larger universe of climate-change-mitigation measures for those that would yield net benefits (positive impacts minus negative impacts) for the priority development objectives identified in part b for the particular country;

f. choose one or more measures or sets of measures for review in in-depth case studies of costs versus benefits, with the criteria for choice being the potential importance of the measures in terms of both greenhouse-gas emissions and interaction with other development goals;

g. completion of the chosen in-depth case studies;

h. discussion and refinement of the findings from the preceding steps for each country at in-country workshops engaging the country teams and their in-country consultants, relevant members of the WHRC team, and selected decision makers and opinion leaders.

Additional workplan elements to be carried out by the WHRC-led project as a whole were to:

i. hold a joint meeting of the project participants to compare, discuss, and refine the findings across the study countries; and

j. propagate agreed findings widely among decision-makers and analysts in the study countries, as well as at the Conferences of the Parties to the UN Framework Convention on Climate Change.

In the course of the period in early to mid 2006 when the workplan was being refined and the country participants recruited, two decisions that somewhat narrowed the scope of the effort were reached by the WHRC and Hewlett Foundation project leadership jointly. The first was to drop Mexico from the list of focus countries for the WHRC effort, in light of the advanced state of the similar effort in Mexico being carried out with Hewlett support by the Center for Clean Air Policy in collaboration with the Mario Molina Center for Energy and the Environment in Mexico City. The second was to confine the focus of the Brazil component of the WHRC-led effort to a case study of the costs and benefits, in the climate-change and development contexts, of approaches to reducing carbon emissions from deforestation and forest degradation in the Brazilian Amazon. This narrowing of the WHRC Brazil effort -- amounting to skipping steps (a)-(e) in the common workplan outlined above -- was motivated by the obviousness of the choice of the deforestation case study (given that 70% of Brazil's greenhouse-gas emissions are from the forests/land-use sector, versus 30% from the energy sector), as well as by the fact that work largely encompassing steps (a)-(e) for Brazil's energy sector was already being performed by the Hewlett-funded project at the Center for Clean Air Policy and its Brazilian partners.

The work of the three country teams and the WHRC-Harvard coordinating team in the rest of 2006 through the COP/MOP meetings in Nairobi in mid-November was described in our Interim Report to the Foundation of 15 December 2006. The efforts in this period included much progress on workplan elements (a)-(f) in China and India, leading to choices of case-study focuses on clean coal and clean vehicles for China and on clean coal, efficiency in the electricity sector, and biomass technologies for India. The work in Brazil pushed ahead with the team's energetic and highly innovative case study on Amazon deforestation/degradation, incorporating sophisticated modeling studies, the development of policy proposals for advancing the critically important concept of compensation for avoided deforestation, and the engagement of key stakeholders and decision makers (up to and including the Environment Minister and the President of Brazil) all along the way.

As related in our 15 December 2006 report, these activities put us in a position to have a considerable impact at the Nairobi COP/MOP meetings in November. The WHRC side event introducing the whole effort -- addressed by Holdren, Nepstad, Moutinho, Zou, and Sagar -- played to a standing-room-only crowd that included the head of the IPCC and the Deputy Director of the Climate Office in China's National Development and Reform Commission. Another side event organized jointly by WHRC, IPAM, and Environmental Defense focused on the rapidly advancing case study on avoiding deforestation in the Amazon; it was addressed by Nepstad, Moutinho, Holdren, Annie Petsonk of Environmental Defense, and the Environment Minister of Brazil, drawing a large crowd that included many analysts and decision makers from other tropical countries. Holdren's presentation on the overall project to a Minister's Breakfast organized with the Center for Clean Air Policy and the UK's Department of Food, Environment, and Rural Affairs reached a further group of high-level officials and climate negotiators from a wide variety of countries. Finally, a WHRC reception and dinner again attracted the head of the IPCC and a number of decision-makers and opinion leaders, with Brazil and the United States most heavily represented.

The year that has elapsed since the Nairobi meetings has been a time of intensive effort by all three country teams, with corresponding progress on all of the case studies (reflected in the individual reports that follow this overview) and a good beginning on jointly mining the findings and experience of the three groups for cross-cutting and transferable insights. The progress made by each country team was achieved with the help of a number of in-country workshops, in this last year and earlier, as anticipated in item (h) of the workplan. These included meetings of the India team in Mumbai on August 2006 and June 2007; meetings of members of the WHRC-Harvard group with the Chinese clean-vehicle team in Beijing in May 2006 and with the Chinese clean-coal team in May 2007; and numerous meetings of the WHRC-IPAM Brazil team members (in Falmouth, Belem, and Brasilia). WHRC and Harvard team members also met separately with the leaders of the country teams on many occasions and in many venues (including Brasilia, Beijing, Mumbai, and Nairobi).

The joint meeting of project participants anticipated in item (i) of the workplan was hosted by Rangan Banerjee at the Indian Institute of Technology - Bombay on October 12-13 of this year. The workshop was attended by the leaders of all of the country teams (Moutinho for Brazil, Zou for China, Banerjee for India); by Holdren, Diamond, Smith, and Nepstad from the Woods Hole Research Center; by Sagar from Harvard (but now in the process of moving to the Indian Institute of Technology - Delhi to lead a new energy-environment program there); by Program Officer Joe Ryan from the Hewlett Foundation; and by India team members from around the country. Indian Steering Committee Member Ajay Mathur took part by phone hook-up, as did Harvard-China participant Hongyan He Oliver. The workshop was considered highly successful by the participants; the exchange of insights among countries exceeded expectations, and the planning that took place there for completion of the Phase I report was indispensable. The agenda for the workshop and PDFs of essentially all of the presentations are available at http://www.me.iitb.ac.in/~rangan/Hewlett/hewlett.htm

Our project is now poised to make a substantial impact on the annual Conference of the Parties to the UN Framework Convention on Climate Change – upcoming in Bali in December – for the second year running. There will be three separate side events linked in various ways to the Hewlett project: one by WHRC, one by IPAM, and one by Environmental Defense with WHRC and IPAM participation. There will also again be a WHRC reception and dinner. We expect the new findings of the Amazon deforestation case study (reported in detail below) to make a particularly big splash. (These findings are also being submitted in the form of an article for SCIENCE in the next few weeks, although review and publication delays are such that, if accepted, it would not appear until early in the new year.) It is worth noting, as well, that the Indian and Chinese members of our project's Steering Committee (Ajay Mathur and Zou Ji) are both members of their countries' official negotiating teams for the Bali COP (as Zou Ji also was in Nairobi), providing an extraordinary channel for our findings into the negotiating process itself.

Some Key Findings from the Country Studies

What follow are merely appetizers to entice the reader into the main courses offered in the country synthesis reports and project reports that follow in this package.

Brazil

Our study indicates that carbon emissions from tropical deforestation and forest degradation in Brazil (the largest or second largest source of such emissions in the world, depending on year) could be reduced to close to zero over a 10-yr time horizon at a cost between \$100 million and \$600 million per year. This result suggests that the cost of reductions in emissions from deforestation and forest degradation (REDD) is much lower than previously estimated using global partial equilibrium economic models. In Brazil, it appears to be feasible to achieve this reduction for a cost that is lower than the opportunity cost of forgone profits from deforestation-dependent agriculture and ranching, since most deforestation leads to cattle ranching of very low profit levels. This is particularly satisfying because Brazil benefits in a number of ways from these reductions in emissions, including through increased income and improvements in livelihoods of indigenous and traditional forest people, greater security for the rainfall system of the Brazilian grain belt and hydroelectric network, and \$10 to 80 million per year of diminished fire-related damages to health, agriculture, and forestry.

China

Coal will continue to be the dominant source of electricity in China for many decades to come. Our study's analysis of three scenarios for future coal-fired electricity generation in China -- Business as Usual, Advanced Technology (emphasizing ultra-super-critical power-plant technology), and Very Advanced Technology (emphasizing carbon capture and sequestration) -- shows that the Very Advanced Technology scenario, while offering by far the largest greenhouse-gas emissions reductions, is prohibitively costly under current circumstances and will not materialize absent drastic changes in economics and/or policy. The more likely path is the one modeled here by the Advanced Technology scenario, which entails accelerating the diffusion of ultra-super-critical coal technology, promoting commercialization of fluidized bed and integrated gasification combined cycle technologies, and significantly increasing R&D on carbon capture and sequestration. Achieving even this much will entail significant strengthening of relevant policies, and still it will be not enough to reduce absolute greenhouse-gas emissions in the face of the overall expected electricity growth.

China's passenger vehicle sector likewise presents enormous challenges in relation to reducing greenhouse-gas emissions. While the number of such vehicles in China grew at a rate of only about 1 million per year between 1990 and 2000, the rate of increase was over 3 million per year between 2000 and 2005. Length of highways is increasing in China far faster than the length of railways, which are much more fuel efficient, and the average fuel-efficiency of the current Chinese fleet is lower than that in OECD countries, vehicle type by vehicle type. Scenarios explored in this study show that full implementation of the passenger-vehicle fuel-economy standards currently projected for China will lead to some reduction in CO_2 emissions compared to "business as usual", but the absolute increase would still more than a doubling by 2020. Larger reductions would require much stronger measures. These would have a variety of co-benefits (e.g., in reduced conventional pollution and reduced oil imports, compared to business as usual), but many barriers experienced and perceived by a variety of stakeholders will need to be overcome for such measures to be realized.

India

India's greenhouse-gas emissions could be reduced by as much as 520 million tonnes per year of carbon-dioxide-equivalent year (Mt/yr CO_2-eq) by 2025 through vigorous pursuit of improvements in coal-power-generation efficiency through the deployment of advanced generation technology; reductions in the large losses currently sustained during transmission and distribution; and electricity-saving programs in the three end-use sectors examined in our study (agricultural pumping, lighting, and solar water heating). Rapid deployment of current biomass gasifier technologies for small industries and power generation, together with enhanced and large-scale development and deployment of newly developed but not yet widely used advanced biomass-cooking technologies, could reduce greenhouse-gas emissions by about 120 Mt/yr CO_2-eq, based on fossil fuel substitution, which is a realistic comparison given trends in the Indian energy picture. This potential has not been widely recognized in the climate-change literature.

The total potential of about 640 Mt/yr CO_2-eq in these two categories is about 18% of India's projected annual emissions in 2025.

Significant development benefits in terms of local and national energy security, rural employment, women's and children's health, and general environmental quality can also be achieved with these measures, above all in the biomass sector where the link between GHG emissions and damage from current inefficient usage is strongest. Improvements in performance in the power sector, particularly to reduce losses and enhance billing through better management of transmission and distribution, will not only save money and reduce GHG emissions but will help bring the state power utilities into sustainable operation, a major development benefit.

There are a number of barriers to the deployment of these technologies, however. This is particularly important in the cases of technologies that need to be deployed at the household level, where there it is not possible to rely completely on commercial dissemination because of low incomes and high effective discount rates. Deployment strategies, to be successful, must be carefully designed to overcome these barriers, including development of new approaches. International cooperation could be helpful by facilitating the availability of the relevant technologies, for assisting in program design (especially drawing on lessons from past experiences), and for building the appropriate technical and programmatic capacity.

Cross-Cutting Issues and Phase II of the Work

Analyses of the costs and benefits of climate-change mitigation measures is inherently a complicated matter, made more so by the desirability of including benefits not easily translated into monetary terms and by inconsistencies and ambiguities in the terminology and methods employed by different analysts in addressing these issues. Project participant Kirk

R. Smith (who was splitting his time, during much of Phase I, between WHRC and his faculty position in the School of Public Health at UC Berkeley) has been deeply involved in trying to systematize the evaluation of co-benefits in the context of the climate-change problem; he summarized some of his insights on the matter, using examples for the India case, in a presentation to our Mumbai workshop in October (posted at http://www.me.iitb.ac.in/~rangan/Hewlett/hewlett.htm), and, using examples from China, in a presentation to the Institute for Global Environmental Strategies Scoping Consultation on the Developmental Co-Benefits of Climate Policies in Asia held in Bangkok in August. (The latter presentation is provided as part of the materials accompanying this report.) With co-author Evan Haigler he offers a more extensively documented inquiry into the methodological aspects of climate-mitigation co-benefits considerations in an article to appear in the 2008 issue of *Annual Review of Public Health* (the manuscript of which is also provided in the accompanying materials). A large chapter on "Mitigation from a Cross-Sectoral Perspective" in the report of Working Group III for the Fourth Assessment of the IPCC (http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter11.pdf) also addresses these issues extensively.

Prof. Smith proposed, at our Mumbai workshop, that following the IPCC our Hewlett-funded project should consistently use "win-win measures" in the climate-mitigation context to mean those that both reduce greenhouse-gas emissions and are economically attractive using standard financial analysis, while the term "measures with co-benefits" should be used to mean those that reduce greenhouse-gas emissions while achieving other societal goals (e.g., improvements in public health, advances in rural development, reductions in conventional pollutants). This proposal was accepted, with the understanding that particular care must be taken in use of the "win-win" terminology because what qualifies as win-win under this definition (or any other we can think of) depends on such variable conditions as the price of the energy forms whose use a potentially win-win measure might reduce and the penalty, if any, being imposed on emissions of greenhouse gases. What is not a win-win measure today in a country with no price on CO2 emissions could easily be win-win tomorrow when emissions permits are required and cost $20 per tonne.

Smith proposed further that the definition and valuation of co-benefits in our work should use, at least for the first cuts, the methods and metrics that have been established for these purposes by the major international collaborative assessments, such as the IPCC, the Millennium Development Goals project of the United Nations, the 2001 Commission on Macroeconomics and Health (whose recommendations have been adopted by the World Health Organization and the World Bank, and the 2004 World Health Organization Comparative Risk Assessment). These methods and metrics, he pointed out, "represent at consensus of world expert opinion on how best to navigate through the complexity of such analyses" (Smith Mumbai presentation -- see above). He suggested that, in our project, we might wish to undertake elaborations of the "base-case" analyses using the internationally certified methods and metrics, based on particular needs or local conditions, but that such departures should be clearly identified and should be restricted to use of methods documented in peer-reviewed, published literature. These suggestions, too, were endorsed by the participants in the Mumbai workshop, with the understanding that bringing the co-benefits analyses of the different country teams to the indicated levels of sophistication and cross-country comparability would be a task of such magnitude as to have to await an anticipated Phase II of the work.

Two sets of cross-cutting questions / research focuses that were developed at different stages of the Phase I effort are helpful now as we assess how far we have come in this work and how far we still have to go. The first set was developed for our original proposal, and after modest changes arrived at during refinement of the workplan in early 2006 ended up as follows:

Q1. How can the possibilities for advancing climate-change-mitigation approaches that simultaneously facilitate the non-climate development objectives of each country most effectively be pursued?

Q2. What role can appropriate technologies play in achieving development priorities while reducing greenhouse-gas emissions?

Q3. What are the main barriers to the implementation of policies to help each country "leapfrog" to low-GHG emitting technologies that also meet other development priorities?

Q4. How can the study countries cost-effectively collaborate with others internationally on research, development, demonstration, and accelerated deployment of greenhouse-gas-reducing technologies that also meet other development priorities?

Q5. How can equity concerns of developing countries be protected if they participate actively in the post-Kyoto process and agree to limit the growth of greenhouse gas emissions?

A distinct, albeit overlapping formulation of the aims of the effort resulted from interactions between the WHRC team and the architects/overseers of the project at the Hewlett Foundation, emerging in mid-2007 as a set of ingredients it was hoped each country study would ultimately contain. These were:

1. Identification and elaboration of the key technologies, industries, and sectors offering the most promising win-win and co-benefit opportunities

2. Estimation of potential savings in terms specific opportunities, compared to accepted baseline scenarios, to the extent possible.

3. Assessment of the barriers (technological, economic/financial, infrastructural, political) to achieving these savings.

4. Identification of the elements of a strategy for overcoming those barriers (needed programmatic and policy elements).

(The Brazil team in the WHRC-led effort was exempted from much of item 1, however, by virtue of the pre-selection of the Amazon deforestation issue as its focus and the relegation of the assessment of other mitigation opportunities in Brazil to the Hewlett-funded effort being led by the Center for Clean Air Policy.)

A careful reading of the country reports that follow here will reveal much content germane to questions Q1-Q3 and aims 1-2, variable amounts of content germane to aims 3-4, and rather little germane to questions Q4-Q5. It would be wonderful to be able to offer here a more systematic, comparative synopsis of the extent to which the different country studies have answered each question and achieved each aim, and more wonderful still to pursue an iterative and interactive process designed to fill the principal gaps that such a synopsis would reveal. Alas, the timing of the Mumbai workshop and of the production of the various country reports did not allow for even the first of these desiderata to be achieved within Phase I, never mind the second one. (Clearly, the process of organizing and carrying out as complex a multi-country effort as the one in which we have been engaged was considerably more demanding and time consuming than the original workplan and timetable envisioned.) Some of the translation of the findings of the country reports into frameworks, tables, and charts that help with summary and comparison will go on in the period remaining before our presentations at the Bali COP meeting in December. But the effort that will be needed to extract all the value potentially to be had from "mining" these studies is larger, and that needed to fill the gaps that systematic comparison of the studies against the above lists of questions and aims will reveal is larger still. Those efforts will need to await the anticipated Phase II of the effort, where they would be carried out in parallel with the systematization of the approaches to win-win and co-benefits issues discussed above.

Phase II would contain two other major ingredients. The first of these would be a continuing interactive effort involving the country teams and the WHRC-Harvard participants in order to draw out the insights from these studies that are transferable across countries, including to countries not initially studied as part of this project. The second would be an expansion of the efforts already underway to communicate the findings to the wider analytical and policy communities within the study countries and internationally. There is much material in the work already completed that is worthy of being propagated in this way, so expansion of the communication effort need not and should not await completion of the additional analytical work envisioned for Phase II.

A proposal to the Hewlett Foundation with workplan, timetable, and budgets for Phase II will be forthcoming.

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Appendix

Brazil

The costs and benefits of reducing carbon emissions from the Brazilian Amazon region

Daniel C. Nepstad, Paulo R. S. Moutinho, Britaldo Soares, Frank Merry, Maria Bowman, Stephen Schwartzman, Oriana Almeida, Sergio Rivero

Woods Hole Research Center
Hewlett Report

Executive Summary:

A. Brazil has one of the world's cleanest energy sectors, with 40% of total energy consumption supplied by renewable sources. But Brazil also has the world's highest rate of tropical deforestation and forest degradation, which represents 70% of this nation's total greenhouse gas emissions. Most of these emissions take place through the expansion of livestock and agriculture in the Amazon region, with forest fires contributing further emissions. Brazil is a prime candidate for compensation of nation-wide reductions of greenhouse gas emissions from tropical deforestation and forest degradation (REDD). This important new carbon credit regime is under negotiation for the post-2012 period of the UN Framework Convention on Climate Change (UNFCCC) and would compensate tropical countries for demonstrated reductions in emissions below an historical or adjusted historical baseline.

B. We estimated the annual and 30-year costs of reducing carbon emissions from deforestation and forest degradation in the Brazilian Amazon to close to zero over a ten year period. We also conducted an initial assessment of the benefits to Brazilian society of these reductions. We do not analyze the institutional and financial innovations that would be necessary to implement this very large new carbon credit regime. Rather, our aim is to provide a conceptual framework for approaching REDD programs, and initial calculations of how much a viable REDD program might cost.

C. We use three general categories of compensation for the Brazilian Amazon that could be applied in other countries: (a) a Public Forest Stewardship Fund, (b) a Private Forest Stewardship Fund, and (c) a Government Fund. In the scenario presented here, the eventual allocation of the 3.2 million square kilometers of forest remaining in the region would be: 40% "Social" Reserves; 30% "Biological/Ecological" and "Production" Reserves; and 30% private land reserves.

D. REDD programs should begin with an estimate of the opportunity costs of maintaining forests on lands that would provide higher rents under agricultural or livestock production than under timber production. This estimate provides an outer bound to the total cost of REDD for that country, since opportunity costs of forgone profits from agriculture or livestock production do not reflect the in-country non-market benefits of forest conservation, including protection of regional rainfall systems, water quality protection, and biological conservation.

E. We estimate the opportunity costs of reducing deforestation in the Brazilian Amazon to approximately 1,000 km2 per year (from a current baseline of 20,000 km2 per yer) for a 30-year period using spatially-explicit models of potential rents from soy, cattle and timber production. For each forested pixel, rents for each competing land use (soy, cattle, timber) are summed for 30 years assuming a 5% discount rate and a pre-determined schedule of highway paving. Opportunity costs are registered when deforestation-dependent rents (soy, pasture) are higher than forest-dependent rents (sustained timber production). The average opportunity cost of forest protection for 94% of Brazilian Amazon forestlands is US$3 per ton of carbon. In present day dollars, it would cost Brazil approximately US$140 billion to *fully* compensate the opportunity costs of conserving 94% of the Brazilian Amazon forests, containing 46 billion tons of carbon. The real costs to Brazil are considerably lower because of the substantial non-monetized benefits of forest conservation realized nationally. Within a REDD program, Brazil would be compensated for its opportunity costs over the period during which the emissions would have occurred: 70 to 80 years.

F. Indigenous groups, rubber tappers, and other forest-based populations defend public forests—or could potentially become forest defenders—but have rarely received compensation to do so. They control 26% of the forests of the Brazilian Amazon, and we assume will eventually control 40% through the creation of new reserves. The Public Forest Stewardship Fund would compensate these populations with the goal of increasing the viability of forest-based livelihoods and strengthening their role as forest stewards. Payments would be tied to performance. To provide the annual equivalent of a 1/2 minimum salary ($1,200 per year) to all ca. 150,000 forest steward families living in "social" reserves (indigenous lands, extractive reserves, sustainable development reserves) would cost $180 million per year. Another $13 million would be needed to support these groups in perimeter patrol of their reserves. Annual compensation equivalent to one half of a minimum salary would enable an additional 50,000 smallholder families ($60 million per year) living in government agricultural settlements to restore forests on degraded land as they shift to high-carbon, stable production systems. Payments would decline over time as forest stewards shift to forest-based economies.

G. Private forest stewards in the Brazilian Amazon are private landholders with legal—or legalizable—titles to their land. They are currently required to maintain 80% of their land in forest, but compliance is low and repeal of this law is frequently threatened. It is therefore appropriate that private landholders receive partial compensation (e.g. 20%) of the opportunity costs of their private land forest reserves that are required for compliance with the law, and higher compensation (60%) of the opportunity costs of their private land forest reserves in excess of the legal requirement. If we assume that 10% of the forests of the Brazilian Amazon are privately owned, annual compensation of private forest stewards would begin at US$1.8 million, climbing to a maximum of US$18 million after ten years.

H. The governments of Brazil (federal and state) will incur added costs to achieve a gradual reduction of carbon emissions.. We estimate the annual added costs of monitoring, protecting, and managing existing public forests at US$25 million, with an additional US$8 million per year to establish new public forests. The development of a private forest monitoring and licensing system would cost US$16 million per year to establish and implement. Additional services beyond current levels of support (education, health, justice, technical assistance) would cost an additional $140 million per year for 200,000 rural families. Total annual government fund outlays would be $190 million per year.

I. Over the first 10 years of a Brazilian REDD program, annual costs to Brazil would climb from $100 million per year to $530 million per year as annual emissions fall from the 300 million ton-C baseline to roughly 10 million. Ongoing costs after year 10 decline as public forest stewards shift to forest-based economies, the pool of uncompensated private land forest declines, and government costs decline through greater efficiency and tax revenues. By the end of 30 years, approximately 6 billion tons of carbon emissions would be avoided at a cost of $8 billion. Full payment of the opportunity costs of these avoided emissions would be approximately $18 billion.

Implicit in our calculations, therefore, is the assumption that roughly half of the forgone profits from agricultural and livestock production are compensated by in-country benefits of forest conservation.

J. Substantial co-benefits of this program include: the doubling of income of 200,000 rural forest-based families, a reduction in fire-based costs to society (respiratory illness, deaths, agricultural and forestry damages) of $60 million per year, and protection of the rainfall system that supplies much of the Brazilian grain belt and hydro-electric energy production of the industrial southwest of the country. Substantial non-monetized benefits include biodiversity conservation, including avoiding the near-elimination of five ecoregions.

1. Introduction

Tropical deforestation releases 1.5 to 2.0 billion tons of carbon each year, and is therefore 15 to 20% of the annual worldwide human-induced emission of carbon to the atmsosphere (Canadell et al. 2007, Houghton 2005). During El Niño episodes, when severe drought affects large areas of tropical forests in the Amazon, SE Asia, and elsewhere, emissions can double through fires that burn forests and tropical peat soils (Nepstad et al. 2006a). Tropical deforestation emissions may increase in the coming decade as rising worldwide demand for animal ration, meat, and biofuel places new pressures on potential agricultural lands in the tropics (Nepstad et al. 2006b, Nepstad and Stickler in press). Although a system for compensating efforts to reduce carbon emissions from tropical deforestation and forest degradation was excluded from the UN Framework Convention on Climate Change negotiations of the Kyoto Protocol (Fearnside 2004), such a system is part of the current negotiations focused on the post-Kyoto (post-2012) period. A proposal to compensate tropical countries for nation-wide reductions in greenhouse gas emissions from deforestation and forest degradation (referred to here as "REDD"), first presented at the Milan Conference of the Parties in 2003 (Santilli et al. 2005), was formally endorsed by Papua New Guinea, Costa Rica, and other tropical nations at the Montreal COP in 2005. Brazil endorsed a similar "tropical forest fund" at the Nairobi COP (2006), but did not support a market mechanism for supplying this fund. The REDD proposal will be voted on at the 13th COP in Bali, Indonesia, in 2007.

Brazil's opposition to the carbon market-funded compensation of reductions in carbon emissions from deforestation is surprising since it is superbly positioned to benefit from a REDD program. Roughly two thirds of Brazil's annual carbon emissions come from deforestation, mostly in the Amazon (Moutinho and Schwartzman 2005), and Brazil has been a world leader in developing innovative and successful approaches to forest conservation. For example, from January 2004 through December 2006, 23 million hectares of public forest reserves in the Brazilian Amazon were created, including large forest reserves at the edge of the active agricultural frontier (Campos and Nepstad 2006). Brazil has a sophisticated system of private forest reserve monitoring (Fearnside 2003) and one of the world's most advanced systems of rainforest monitoring (INPE 2007).

One of the obstacles to the eventual approval of the REDD proposal within the UNFCCC process is uncertainty about how REDD would work and how much it would cost. In this report, we provide a conceptual framework for the development of a REDD program for the Brazilian Amazon and estimate the cost of implementing this program over a thirty year period. We complete the report with a preliminary assessment of the co-benefits of a Brazilian Amazon REDD program.

2. *The conceptual framework of a Brazilian Amazon REDD program*

Most of the efforts to quantify how much it would cost to reduce greenhouse gas emissions from tropical deforestation and forest degradation have focused on estimating the opportunity costs associated with forgone profits from agriculture and livestock production that are incurred when restrictions to forest clearing are imposed. These analyses have employed equilibrium and partial equilibrium global economic models to estimate these opportunity costs and have had to make simplifying assumptions about potential rents from agriculture and livestock on tropical forest lands (Sayath et al. 2006, Obersteiner et al. 2006, Sohgen and Sedjo 2006). We are unaware of published analyses that estimate the costs of REDD programs beginning with the biophysical, climatic, and infrastructure constraints to agriculture and livestock expansion in tropical forest regions. In this report, we present results of a model of opportunity costs of forest maintenance estimated using spatially-explicit rent models for high-carbon (timber) and low-carbon (agriculture, ranching) uses of Brazilian Amazon forests.

We estimate opportunity costs of forgone profits from non-forest land uses as an upper limit to the cost of REDD programs. The actual costs of REDD programs should be considerably lower than full compensation of these opportunity costs since there are numerous benefits to Brazilian society of forest maintenance. For example, there is strong evidence that the rainfall system of central and southwestern Brazil is partially dependent upon moisture coming from the Amazon region and that this moisture is, in turn, dependent upon Amazon forest evapotranspiration (Clements and Higuchi 2006). Hence, the rains that feed Brazil's grainbelt and extensive hydroelectric reservoir network appear to depend upon Amazon forests.

The institutional steps to achieving lasting reductions in carbon emissions from tropical deforestation and forest degradation are also in need of a clarifying conceptual framework. REDD programs will depend upon effective governance of remote forest regions and an equitable, efficient system of channeling these incentives to the people who control tropical forests. We propose three general targets of REDD funding to help meet these goals. First, a "Public Forest Stewardship" fund would compensate those people who have defended forests against forest replacing economic activities, or who could potentially defend forests. This funding targets forest-based indigenous groups, traditional rural populations (such as rubber tappers, Brazil-nut gatherers, and others), and some smallholder populations that are taking steps towards stable land-use systems that maintain or expand carbon stocks in forest vegetation.

A "Private Forest Stewardship Fund" would compensate those private landholders who retain forest on their properties. (This fund is complicated by the difficulty of defining land ownership in the Brazilian Amazon.) We proposed a differential rate of compensation for forest conservation on private land, with lower compensation going to forest reserves that are legally required, and higher compensation going to reserves that are above and beyond this legal requirement.

A "Government Fund" would compensate government programs and expenditures that are necessary for REDD above and beyond current budget outlays. These expenditures include heightened monitoring and management of public forests, expansion of the protected area and indigenous land network of public forests, improved provision of services (education, health, technical assistance) to rural populations, and the expansion of existing systems for environmental licensing and monitoring of private land forests to the entire Brazilian Amazon region.

3. *A spatial map of opportunity costs*

The opportunity costs of maintaining those forests that lie outside of protected areas in the Brazilian Amazon (Figure 1) was mapped using spatially-explicit models of potential rents for soy, cattle, and timber production. These models were developed as part of the "Amazon Scenarios" program of the Woods Hole Research Center, the Universidade Federal de Minas Gerais, and the Instituto de Pesquisa Ambiental da Amazonia. The soy model integrates a biophysical yield model, a transportation model, and a production cost model in estimating the economic returns to soy production for the Brazilian Amazon (Vera Diaz et al. 2007). Soy expansion is constrained by a soil and climate suitability map that is applied as a filter. Soy rents are positive only in areas where suitability is high. The cattle ranching model integrates a herd development model, a production cost function (that includes land purchase, herd establishment, and periodic pasture reformation), and a transportation cost model (Merry et al. in preparation). The timber model integrates a transportation model, a harvesting and processing cost model, and simulates the expansion, contraction, initiation, and extinction of timber processing centers depending upon each center's neighborhood of timber stocks that could be profitably harvested (Merry et al. in review).

These three rent-based models are integrated within the "SimAmazonia" modeling system (Soares et al. 2006). In this report, the net present value of each of the three competing land uses is estimated over a 30-year time period by summing rents into the future for each forested pixel of the Brazilian Amazon (Figure 2-4). Future rents are discounted at a 5% annual rate. All three models are highly sensitive to changes in transportation costs. We therefore developed a schedule of highway paving based upon an analysis of current policies and capital availability (Soares et al. 2006). Hence, the rent of each forested pixel changes differentially through time for each competing land use depending upon paving of the highway network as prescribed.

We estimate the opportunity cost of maintaining forest for each pixel located outside of protected areas as the difference between the net present value of deforestation-dependent land use (the maximum rent of soy and cattle ranching) and the net present value of timber production. In this report, we "force" the timber industry into a sustainable mode by limiting annual harvest for each processing center to 1/30th of the total timber volume around each processing center that could be profitably harvested. (This assumes that each forested pixel can be harvested every thirty years because of tree growth.) This opportunity cost is divided by the carbon stock for each forested pixel, using Saatchi et al. (2007, Figure 5), to estimate the payment per ton of carbon that would fully compensate the opportunity costs of forest maintenance (Figure 6, 7).

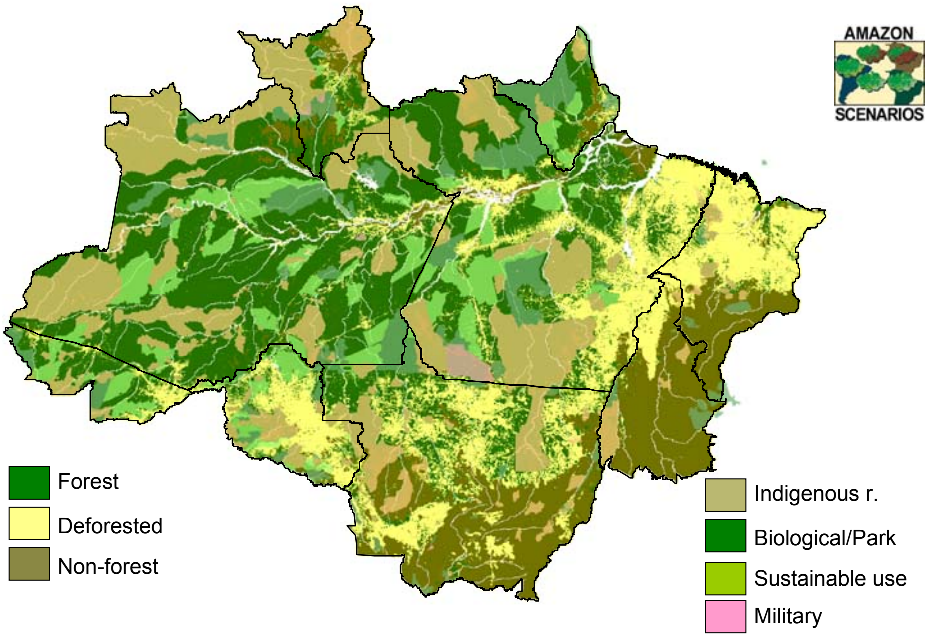

Figure 1. The forests in the Brazilian Amazon. This 5-million square kilometer region has 3.2 million square kilometers of forest, with roughly half in public forests, including indigenous reserves, biological reserves and parks, "sustainable use" (community development forests and production forests), and military reserves. Source: see online supplement (www.whrc.org/Brazilcarbonsupplement)

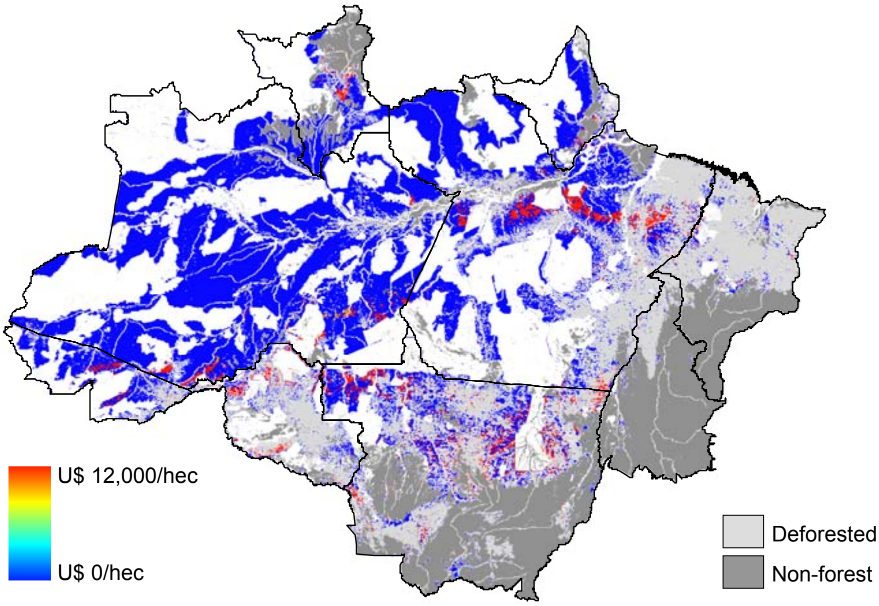

Figure 2. The potential net present value (2007 through 2037) of soy production on the forested lands of the Brazilian Amazon (excluding public forests). See online supplemental information for model description, and Vera Diaz et al. 2007.

Of the 1.6 million square kilometers of forest lying outside of protected areas in the Brazilian Amazon, containing 30 billion tons of carbon, 90% of the opportunity costs are less than US$5 per ton of carbon, and 94% are less than US$10 per ton of carbon (Figure 6). This surprisingly low value is attributable to the low profitability of cattle ranching in the Amazon (Figure 3). The animal grazing density of Amazon cattle pastures averages 0.8 animal units per hectare, and yields profits that are generally well below $50 per hectare per year (Arima et al. 2006, Margulis 2003, Mattos and Uhl 1994). The cost of compensating the opportunity costs of forgone profits from soy production (Figure 2, 6) represent the steep part of the carbon supply curve in the final 6% of the forest carbon stock.

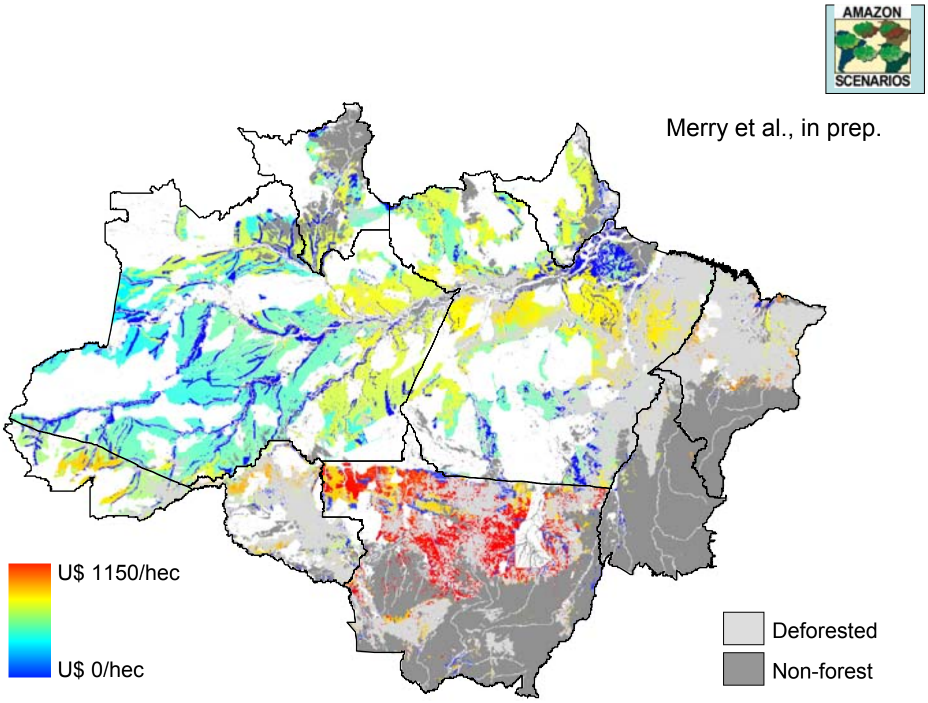

Figure 3. Potential net present value of cattle production (2007-2037) on the forested lands of the Brazilian Amazon (excluding public forests). See online supplemental information for model description.

4. A deforestation reduction schedule and forest allocation

Our analysis is based upon a ten-year timetable for lowering deforestation to 1,000 square kilometers per year from an historical baseline of 20,000 km^2 per year (Fig. 8). We use a 20,000 km^2 per year rate as our baseline since deforestation for the last 10 years was 19,200 km^2 but reached an average of 24,000 km^2 per year during the 2002-2004 period (INPE 2007). Deforestation is assumed to reduce 2,000 km^2 per year until year ten, when the reduction is only 1,000 km^2. We assume that ongoing deforestation of 1,000 km^2 per year will be necessary for many years as swidden farmers clear forests for subsistence livelihoods. The deforestation reduction schedule is presented for 30 years, which is the time period for which opportunity costs were estimated. In fact, compensation would continue into the future until the development rights of remaining forests have been "retired". During the 30-year period, the deforested area would be reduced by 490,000 km^2 and carbon emissions would be reduced by 5.9 billion tons[1].

[1] We assume that logging decreases carbon stocks (aboveground and roots, the latter estimated as 20% of the former) by 15% (Asner et al. 2005) while soy and pasture reduces stocks by 85% (Fearnside 1997). Carbon emission avoidance is taken as the difference between these two for a given forest pixel that is not cleared.

Our calculations also depend upon the ultimate allocation of forest land. Roughly one third of Brazilian Amazon forests today are without formal designation (called "terra devoluta"). Thirty-one percent of forests are public forest reserves (26% of these being social reserves). The remainder of the land is private. We assume that remaining forests of the Brazilian Amazon will be allocated as: 40% social forests (where the public forest stewardship fund applies), 30% biological and production forest, and 30% private land.

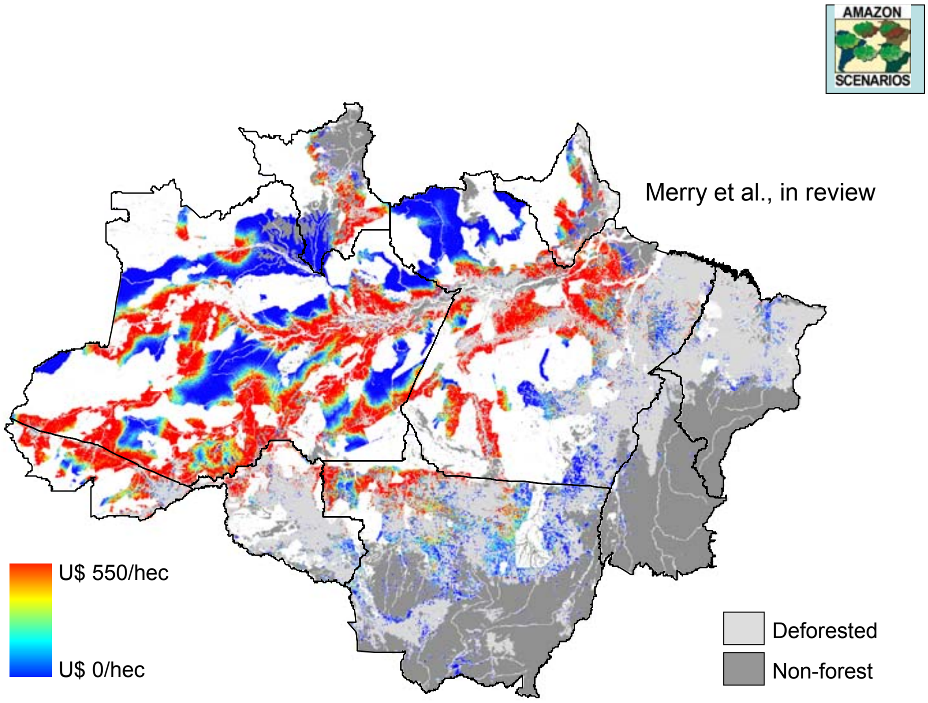

Figure 4. Potential net present value of sustainable timber production (2007-2037) for the forests of the Brazilian Amazon (excluding public forests). Processing centers in this run of the timber rent model are restricted to 1/30th of the profitably harvestable timber stocks, thereby "forcing" the industry into sustainable, 30-year rotations. See online supplemental information for model description.

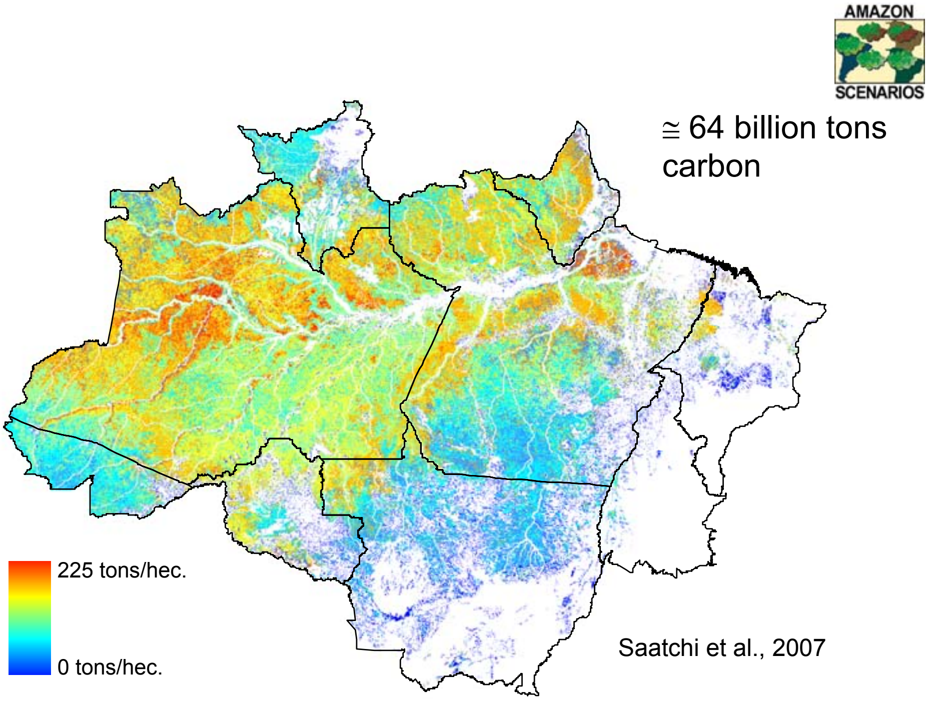

Figure 5. Forest carbon stocks of the Brazilian Amazon. Aboveground and roots. (Assumes that roots are 20% of aboveground.) Source: Saatchi et al. 2007.

5. *The Public Forest Stewardship Fund*

Indigenous lands inhibit deforestation at the same level as biological reserves and parks (Nepstad et al. 2006a), providing an important rationale for strengthening their role as stewards of these public forests. This rationale is further supported by the fact that 25% of current Brazilian Amazon forests are allocated to some form of "social forest" use (indigenous land, extractive reserve, sustainable development reserve), and these social reserves are much more common in active deforestation frontiers than are biological reserves and parks (Nepstad et al. 2006a). Hewlett funding allowed us to help organize the "Alianca dos Povos da Floresta" (the Forest Peoples' Alliance) in its positions on REDD. Through this process, we were able to identify and refine the core proposals for compensation that are advanced by this alliance of indigenous, traditional, and smallholder groups. These forms of compensation include economic incentives for forest-based livelihoods, improved health, education, and technical assistance services, and payments for patrolling reserve perimeters.

We estimate the cost of providing incentives for forest-based livelihood on a per-family basis. We simplify this calculation by assuming that a payment of one-half of a minimum salary ($1,200 per year) would be sufficient to provide a strong incentive to stabilize agricultural systems (through a shift to swidden fallow that does not depend upon primary forest clearing) and to develop forest-based economies (e.g. McGrath et al. 2006). The exact form of compensating forest stewards will depend upon a deeper analysis, and may include price subsidies for non-timber forest products such as have already been established in Acre and Amazon states for native rubber. Direct payments to forest families also have a precedent in the Amazon through the Proambiente program and, more recently, through the Amazonas state "bolsa florestal" program. In the case of Proambiente, payments of $50 per month (half of our estimate) were sufficient to foster changes in farmer agricultural strategies. A payment of $1,200 per year for 50,000 indian families, 50,000 extractivist families, and 50,000 forest-margin smallholder families would cost $180 million per year (Table 1). We assume that it would take ten years of linearly increasing payments to reach all families contemplated.

We estimate the cost of perimeter control based upon estimates from the Aliança dos Povos da Floresta at $10 per square kilometer. The 1.3 million square kilometers of social reserves would require $13 million per year to monitor by their residents (Table 1).

An additional incentive is included for those smallholder families that are in public settlement projects that hold potential for forest restoration and a shift to stable agricultural systems. Sixty million dollars per year would be necessary to compensate 50,000 smallholder families (out of a total of 650,000 smallholder families across the Brazilian Amazon) (Table 1).

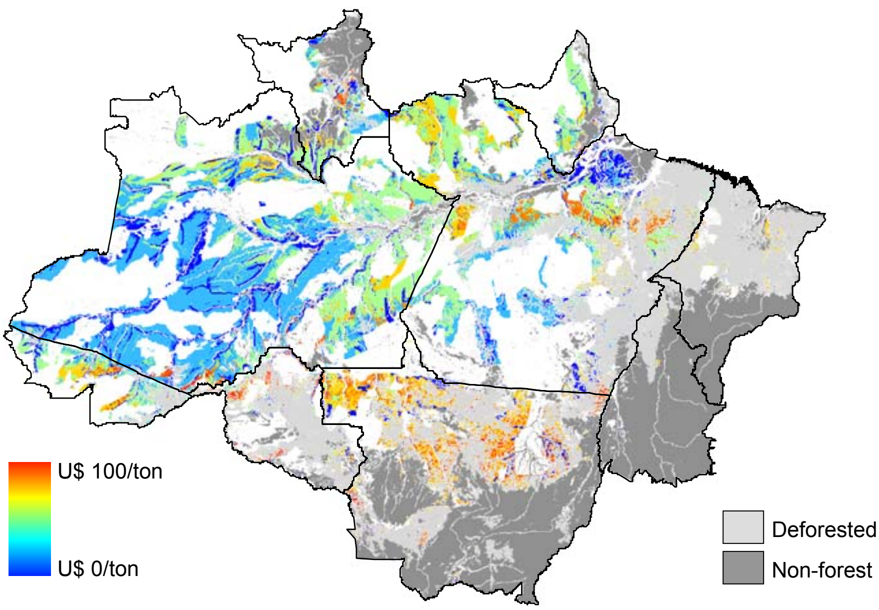

Figure 6. Net opportunity cost of forest protection in the Brazilian Amazon. Calculated as maximum net present value of soy or cattle production minus NPV of timber. The value was then divided by forest carbon stocks (Figure 5).

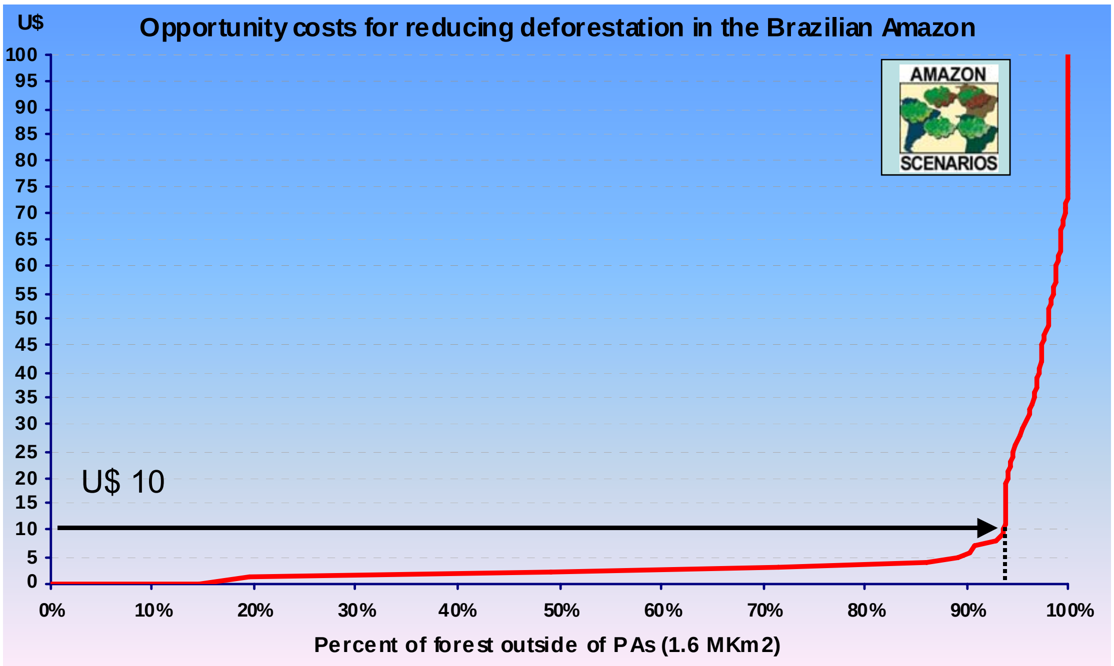

Figure 7. Carbon supply curve for the forests of the Brazilian Amazon (excluding public forests). This graph plots the net opportunity cost per ton of carbon, as described in Figure 6, from the cheapest to the most expensive. Ninety percent of the opportunity costs are less than \$5 and 94% are less than \$10. The total opportunity cost to maintain 94% of the forests outside of protected areas is \$69 billion, with carbon stocks of 23 billion.

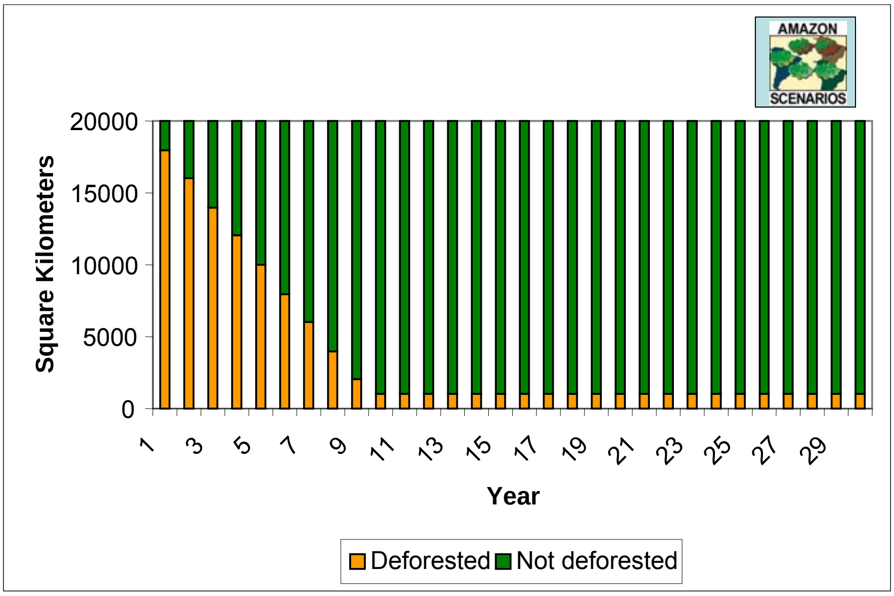

Figure 8. Trajectory of deforestation and avoided deforestation in the Brazilian Amazon for a thirty-year period. This trajectory of deforestation is the scenario used for estimating the cost of the REDD program.

Table 1. Summary of costs of Brazilian Amazon REDD program in Year 10.

Public Forest Stewardship Fund (Forest People)	
a. Forest steward compensation	
Annual payment per family	$1,200
100,000 indigenous and extractivist families	$120,000,000
50,000 qualifying forest margin smallholders	$60,000,000
b. Forest monitoring, protection, management	
Average annual cost per square kilometer	$10
1,000,000 km2 indigenous reserves	$10,000,000
200,000 km2 extractive reserves	$2,000,000
100,000 km2 community reserves	$1,000,000
c. Forest settlement restoration	
Average annual cost per family	$1,200
50,000 smallholder families	$60,000,000
d. Total annual forest people payments	**$253,000,000**
Private Forest Stewardship Fund	
Opportunity costs compensation, extensive ranching	**$90,000,000**
The Government Fund	
a. Public forest protection, management, creation	
Monitoring: average annual cost per square kilometer	$20
Maintenance of current public forests	$24,800,000
Cost to create new protected area ($/km2)	$50
Creation of new protected areas (10%/yr)	$7,800,000
b. Private forest registration, monitoring	
Env'l registration system establishment (10%/yr)	$10,000,000
Cost to register private lands ($/km2)	$50
Property registration (10% per year, $200 per km2)	$6,000,000
c. Services (health, education, justice, technical support)	
Annual payment per family	$700
Annual payments for forest peoples	$140,000,000
d. Total Government Fund	**$188,600,000**
Total cost of all funds in year 10	**$531,600,000**

6. The Private Forest Stewardship Fund

It is very difficult to quantify the area of Amazon forests that are legally (or legalizabley) owned (Alston et al. 199X). Antiquated titling processes, competing land claims, and sophisticated illegal land grabbing operations make it virtually impossible to map legal land claims. For the purposes of this report, we assume that one half of the forests cleared each year are on private properties that are legally held or that will eventually be legalized. Those who purchase forest lands in the future do not qualify for compensation of their opportunity costs, since these costs should be reflected in the sale price of the land. (If we assume that Brazil will enter a regime of forcefully lowering deforestation rates, land prices should decline as the possibility of forest conversion to agriculture or livestock declines.) We estimate compensation of 20% of the opportunity costs of forest maintenance on these private forests. (Landholders are legally required to maintain 80% of their property as private forest reserve.) Compensation of opportunity costs should be higher for forests held in excess of this 80% requirement, but the number of properties with more than 80% forest cover is too small to affect these estimates. We estimate that compensation of private forest stewards increases linear until year 5, when these payments would equal $90 million per year (Table 1).

7. *The Government Fund*

Government monitoring and management of existing public forests is estimated at $20 per km^2 and would cost an additional $28 million per year to be accomplished successfully. We assume that protected area expansion would take place over 10 years to achieve the final land allocation of 40% in social reserves and 30% in biological and production reserves, adding 156,000 km^2 each year. If protected area creation costs $50 per km^2, this cost would be $7.8 million per year. (The added burden on the government of an expanding protected network is counterbalanced by the growing capacity of public forest stewards to defend and manage these areas.) Development of state-run private land environmental licensing and monitoring systems, similar to Matto Grosso State's "Sistema de Licensiamento Ambiental de Propriedades Rurais" (Rural Property Environmental Licensing System) (Fearnside 2003), would cost $10 million per year for ten years, with an additional $50 per km^2 to bring new private properties into the system ($6 million) (Table 1)

The largest government cost would be enhancement of its services provided to forest stewards. Additional investments in and improvements to public health, education, and technical support programs are estimated at $700 per family, for a total of $140 million per year (Table 1)

8. *The costs of REDD in the Brazilian Amazon over 30 years*

We estimate the costs to Brazil of carrying out this REDD program over 30 years, which is the period for which opportunity costs were calculated (Figure 7). We assume that the Public and Private Forest Stewardship Fund increases linearly over ten years to there maximum values presented in Table 1 (Figure 9). Government costs must build up more rapidly to provide necessary law enforcement early on in the program. We assume that the Government Fund builds up linearly over a five-year period. First year combined expenditures of $80 million climb to $600 million in year 10 as deforestation declines from 20,000 km^2 to 1,000 km^2 and emissions decline from 300 to 10 million tons of carbon per year. After the initial ten-year period, ongoing costs are incurred as Brazil continues to compensate remaining private land forest stewards, and protect/manage the 2.8 million km^2 public forest estate. These ongoing payments are theoretically justified as the continuing compensation of opportunity costs which will end only 70 to 80 years into the future. This long time horizon is necessary to fully compensate these opportunity costs because they must only be compensated as they are incurred, which is determined by the 20,000- km^2 per year baseline. This long payment schedule also provides an ongoing incentive to Brazil to continue its forest governance. We assume that the cost of achieving forest governance declines over time as institutional efficiency increases, and as the tax base of the government expands through a thriving timber industry.

Over the thirty-year period, roughly $8 billion are expended to avoid the emission of 6 billion tons of carbon. In other words, for a bit more than a dollar per ton of carbon, more than one half year of current worldwide emissions of carbon to the atmosphere could be avoided, while conserving the world's largest tropical rainforest. The fully opportunity cost of avoiding the emission of 6 billion tons of carbon would be $3 per ton. Hence, our estimates assume that two thirds of the opportunity costs of reducing carbon emissions from deforestation are compensated for by benefits to Brazilian society of forest conservation or are simply forgone.

9. Co-benefits of REDD

The proposed REDD program would have direct impacts on the livelihoods of 200,000 low-income rural family, including all of the indigenous and traditional families of the Brazilian Amazon. These families would more than double their incomes as they shift to forest-based economic activities. They would also receive $700 per family per year in added educational, health, and technical support services. The program would reduce the likelihood of deforestation-driven reductions in rainfall in the Brazilian grainbelt, and would also reduce the likelihood of drought-driven energy shortages, such as the one that crippled the Brazilian economy in 2003 when hydroelectric reservoirs dried up. By reducing the incidence of fire, the program would avoid $11 to 83 million dollars per year in fire-related costs associated with respiratory ailments, agricultural damages, and damages to timber (Mendonça et al. 2003). The slowing of deforestation would also prevent the devastation of at least five ecoregions whose ranges would decrease by at least 85%. These ecoregions include the Maranhão babaçu forest, the Marañon dry forest, and the Tumbes/Piura dry forest (Soares et al. 2006).

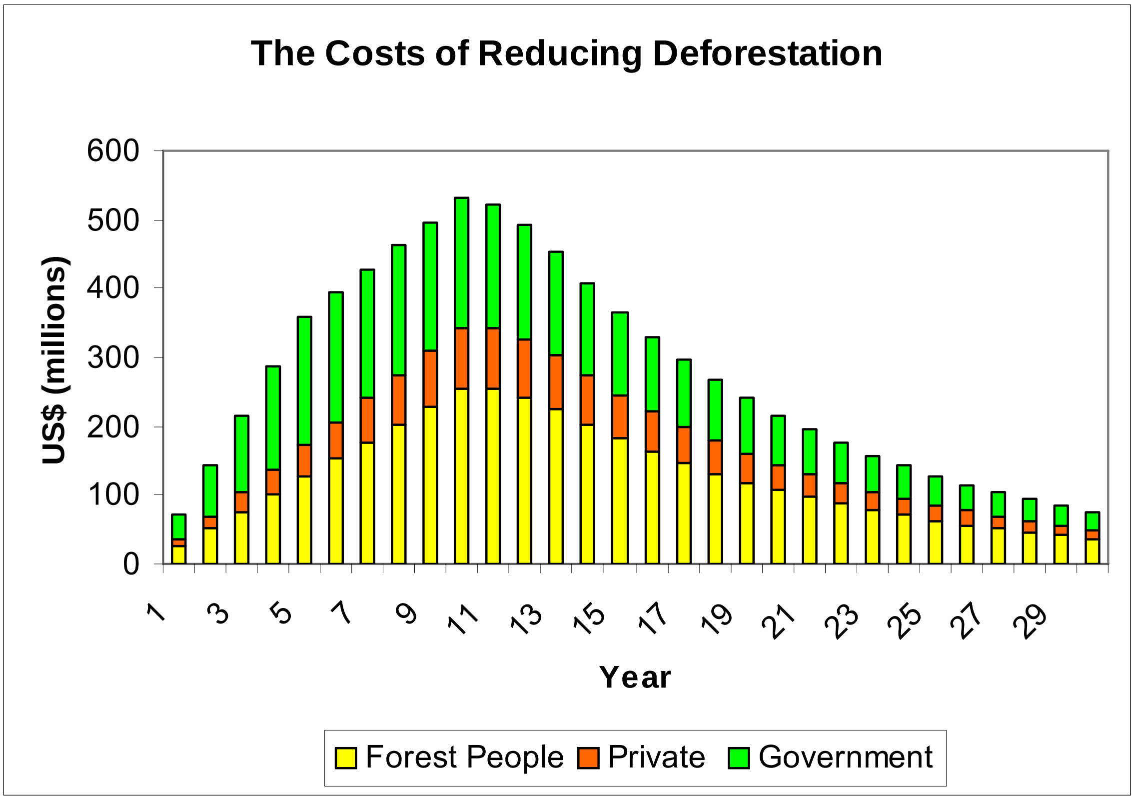

Figure 9. Summary of the costs of the Public Forest Stewardship Fund (Forest People), the Private Forest Stewardship Fund, and the Government Fund over a thirty-year period.

10. Conclusion

This analysis indicates that carbon emissions from the Brazilian Amazon might decrease by six billion tons over a thirty-year period through a fairly modest flow of funding into the region--$8 billion. This estimate is far lower than previous estimates of REDD (Sayathe et al. 2006, Stern 2006), largely because opportunity costs are not fully compensated, and spatially-explicit modeling of land use rents demonstrates that most carbon emissions carry very low opportunity costs. A REDD program that compensates at a level that is less than opportunity cost is justifiable given the very substantial benefits that this program would provide to Brazilian society. These include the doubling of income and improved health, education, and technical assistance services for 200,000 forest-dwelling families. The benefits also include a more secure rainfall system for central and southern Brazil, and the avoidance of $10 to 83 million per year in fire-related damages to the Amazon economy.

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China

Economics of Win-Win Energy Policies in China: Cases on Policies of Clean Coal Electricity and Vehicle Fuel Economy

1. Introduction

1.1 Driving Forces to Future Energy Developments

1.1.1 Population growth

It is generally expected that population growth will continue in the next three to four decades before the Chinese population reaches a peak of 1.5 billion from the current 1.3 billion and begins a slow decline. A population growth of around 200 million in the next few decades will be a major driving force to energy and power demand.

1.1.2 Rapid urbanization

China is in the stage of rapid urbanization. China's urbanization rate is 43.9% in 2006, far lower than the ~70% seen in developed countries. Since 1978, the share of urban residents in China's total population has increased from 18% to the current 44% (Table 1). The labor opportunities and the dramatically higher income levels of cities have created a massive migration from rural to urban areas. It is expected that rapid urbanization will continue for the next few decades.

Table 1 Speed of urbanization in China

	2001	2002	2003	2004	2005	2006
% of urban population in total	37.7	39.1	40.5	41.8	43.0	43.9

Source: China National Statistical Bureau, 2006 & 2007

Major differences in income level and lifestyle mean that an urban resident consumes much more energy than a rural resident in daily life. In 2003, the per capita residential electricity consumption of urban residents is 259 kWh, while rural residents consume 115 kWh. This demographic transition has important implications for residential and commercial electricity demand as well as for heavy industry via civil infrastructure requirements.[i]

1.1.3 Rapid economic growth

China has been undergoing rapid economic growth in the last three decades and so far there is no evidence that the growth is slowing down. In contrast, the growth has remained above 10% in recent years. Based on the current trend of investment and consumption, it is believed that secular and steady growth of China's economy is likely.

1.1.4 Rapid increase in income level

With their income level still low and growing quickly, more and more Chinese families will be able to purchase more consumer products, larger homes, and long-distance travel. This will inevitably lead to greater energy consumption. In recent years, many Chinese families have bought or built their own apartments and houses, leading to a booming real estate sector. Each year, around 600 million square meters of new housing were built and put onto the market. All this leads to higher living standards and consequently more energy consumption. China's energy demand will grow as incomes rise and more households can afford cars and energy consuming household appliances.

1.1.5 Economic and industrial structure

Currently industry contributes over 50% of China's GDP, far higher than the world average of around 33%. Ongoing industrialization continues to make industry the pillar for the country's economic growth.

The rapid growth of industrial sector, especially such energy-intensive sectors as steel, cement, building materials, chemicals, leads to rapid increase in energy demand. Presently, heavy industry is the primary driver of electricity demand growth in China. Discounting electricity used by the power sector itself, 41 percent of the 460 TWh increase in China's electricity consumption from 2002-2004 was accounted for by four sectors: industrial chemicals (9 percent), ferrous metals processing (16 percent), non-ferrous metals processing (9 percent), and building materials manufacture (7 percent) (EBCEPY, 2005). Overall, heavy industry accounted for 56 percent of China's electricity consumption in 2004 (EBCEPY, 2005).

1.1.6 Infrastructure expansion

For integrating the domestic market and taking part in global economic activities on a larger scale and in greater depth, China needs to not only construct highway networks and ports to meet the increasing demand of regional transportation, but also needs to construct scalable and intensive ports, large scale specialized wharfs, airports, high speed railways, and expressways to satisfy the needs of foreign trade. The large scale of infrastructure construction will inevitably result in vast consumption of raw materials and energy, which will challenge the sustainable development of China.

1.2 Consensus on the importance of climate sound technologies (CSTs)

1.2.1 The dominance of coal

An Overview of Electricity, Coal fired power generation and CO2 Emissions in China:
China's electricity generation and capacity have more than doubled every decade since 1980. Over the period 1990-2004, total installed capacity of power generation increased more than three-fold, from 138 to 517 GW (Table 2), and in the same period, electricity output increased from 623 TWh to 2500 TWh[iii]. In 2006, the total installed capacity was up to 622 GW, in which thermal installed capacity was 484 GW, accounting for 77.82% of total capacity in China. Coal-fired capacity comprised more than 95% of thermal capacity, about 460GW. Newly installed capacity exceeds 100 GW, setting a new world record. The time it takes to accomplish a 100GW increase in capacity has steadily been falling. In 1995, total capacity surpassed 200GW. After 5 years, it surpassed 300GW. After 4 years, in 2004 it surpassed 400GW. While in 2005, it surpassed 500 GW and in 2006 surpassed 600GW.

Table 2 Power generation in China

Year	Total capacity (GW)	Thermal Capacity (GW)	Percent (%)
1990	137.89	101.84	73.86
1991	151.47	113.59	74.99
1992	166.53	125.85	75.57
1993	182.91	138.02	75.46
1994	199.89	148.74	74.41
1995	217.22	162.94	75.01
1996	236.54	178.86	75.62
1997	254.23	192.41	75.68
1998	277.29	209.88	75.69
1999	298.77	223.43	74.48
2000	319.27	237.54	74.40
2001	338.42	253.14	74.80
2002	356.60	265.54	74.46
2003	391.41	289.77	74.03
2004	440.70	324.90	73.72
2005	517.18	391.38	75.68
2006	622.00	484.05	77.82

In 2003, electricity generation accounted for 48.6 percent of China's CO2 emissions and Coal-fired generation accounted for 97 percent of these emissions.[ii] It is apparent that electricity generation is one of the fastest growing sources of CO2 emissions in China. Electricity's share of China's total coal consumption increased from 26 percent in 1990 to 49 percent in 2004.[iii]

Coal-fired power plants are unique among fossil fuel infrastructure because they are intergenerational — the typical lifespan of a coal-fired power plant is 40-50 years. As a source of greenhouse gas emissions, coal-fired power plants bridge the divide between short-term and longer-term emissions pathways. Because of this, it poses a special challenge for emission reduction policies.

1.2.2 The rapid increase of vehicle stock and transportation infrastructure

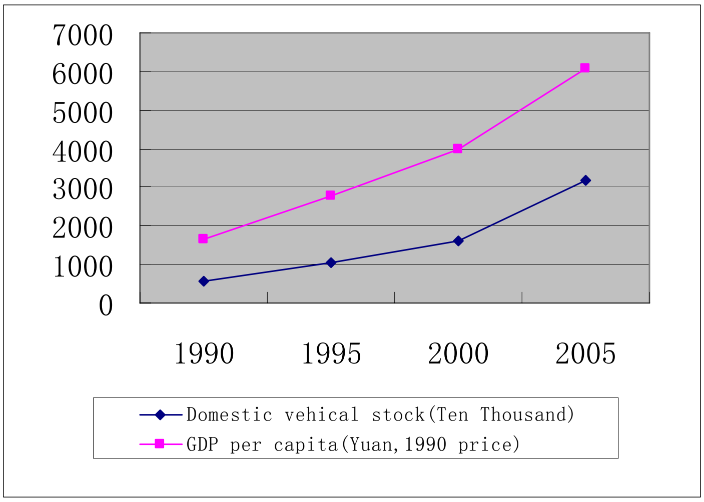

Figure 1. The rapid increase of vehicle stock[iv]

The economic development miracle of China leads to the rapid increase of domestic vehicle stocks. As illustrated in figure 1, between 1990 and 2000, domestic vehicle stock increased 5 million every 5 years, but from 2000 to 2005, the stock increased 15.5 million. And with the increase of GDP per capita and the decrease of car prices, China's vehicle fleet is expected to grow at an even greater rate in the coming years.

Road transport consumed 6.1% of total final energy consumption, while all other transport consumed 3.5% of total final energy consumption in China[v]. But road transport is one of the fastest growing fuel consumers in China, a trend which is only expected to accelerate.

At the same time, the capacity of road transportation is increasing dramatically as compared with railway transportation. As illustrated in table 1, from 1990 to 2005, the total length of railway increased 30% and the total length of highways increased 87.7%. But from 1990 to 1995 the total length of expressways increased 410%, from 1995 to 2000 it increased 676%, and from 2000 to 2005 it increased 151%. And some estimates show that in a few years the total length of expressways will exceed the total length of railways. With the rapid progress of road capacity, passenger transportation and the freight transportation will increasingly rely on vehicle transportation.

The result is that the vehicle consumed oil will increase dramatically and the Chinese oil market will increasingly rely on imported oil. Simultaneously, vehicle transport induced CO_2 and local pollutants will continue to increase.

Table 3. The development of transportation infrastructure in recent years[vi]
(Unit: 10 thousand kilometers)

	1990	1995	2000	2005
Total length of railway	5.78	5.97	6.87	7.54
Total length of express way	0.05	0.21	1.63	4.10
Total length of highway	102.83	115.70	140.27	193.05

The potential to reduce petroleum consumption in vehicles

According to "Background report of vehicle fuel economy"[vii], the fuel efficiency of Chinese cars is much lower than developed countries' by comparing the same or similar type of cars. The Chinese cars' fuel consumption per 100 kilometers is over 20% higher than developed countries, is 20% - 25% higher than Japan's, 10% - 15% higher than EU's and 5% - 20% higher than the U.S.A.'s.

2. Clean Coal Technologies and Corresponding Policies

2.1 Technology Survey and Scenarios of Technology Change/Options in Coal-Fired Power Sector

Future Electricity Demand and Emissions in China: Scenarios and Technology Options

This study provides scenarios of future electricity development and resulting pollutant and greenhouse gas emissions, taking into account the most up-to date data and recent trends. To address the Win-Win effect brought by new technology, two scenarios were defined, which reasonably represent the range of technology deployment for coal-fired electricity development.

2.1.1 Scenario Assumptions

- According to the understanding that coal will play a dominant role in the generating mix for some decades to come and the fact that domestic coal is cheap and abundant, it is expected that coal-fired generation will still comprise the bulk of China's electricity sector, and other options cannot easily compete. Advanced coal-fired power plants should play a growing role in the generating mix over time, despite relatively high costs, because of their high efficiency and superior environmental performance.

Coal-fired generation can be bounded by three parameters: electricity intensity, thermal efficiency, and the penetration of alternative fuels and technologies for electricity generation. A basic projection for these emissions requires some assumptions, and the major assumptions used in this study are given in the following Table 4.

The assumed GDP growth rate is consistent with government targets, other research and recent trends. From a base year of 2005, quadrupling 2000 GDP by 2020 would require that China's economy grow by an (historically moderate) annual average of 6.6 percent from 2005-2020. Considering the fact that the real economic growth always exceeds the target one, and in the first half of 2007, the country's GDP further increasing at 11.5% on fixed-price basis, the assumed GDP growth are some higher than 6.6, see Table 4.

Table 4 key viable assumptions

	2005-2010	2010-2020	2020-2030
Annual GDP Growth Rate	10.00%	8.50%	6.60%
Electricity intensity	1	0.9	0.8
% of coal fired generation in the total installed capacity	78	75	73

In this study, only different technologies are considered other than time frame and site. The technology options considered in this study include sub critical PC, SC PC, USC PC, and IGCC. Table 5 shows the basic technical and financial indicators of different generation technology. We collected most data needed to calculate emission performance, investment cost and electricity generation costs from academia, power companies, manufacturers and coal companies. By our calculations, we try to find out how variations in the proportion of different technology deployed lead to variations in emissions and costs. After the calculations of technology performance and costs, then we will proceed to identify the emission and cost differences among different technology options.

Table 5 Technical and financial indicators of different generation technology[viii]

Technology	small scale sets(<50)	Normal(<300)	sub-critical	SC	USC(>600)	IGCC
Unit capacity	<50MW	50-300MW	300-600MW	300MW-600MW	>600MW	
share of generation sets in capacity terms in 2005, %	19%	40%	41%	0	0	0
capacity volume in 2005, MW	72930	153540	157380	0	0	0
unit coal use, gce/kwh	410	364	305.9	297.7	290.8	303.9
Unit CO_2 emission, g/kWh	1107	982.8	827	805	786	717
Unit SO_2 emission g/kWh	3.141	2.788	2.343	2.280	2.228	0.011
Unit Nox emission, g/kWh	2.042	1.813	1.523	1.483	1.448	0.565
Annual operation hour, h	5000	5000	6000	6000	6000	6000
Capital investment, USD/kWe	NA	NA	461	485	510	978
Capital investment with capture, USD/kWe	NA	NA	1,411	1,295	1,240	1,438
O&M cost, USD/kWe-h, fuel excluded	0.0075	0.0075	0.0075	0.0075	0.0075	0.0090
generation cost, USD/kwe-h, including capital[ix], fuel, and O&M (Notes: the red printed figures for generation cost (<50MW and <300MW) do not include capital cost)	0.0250	0.0250	0.0291	0.0279	0.0268	0.0366

2.1.2 Future Scenarios

In order to analyze future electricity demand, emissions and relevant costs of different technology options in China, we consider three scenarios: a baseline scenario, a technology change scenario and an ultra technology change scenario which adopt the technology of CCS. The three scenarios are defined as follows:

- Baseline scenario: suppose sub critical (600 MW) will be selected as the mainstream technological options
- Technology change scenario:
    - o Remove small sized generation sets
    - o Increase capacity share of USC in the coming decades as a dominant increase of capacity, without significant deployment of SC.
    - o Start demonstration of IGCC now and hopefully increase its capacity share steadily during 2010-30
    - o Combine CO2 with SO2 and NOx
    - o Extra current capital investment (about 10%) to link CCS in the future
- Ultra technology change scenario: technology change scenario with CCS

2.1.2.1 Installed capacity

The former assumptions for efficiency, intensity, and percent of coal fired generation in the total installed capacity in Table 4 result in 3,132TWh of coal-fired generation in China in 2010, 6,130TWh of coal-fired generation in 2020, and 9,045TWh in 2030. Accordingly, the scenarios of Installed capacity change are shown in Table 6 and Table 7 respectively.

Table 6 Scenarios of installed capacity change, GW

	small scale sets(<50 MW)	Normal(<300MW)	sub-critical(300-600MW)	SC(300-600MW)	USC (>600MW)	IGCC
capacity volume in **2005**	72.9	153.5	157.4	0.0	0.0	0.0
2010	-40.0	-20.0	200.0	0.0	30.0	0.0
2020, assume total coal-fired capacity is up to 1040 GW, in which 350 GW from USC (>60 MW)	-32.9	-50.0	189.0	0.0	350.0	30.0
2030, assume total coal-fired capacity is up to 1510 GW	0.0	-60.0	0.0	0.0	430.0	100.0

Table 7 Baseline of capacity change, GW

	small scale sets(<50 MW)	normal(< 300MW)	sub-critical(300 -600MW)	SC(300-600MW)	USC(>600)	IGCC
capacity volume in **2005**	72.9	153.5	157.4	0.0	0.0	0.0
2010	-40.0	0.0	210.0	0.0	0.0	0.0
2020, assume total coal-fired capacity is up to 1040 GW	-32.9	-20.0	539.0	0.0	0.0	0.0
2030, assume total coal-fired capacity is up to 1510 GW	0.0	-50.0	520.0	0.0	0.0	0.0

2.1.2.2 Emission scenario

The environmental performances for emissions of CO_2, SO_2, NOx, are summarized and presented in Figure 2-4, Table 8-10.

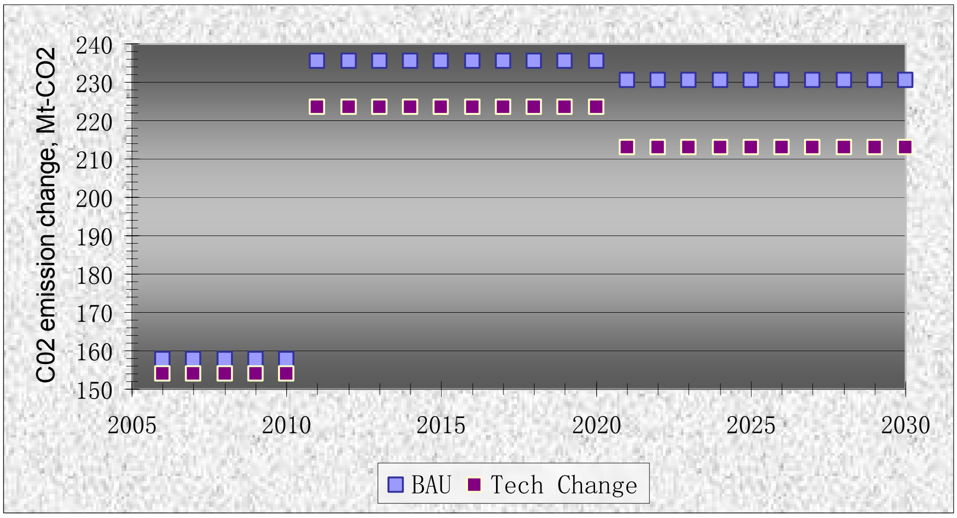

Figure 2 Scenarios of CO2 emission change

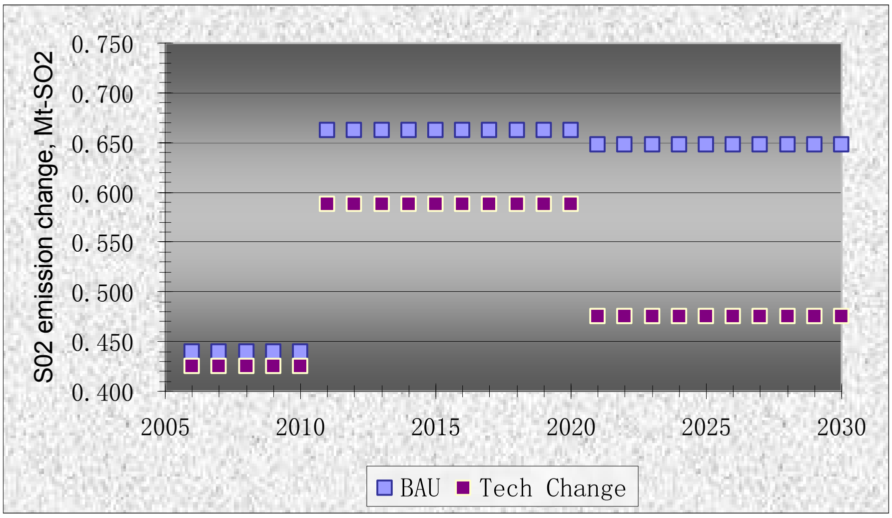

Figure 3 Scenarios of SO2 emission change

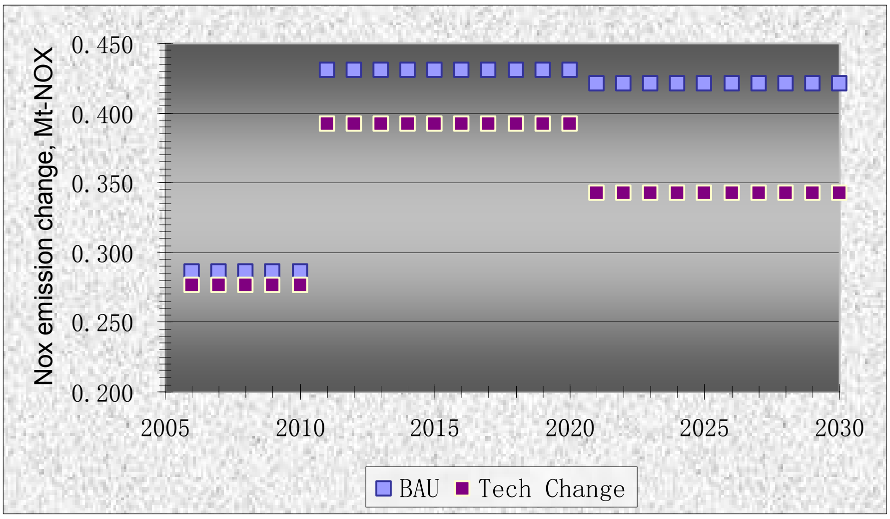

Figure 4 Scenarios of NOx emission change

From Figure 2-4, we can find out that the newly added emission of CO_2, SO_2, and NOx are all controlled to a certain extent according to the technology update.

Table 8 Total CO_2 emission mitigation according to the two scenarios, Mt-CO_2

	BAU	Tech-scenario	emission mitigation	% of emission mitigation
2010	2871.5136	2853.8516	17.6620	0.62%
2020	5226.8564	5088.1573	138.6991	2.65%
2030	7532.2764	7217.0076	315.2688	4.19%

Table 9 Total SO2 emission mitigation according to the two scenarios, Mt-SO2

	BAU	Tech-scenario	emission mitigation	% of emission mitigation
2010	8.3545	8.2803	0.0742	0.89%
2020	14.9778	14.1604	0.8174	5.46%
2030	21.4525	18.9103	2.5422	11.85%

Table 10 Total NOx emission mitigation according to the two scenarios, Mt- NOx

	BAU	Tech-scenario	emission mitigation	% of emission mitigation
2010	5.4312	5.3830	0.0482	0.89%
2020	9.7367	9.3065	0.4303	4.42%
2030	13.9457	12.7298	1.2160	8.72%

From Table 8-10, it is apparent that the total CO2, SO2 and NOx emissions will also decrease in the tech-scenario compared to the BAU scenario. But because the newly installed generation capacity is huge, the percent of emission mitigation achieved though technology change is not as large as expected. Because IGCC has the ability to remove sulfur after gasification, its SO_2 emission are near zero, and its NOx emission are also much lower than other technologies, the percent of NOx and SO_2 emission mitigation are greater than that of CO2.

2.1.2.3 Cost scenarios

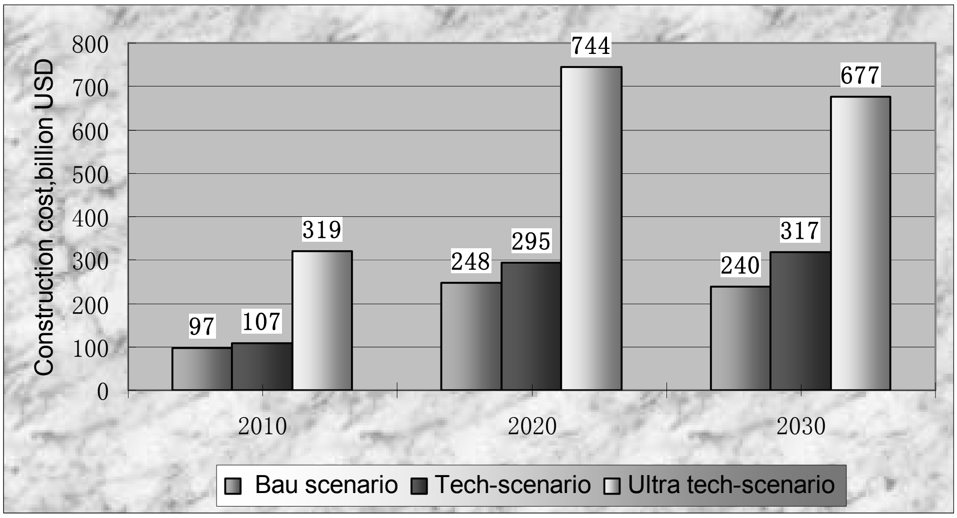

Figure 5 Comparisons of Construction cost in 3 different scenarios

The figure 5 shows us construction capital cost among different scenarios. The cost of technology scenario is about 10-30% greater than the BAU scenario. The ultra tech-scenario presents a far more dramatic difference in capital costs, nearly a three-fold increase on the BAU scenario Hence, the incremental cost brought by the CCS (under the ultra-tech scenario) would be prohibitively high. At present, the costs and feasibility of large-scale geological sequestration in China are uncertain, and national and multilateral incentives are presently too weak to support more extensive, detailed research. While it may be counterproductive to expect China to establish short term targets for emission reduction, international technology cooperation could be an important and innovative way to help China mitigate its CO2 emission as early as possible.

2.2 Options of Policy Instruments to Promote Win-win Coal Electricity Technology in China

2.2.1 China's Strategy for Clean Coal Electricity Technology

With this review and assessment on advanced clean coal electricity technology options, China's technology strategy for clean coal electricity can be described as:

- First, to accelerate the diffusion of mature technology, USC will be the dominant technology for newly-increased power generation units
- Second, to promote demonstration and deployment of technology that can be commercialized in near future, including large scale CFB and small scale IGCC demonstration
- Third, to encourage R&D of technology that has long term importance in terms of building a low-carbon economy: such as gasification of coal, and CCS etc

2.2.2 Existing Policies Related to Advanced Coal Electricity Technology: General Review and Assessment

2.1.1.1 Overall change of policy environment in China: political wills and legal basis

- Generally speaking, there is no domestic Climate Policy formulated, which means carbon emission controls are not a compulsory requirement for industry. However, there are already very clear and strong commands on energy-savings and conventional pollutants emissions reductions Energy-saving activities will directly and positively contribute to reduced coal consumption and carbon emissions reductions. Emissions reductions requirements will also promote technological and structural reform in the power sector, which may leave different room for different power generation technologies.

- Energy Conservation and Emissions Reductions are key words on the political agenda of the Chinese Government, which provide a historical opportunity to achieve technology improvement in energy-intensive sectors. On June 3, 2007, the State Council officially released the Integrated Work Plan on Energy Saving and Emissions Reduction, which sticks to the original target of reducing the per unit of GDP energy consumption by 20% and total emission of SO2 by 10% from 2005 to 2010. The State Council then set up a leading group on energy saving and emission reduction with Premier Wen Jiabao as the team leader. On July 9, 2007, the first meeting of the national leading group on energy savings and emissions reductions was held in Beijing. This meeting launched a national campaign to achieve the goal of energy savings and emissions reductions. This means that all industries, especially energy-intensive sectors, will come out with concrete measures to achieve these goals.

- Climate Change more and more is becoming a hot political topic of Chinese Government. On June 4, 2007, China issued National Climate Change Program to show its determination to reduce greenhouse gas (GHG) emissions. Although the program does not include any quantified targets for carbon dioxide emission, this is for the first time that a developing country has pledged to restructure its economy, promoting clean technologies and improving energy efficiency. Through this new program the Central government has for the first time delivered a signal to the local provincial governments that the climate issue is an emerging concern that could effect domestic issues.

2.1.1.2 Policy Objectives

The overall policy objective is: to promote the implementation and fulfillment of technology strategy. Specifically, policies should be supplied to accelerate the diffusion of mature technology; to promote demonstration and deployment of technology that can be commercialized in near future; and, to encourage R&D of technologies that are important for building a low-carbon economy in the long-run.

2.1.1.3 Industrial Policies

From a technological point of view, coal efficiency is mainly decided by the technology employed and scale of the power plant as plants gain efficiency with scale. Thus, **technological improvement and restructuring will be the fundamental way** to achieve efficiency. In this way, government has set the policy of “Encouraging Large, Compressing Small”, which encourages the development of cleaner power generation and combined heat & power, while phasing out obsolete technologies and closing down small size plants. Several key activities will be taken as:

- Shutting down existing small scale generation units
  - The General Work Plan for Energy Conservation and Pollutant Discharge Reduction issued by the State Council in June 3, 2007, has set up targets to scrap out-dated production capacity for power sector, which is to shut down small thermal power generating units with a combined capacity of up to 10 GW in 2007 and 50 GW in the period of the 11th Five-year. This document set up 6 criteria for coal-fire electricity generator that should be shut down: individual capacity smaller than 50MW; or individual capacity smaller than 100MW and running time over 20 years; or individual capacity smaller than 200MW and expiring its designed life-time; or generators with average coal consumption 10% higher than provincial average or 15% higher than national average; or those that exceed the emission standards.
  - Both positive and negative incentives are provided to promote the shutting down of small units. For example, small units can still get free electricity sales quota for the first 3 years after shutting down and sell them to large units to gain profit as compensation. Electricity price for small units should be cut down to below the standard grid price in same region, and no price subsidies be provided.[x]

- Approval for New Projects
  - Project Approval has traditionally been and will continue to be a powerful tool for guiding the investment of power companies.
  - First, approval for new electricity project should be on the condition of shutting down a prescribed percentage of small units in the same enterprise or same area.
  - Secondly, to encourage large scale facility, new facilities smaller than 300MW will in principle not be approved in the region which is covered by large grid.
  - Thirdly, Energy Conservation Assessment and Examination is now discussed to be involved in the project approval process, which means energy efficiency of electricity technology will be a big strength for getting approval on projects.
  - These policies have set Entry Conditions for new project approval, and will no doubt push the restructuring of power sector. Power generation technology with large scale, high performance of energy-savings and emissions reductions will be favored.

- Electricity Pricing and Sales Quota allocation
  - Electricity Price and Sales Quota are two of the most

important components that affect the profit of power production. Under the traditional plan economy, both electricity price and sale volume were decided by government. With the deepening of reform in power sector, more and more competition is being introduced into power generation side. NDRC has set a uniform standard price for all newly-constructed facility in specific region, instead of setting a price for each individual plant or even unit based on its costs, while green electricity or other electricity favored by sector policy can get price premium, de-sulphurization electricity is an example.

As for sales quota allocation, a large part of electricity volume bought by grid company is allocated evenly among different facilities, while a small part has been allocated among power companies based on a price bid process. But this process is unable to provide incentive for clean electricity based on existing pricing system, because old utilities with low coal efficiency are normally more competitive in terms of price than new utilities with high coal efficiency. A new policy called “Energy Conservation Electricity Allocation” was just launched a trial on five south china provinces in August 2nd, 2007, and will be put into effect since early next year. This is an important reform in sales volume allocation in power sector since the price reform in previous years. According to this policy, sales volume will no longer been allocated to all generators evenly, whereas, it will be based on a Ranking List, which is decided by coal efficiency and pollutants emission performance, so renewable energy, efficient coal and clean electricity will have priority in getting the sales quota. This will ensure clean electricity generators are fully used and get an advantage over small and dirty ones.

In the long term, both electricity price and sale volume will become competitive components for power plants which directly contribute to the final profit, while they can still serve as incentives to guide the power plants moving on an appropriate direction of technological change.

Generally speaking, industrial policy has been a very powerful tool and played an important role in achieving the goal of energy conservation and pollution emission reduction. These administrative mandates can come out with quite certain policy effects on energy conservation and emission reduction. At the same time, these policies are clearly encouraging the deployment of large scale units, which will be favorable for the development of USC +FGD, this is a necessary choice to ensure power supply to meet the demand of rapid growth of China’s economy.

2.1.1.4 Environmental Policy

China's environmental policies for power sector mainly focus on controlling conventional pollutants, such as particulate, sulphur, and nitrogen. Total emission control, Emission Standard, Pollution Levy, Two-control-zone, and Environmental Impact Assessment are key environmental policies.

SO2 Reduction

China's SO2 emission has already exceeded US to rank the largest emitter in the world, and coal burning power plants contribute more than 50% of China's total SO2 emission. SO2 emissions controls in power sector have become one of the major steps toward the goal of 10% SO2 reduction before 2010 set by 11th FYP. Specifically, the country's total SO2 emission control target is 22.94 million tons in 2010, of which the power sector is allocated 9.52 million tons, 30% lower than its emission in 2005. This will translate into a reduction of SO2 emissions from 6.4 g/kWh in 2005 to 2.7 g/kWh in 2010.[xi]

To control emissions, the government requires that new coal-fired units must be synchronously equipped with FGD, existing plants must have begun to be retrofitted with FGD technology before 2010.

A price premium of 1.5 cent per KWh for desulphurized electricity has already been applied to both newly-constructed and the existing power plants to encourage their desulphurization operation since 2005.

NDRC and SEPA jointly release a specific 11th FYP on SO2 Mitigation in Existing Coal-fired Power Plant in early August 2007. This document set clear goal for SO2 emission reduction in power sector, which is that compliance rate of SO2 emission in existing coal-fired power plants reach 90% till end of 2010, total SO2 emission controlled below 5.02 million tons; Units installed with or under construction of desulphurization facilities reach 230 million KW (excluding CFB); and SO2 emission performance of coal-fired power plants reduced by 57.8%, from 6.4 g/KWh to 2.7g/KWh. This document lists a detail inventory of 221 projects required to be retrofitted with FGD, covering almost all non-compliance units larger than 100 MW, without including any unit burning coal with sulphur content higher than 0.5%. The construction expenditure will be 34.2 billion RMB (about 250 RMB per KW), which is required to be invested by company and complemented by Pollution Fee Fund. Several other policies measures are proposed to provide incentive for the implementation of this policy, including preference in getting access to grid, preference in getting subsidy from Pollution Fee Fund, preference in getting fiscal grant from central government for demonstration FGD project with domestic IPR, tax exemption for key equipment and comprehensive utilization of side-products, strengthening enforcement, etc.

This policy will no doubt boost a new round of investment on FGD equipment. With the maturing and upgrading of FGD technology, the competitiveness of pulverized coal burning technologies, such as SuperC, USC may not be hampered due to the requirement of SO2 emission control. But currently Chinese companies are still lack IPR on FGD technology and are weak in terms of assimilating existing technology and technology innovation.

In order to promote the de-sulphurization in power production, a premium of 1.5 cents/ kWh for grid price has been given by Jing-jin-tang Grid to de-sulphurized electricity for newly constructed units since April 2004, and this policy has been extended to all existing and newly constructed units for all Grids up to end of 2005.

Management Measures on De-sulphurization Price and De-sulphurization Facility Operation in Coal-fired Electricity Units have just been put into effect on July 1st, 2007;

A pollution charge on SO2 emissions will be increased from 0.63 RMB per ton to 1.2 RMB per ton.

NO_X Reduction

NOx is increasingly contributing to local urban pollution and the forming of regional acidification. NOX emission did not receive as much attention as SO2 emissions. NO_X emissions controls in the power sector also started later than SO2. NOx emission standard and corresponding policy is not well developed. It was not until July 2004, had NO_X emission for the first time been levied at a rate of 0.63 RMB/kg.

Up until 2005, all newly constructed coal-fired power plants of 300MW and above were required to apply Low Nitrogen Burning Technology (LNB_s), existing electricity facilities of 100-300MW are required to be gradually retrofitted with LNB_s. New plants had to set aside space for future flue gas de-nitrification equipment installations, and some demonstration projects of Fluid Gas De-nitrogen technology were already launched, with an investment of 150 RMB/kW, and running cost at 0.6 cents/kWh.

There is no certain time table for NOx control yet, but with the rapid increasing tendency of NOX emission, it is for sure that government will further strengthen the NO_X emission control. If so, only with LNBs, which can remove about 30-40% of nitrogen, facilities may not be able to meet the emission standards. More stringent requirement on Fluid Gas De-nitrogen will be made and corresponding technology should be developed. Up to now, almost all existing or under-construction fluid gas de-nitrogen projects are demonstration projects, with none in commercial operation.

From the above analysis, we find out that:

1) The development of FGD technology has already proved that environmental policy play an important role in accelerating the investment, reducing the costs and promoting the localization of FGD technology.
2) The development of technologies to control these conventional pollutants such as SO2 and NOx, is in the same line with the needs of developing USC.
3) Enforcement should be strengthened in order to ensure full operation of installed facility to achieve real environmental effects.

2.1.1.5 Technology Management Policy

The Chinese government has paid much attention to the development and promotion of cleaner coal technology in recent years.

With the implementation of "973" basic research program, "863" advanced technology program, National Program for Tackling Key Problem, Important Technology Specific Program, etc, China has supported the major advance coal electricity technology including USC, CFB, PCFB, IGCC, and FGD, by systemic investments in the research, innovation, and industrialization of these technologies.[xii]

The State Council of China issued guidelines on its national medium- and long-term program for science and technology development (2006-2020) on February 09, 2006. The guidelines noted several important technological research and development areas, including natural resources, the environment, agriculture, and information technology, but energy received the highest priority. Technologies specific to advanced coal in the guidelines that were highlighted for increased research, development and demonstration included: high efficiency mining technologies and facilities, heavy gas turbines, IGCC systems, USC PC facilities, supercritical CFB power generation technologies and facilities, coal conversion technologies involving coal liquefaction, coal gasification and coal chemical engineering, coal gasification based co-production technologies, and comprehensive pollution control technologies and facilities.

2.1.1.6 Other Economic Policies

- Taxation

Taxation is an important tool for government to encourage resources and energy conservation. Rate for Resources Tax on coal has already been increased for the sixth time since 2004. In 2006, the State Council issued an Implementation Program for Pilot Reform on Deepening the Payment

Rules for Using Coal Resources, which has indicated that to increase the tariff of coal resources will still be the direction of Resources Taxation reform in future years.

Besides the Resources Tax, Coal Resources Compensation Fee has been charged to increase the coal price to reflect the cost of resources degradation and environmental treatment. For example, Shaan'xi Province charges 15 RMB per ton as coal price adjustment fund since 2006.

But up to now the rates on coal resources taxes are still low and contribute to only a small part of the overall coal price.

- Tax Exemption

Tax exemption has already been one of the major tax tools to encourage efficient resource use or clean technology. For example, income tax exemption, VAT exemption and accelerated depreciation have already been applied to encourage advanced technology transfer, and domestic equipment manufacturing.

- Pricing

Prices for refined oil, natural gas and electricity are still controlled by the government. The high price of oil and low availability of natural gas reinforce the role of coal as the major fuel for electricity.

Coal has already been priced on the market and kept at a high price in recent years. The higher the coal price, the more efficient coal plants will gain economic advantages. But government failed to suck the rent of resources by taxation from the high coal price.

2.3 Recommendations on Complementary Policy Instruments

Table 11. Policy Instruments Matrix for Accelerating Technological Improvment

		Invention, R&D	Innovation: Demonstration	Diffusion	Market streamlinin
Carrot	Public expenditure, subsidies, soft loan, government investment/purchase	+ +	+ +		
Positive incentives	Loan guarantee			+	++
	Tax exemption, tax holidays		+	+	+
	Tradable credit (sell) – cap and trade				
	Favored treatment in project approval and other permits in land use, loans, etc.		+	+	+
Sticks	Pollution charge				+
	Energy taxation				+
Negative incentives	User fee				
	Tradable credit (buy) – cap and trade				
	Ban or limited permits			+	+

Through the above review, we can see that: the policy for encouraging USC has already been formed, further policy is required for enforcement; there still needs policy to push the demonstration of IGCC; there is no clear consideration about CCS in current policy matrix. In terms of the policy instruments, government mainly rely on regulatory policy instruments to achieve energy conservation and emission reduction, but economic instruments and indirect incentives should be applied as lubricant to balance the interests of different stakeholders or for better enforcement. In addition, the clean coal technologies were mainly pushed or pulled by industrial policies, instead of environmental policies or technology management policies, although environmental policy can provide strong incentive for clean technology innovation, which has already been proved by the FGD.

These should be major points for further policy recommendations.

2.3.1 Coal Efficiency Criteria

Coal Efficiency is an important parameter to measure the technological economic performance of coal electricity generation facilities. It is largely decided by the systematic design of the facility, and can also be measured to show its operational performance, only that it has never been taken seriously when there is no strong or compulsory requirement on reducing the coal consumption, especially in the state-owned monopoly sector where competitiveness mechanism does not work well. But it is a practical and powerful tool for management in achieving higher coal efficiency in two ways: to be a benchmark for project approval, or to be a criteria to decide the priority in allocation of sales quota, though both of which an incentive for enhancing coal efficiency can be provided to the facilities.

We recommend that performance standards on coal efficiency for the power sector should be set up. This can provide investors with guidance on the direction of technology innovation, while still leaving the choice of technology adoption to enterprises themselves.

2.3.2 Price and Sales Quota

For mature technology, price and sales quotas are the key elements to determine its financial feasibility and thus the market diffusion speed. Although price competitiveness has already been introduced to the power generation side to some degree, the whole system is still controlled by the government. Therefore, the government should keep providing favorable conditions with price and sales quotas to help these technologies penetrate the market, especially in this transition period of the economy.

Generally speaking, a two-part-tariff electricity pricing system will increase the competitiveness of large scale and high parameter units, so the government should accelerate the pricing reform toward a two-part-tariff electricity price.

A sales quota allocation system has already been oriented toward encouraging clean electricity technology, and is expected to reconcile the potential conflicts between introducing competitiveness in the electricity pricing system and achieving energy conservation and emission reduction. But this system should be based on a transparent information system to avoid new rental-seeking and market distortion in this process.

In terms of specific types of technology, USC requires a large initial investment but has good financial feasibility, especially large-scale economy, which means it will get better competitiveness when its large capacity can fully be operated. So the market diffusion process of USC mainly depends on whether a USC facility can get a large enough sales quota.

2.3.3 Public Investment

Public Investment should support demonstration projects to facilitate the technological innovation process. For example, most of the major technologies adopted by electricity groups are required to have experience of commercial operation, government can provide opportunity for enterprises to get commercial operation experience through demonstration project. Technologies such as IGCC, Large-scale CFB, and domestic-made FGD, need demonstration before adopted by the market.

Demonstration projects are not necessarily fully-supported by public expenditure; rather the public money is meant to attract private investment to set up a Public-Private Partnership.

As we can see from the above scenario, enhancing coal efficiency can contribute to carbon reduction by reducing the coal consumption, but it is not enough in terms of carbon reduction to confront the climate change by only enhancing the coal efficiency, the policy has to leave room for other technologies to get more carbon reduction, such as CCS. We also realize that there is no mandate on carbon reduction, so it is impossible to expect that the technological innovation toward CCS can be driven only by market forces. Instead government and the international community have to support the R&D on low-cost technological route to retrofit the USC/ IGCC with CCS when CCS is available.

The international community should push for intentional technology transfer to China as a way to speed up clean technology development, especially for those technologies without sufficient local co-benefit such as CCS.

2.3.4 Other policies providing economic incentives

With the reform of the power sector, the government should increasingly use indirect economic instruments such as tax, loan, subsidy support or fiscal transfer to provide incentives for technology adoption without too much intervening in the market choice.

For premature technology, project demonstration is necessary, but normally has high investment risk. The government should provide surety or loan guarantee to help enterprises get access to capital, or directly provide a government soft loan.

The pollution charge and coal resources tax tariff should be further enhanced to reflect the real environmental and social cost, which will provide incentives for developing clean coal electricity technologies.

Before China takes a carbon reduction target, it is not expected that emission trading will make effects.

2.3.5 Policies on demand management

As our scenario has shown, even with good enforcement, the current policy direction will not lead to enough carbon reduction in addressing the climate change issue, so policies on the demand side will be needed, such as encouraging clean electricity purchases, or promoting electricity savings in all major users, such as manufacturing, construction, steel and iron industry, etc.

2.3.6 Policy Implementation and Stakeholder Feature

2.3.6.1 Stakeholder Feature

Surrounding the advance coal electricity technology, there are different stakeholders:

- Government:
  - Central government, local government
  - Governmental sector: NDRC, MOST, STA, MOF, SEPA;
- Multilateral Organization: UN, WB, ADB, ...;
- Enterprises:
  - Coal industry
  - Equipment manufacturers
  - Electricity companies: Hua Neng, Shen Hua, and others
  - Grid company
  - Chemical industry
- Financial organization/mechanism: banks, funds, other potential investors
- Academia: basic research and applied development
- Household

NDRC, MOST, STA, MOF, SEPA are key governmental sectors related to advanced coal electricity technology development. Environmental policy designed by SEPA primarily focuses on end-of-pipe control of conventional pollutants, so it has been successful in promoting the clean technology of end-of-pipe treatment, but failed to drive the clean combustion technology.

As for enterprises, because government has set up clear signal for developing SuperC and USC, equipment manufacturers and electricity companies have already been oriented on this track. Grid companies should provide infrastructure for the large scale deployment of SuperC and USC, but is not on the same pace. Coal industry, electricity industry and chemical industry should cooperate with each other to promote IGCC on combined production, but this cooperation has not started yet due to institutional obstacles.

Domestic investment played the major role on electricity technology development.

2.3.6.2 Policy stability

Long term technology strategy and its implementation policies should be clarified as early as possible. Technology choice in the power sector has a significant impact on the whole economy, and should meet the national interests. Different technology choices always mean different “winners” and “losers”, the key is to provide a predictable environment for all stakeholders.

To be exact, a clear requirement and timetable for de-nitrogen should be set up as early as possible, so as to encourage de-nitrogen technology innovation, or other technologies achievement combined reduction of sulphur and nitrogen.

No matter when China takes a quantitative carbon reduction target, government should set up a long-term time table for the technological strategy for carbon reduction technologies.

2.3.6.3 Improving the grid and electricity transfer system.

Some research has already identified the potential constraints from the grid capacity on developing large scale high parameter units. So increasing the grid capacity and other infra-structure of electricity should be seriously considered to avoid creating a secondary problem in the future.

2.3.6.4 Setting up clear and transparent system for electricity pricing and sales quota allocation

Electricity pricing and sales quota allocation system are still on the way of reform. Uncertainty in electricity price policy, as well as the sales quota policy, will no doubt bring investment risk for technology adoption. Government should aim to establish a fair and transparent investment environment to reduce the risk of investment on advanced technology, by establishing a clear and transparent decision process on electricity prices and sales volumes.

3. Automobile Fuel Economy: Technologies, Effects, and Policy Integration

3.1 Analytical framework

To analyze the current situation of vehicle’s fuel economy and the possible win-win policies in China, we must consider the key elements which can influence the total fuel consumption of vehicles. There is a formulation,

$$\mathrm{TFC}_j = \beta \times \sum_i \left(\mathrm{VS}_{i,j} \times \mathrm{AMV}_{i,j} \times \mathrm{AFE}_{i,j}^{-1}\right).$$

In the above formulation, *i* means types of vehicles, *j* means different years, *VS* means *Vehicle Stock*, *AMV* means *Average Mileage per Vehicle per year*, *AFE* means *Average Fuel Economy per car,* and β is a constant. *TFC* means *Total Fuel Consumption.*

From the formulation, we know there are 3 factors to influence total fuel consumption of vehicles: vehicle stock, average mileage per vehicle per year, average fuel economy per car.

As illustrated in figure 6, we draw the analyzing framework, in fact, vehicle technology and fuel technology as well as the road and drivers can influence the average fuel economy per car (AFE), the economic variables such as per capita GDP and some policy measures with economic incentives (such as fuel tax, congestion toll & parking fee) can influence the vehicle stock (VS), whilst this kind of policy measures also can influence average mileage per vehicle per year (AVM).

The motor system determines the efficiency with which fuel is converted into vehicle power. The motor technology and transmission technology can improve the convert efficiency. Simultaneously the fuel quality determines the fuel economy and the main options are substitute fuel, fuel cell, hybrid, and battery-electric.

Car weight and aerodynamics have a major influence on the amount of fuel used per kilometer. Use of different materials can reduce weight.

At the same time, speed, style of driving, tire pressure, load factors, congestion and road surface all have impacts of fuel consumption.

Ultimately, the CO2 emission by vehicles is determined by total fuel consumption (TFC), and directly or indirectly, local air pollution and oil safety is determined by total fuel consumption (TFC).

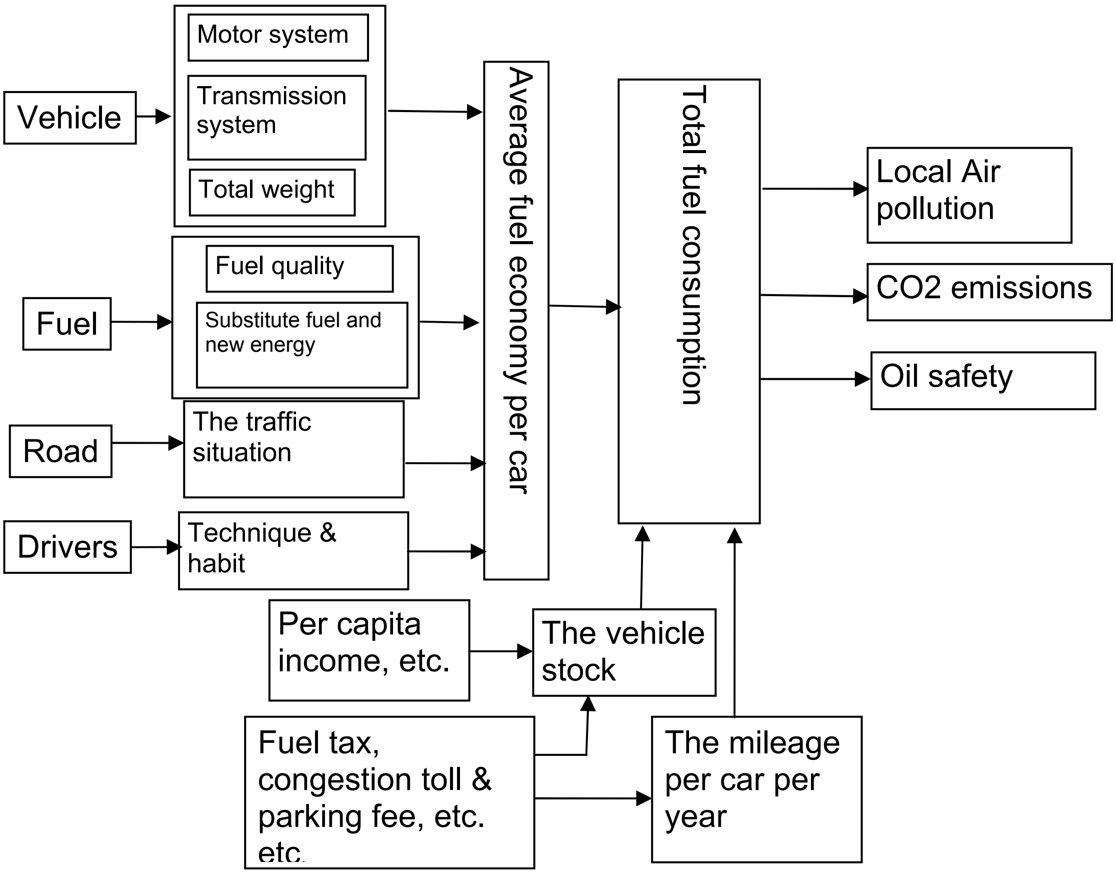

Figure 6. The analyzing framework

3.2 Technology options and potential assessment

3.2.1 The technology choices to reduce total fuel consumption of vehicles

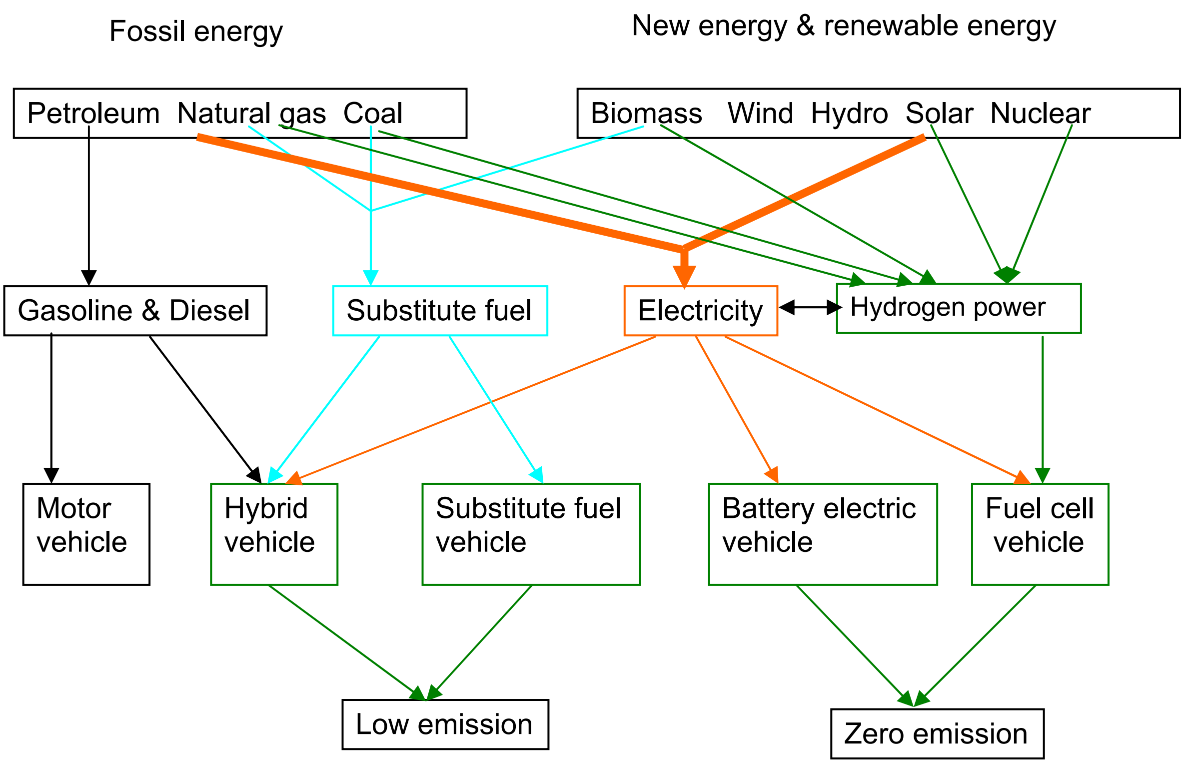

Figure 7. The technology choices to reducing the vehicles' fuel consumption and CO2 emissions[xiii]

Fuel is an energy carrier through which the primary energy source (e.g. oil or wind) is converted into final energy that powered our life (i.e the movement of the vehicle). As illustrated in figure 7, vehicle's fuel such as gasoline & diesel, substitute fuel, electricity and hydrogen power has a variety of primary energy sources, but currently, gasoline & diesel, whose source is mainly petroleum, dominates the vehicle's fuel.

Choice of energy source is the key determinant of vehicle's CO2 emissions. Sources such as coal, natural gas and biomass can be processed directly into liquid substitute fuels. All energy sources (including solar, wind, hydro and nuclear) can be used to make electricity to charge batteries or to produce hydrogen.

Compared with motor vehicle, hybrid vehicle and substitute fuel vehicle have a lower emission, battery electric vehicle and fuel cell vehicle have totally zero emission.

Table 12 shows the costs and effectiveness of fuel efficiency improving technology combinations. It focuses on the gasoline & diesel fueled motor vehicles, and the technologies are catalogued into three parts, the motor technologies, the transmission technologies, and weight and aerodynamics technologies. The data is collected from engineers of some Chinese automobile manufacturers. So the cost information only represents the Chinese automakers' cost.

Table 12. Costs and effectiveness of fuel efficiency improving technology combinations[xiv]

Technology combinations		Costs/yuan	Fuel reduction	Local pollutants reduction
Motor technologies	increase inlet air	1. Optimize air inlet pipe, 2. single cylinder 4-valve	3% reduction	Little effect
	Reduce exhaust pressure	Three way catalyst, muffler design optimization and matching, +100	Efficiency improve 1kw/5kPa, 1% oil reduction	Emission reduction
	Reduce motor friction loss	1. double over head camshaft (DOHC), +1400 2. optimize friction accessory, including piston, piston ring, cylinder sleeve, bearing shell, etc. +100	3% reduction	Little effect

	Reduce accessory power loss	1. electromotor water pump +500 2. electromotor oil pump,+800 3.electronic control assistant system (power steering, air compressor, generator, etc)	4% reduction	Emission reduction
	Multi point injection	+2000	10% reduction	Emission reduction
	Motor working process optimization	Little cost	Oil consumption reduction	Emission reduction
	Increase motor pressure	Increase pressure + inter cooling, +3000	3% reduction	Emission reduction
	Exhaust gas recirculation	+200	Not obvious	Emission reduction
	variable valve timing	+400	3% reduction	Emission reduction
	Exhaust gas post processing (diesel oxidation catalyst converter, diesel particulate filter, selective catalyst reduction etc.)	+2000	Oil consumption increase	Emission reduction
	Gasoline direct injection technology	+3500	10% reduction	Emission reduction
	Diesel (direct injection) high pressure common-rail technology	+4000	3% reduction	Emission reduction

	Lightweight motor	1、aluminum cylinder body, +500 2、plastic inlet pipe, -80(large amount)	Oil consumption reduction	Little effect
Transmission technologies	Increase shift gears(manual、automatic)	Cost increase	Oil consumption reduction	Little effect
	Gearbox form change	Cost increase when change from manual to automatic shift gear	Oil consumption increase	Little effect
	Continuously variable transmission	Cost increase	Oil consumption reduction	Emission reduction
Weight and aerodynamics technologies	Decrease wind resistance factor	Optimize design, cost increase	Oil consumption reduction	Little effect
	Decrease rolling resistance factor	Optimize design, cost increase	Oil consumption reduction	Little effect
	Decrease car weight	Optimize design, cost increase	Oil consumption reduction	Little effect
	New material	Cost increase		Emission reduction

3.2.2 Technology development in China

Technology choices describe a bright future for vehicles, but on the way to this future, there are many challenges, obstacles and uncertainties.

In "China Medium and Long Term Energy Conservation Plan", National Development and Reform Commission of China issued the following priorities to reserving petroleum consumption in road transportation sector[xv]:

- Eliminate old energy intensive automobiles by improving motor technologies;
- Develop diesel automobiles;
- Develop fuel cell vehicles;
- Develop hybrid vehicles;
- Popularize gas vehicle among such fields as city public buses and taxies;
- Promote methanol and alcohol-powered automobiles and develop substitute fuels.

But it will not be easy to achieve the goals of "China's Medium and Long Term Energy Conservation Plan".

China's auto makers have done a lot of work in the traditional engine technologies, but they still lag behind the standards of automakers from advanced economies.

Compared with the current gasoline vehicles, the advanced diesel vehicles consume 20% to 30% less fuel, but emissions of particulate and nitrogen oxides are higher than gasoline cars. However, China's goal of controlling urban pollutants limits its ability to promote diesel vehicles in the short run.

China's substitute fuel vehicles already account for a certain proportion of the vehicle fleet, but problems persist. The current large domestic natural gas bus engines mainly rely on imports, which is very expensive. Although the ethanol fuel technology has matured, it has to consume a large amount of grain. Because China has such a large population and little arable land, biomass ethanol fuel technology also has limitation.

Japanese and American automakers began developing hybrid vehicles 30 years ago, bringing them to market a decade ago, these vehicles are now part of mainstream vehicle fleets. In China, battery energy density, charge time, cycle life, and other technologies have not yet been resolved, these vehicles are not yet ready for the market. China's hybrid, battery electric vehicle technology development is faced with the following questions: battery electric vehicles, hybrid electric vehicle battery technology development and industrialization; engine electronic control technology and motor control technology development and industrialization; hybrid power matching and dedicated transmission lines and related technology development and industrialization; improve electric vehicle's power system energy efficiency, including increasing the electrical efficiency of controller, transmission efficiency; regenerative braking and vehicle braking system optimization. Battery electric vehicle technology's barrier is battery technology, and its continued ability, and fuel cell vehicles still in the stage of research and development, commercialization has a long way to go[xvi].

3.3 Options of enabling policy instrument

3.3.1 Integrated policy package

M1 passenger fuel economy standards in the implementation of Phase I have obvious effects on oil conservation and emission reduction. However China's total motor vehicle fleet and motor vehicle usage are both growing dramatically, so that road transport will become the fastest growing fuel consumer in the next few years.

At the same time, China's large cities have to bear the pain of traffic congestion. Traffic jams will further increase fuel consumption.

For the effective control of fuel consumption and transport sector's emissions of greenhouse gases, we must gradually perfect and implement mandatory policy measures and market-based policies with economic incentives. For example, in addition to fuel economy standards, a nation wide fuel tax could help control the vehicle usage. A nation wide consumption tax on purchased automobiles could encourage purchases of smaller cars. At the city level, traffic and road management policy could improve the traffic congestion.

Increasing funding for public transport will decrease usage of personal vehicles and therefore reduce greenhouse gas emissions. By increasing fiscal spending, Governments can further promote the development of the public transport system by reducing fares for passengers, give passengers subsidies and other measures.

For example, Beijing in 2005 promulgated the "Outline for the Development of Beijing traffic," to speed up the construction of large-capacity rail transit and rapid transit as the backbone, ground public transportation as the main body and the car to complement the integrated public transport system. During "11th Five-Year Plan" period, the public transport investment will be 45% of all transport investment. For this reason the Beijing municipal government has adopted a series of policies and measures, including: public transportation network optimization; Perfect transfer facilities; Bus priority right to increase the intensity of the road; A low fare policy; Accelerating public transport legislation to strengthen government supervision and standardize bus operator service standards, improve the operating efficiency of public transport and service levels.

Figure 8 shows the policy analysis framework to reduce road transportation's fuel consumption and CO2 emissions.

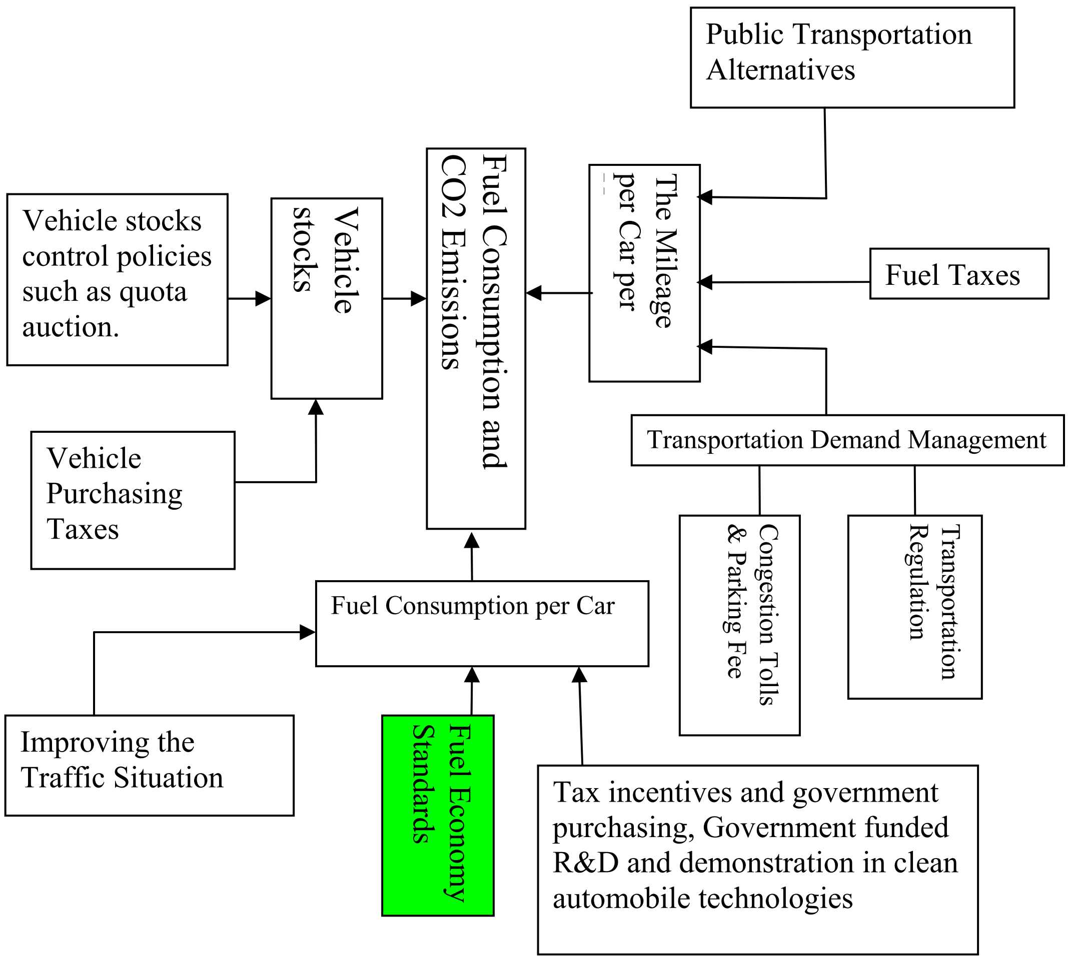

Figure 8. The policy package to reduce the vehicle's fuel consumption and CO2 emission

3.3.2 Fuel economy standard scenarios

Figures 9 and 10 show fuel consumption and CO2 emissions scenarios, which are based on the implementation of phase I fuel economy standards, whose effect will be an 8% improvement which will be increased a further 7% in phase II and 5% in phase III.

As to the vehicle stock, we assume that from 2002 China's vehicle stock increases at the speed of more than 10% per year. After 2008, China's auto market will enter a period of relatively slow development. The growth rate of vehicle stock will be lower than 10%. According to data obtained under the western countries regression curve equation $Y=29.551X^{0.8545}$ to calculate the vehicle stock in the future years.

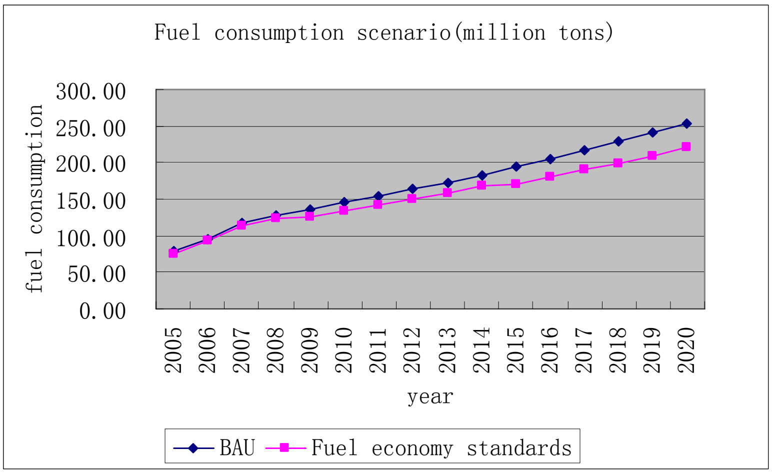

Figure 9. Fuel consumption scenarios (Fuel economy standards v.s. BAU)

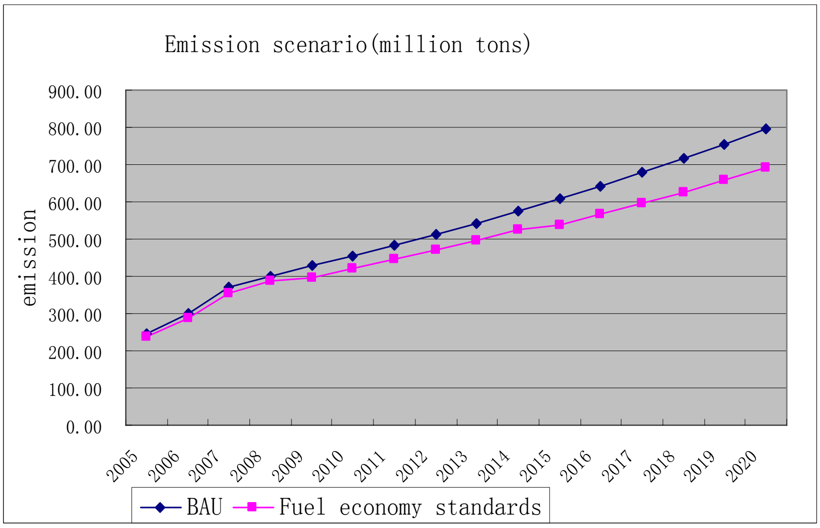

Figure 10. Emission scenarios (Fuel economy standards v.s. BAU)

3.3.3 Fuel tax scenario

Fu Sha used the CGE model to simulate a fuel tax scenario, if China implements a 20% fuel tax. From Table 13 we can see that in 20% fuel tax scenarios, the transport sector's CO2 emissions can be reduced 4.687%. Fuel taxes can have a substantial effect of emission reduction.

Table 13. Fuel tax scenario: the CO2 emission changes by sectors[xvii]

	Oil exploitation	Oil process	Natural Gas	Coal exploitation	Coal process	Electricity
CO2 emissions	-11.553%	-13.648%	-10.597%	3.158%	1.731%	2.991%
	Agriculture	**Light industry**	**Heavy industry**	**Building**	**Service**	**Transportation**
CO2 emissions	0.096%	0.350%	0.409%	-3.148%	-0.320%	-4.687%

Vehicle fuel economy standards have proven to be one of the most effective policy instruments in controlling fuel demand and greenhouse gas (GHG) emissions from the transportation sector in many regions and countries around the world. On 20th September 2004, the first mandatory fuel economy standards for the passenger vehicle fleet was approved and issued by Chinese government. The standards were designed to be implemented in two phases: Phase 1 has come into effect on July 1, 2005, for new vehicle models, and on July 1, 2006, for continued vehicle models. Phase 2 will take effect on January 1, 2008, for new models and on January 1, 2009, for continued vehicle models.

The standards mainly apply to the passenger vehicles whose maximum designed speeds are more than 50km/h, whose maximum designed weights are less than 3,500 kg with less than 9 seats. Only gasoline-fueled or diesel-fueled passenger vehicles are regulated under the standard, instead of those with other fuels. The standards are classified into 16 weight classes, ranging from vehicles weighing less than 750 kg to vehicles weighing more than 2,500 kg. The standards deal with passenger cars, SUVs and multi-purpose vans (MPVs), collectively defined as M1-type vehicles, separate standards for passenger cars with manual and automatic transmissions. SUVs and MPVs, regardless of their transmission types, share the same standards as passenger cars with automatic transmissions.

3.3.4 Standards and its economic implications

In China today, the legislation of the standards is considered one of the important policies and measures to establish & perfect the energy-savings standard system towards vehicles. The standards not only favor strained energy supply situation, but also promote the technology development in the transport sector. Furthermore they will contribute to the reduction of relevant negative externalities towards vehicles, such as that of GHG emission.

In a broad sense, besides the above standards, China's fuel economy standards also include the ones towards the commercial vehicles which were just issued on July 19, 2007. Strictly speaking, the correspondent test methods, examination & approval systems, standard labeling management, monitoring institutions and "carrots & sticks" measures should be included in such a complete standard system, too. Therefore the standards can be considered one of the comprehensive commands & controls instrument, including some economic incentives and the other measures towards awareness shift.

International comparison of the standards: Qualitative comparison

Relevant literatures show that presently there are at least nine countries and regions in which fuel economy standards are being executed or under discussion. Due to different historical, cultural and political backgrounds, the standards in these countries and regions are different in forms, types (mandatory or voluntary), measure units, application scale and test cycles, etc.

Table 14. Comparison of Fuel Economy and GHG Emission Standard around the World

Country/Region	Type	Implementation	Measure	Structure	Target Fleet	Test Method
Japan	Fuel	Mandatory	km/l	Weighted-based	New car model	JC08
EU	CO2	Voluntary	g/km	Overall light-duty fleet	All car models	EU NEDC
China	Fuel	Mandatory	l/100km	Weighted-based	New car model	EU NEDC
Canada	GHG	Voluntary	To reduce 5.3T in 2010	Cars and light trucks	New car model	U.S.CAFE
California	GHG	Mandatory	g/mile	Car/LDT1 and LDT2	New car model	U.S.CAFE
USA	Fuel	Mandatory	mpg	Cars and light trucks	New car model	U.S.CAFE
Australia	Fuel	Voluntary	l/100km	Overall light-duty fleet	New car model	EU NEDC
South Korea	Fuel	Mandatory	km/l	Engine size	New car model	U.S.CAFE
Taiwan	Fuel	Mandatory	km/l	Engine size	New car model	U.S.CAFE

Source：AN Feng,(2007),Comparasion of passenger vehicle fuel economy and GHG emission standards around the world (PPT),Seminar on fuel economy standard used in China held on 6th August, Beijing (China)

It indicates from table 14 that the fuel economy standards currently include three main types, such as fuel consumption control standard, CO2 emission standards and GHG emission standards. Most of countries and regions control vehicle fuel consumptions by means of fuel standard, voluntary agreements in terms of CO2 emission for EU and GHG emission standard for California and Canada.

Different from the standards in other countries and regions, a few features of the Chinese standards are as follows:

- The standards set up maximum allowable fuel consumption limits by weight category, instead of being based on fleet average. Every individual vehicle model sold in China must meet the standard for its weight class.
- The standards lack of relevant incentive or disincentive measures.
- The monitoring institutions are based on prototype vehicles, rather than production consistency.
- There is much work to do in terms of labeling management and information announcement of fuel economy.
- There is a small amount of capital used for standard research, not matching with the importance of the standards.
- Legal position of the standards should be further strengthened in the near future.

Quantitative comparison

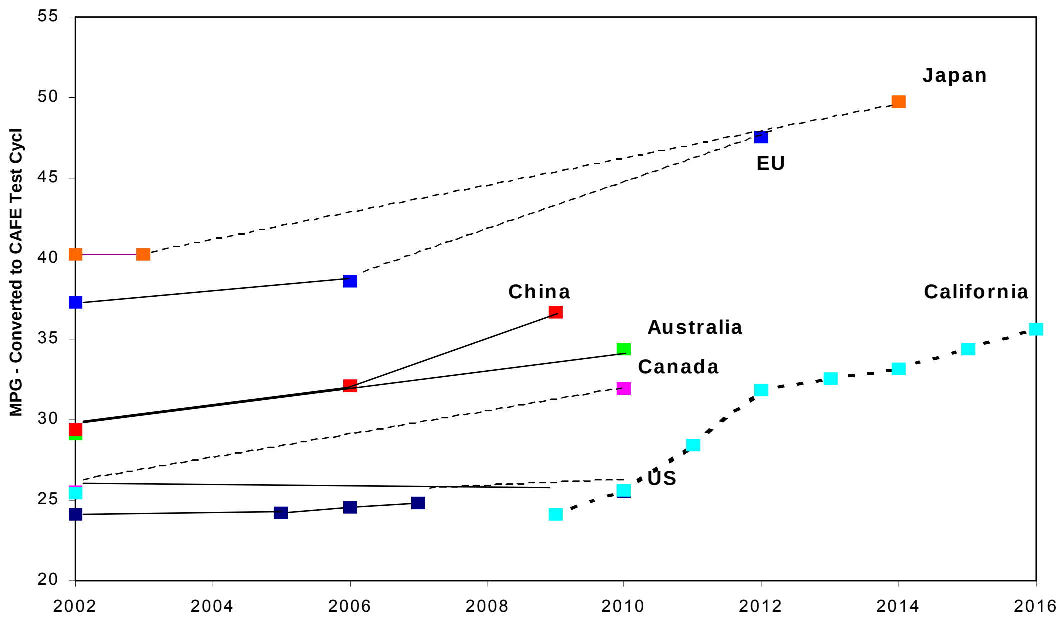

Figure 11. Comparison of fuel economy and GHG emission standards normalized by CAFE-converted mpg

Source：AN Feng,(2007),Comparasion of passenger vehicle fuel economy and GHG emission standards around the world (PPT),Seminar on fuel economy standard used in China held on 6th August, Beijing (China)

Figure 11 indicates that the European Union and Japan have the most stringent standards, and that the United States and Canada have the lowest standards in terms of fleet-average fuel economy rating. The figure also shows that the new Chinese standards are more ambitious than those in Australia, Canada, California, and the United States.

3.4 Analysis on stakeholders and evaluation of policy impacts in the last Phase I

3.4.1 Identification of main stakeholders

Similar to the standard system, in other countries, the main stakeholders of Chinese standards include governments, vehicle manufacturers, consumers, and the public as well.

(1) Governments

By the fuel economy standards, governments, as policy makers, are with the following multiple functions:

- To promote the technology development in the automobile industry;
- To address the vehicle energy supply security and climate concerns;
- To make the public benefit from the standards in terms of environment.

Similar to other product management systems, the standards in China have many corresponding administrative ministries, such as NDRC, MOST, SEPA and MOC, etc.

(2) Manufacturers

Manufacturers are major actors for the standards. According to current circumstances, they can be divided into three categories: joint ventures, domestic enterprises with one's independent marques and foreign manufacturers. At present, Chinese cars are mainly produced by joint ventures, which are usually supported in technology options by the foreign parent companies. Therefore they can easily meet the requirements of the standards, like foreign vehicle producing partners. As for the other domestic enterprises, they usually need a large amount of capital invested in design. And they might be influenced by an ambitious fuel economy standard system.

(3) Consumers

Consumers are one of the major stakeholders. On the one hand, they are indirectly the final undertaker of incremental costs from manufacturers which choose advanced efficient technologies to meet the standards. On the other hand, effective labeling and information announcement will contribute to their awareness shift in energy-saving and emission-reduction. If combined with relevant economic incentives, the demand towards vehicles will become more rational. So consumers play a crucial role in the implementation of the standards.

(4) The public

For governments, the interests of the public should be considered sovereign, especially in the democratic countries. As for the standards, the public can gain a lot of environmental benefits.

Besides, some research institutions and universities are also main stakeholders, which usually provide technique support in basic R&D. As for the standards, CATARC, Tongji University and Tinghua University are deeply involved.

3.4.2 Evaluation of policy impacts

(1) Impacts on governments

Implementation of the fuel economy standards not only contributes to the realization of targets in terms of energy savings and emission reduction, but also promotes the sustainable development in the automobile industry. Simultaneously, public revenues increase in a certain degree, by VAT, excise tax and income tax. Certainly, public expenditures are needed to invest in key energy-efficient technology R&D such as clean fuel technologies, by subsidies or soft loans.

With the implementation in the Phase I, oil savings of more than one million tons are gained. The average fuel economy in all regulated passenger vehicles has risen by about 8% during the period 2002-2006. The fuel consumption levels of high-weight categories reduced remarkably, compared with those of low-weight ones.

As emission reduction, the standard research institute of CATARC estimate that the average fuel economy of an individual passenger vehicle is presently at 200g CO_2/km or so, with a reduction of 8% compared to that in 2002.

In the automobile sector, due to the implementation of the standards, many advanced engine and transmission technologies have entered the passenger vehicle fleets in China. For example, multipoint injection, double overhead cam and variable valve timing are being substantially applied in the engine system. In transmission system, such technologies as continuously variable transmissions (CVTs), begin to be used gradually. Simultaneously, we can see that the use of high strength steel and light materials, such as Al, Mg and plastics, has increased a lot.

Besides, public revenues have been increasing by various taxes, with the growth of vehicle population. However, the prosperity of passenger vehicles has brought about a series of environmental issues such as air pollution, GHG emission and congestion. All the issues lead to the higher cost of administrative management.

(2) Impacts on manufactuers

Manufacturers have been paying much attention to fuel economy. Before the standards, they mainly focused on criteria pollutant emission, safety and motility, rather with fuel economy. To meet the standards, engine suppliers also have to be required to produce high efficient engines by manufacturers.

The low-emission or economy cars have gained a large share in the market, especially the ones with less than 1.6l. We find that the market share of these vehicles with 1-1.6 l has risen to nearly 50%.

To meet the standards, the pressure of various producers is increasing and the technique incremental cost is necessary for these stakeholders. Japanese or European joint ventures face with a lower pressure due to sufficient technology reserves from their parent companies, compared with other domestic manufacturers whose products are economy cars with lower profits.

(3) Impacts on consumers

According to a social survey conducted in 2006, it is found that consumers pay the greatest attention to car prices, and fuel consumption is ranked the third. Such results show that fuel economy standard plays a limited role in reducing energy consumption in transport sector. Simultaneously, the high sensitivity towards car prices implies that it would be feasible to introduce financial incentives in buying the high fuel economy vehicles.

(4) Impacts on the public

In a certain degree, the standards contribute to reducing the emission of criteria pollutants in the regional level and further improve public health.

3.5 Major findings and major issues

- As the first mandatory fuel economy standards, they play a positive role in promoting technology development in the auto industry. Although the standards greatly contribute to energy savings and emission mitigation in China, we can see the pressure of energy savings and GHG emission in transport sector has been rising with rapid motorization in this country.
- The policy target of “tightening big loosening small” has been substantially achieved with the implementation of the standards.
- Compared with other manufacturers, domestic producers with self-independent marques have fewer technology reserves and lower R&D capacities. So they will have great difficulty in meeting a more stringent standard system.
- At present, it is found that China lacks effective management institutions to regulate imported cars.
- China lacks the relevant incentive or disincentive measures for the standards.
- There is much work to do in terms of monitoring, labeling management and information announcement of fuel economy.
- There is a small amount of capital used for standards research, not matching with the importance of the standards.
- A policy portfolio, in which the fuel economy standard is one of the important instruments, is important and necessary to reduce transport energy consumption and mitigate GHG emission.

3.5.1 Technology implication

The currently implemented fuel economy standard (phase I for M1 passenger cars) has had a substantial effect of fuel consumption and CO2 emissions. To meet the standard requirements, automakers developed the motor and transmission technologies. But in the long term, since the traditional motor's efficiency improvement potential is decreasing, and the substitute fuel technology has some limits, especially in China, auto makers will develop or import hybrid, battery electric and fuel cell technologies to meet the next generation of standards.

3.5.2 Policy implication

M1 passenger fuel economy standards in the implementation of the Phase I have obvious effects for oil conservation and emissions reductions. However, China's total motor vehicle fleet and vehicle usage is growing dramatically, making road transport the fastest growing fuel consumer in the next few years. Thus, solely employing fuel economy standards will not be enough, China will need to adopt an integrated policy package, including mandatory policy measures and market-based policies with economic incentives, such as the fiscal and taxation policies.

Conclusion

The challenge of mitigating greenhouse-gas emissions in China is magnified by the expected addition to the population of about 200 million people over the next few decades; by continuing rapid urbanization and the associated increased energy use per capita; by continued growth of incomes and consumerism; by the expected especially rapid growth in energy-intensive industries such as steel and cement; and by the energy demands associated with the expanded transportation infrastructure necessary for China to participate more fully in the global economy. While there is a growing consensus in China on the importance of deploying climate-friendly energy technologies to ameliorate the greenhouse-gas impacts of all this growth, the economic incentives and government policies needed to adequately promote such technologies do not yet exist.

Coal will continue to be the dominant source of electricity in China for many decades to come. Our study's analysis of three scenarios for future coal-fired electricity generation in China -- Business as Usual, Advanced Technology (emphasizing ultra-super-critical power-plant technology), and Very Advanced Technology (emphasizing carbon capture and sequestration) -- shows that the Very Advanced Technology scenario, while offering by far the largest greenhouse-gas emissions reductions, is prohibitively costly under current circumstances and will not materialize absent drastic changes in economics and/or policy. The more likely path is the one modeled here by the Advanced Technology scenario, which entails accelerating the diffusion of ultra-super-critical coal technology, promoting commercialization of fluidized bed and integrated gasification combined cycle technologies, and significantly increasing R&D on carbon capture and sequestration. Achieving even this much will entail significant strengthening of relevant policies, and still it will be not enough to reduce absolute greenhouse-gas emissions in the face of the overall expected electricity growth.

China's passenger vehicle sector likewise presents enormous challenges in relation to reducing greenhouse-gas emissions. While the number of such vehicles in China grew at a rate of only about 1 million per year between 1990 and 2000, the rate of increase was over 3 million per year between 2000 and 2005. Length of highways is increasing in China far faster than the length of railways, which are much more fuel efficient, and the average fuel-efficiency of the current Chinese fleet is lower than that in OECD countries, vehicle type by vehicle type. Scenarios explored in this study show that full implementation of the passenger-vehicle fuel-economy standards currently projected for China will lead to some reduction in CO_2 emissions compared to "business as usual", but the absolute increase would still more than a doubling by 2020. Larger reductions would require much stronger measures. These would have a variety of co-benefits (e.g., in reduced conventional pollution and reduced oil imports, compared to business as usual), but many barriers experienced and perceived by a variety of stakeholders will need to be overcome for such measures to be realized.

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Annex 1. Review of existing scenarios of electricity demand and power capacity

Projections of future electricity demand in China are also of special interest since the amount and fuel mix of electricity generation will affect gas and coal markets and the environmental impacts of fossil fuel use. Figure 12 shows some recent projections of China's electricity demand. Figure 13 shows some recent projections of China's installed capacity.

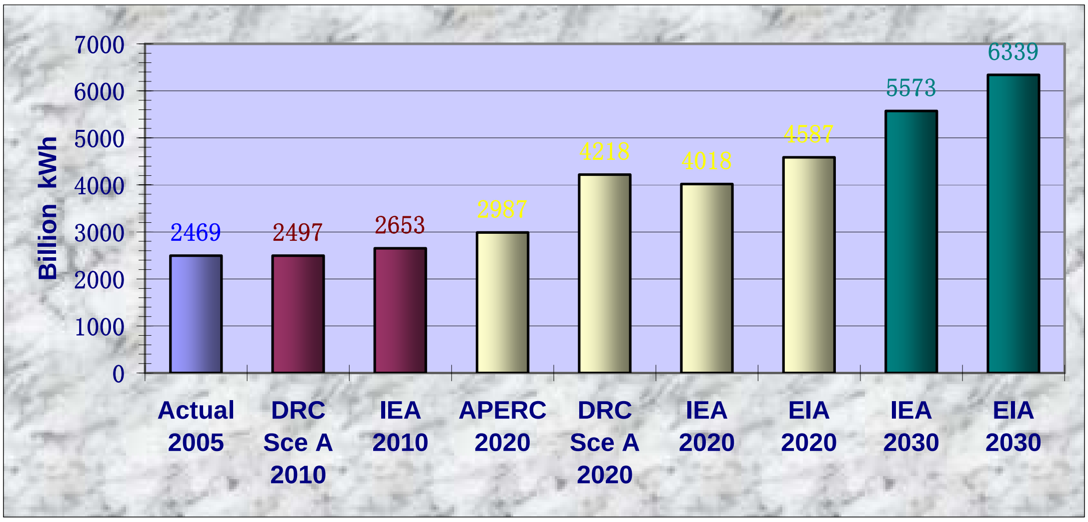

Figure 12 Alternative projections of Electricity Demand in China, 2010, 2020 and 2030
Source: NDRC (2006); APERC (2004); EIA (2007);DRC (2004); IEA(2004)

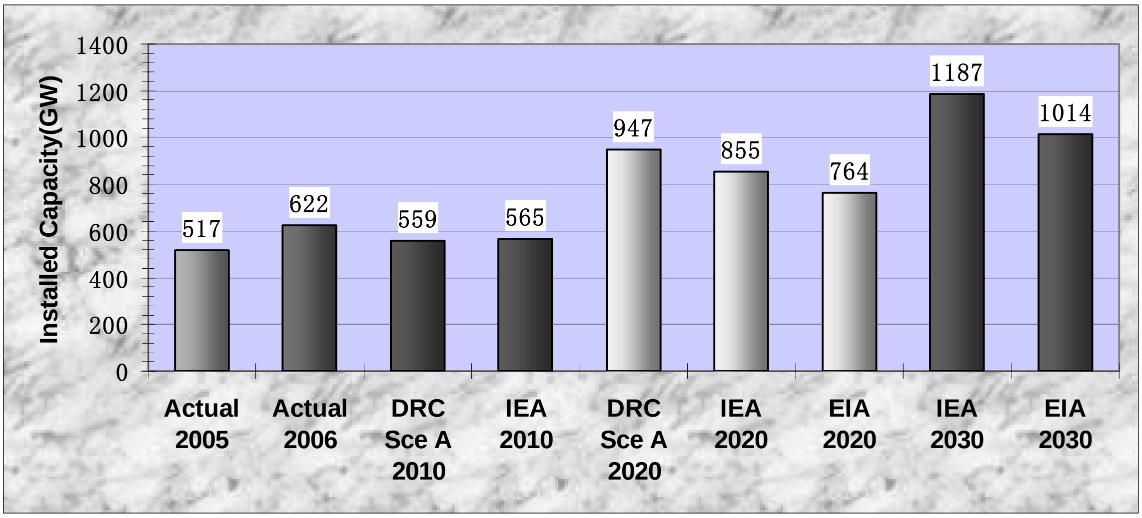

Figure 13 Alternative projections of Installed Capacity in China, 2010, 2020 and 2030
Source: NDRC (2006, 2007); EIA (2007); DRC (2004); IEA (2004)

Internationally, the most well-known projections are those of the International Energy Agency (IEA) and of the Energy information Administration (EIA), published in its Energy Outlook. In the 2004 edition, IEA projects 4,018 TWh of demand in 2020 while APERC and EIA (EIA, 2007) projections of 2,987 TWh and 4,587 TWh, respectively. Yet by 2030, IEA projects 5,573 TWh of demand, while EIA (EIA, 2007) projections of 6,339. For installed capacity, IEA projects 855 GW in 2020, while EIA projection of 764 GW. Yet by 2030, IEA projects 1187 GW of installed capacity while EIA projects 1014, 10% high compared to the EIA projection.

Within China, the main projection exercise has been that coordinated by Development Research Center (DRC) of the State Council, which assembled leading energy research institutes in China to prepare a National Comprehensive Energy Strategy and Policy for China. This strategy was released in Chinese in 2004, with an abridged English version also being released (DRC, 2004). It includes scenarios projecting energy use and CO2 emissions for China to 2020 on three bases: existing policies (scenario A), alternative policies, focusing on energy efficiency and sustainability (scenario B), and an 'advanced policy scenario' (scenario C). Scenario A has a higer rate of growth in Power demand than the other two scenarios.

Although the IEA, EIA and NDRC unchanged policy projection contains a significantly higher rate of growth in electricity demand and installed capacity than the other projections, figure 1 and figure 2 shows clearly that electricity use in China is expanding much more rapidly than envisaged in scenario A, EIA scenario and IEA scenario. Actual electricity demand in 2005 is 2469 TWh, very closer to the projected 2010 level of scenario A and IEA scenario. Actual Generating capacity in 2006 is 11.3% above the projection of scenario A for 2010 and 10% above the projection of IEA for 2010.

Linking Climate Policy with Development Strategy
in
Brazil, China, and India

Study on the Fuel Economy Standards of Passenger Vehicles in China

Sponsored by the Flora and William Hewlett Foundation

TIAN Dongmei, GUO Jiaqiang, ZHANG Jinhua i

China Automotive Technology & Research Center

Final Report COP-13
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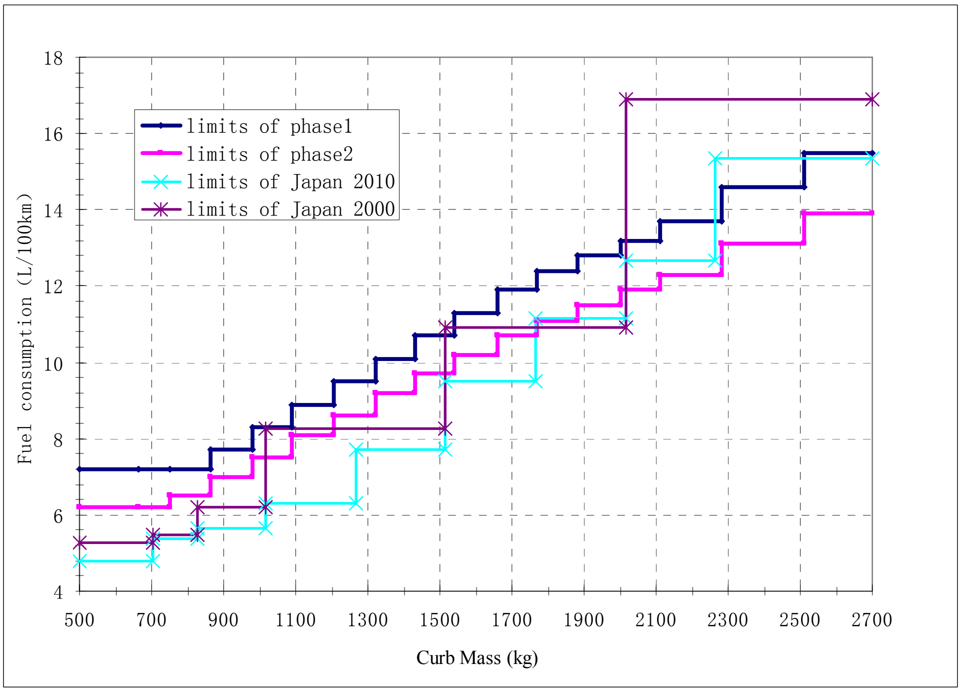
CONTENTS *(CLCIK ON HEADING)*

Executive Summary

The rapid growth of automobile industry contributes greatly to human development, but it brings along severe issues in energy consumption and environmental pollution. The Chinese automobile industry experienced a much rapid development from the 1980s, especially after 2000. China's vehicle population had increased at an average rate of 14.5% annually from 1985 to 2000 and the total vehicle population in 2000 was five times of that in 1985. In particular, in 2002, vehicle output & sales increased by more than 40% than 2001. The increase rate of passenger vehicle sales was over 50%. In that year, the vehicle output & sales totaled 3.6 million and the total vehicle population reached to 20 million in China. The Chinese government became very concerned about increasing oil demand from road transport and began to formulate a national fuel economy standard.

In 2001, several Chinese central agencies commissioned studies on energy saving standard for vehicles and on policies supporting such a standard. After much systematic effort, including collecting and analyzing vehicle fuel consumption and technology data, formulating standard draft, and soliciting comments from other government agencies, automakers and consumers, *Limits of Fuel Consumption for Passenger vehicles*, the first set of compulsory national standards on vehicle fuel consumption in China, were issued in September 2004,. In contrast to the corporate average fuel economy standard of the United States, the Chinese Standards are weight-based and comprised of standards for 16 different weight groups. (This method is similar to the method used by Japanese fuel economy standards.) The Chinese Standards include two phases: Phase 1 took effect on July 1, 2005, while Phase 2 will take effect on January 1, 2008. Phase II standards are 10-15% more stringent than the corresponding Phase II standards. The chart below shows the two phases of Chinese fuel economy standards by weight class, in comparison with Japanese ones.



Graph FS1. Compare of Fuel Consumption Limits for Passenger vehicles Between China and Japan

To date, the Phase I Standards have been implemented for nearly three years and Phase II standards are about to take effect. There were some questions to be answered: how have automakers responded to the standards? Are they ready to comply with Phase II standards? Could China adopt more stringent standards in the near future? To answer these questions, we carried out this study to investigate and analyze the effects of the Phase I standards, and to understand the potential for and challenges to more stringent fuel economy standards.

In this report, we have aimed to achieve the followings:

- A review of the process of the formulation of the existing fuel economy standards
- Assessment of the impacts of the Standards
  - Changes in fuel consumption of new passenger vehicles
  - Consequential government actions and policies
  - Influences on automobile and engine manufacturers
  - Oil saving benefits
  - Social benefits
- Assessment of the possibility of strengthening the existing Standards
  - Challenges from stricter fuel economy standards for passenger vehicles
  - Chinese government' view on more stringent standards
- Recommendations on potential policies for promoting better vehicle fuel economy

Important findings from this report include:

- The current Chinese fuel economy standards were mainly the results of the government's concern for oil security.
- The high attention given by the Chinese government to oil security and the participation of automakers during the formulation the Standards ensured the success of the standards.
- The standards caused considerable decrease of fuel consumption of new passenger vehicles. During the period of Standard formulation, the weighted average oil consumption of passenger vehicles was 9.21L/100km, almost 50% of cars failed to meet the Phase 1 requirements and 84% for Phase 2. While in 2006, the total weighted average oil consumption of passenger vehicles was 8.27 L/100km, down by 10% compared with 2002.
- The Standards promoted R&D and the application of new technologies for fuel economy by automakers.
- The Standards led to a small reduction of gasoline consumption and brought out social benefit.

  According to the Standard, fuel consumption of new passenger vehicle models in 2008 will be 15% lower than those made in 2002 and 2003. We estimate that about 600,000 tons of gasoline will be saved annually in 2008, and avoided expenses on gasoline would be 2.8 billion RMB.
- The Standards provided foundation for further government actions on transportation-related oil saving. China government put forward specific target on vehicle energy saving in several documents, such as the *Medium & Long-term Special Plan for Energy Saving* and *The 11th Five-Year Plan for Development of China Economy and Society* and so on. Meantime, the government also took active part in further study on more stringent standard for fuel economy.
- We believe that it's possible for China to launch more stringent standards on fuel economy for passenger vehicles in the future. The limits could be pushed up by 10% to 15% after 2012.

Background

Rapid growth of passenger vehicles urged the administrative departments of China Government initiated in 2001 a study on vehicle energy saving standards and policies. And then in September 2004, *Limits of Fuel Consumption for Passenger vehicles* (the Standard), the first compulsory national standard on vehicle fuel consumption in China, was issued. This Standard is supposed to be executed in two phases. Phase 1: since July 1, 2005, the Standard will become effective for all the newly approved models and for all models under production after a year; Phase 2: since January 1, 2008, the Standard will be effective for all the newly approved models and become effective for all models under production after a year.

The Standard has been executed for some time and is going to enter the second phase. However, we should solve some issues before the beginning of the Phase 2. For example, whether have the automakers made full preparation for the second phase? What're the responses from various parties? What issues prevent the Standard goes more severe? To solve these key issues in the development of China's automotive industry, we carried out this study program, which is supposed to be a reference for standard making and governmental administration.

Review on the Formulation of the Current Fuel Economy Standard

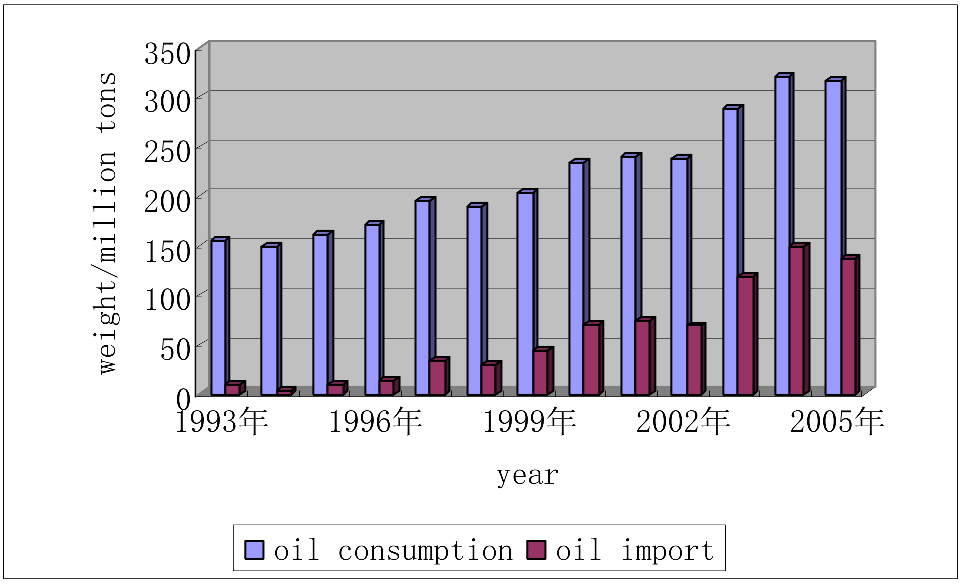
Background

Ever since a long time ago, environmental protection and population control have been two basic state policies of China. The current government advocates building an economized society and is planning to carry out a new state policy in respect of resource saving.

With the rapid development of national economy, China's vehicle population has been increasing at 14.5% annually from 1985 to 2000 and the total vehicle population in 2000 was 5 times of that in 1985. In 2002, China saw a great growth of more than 40% in vehicle output & sales compared with the previous year. In particular, the increase of passenger vehicles was over 50%. The output & sales totaled 3.6 million units and the total vehicle population reached to 20 million units. Rapid growth of vehicles, especially passenger vehicles, causes increasing fuel consumption. Automotive industry is faced with more and more severe issues in energy consumption and environmental pollution.

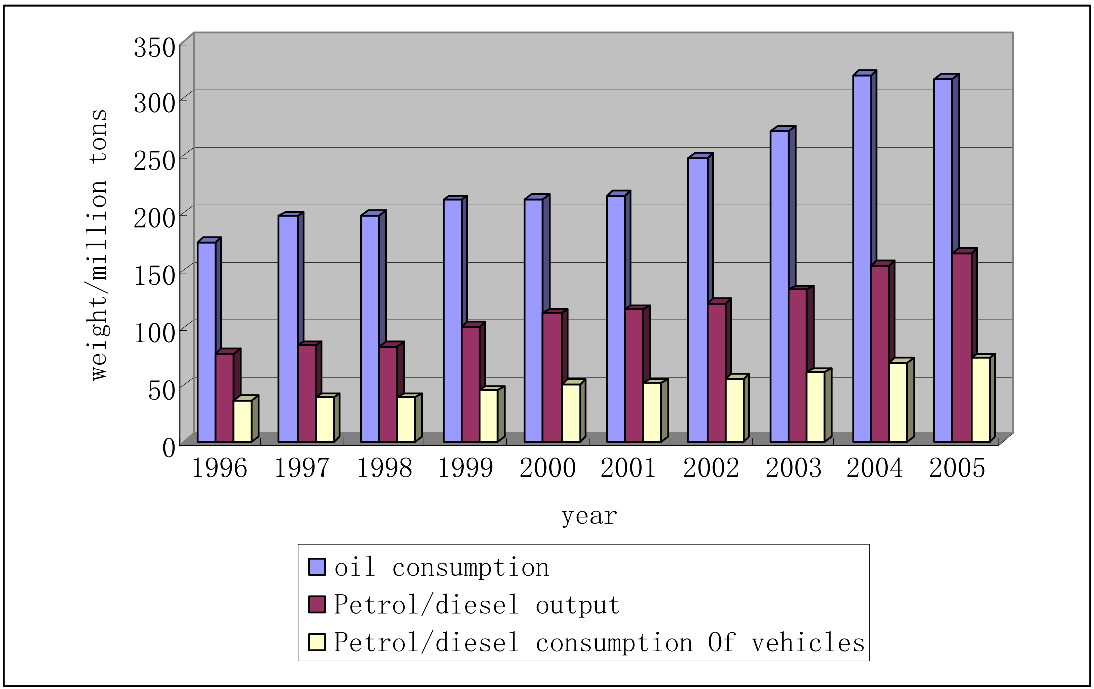
Tension between Oil Supply and Demand Calls for Fuel-efficient Vehicles

Since became a net oil importer in 1993, China depends more and more on imported oil and natural gas (as shown in Graph 1.1) to keep rapid economy growth in recent years. So the government calls for energy saving in various industries. As a big oil consumer, vehicle is consuming more and more petrol and diesel. Graph 1.2 shows that in 2005, 44.3% of petrol and diesel was consumed by vehicles, accounting for 24% of the total oil consumption. According to relevant forecast, by 2020, China will have to import more than 60% of oil. And vehicles will consume over 50% of the total oil consumption. Therefore, energy saving is a quite crucial issue for automotive industry.



Graph 1.1 China’s oil consumption and import

（Source：China Energy Statistical Yearbook，1994~2006）



Graph 1.2 Petrol/diesel consumption of China's vehicles

（Source：China Energy Statistical Yearbook &China Automotive Industry Yearbook，，1997~2006）

Greenhouse Gas Effect Calls for Fuel-efficient Vehicles

Greenhouse gas (GHG), mostly consisted of CO_2, is the direct reason for global warming, which poses increasing threat to people's living and social development.

Vehicle, as one of the main moving polluters and therefore a main field for GHG reducing, is highlighted by all the countries around the world. For traditional oil-fueled vehicles, as CO_2 is the main content of the exhaust gas, to reduce CO_2 emission is to reduce oil consumption. Currently, many countries have issued limits of fuel consumption for vehicles or limits on CO_2 emission to reduce GHG emission.

China Lacked Limits over Vehicle Fuel Consumption

According to the *Kyoto Protocol*, most developed countries should undertake the obligation of emission reduction. Although there's no concrete requirement for developing countries, China, the second largest CO_2 emission country, has been acting with a sense of responsibility to the world to strive for GHG emission reduction in various areas and has worked out a plan for energy saving and emission reduction.

In the past, there were only recommended fuel consumption test methods in China. Various automakers chose different test methods according to their own requirements. As a result, the data of fuel consumption reported to the government and users deviated from the actual data.

In addition, as there was no state standard to limit fuel consumption, when researching or introducing new models, automotive industry only focused on emission, safety and drivability, while turn a deaf ear to fuel efficiency. The abovementioned situation urged China to make a reasonable fuel economy standard, which is supposed to promote application of new technologies, improve fuel efficiency of each vehicle and enhance control over oil consumption of vehicles.

In 2001, for the purpose of accelerating the formulation of energy saving standards and regulations for vehicles, China's administrative departments initiated this program of study on energy saving standard and relevant policy for vehicles.

Review of Standard formulation

High attention from administrative departments of the central government

Making fuel economy standard is a concrete measure for energy saving in transport field. And relevant administrative departments give close concern to the standard from formulation to execution.

1) To decrease energy consumption of automobile industry and reduce CO_2 emission, the former State Economic and Trade Commission of (SETC) imitated a *Study on Fuel Economy Standard and Policy for Vehicles in China* in 2001.
2) In 2002, Standardization Administration of the People's Republic of China issued a plan of formulating the standard of *Limits of Fuel Consumption for Passenger vehicles*. CATARC was appointed to be responsible for the study on vehicle fuel efficiency in China and helped built the standard drafting group, and the group members held lots of meetings to discuss troubles during drafting.
3) On Mar. 6, 2003, the former SETC issued a document of Industrial [2003] 21, *Notification on Fuel Economy Data Report for Automotive Products*. According to this document, all the automakers should adopt test method according to national standard of GB/T19233-2003 and report fuel consumption data of new approval models.. Meanwhile, the data should be publicized on the below website *http://www.mvgg.com/index.html*.

The abovementioned ministries and commissions conducted relevant studies with respective emphasis according to their functions. As the administrative authority of automobile industry, the former State Economic and Trade Commission (SETC) focused mainly on reduction of vehicle fuel consumption. Thus SETC started the study with controlling the fuel consumption of individual vehicle. Standardization Administration of PRC, as the administrative authority of standards, focused on technical section of standard drafting in its study. However, these authorities had the same goal, that is, to issue China 's standard of fuel consumption limits as soon as possible and to reduce vehicle fuel consumption as early as possible.

The measures taken by relevant departments show China government has been paying great attention on the formulation of vehicle fuel economy standard and trying to push forward the formulation via initiating major programs, issuing governmental documents and holding meetings.

Automakers took active part in the formulation and execution of the Standard

As automakers are directly influenced by the Standard, without the cooperation and support from the automakers, the formulation and execution of the Standard will not proceed smoothly. In fact, most of the automakers cooperated with the drafters and they agreed that the Standard could not only show the fuel consumption of various models, but also promote application of energy saving technologies and reduce fuel consumption of vehicles.

At the beginning, drafters had no related data. Then administrative departments notified automakers to collect and submit the data needed (as described in 1.2.1). And at the same time, drafters got some other data from state test centers. Thus drafters obtained a number of applicable data. To compare the fuel consumption between China and other countries, they also collected and analyzed many data from abroad.

In addition, some domestic automakers such as Guangzhou Honda, Shanghai Volksvagen, Shanghai GM, Dongfeng Peugeot Citroen, FAW-Volksvagen, Hafei Automobile, ChangAn Automobile, Pan Asia Technical Automotive Center and China FAW, sent their technicians to the drafting workgroup and help CATRC for the Standard drafting.

Apart from providing fuel consumption data, the automakers also participated in the discussions over various plans drawn by the drafters. And to match with the Standard, the automakers upgraded their technologies ahead.

To formulate this Standard, the drafters collected the following data and made further analysis:

- Passenger car fuel consumption evaluating systems in other countries;
- Domestic passenger car fuel consumption data;
- Fuel consumption data of passenger vehicles in other countries;
- Established fuel consumption databank for passenger vehicles of both home and abroad;

- Analyzed the characteristics and distribution of fuel consumption of passenger vehicles both home and abroad;
- Made economic analysis on the technique of reducing fuel consumption of passenger vehicles.

With the abovementioned data and analysis, the drafters formulated the limits of fuel consumption eventually, which is suitable for China's passenger car development.

Effect of the Current Standard on Passenger Car Fuel Economy

Changes in Fuel Consumption (Passenger vehicles) before and after the Execution of the Standard

Evaluating Systems

There are two major evaluating systems for fuel consumption in the world, one is Corporate Average Fuel Economy (CAFE) from America and the other is corporate average fuel economy in every weight group from Japan.

- **CAFÉ System of America**

The America established CAFÉ system, that is, the weighted average fuel economy value of annual sales of various models of one automaker should satisfy the Standard limits. To meet the requirements of CAFÉ, automakers can upgrade vehicle technologies or regulate the outputs of various models. CAFÉ system has been evaluating since the oil crisis in 1970s. As a kind of gross control system, CAFÉ isn't a limit on single model, but the models as a whole. Thus energy efficiency will be improved and CO2 emission will be controlled within emission targets, such as the targets listed in the Kyoto Protocol. Automakers are allowed to trade fuel economy quantum with each other or keep the remaining quantum for future.

Currently, the standards of CAFÉ are: 27.5miles/gallon (11.69km/L) for cars, 20.5miles/gallon（8.71km/L）for light-duty trucks (including SUVs and microbuses).

Although CAFE limits the total fuel consumption, the automakers can meet the limits by regulating the outputs of various models, as CAFE is an average value. Therefore many automakers do not try to research advanced technologies for oil consumption reduction. Instead, they reduce the average oil consumption by manufacturing some small-displacement vehicles with lower oil consumption. So the US automakers are slow in energy saving technology upgrading and as a result, the US automobiles become less competitive in international market in recent years.

- **Weight Classification System of Japan**

Japan classifies passenger vehicles according to the weight of cars and carries out different limits for different weigh groups. The weighted average fuel economy value of annual sales of various models in each weight group of one automaker should satisfy the Standard limits. Different weight groups have different standards. Automakers could transfer the remaining quantum of one group to another with a discount of 50%.

As weight is the basis of this system and fuel economy is influenced directly by vehicle weight, so automakers, whether light or heavy-duty car manufacturers, are faced with the same pressure in improving fuel economy.

- **Europe and Other Areas**

So far, Europe has no compulsory standard for vehicle fuel economy. But the European Union reached an agreement with European Automobile Manufacturers' Association. According to the agreement, automakers could meet the average corporation CO_2 emission target at their free will. However, some countries suggest promoting this agreement by emission quantum trading.

- **China**

In China, there're many automakers while vehicle models are few. Therefore, the range of vehicle weights is narrow in one automaker. As vehicle weight is a main factor for fuel economy, if China adopts CAFE system, the space to improve fuel economy will be different for the automakers if they observe the same standard. And CAFE system will not promote automakers to upgrade their technologies, especially the demand for family cars is increasing rapidly in recent years and most Chinese families prefer small economic type cars. To improve vehicle fuel economy as a whole, China should upgrade the technologies of both heavy-duty cars and small cars. So weight classification system is chosen as fuel economy estimating system in China, in addition the fuel economy value of every model should satisfy the Standard limits instead of weighted average value in each weight group of one automaker in Japan. Such a system will help to improve the fuel economy of all kinds of models and reduce the whole oil consumption.

Fuel Consumption Lowered Obviously after the Implementation of the Standard

Most automakers believe the formulation of fuel economy standard could promote technology upgrade and improve fuel economy and is a main energy-saving measure in China. Before initiating the compulsory Standard, automakers concerned more about emission, safety and power performance, R&D and application of new technologies to improve fuel economy were not the first concern, although oil price was growing and consumption tax was levied according to different displacements. However, early when the Standard was under formulation, automakers began to prepare for improving the fuel economy of their products. Many automakers even took the limits of Phase 2 as fuel consumption standard of their newly developed products. Some automakers sent the Standard to their engine suppliers and asked for engine upgrade. In recent years, although the increasing oil price and high consumption tax levied on large-displacement vehicles have posed some impact on the product structure of passenger car makers, the ultimate reason of increased fuel economy is the execution of the compulsory Standard, because the Standard defines the limits and timetable for fuel economy control.

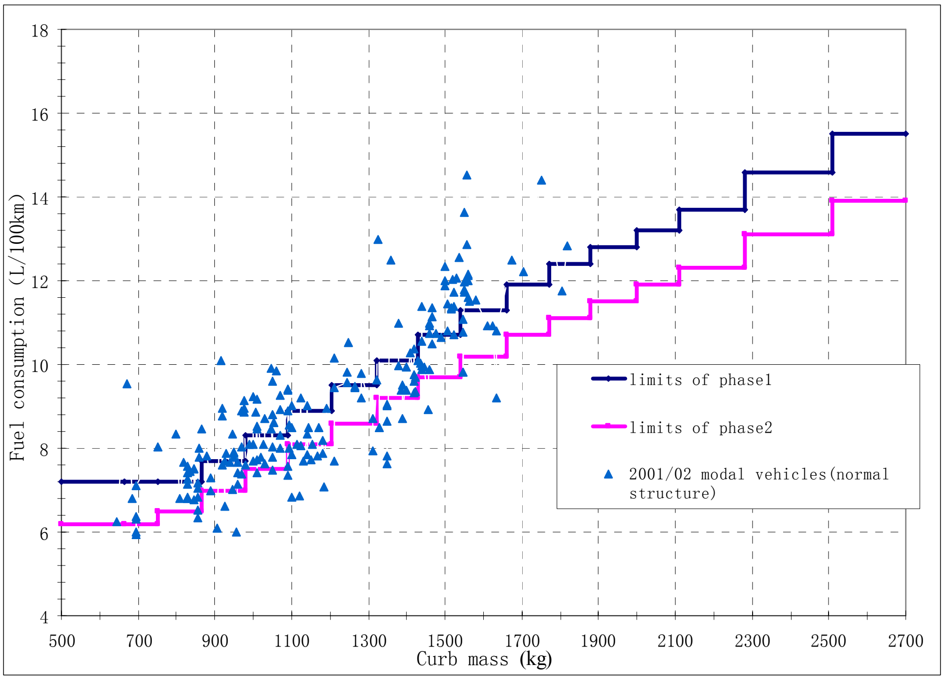
Since the issue of the Standard, fuel economy of each model has been increased obviously.The followings are the changes:

Note: Special structure passenger vehicles in the below graph refer to the cars with one or more of the following characteristics:

a) cars with automatic transmissions;

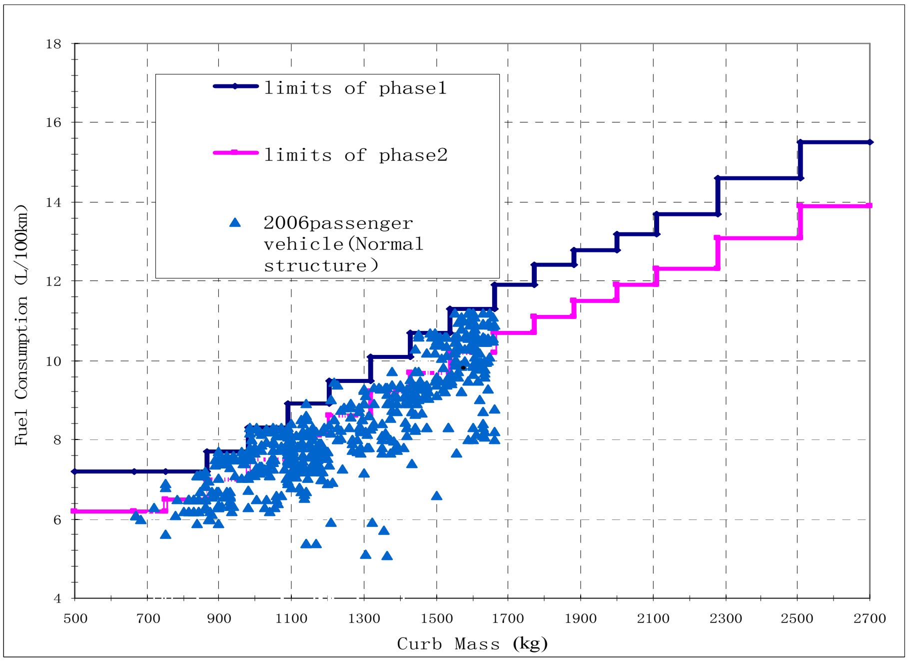
b) Arranged with 3 or over 3 rows of seats;

c) M_1G vehicles being coincident with sector 3.5.1 in national standard of GB/T 15089-2001.



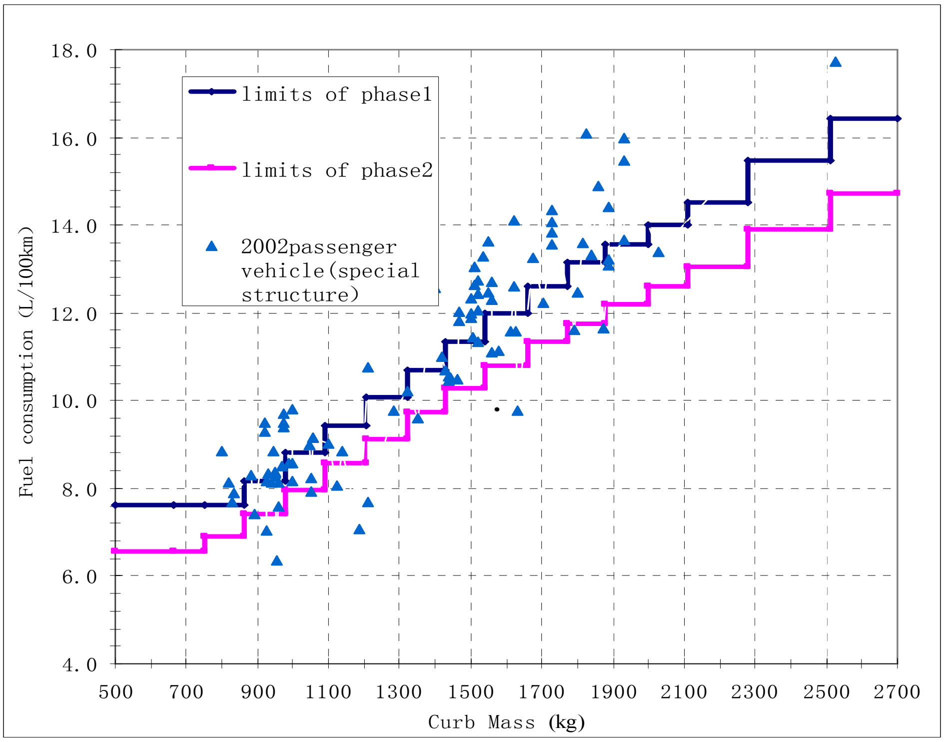
Graph 2.1 Fuel Consumption of Normal Structure Passenger vehicles in 2002

source:（CATARC，2002）



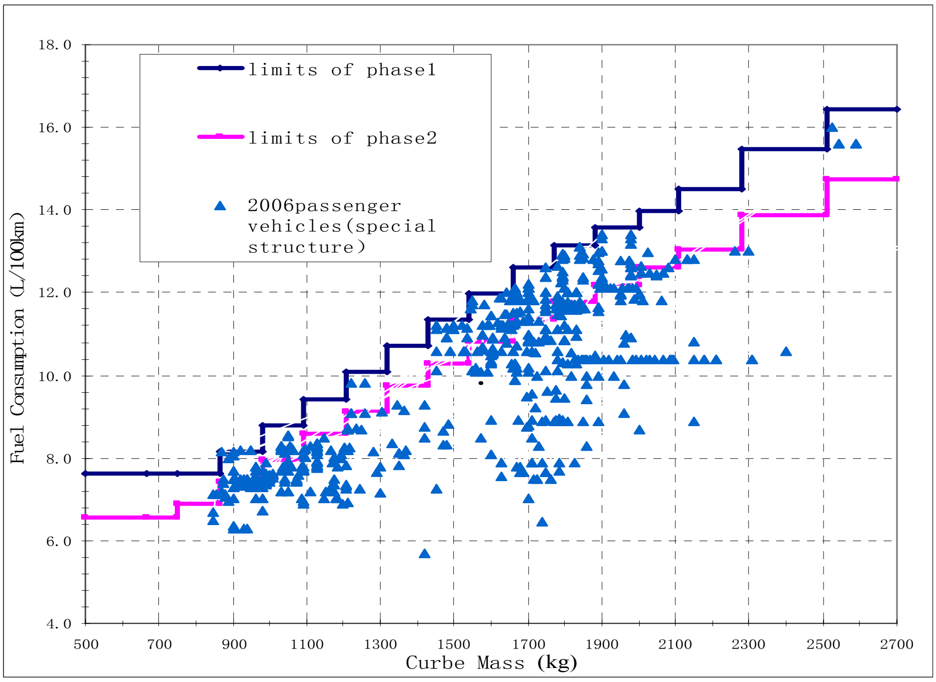
Graph 2.2 Fuel Consumption of Normal Structure Passenger vehicles in 2006

source:（CATARC，2007）



Graph 2.3 Fuel Consumption of Special Structured Passenger vehicles in 2002

source:（CATARC，2002）



Graph 2.4 Fuel Consumption of Special Structured Passenger vehicles in 2006

source:（CATARC，2007）

We can see from Graph 2.1-2.4, data collected during the Standard formulation period (from 2001 to 2002) show that the weighted average oil consumption of normal structure passenger vehicles was 8.94L/100km. Compared with the limits on fuel consumption, around 40% of these cars failed to meet the requirements of Phase 1 and 82% for Phase 2. However, in 2006 the weighted average oil consumption of normal structure passenger vehicles was 7.63L/100km, reduced by about 15% compared with that of 2002. All the new models met the requirements of Phase 1 and about 68% met the requirements of Phase 2.

During the period of Standard formulation, the weighted average oil consumption of passenger vehicles was 9.21L/100km, almost 50% of cars failed to meet the Phase 1 requirements and 84% for Phase 2. While in 2006, the total weighted average oil consumption of passenger vehicles was 8.27 L/100km, down by 10% compared with 2002.

Thus it can be seen that fuel economy of passenger vehicles improved obviously.

Consequential Government Actions and Policies

Vehicle Production Management and New Product Test

- Adopted by National Development & Reform Commission (NDRC)

  The Standard of *Limits of Fuel Consumption for Passenger vehicles* becomes a significant technical gist for NDRC to enhance management over automobile products and relevant formulate energy saving policies and management systems for automobile industry.

- Adopted by Test Institutions in New Product Testing and Certification

As a compulsory national standard, *Limits of Fuel Consumption for Passenger vehicles* is used by test institutions in new product certification tests. These tests are made in accordance with the Standard and provide strict and detailed test data to administrative departments. Also, execution of the Standard promotes the application of advanced technologies in automobile industry, therefore all the models could meet the requirements of the Standard. In addition, this Standard is a reference for automakers in new technology research and development (R&D).

Basis of Formulating Related Preferential Policies

- Adopted by Ministry of Finance (MOF)

As a national standard, *Limits of Fuel Consumption for Passenger vehicles* is the main reference and technical gist in making energy saving policies, environmental protection policies and fiscal-tax policies in relation to vehicles.

"Compulsory limited standard plus fiscal-tax policies" is a general approach applied across the world for energy consumption controlling in automobile field. The State Council just issued a *Notification on Solving Some Main Issues in Near Future to Build an Economized Society*. To control energy consumption caused by rapid growth of passenger vehicles, MOF is studying this approach together with relevant ministries and commissions in order to formulate proper tax policies. These tax policies are supposed to encourage the development of vehicles with low fuel consumption and small displacement. Also these tax policies are hoped to be the basis of a long-term fiscal-tax mechanism on vehicle energy saving management.

Recently, MOF is discussing with relevant ministries and commissions on implementing different preferential tax rates to automakers in accordance with the percentages of the actual fuel economy of their cars lower than the limits of Phase 2. Also they are researching policy measures on application of some key energy-saving technologies.

China's 1st Energy Saving Standard for Vehicles

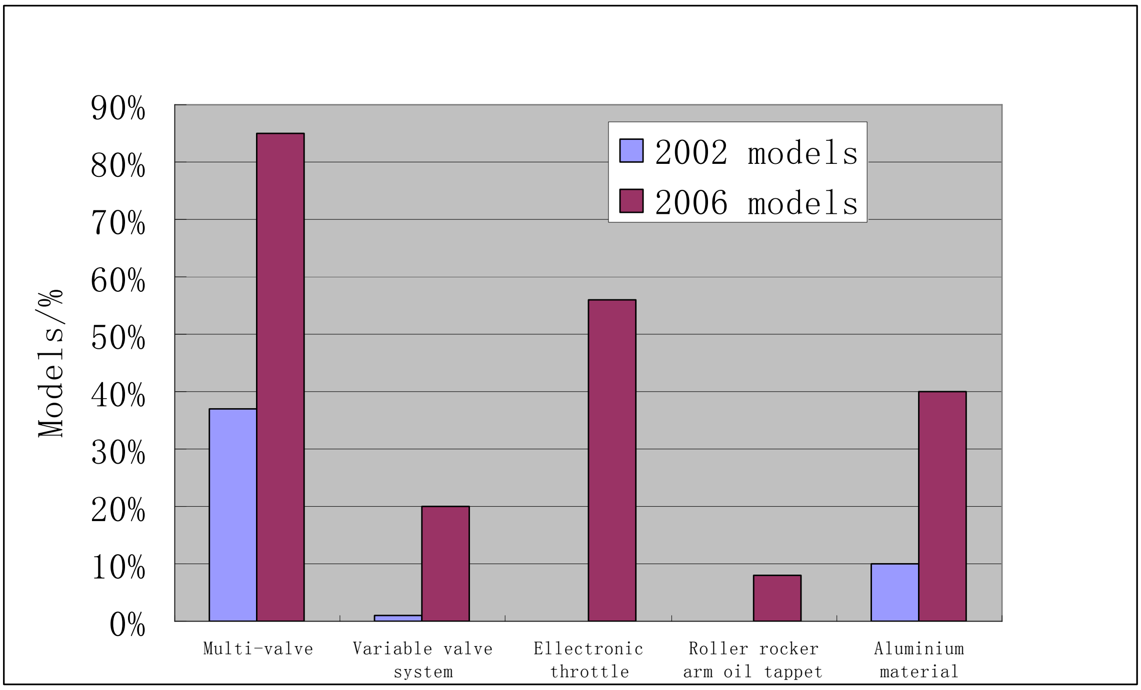
As China's first compulsory national standard on vehicle fuel consumption control, *Limits of Fuel Consumption for Passenger vehicles* further improved China's compulsory standard system on automobile products. Also it is quite helpful in promotion and application of energy-saving and environment-friendly technologies and facilitates the overall improvement of passenger car technologies.

The execution of the Standard for passenger vehicles creates wide influence. Based on the experiences from formulation and execution of this Standard, Standardization Administration of PRC had compiled fuel consumption standards for light-duty commercial cars which had been issued on July 19, 2007 and will be executed from Feb 1,2008. Meanwhile, drafting of fuel consumption standards for other models is also under preparation.

Influences on Automobile and Engine Manufacturers

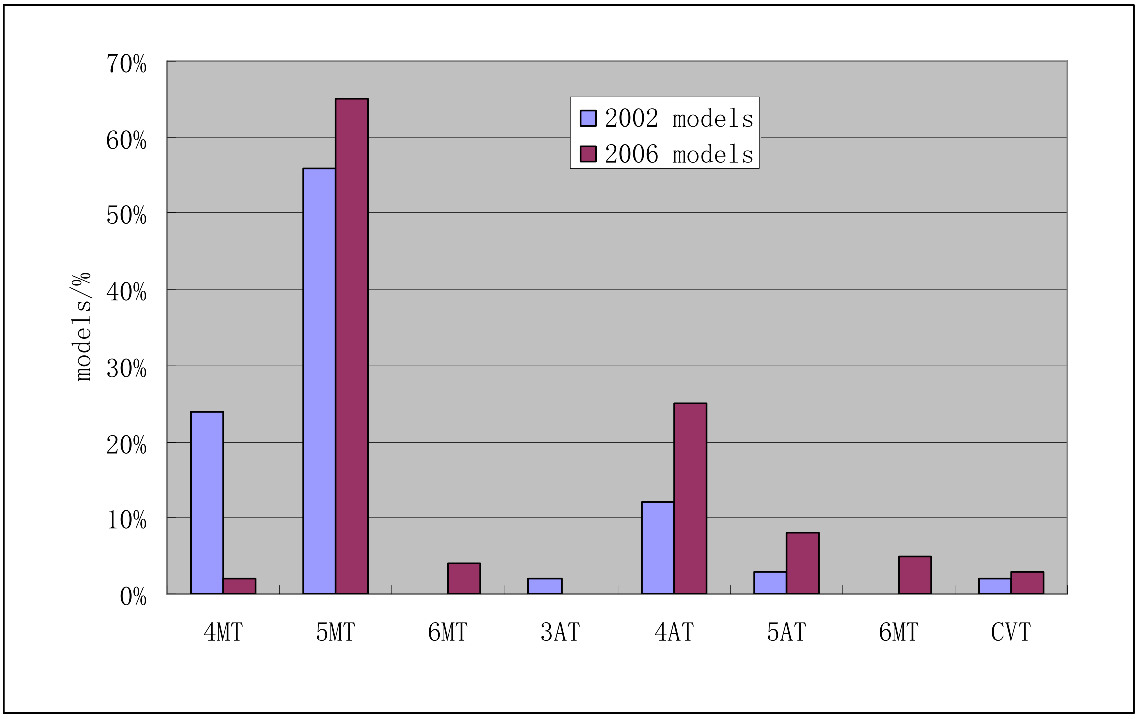
Promote R&D and Application of New Technologies

Since September 2004 when the Standard was issued, domestic automakers began to focus on developing or introducing new technologies that could improve fuel economy. In last few years, automobile JVs considered little about fuel economy when introducing new models. Some even introduced "eliminated" models from their parent companies into China. However, after the issuing of the Standard, they had to consider China's requirements on fuel economy and began to introduce models with advanced technologies. Thus the overall technology level of introduced models was improved. The technologies of China-owned brands have been upgrading all along. Execution of the Standard accelerates their technology upgrading and R&D. These automakers tried all efforts to meet the requirements of the Standard, via either technology R&D, or cooperation with foreign partners. Visible improvement is achieved in many aspects, such as engine technology, powertrain system and vehicle technology as a whole. Compared with old models, new models have higher compression ratio, lower drag coefficient and coefficient of rolling resistance. Also new engines use lubricant of higher classes. In addition, many advanced energy saving technologies have been applied in passenger vehicles, for example, multi-valve technology, variable valve timing technology, 6-speed automatic transmission and continuously variable transmission（CVT）, etc. The detailed proportions of these technologies can be seen in Graph 2.5 and 2.6.



Graph 2.5 Upgrading of Engine Technologies

source:（CATARC, 2007）



Graph 2.6 Upgrading of Transmission Technologies

source:（CATARC，2007）

To meet the requirements of the Standard, passenger car makers adopted some main measures such as upgrading engine technology, reducing car weight and upgrade driving system.

- Engine Technology Upgrade

Engine technologies are updated in the following aspects:

Firstly, multi-valve technology is widely adopted in most of the models. Multi-valve technology improves the volumetric efficiency of engine, optimizes the structure of combustion chamber and therefore improves fuel economy. Secondly, variable valve technology is gradually applied in passenger vehicles. This technology can greatly improve fuel economy. Open and close timing of inlet valves is controlled according to the RPM and load of engine, thus the performance of engine is improved and fuel consumption is reduced. A few of models even adopt variable timing systems both in inlet valves and outlet valves, which largely improves fuel economy. As electronic throttles are widely used, the opening of throttles is accurately controlled. In addition, some models adopt technologies that can decrease friction, such as roller rocker arm oil tappets, sliding bearings and low-friction lubricant.

In addition, some domestic automakers has introduced or developed gasoline direct injection technology which can improve fuel efficiency greatly.

The Standard also promotes the development of diesel engine cars. A few companies have introduced diesel engine models and at the same time, some domestic automakers are developing diesel engine cars.

Domestic automakers also show great interest in new driving system hybrid technology because of its excellent performance in oil saving. A lot of money and labor have been invested in the development of hybrid technology. To encourage the R&D of hybrid vehicle, China has established a special program for development of HEV. So far, several models of China-owned brand have passed the *Affiche of Manufacturers and Products of Automobile Industry*. Although the throughput of these new models is small, the manufacturing and marketing are underway. In addition, hybrid vehicles are running in 4 cities as demonstration.

- Car Weight Decreasing

To reduce oil consumption, automakers have kept running on the way of decreasing car weight, especially the weight of medium and high-end models. Some measures have been taken to make cars less heavy, including adopting aluminum sound insulation layer or very light sound insulation cotton, using high-strength thin sheet instead of low-strength thick sheet as car body material and choosing aluminum parts for engine.

- Driving System Technology Upgrade

Driving system is upgraded via increasing the number of shifts and adopting CVT. Among the MT cars manufactured in recent years, 4-shift cars are decreasing and in 2006, over 60% of the new cars are 5-shift cars. For AT cars, 3-shift cars are reducing while 4 and 5-shift cars are increasing. Moreover, 6-shift MT cars and 6-shift AMT cars have been unveiled. With increased shifts, the engine will be able to work in high-efficiency area longer. Thus the fuel economy is up and oil consumption is down. CVT also keeps engine working more in high-efficiency area. Some of domestic models adopt CVT technology.

The abovementioned new technologies show that the Standard accelerates the research and introduction of new technologies and fuel economy of newly approved models are improved. Thanks to the Standard, the fuel economy gap between China and international advanced level is narrowing.

Accelerate Product Renewal

Execution of the Standard lifts the market access threshold of passenger vehicles. As a result, outdated models are eliminated quickly and development of new models is accelerated.

After the execution of the Standard, some automakers asked their engine suppliers to upgrade engines in accordance with the limits of fuel consumption. Most automakers adopted directly the standard of Phase 2 when developing new models. So engine makers had to introduce or research new engines to meet their requirements. Some automakers even asked for new engines as early as the Standard began to be formulated.

Models and engines introduced from abroad also accelerated the application of advanced technologies in domestic products. In 2004 when the Standard was issued, Guangzhou Honda equipped DOHC i-VTEC engine, adopted electronically controlled variable valve timing system, into the new generation of Accord. POLO and Cross employed roller rocker arm technology，BORA and Passat adopted turbo-charge technology and Passat even introduced variable length intake tubes. Meanwhile, high strength steel and corrosion resistance coated aluminum alloy were widely used as material of car body. And CVT was used in some models such as Fit from Guangzhou Honda.

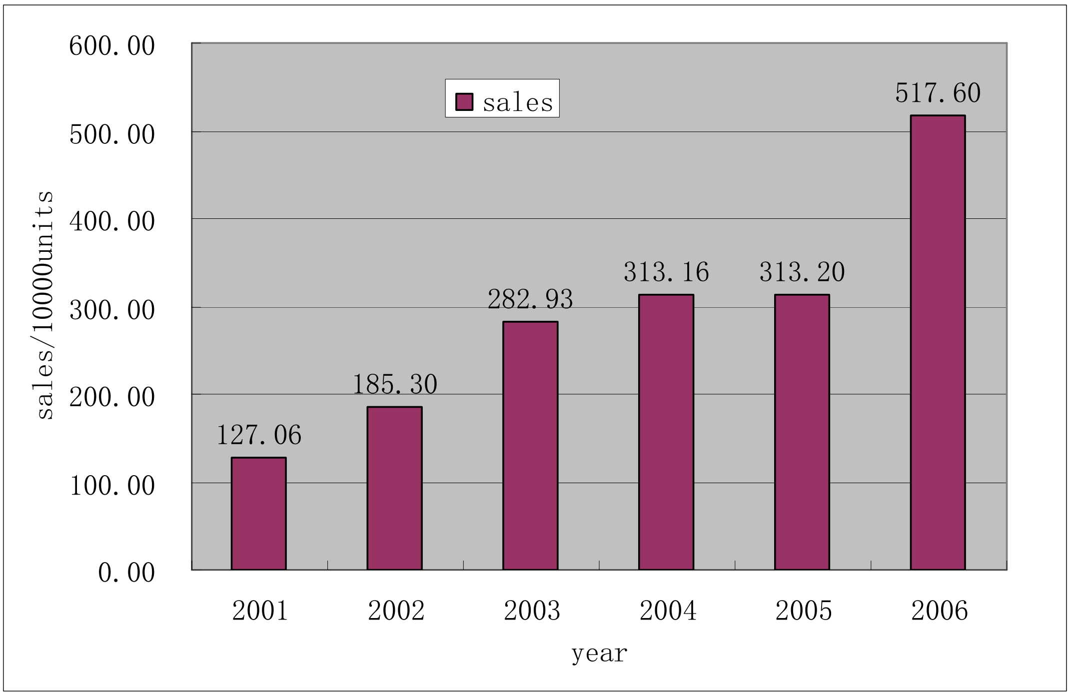
China-owned brands automakers accelerated R&D to assort with the Standard, Chery, a Chinese automaker that has been following the way of independent innovation, also accelerated R&D ,On one hand, Chery invested more in technology R&D, application and reserve, and built a research team of high technology level and high efficiency; on another, Chery established long-term strategic partnership with world famous design companies. Cooperative R&D was adopted in some projects and development cycle was thus shortened and product launching was accelerated. Meanwhile, technicians of Chery learned advanced technologies and design philosophy from their partners, thus narrowed the gap between China and world advanced level. Futwin Coupe –IV, was upgraded by Chery and its partner AVL, a globally notable engine design company. These upgrades were involved in many aspects, such as inlet system, outlet system, shape of combustion chamber, length of intake manifold, piston and so on. Thanks to these upgrades, fuel consumption of Futwin Coupe IV decreased greatly.

Also, the Standard promotes the development of small-displacement passenger vehicles. The sales of economic-type passenger vehicles kept increasing in 2004. Automakers also introduced many new models. In recent years, small-displacement cars are becoming the dominating force of passenger car market and market potential of small-displacement cars is huge.

Influence Automobile Sales

- Automobile Sales Structure Changed

Rapid growing economy boosts the sales of passenger vehicles in China market (as shown in Graph 2.7). The execution of *Limits of Fuel Consumption for Passenger vehicles* and the increasing gasoline price make more and more consumers choose small-displacement cars which are energy saving and environment friendly. Automakers take fuel economy as a very important index to lift their competitiveness.



Graph 2.7 Passenger Car Sales in China Market until 2006

source:（CATARC，2007）

Graph 2.8 shows the market shares of passenger vehicles with different displacements in China. We can see that market shares of passenger vehicles with displacement below 1.6L are increasing and almost 50% of the market shares are occupied by these cars. However, market shares of cars with displacement of 1.6L-3.0L are reducing in different extent. Because of the special users and applications, market shares of medium and high-end passenger vehicles with displacement over 3.0L have been influenced little by the Standard because of its specific characteristics for users.

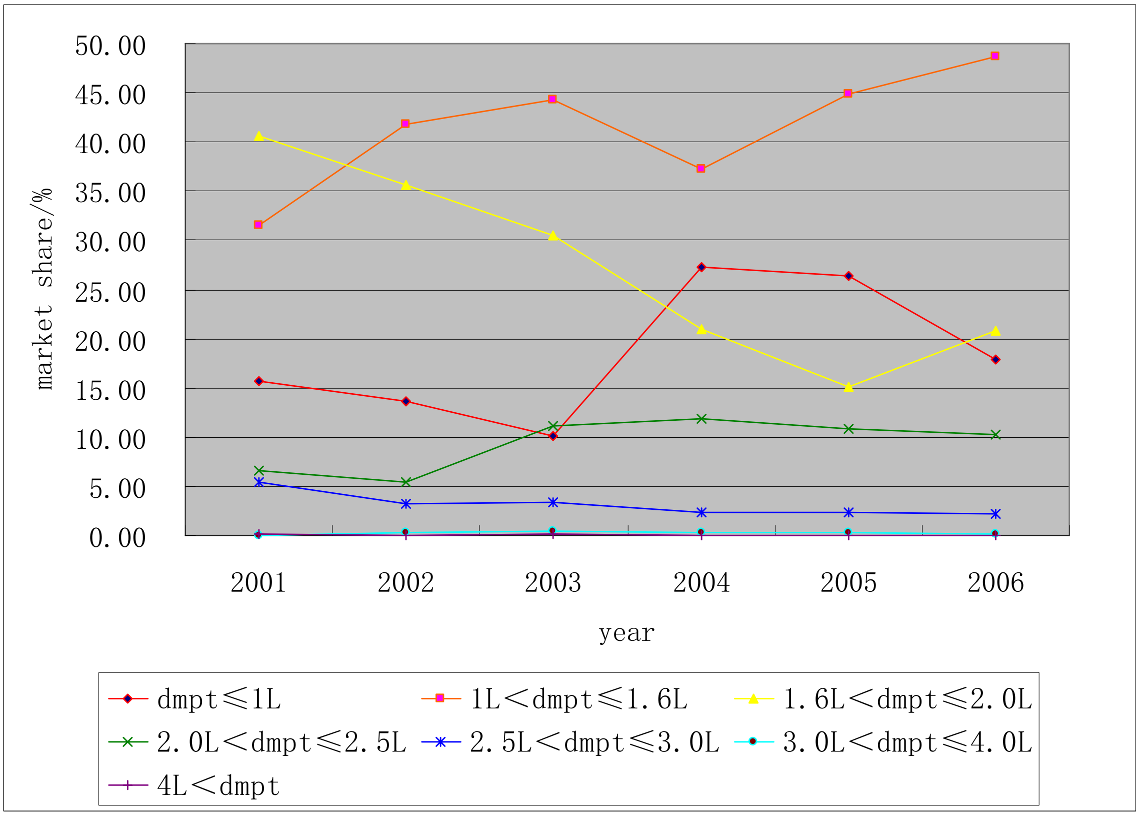
By 2004, some areas in China had issued some measures to control the development of mini-cars. In 2004, China issued a series of policies to encourage the development of small-displacement mini-cars. According to these policies, the local governments were not allowed to limit the development of small-displacement mini-cars. So mini-cars enjoyed an increasing market share in 2004 and there came over 10 mini-car brands, such as Xiali from Tianjin FAW, QQ from Chery, ALTO from ChangAn and Geely series. However mini-car's market share decreased in 2005 and 2006. The followings are the main reasons for the decline:

- After a price war, automakers of cars under 1.0L were in the red or earning very poor profits. The main mini-car makers, such as Tianjin FAW, Geely and Chery, began to focus more on higher-end products and almost launched no new mini-car models in recent years. The automobile JVs had no time for or distained to this low-profit section.

- Although it was jointly issued by six ministries and commissions in April 2006, the policy releasing mini-cars from prohibition was not well executed. Some cities still limit the development of mini-cars in disguised forms.
- According to the new consumption tax rates over vehicles implemented on April 1,2006, the consumption tax rates over mini-cars have not changed thus defeated the anticipation saying that consumption tax over mini-cars will be exempted, which also had some influence on the sales of mini-cars.
- New economic type models with displacements around 1.4L were more attractive to car buyers. These new models, such as Fit, Aveo, Lova and Accent, charactering advanced engines and low fuel consumption, were more competitive in both appearance and performance.
- The new tax policy lowered 2% of the tax rates over cars between 1.0L to 1.5L, thus the profit margin was increased. And consumption of these cars was spurred.

With the abovementioned factors， economic-type cars developed rapidly from 2005 to 2006 and occupied the market share of mini-cars. The growth of mini-cars was slowed down, while economic type cars saw an overall growth. Cars with displacements below 2.0L enjoyed most of the market shares.

Thus it can be seen that the execution of the Standard promotes the development of economic-type passenger vehicles and thus changes the overall sales structure of passenger vehicles without impact on the total sales of passenger vehicles.

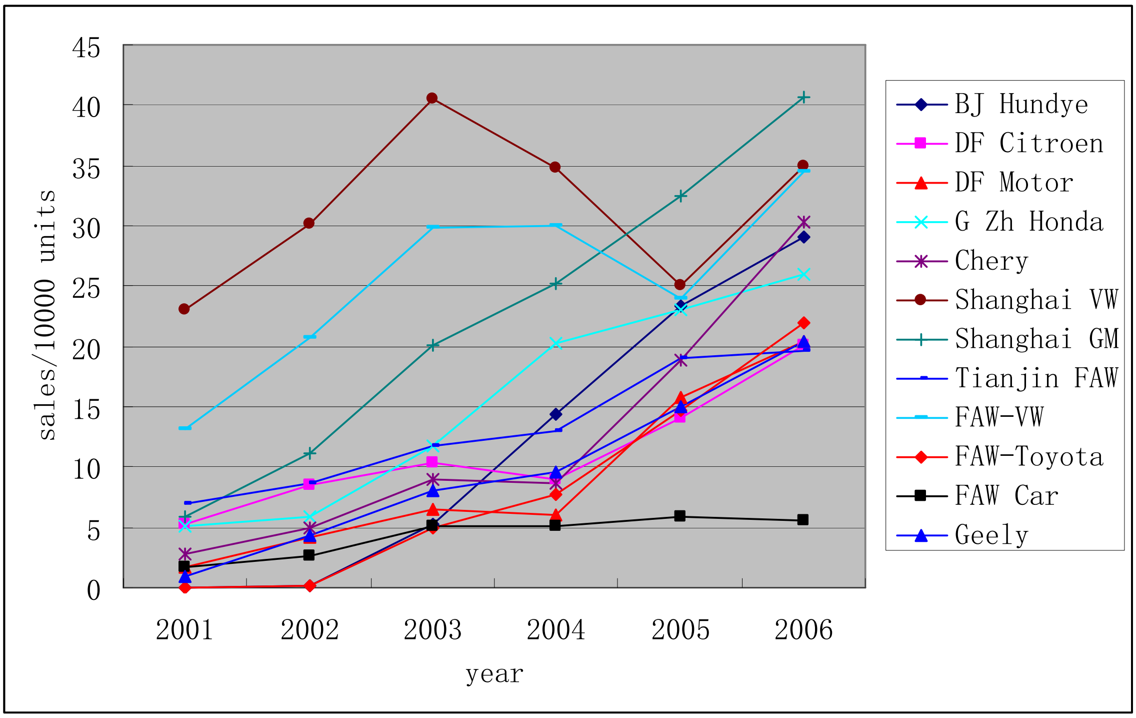


Graph 2.8 Changes of the Overall Structure of Passenger vehicles until 2006

source:（CATARC, 2007）

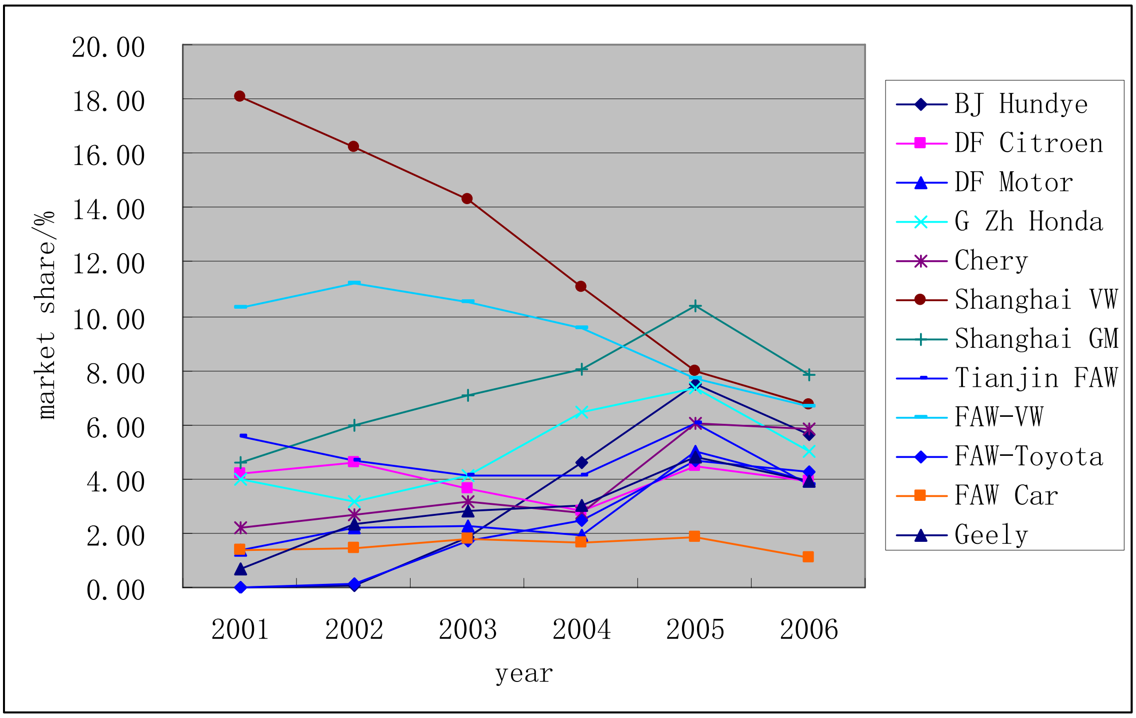
- Product Structures Changed

As different passenger car manufacturers have different basic models with different technical levels, the impacts of execution of the Standard on the manufacturers are different. Manufacturers whose products were more fuel-efficient are influenced less than those whose products were less fuel-efficient. However, as the manufacturers had begun to regulate their product structure before the execution of the Standard, the total sales and market shares of each manufacturer show that they have not suffered long-term impact from the execution of the Standard. The followings are the sales and market shares of some major passenger car makers in recent years:



Graph 2.9 Sales of Some Major Passenger Car Makers in China until 2006

(Source: China Automotive Industry Yearbook，2002-2007)

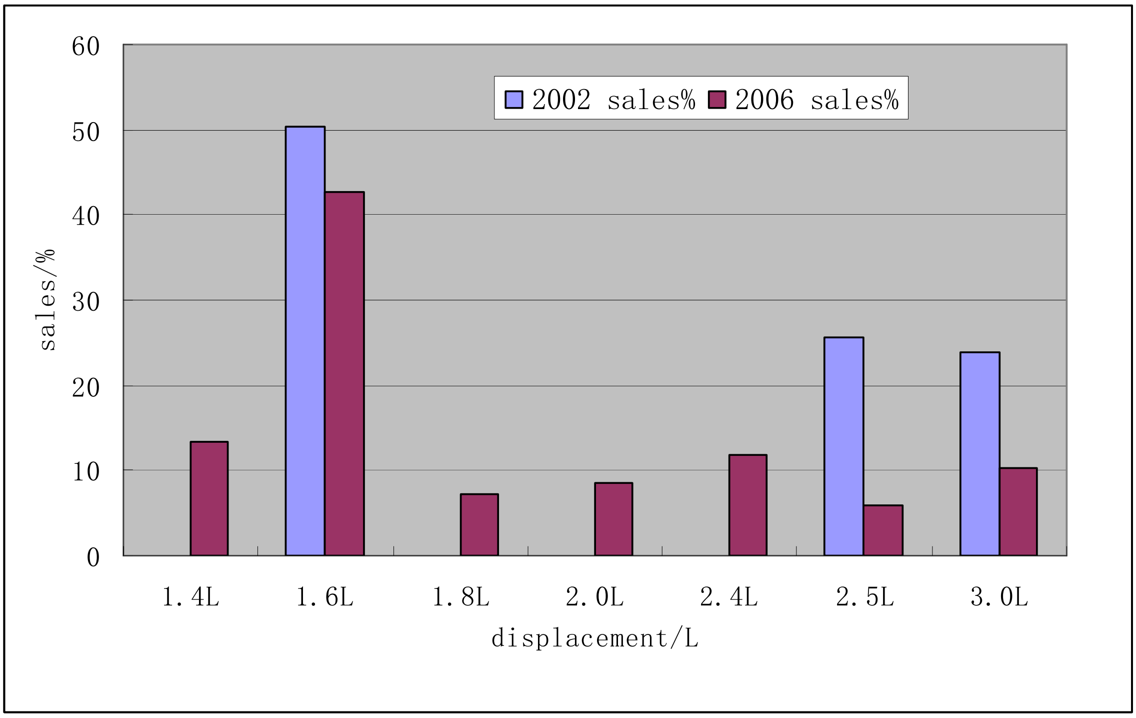


Graph 2.10 Market Shares of Some Major Passenger Car Makers in China until 2006

(Source: China Automotive Industry Yearbook，2002-2007)

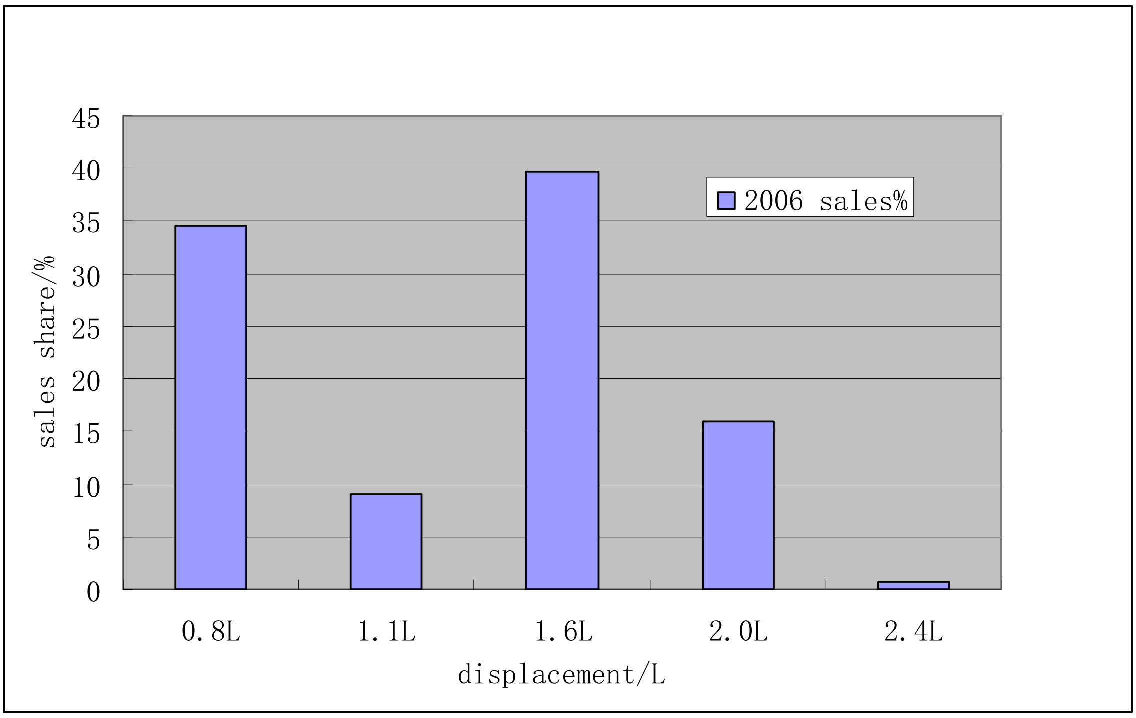
Companies with low fuel efficiency products, such as Shanghai GM who had only cars of two displacements in 2001: 3.0L（Buick G Class, Buick and Buick GL8）and 1.6L（Buick Sail）. The sales of these two displacements cars were almost the same. In 2004, to meet the requirements of the Standard, Shanghai GM employed low fuel-consumption engines and upgraded widely its products. In recent two years, Shanghai GM has been regulating product structure by increasing products with wider range of displacements, especially those under 1.8L. In 2006, sales of cars over 2.0L accounted only 30% of the total（see details in Graph 2.11）.

In recent two years, thanks to correct market positioning, Chery sees soaring sales. To meet the requirements of the Standard, Chery keeps only two models with displacement over 2.0L among over 10 models. In 2006, sales of 1.3L and 1.6L Qiyun and mini-car QQ (below 1.1L) accounted for 70-80% of the total sales (see details in Graph 2.12).



Graph 2.11 Product Structure Change of Shanghai GM

(Source: China Automotive Industry Yearbook，2003, 2007)



Graph 2.12 Product Structure of Chery in 2006

(Source: China Automotive Industry Yearbook，2007)

Product structures of other automakers are almost the same. Considering the impact of the Standard on consumers, automakers increased the percentage of economic-type passenger vehicles.

Promote R&D of Energy-Saving and Alternative Energy Cars

Tense resource supply and environment pollution pose more and more pressure on traditional vehicles. Automakers begin to pay more attention on energy-saving and alternative energy cars, such as CNG/LNG-fueled cars, LPG-fueled cars, ethanol-fueled cars, bio-diesel cars and HEVs.

So far, domestic automakers have made some achievements in R&D of energy-saving cars and alternative fueled vehicles. For example, Tianjin Qingyuan Electric Vehicle Co., Ltd. (Tianjin Qingyuan) and Tianjin Automobile Industry Group developed jointly an electric car with maximum speed of 120km/h and 252km running for each recharge. On December 20, 2005, Tianjin Qingyuan exported the first batch of "Xingfu Shizhe" (name of the net electric mini-cars) to America. In addition, Dongfeng and FAW have issued hybrid electric vehicles (HEVs) with China-owned brands. During the 10th Five-Year Plan, HEVs were seen running for demonstration in 4 cities: Wuhan, Shenzhen, Weihai and Zhuzhou. ChangAn has also developed its HEVs. In AUTO China 2006 (the automobile exhibition held in Beijing), Chery showed its HEVs for mass production.

So far, traditional cars have been depending on introducing technologies from other countries to meet more and more severe requirements. In this energy-saving and alternative-energy age, domestic automakers hope to seize the opportunity to develop China's independent-brand models and national automotive industry.

Economic Benefit of the Standard

According to the limits of the Standard, oil consumption of new models in 2008 will be 15% lower than those made in 2002 and 2003. That is 3 percent on average annually. And suppose that models under production account about 30 percent every year, so actually the average oil consumption of individual model will be decreased by 2% annually. 38 million tons of oil was consumed by automobiles in 2003, on modest estimation, 30 million tons of gasoline were consumed by passenger vehicles then after the execution of the standard, 600,000 tons of gasoline will be saved annually at least, equal to 2.8 billion RMB.

Social Benefit of the Standard

Execution of the Standard will save a number of oil and will be much helpful in relieving energy tense and increasing energy security of China.

To reduce GHG emission is a big challenge for all countries. According to Kyoto Protocol, China, as a developing country, will not undertake obligation of emission reduction. However some developed countries refused to sign Kyoto Protocol by arguing that China is the second largest GHG emission country. The issue of the Standard arose great response in these countries and reports and comments were found in many famous medias, such as *New York Times*. The issuing of the standard shows China is willing to undertake its responsibility and make its contribution in GHG emission control.

Estimated Possibility of Improving Fuel Economy of Passenger vehicles in China

Demand of Improving Fuel Economy

Energy Saving

In 1993, China became a net crude oil importer. In recent two years, imported crude oil of China has been increasing by 15%. In 2006, China imported 83.97 million tons of crude oil, 14.8% more than that of the previous year. According to the latest data from The General Customs Bureau of China, the crude oil output and import totaled 30.30 million tons in July 2007. Among which, 15.47 million tons were domestic output, reduced by 1.7% compared with the same period of 2006; 14.83 million were import, increased by near 40% compared with the same period of 2006. That means China created a historical high record of 48.8% in crude oil import, quite close to the alarm line of 50%.

Estimated on the basis of current explored oil reserve and the productivity of China's main oil fields, the crude oil output will be around 180 to 200 million tons annually. However, liquid fuel demanded by China's economy growth is soaring. By 2020, China's oil consumption will go up to 500 million tons, and 300 million tons of which will be imported. Then China's dependency on imported oil will grow up to

60%, much higher than 60% of the US in 2006.

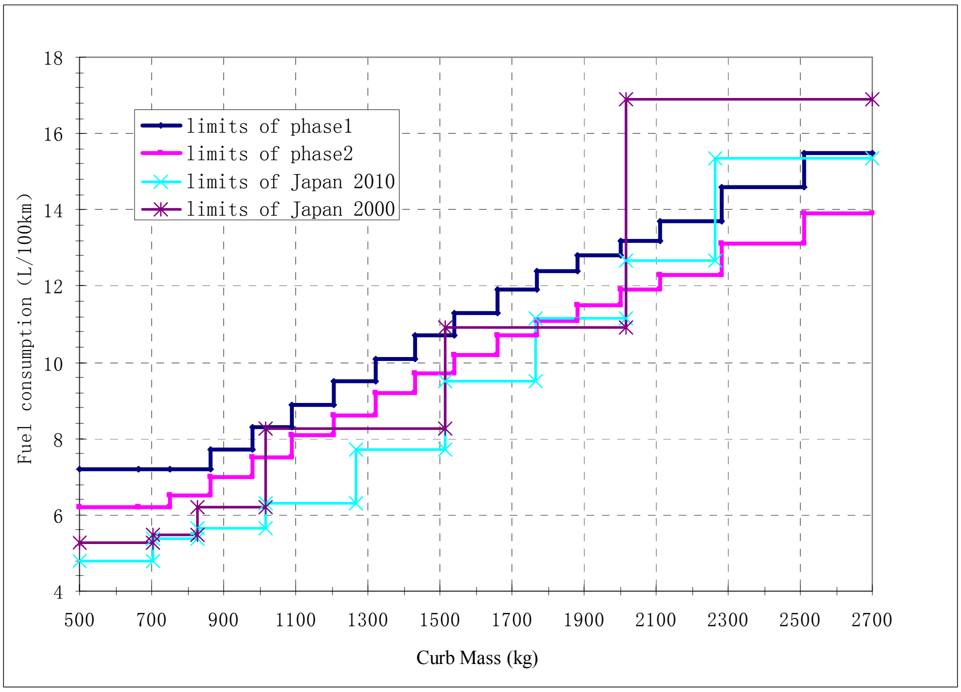
According to forecast, by 2020, oil consumed by vehicles will surpass 50% of the total. Therefore, controlling over fuel consumption of vehicles will be crucial for overall energy consumption reduction. So the formulation of severer fuel consumption standard for passenger vehicles will be a powerful measure to reduce energy consumption of vehicles.

Environmental Protection

In recent years, human being is suffering a lot from deteriorating environment and increasingly severe global warming caused by GHG. Exhaust gas from vehicles is consisted of much of GHG and vehicles become one of the main GHG emitters. Controlling over vehicle pollution is highlighted by many countries. China's automotive industry has made great efforts in R&D of new clean energy automobiles. Newly developed alternative fuel vehicles employ natural gas, methanol, ethanol, dimethyl ether, bio-diesel and GTL as fuel. Also vehicles driven by electricity and hydrogen have been applied. However alternative energy can't totally take the place of oil. Currently, oil is still the main fuel of vehicles. So energy saving is still crucial for traditional vehicles. A more severe standard for fuel economy of passenger vehicles will be helpful for environmental protection.

Trend of International Standard

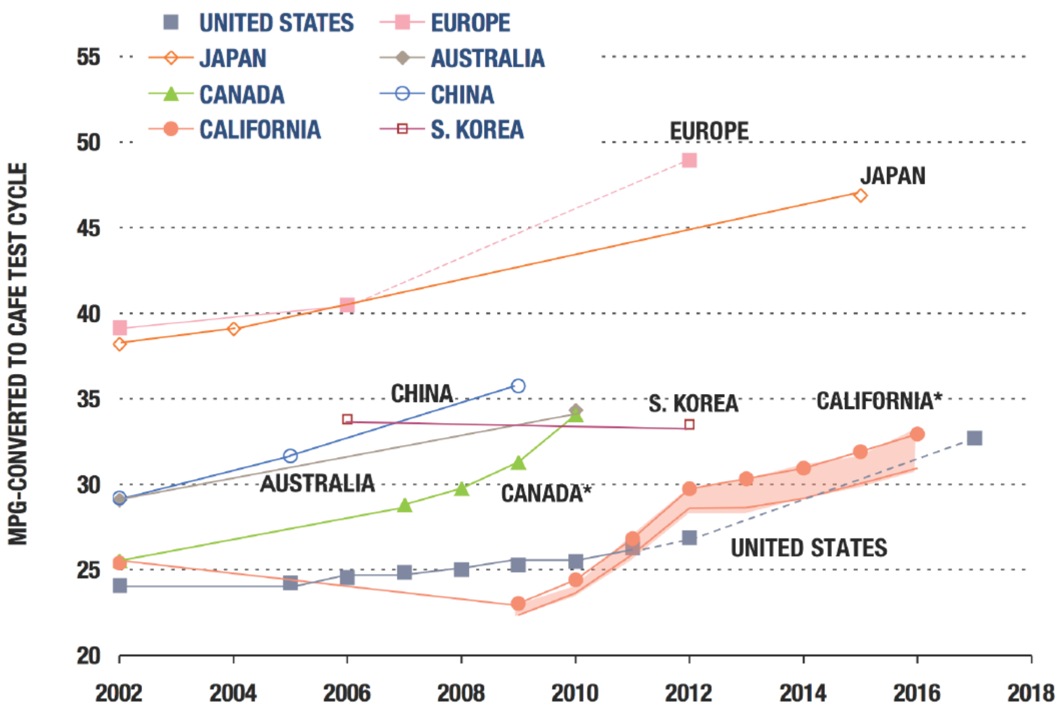
According to Chinese system, fuel economy value of every model should satisfy the Standard limits instead of weighted average value in each weight group of one automaker in Japan, which will put more pressure on automakers Graph 3.1 shows the differences between the standard of China and Japan:



Graph 3.1. Compare of Fuel Consumption Limits for Passenger vehicles Between China and Japan

The above graph shows that Japan's fuel consumption limit of each weight group is higher than China's. But limits value above the 1800kg weight is lower than those of Japan, which indicate the principle of "encourage smaller weight models and limit bigger one" during the formulation of the Standard.

Graph 3.2 shows the average values of fuel economy limits being or to be executed during the period from 2002 to 2018 in various countries. The values are CAFE equivalent. We can see from the graph that in 2002, Europe and Japan executed the most severe limits of 39mpg over passenger vehicles. But there is a difference here: there are more than 40 percent diesel passenger vehicles in Europe, which contribute much to the whole fuel consumption value, while there are mainly gasoline engine for passenger vehicles in both China and Japan, therefore, Japan's fuel efficiency standards is the strictest in the world in fact. As is shown on the graph, there're gaps between Phase 2 limits of China and the world's most severe limits. Also we can see that each of the foreign countries is planning to issue more severe limits. China will follow the trend and make further severe standards.



Graph 3.2 Fuel Economy Standards of Some Countries Being or to Be Executed from 2002 to 2018

(source: Passenger Vehicle CO2 and Fuel Economy Standards A Global Update, International Council on Clean Transportation, 2007)

Note: *continuous lines embody actual fuel economy or determined limits for future;*

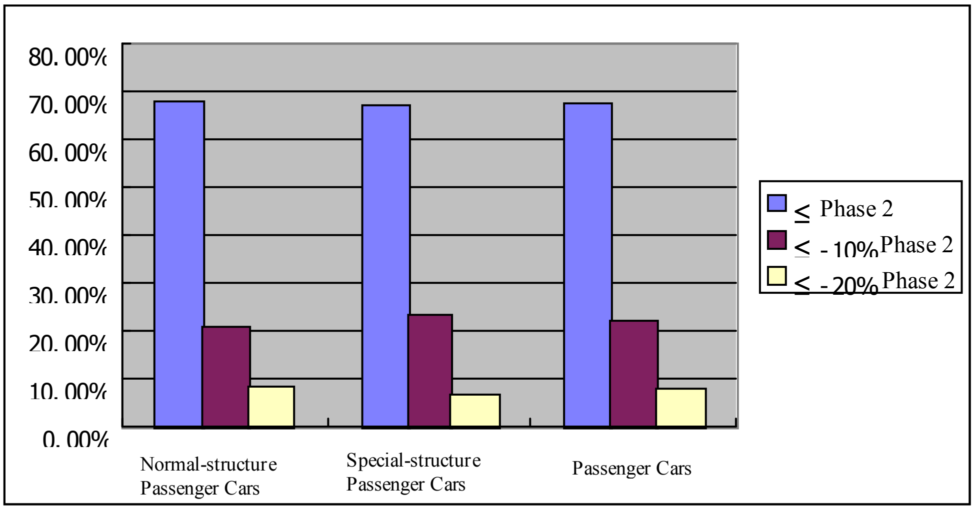
broken lines embody limits being proposed.

Challenges from More Severe Fuel Economy for Passenger vehicles

2002 is a watershed for China's automotive industry. In 2002, passenger vehicles became popular among China families and China saw historical high in both automobile output and sales. At the same time, China began to improve related standards and regulations. To match international standards, China set two-phase limits of fuel economy for passenger vehicles. According to the Standard, Phase 1 limits standard was executed on July 1, 2005 and Phase 2 limits standard will be executed since January 1, 2008. So far, most models have reached the requirements of Phase 2 limits. However, China will face more challenges and opportunities if it further lifts the limits of fuel economy. The followings are the main challenges.

Maturity of Related Technologies

So far, 2/3 of the passenger vehicles approved in 2006 could meet the Phase 2 limits. Fuel consumption of about 20% of passenger vehicles is 10% lower than Phase 2 limits and about 7% is 20% lower than Phase 2 limits (see Graph 3.3). However, the actual data show that most of the models whose fuel consumption is 20% lower than Phase 2 limits are diesel cars. Although most passenger vehicles have met the Phase 2 limits, there's still a long way to go to meet further severe standard.



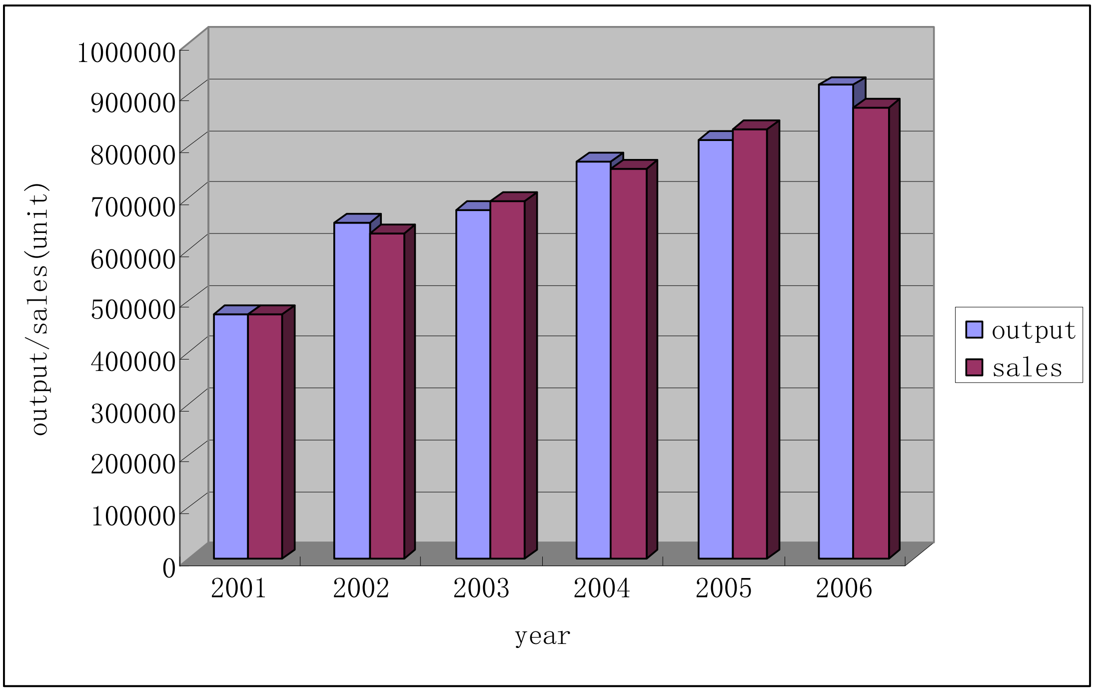
Graph 3.3 Percentages of Different Models of Passenger vehicles that Met Phase 2 Limits in 2006

Note: Diesel passenger vehicles (1.3% of the total) were included.

(source：CATARC，2007)

As the basic models and technologies are quite different from one automaker to another, the technical maturity and obstacles for more severe standard of fuel economy are different.

In the past few years, sales of passenger vehicles, especially mini-cars,(mini-cars means the cars whose length ≤ 3.5 meters) has kept rising (see Graph 3.4). Most of the mini-cars are developed by China's domestic automakers. Outdated technologies cost much of their effort to meet the requirement of Phase 2 limits. To match more severe standard, these automakers must upgrade the engine technologies.



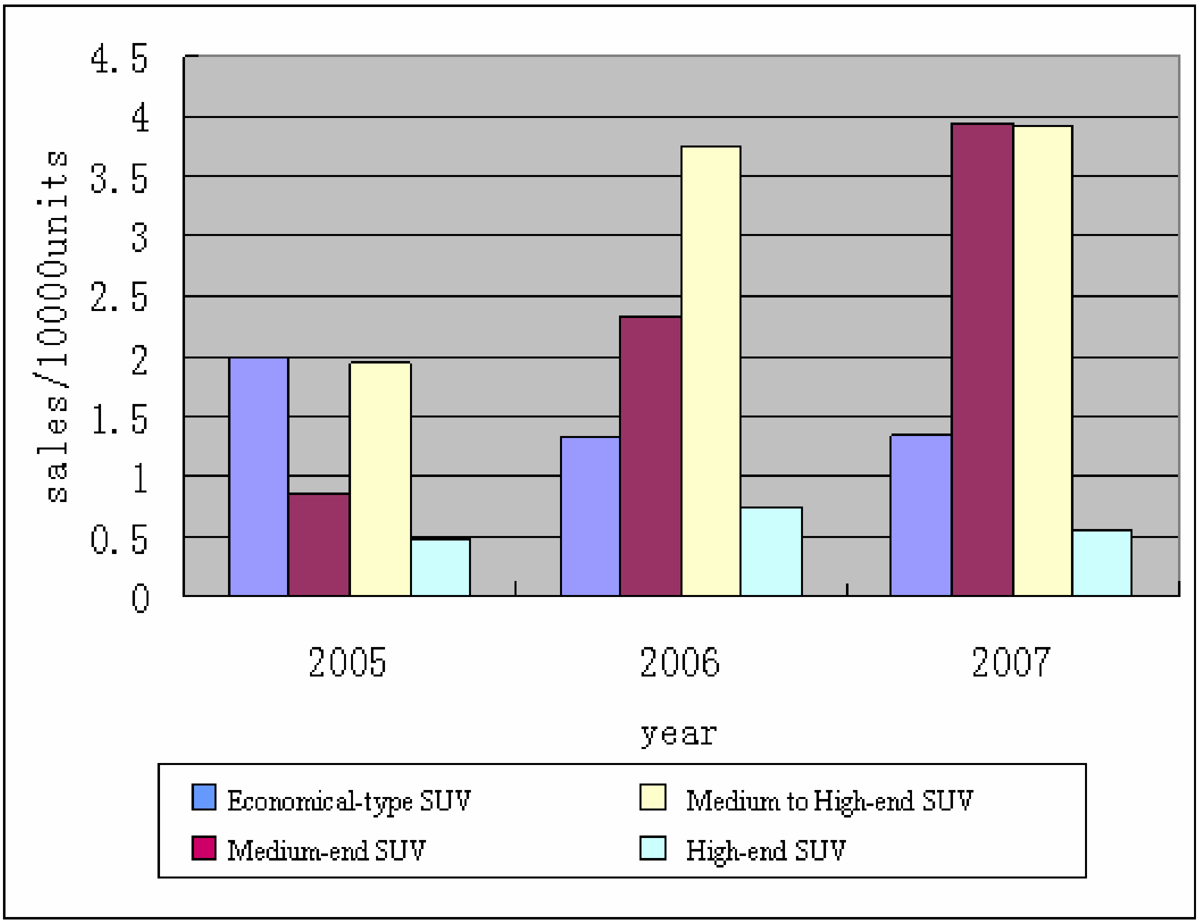
Graph 3.4 Output/Sales of Mini-cars from 2001 to 2006

(Source:http://www.autoinfo.gov.cn website)

Models with displacements from 1.6L to 2.0L enjoy larger market share of China's passenger car. Both domestic manufacturers and JVs are quite positive in developing technologies. JVs usually introduce technologies directly from other countries with more advanced technologies, especially from Japan and Europe who have adopted more severe fuel consumption standards. These JVs even have developed products with better fuel economy than the standards of Phase 2 limits. Although domestic automakers with China-owned brands have upgraded their technologies in last few years, their strength of R&D is still weak compared with world leading automakers. Domestic automakers will face more difficulties in further improving fuel economy.

Currently, most of passenger vehicles with displacement over 2.0L are made by JVs. The manufacturers apply most advanced technologies in these models. For example, FAW Volkswagen integrates many advanced technologies into Audi series, including variable valve timing, waste gas turbo-charge, FSI and Quattro all-time 4-wheel driving. These manufacturers will introduce existing technologies from abroad when asked to meet more severe fuel economy standard. Automakers of China's own-brand passenger vehicles with displacement over 2.0L usually introduce technologies from abroad or ally foreign partners to develop new technologies. Therefore technology upgrading of these cars is also quick.

SUV can be divided simply into four classes in China, which is economical-type SUV, medium-end SUV, medium to high-end SUV and high-end SUV. And economical-type SUV means those whose price are below 100 thousand RMB, and medium-end SUV means those whose price are between 100 thousand RMB to 150 thousand RMB, and medium to high-end SUV means those whose price are between 150 thousand RMB to 300 thousand RMB, and those whose price are above 300 thousand RMB are called high-end SUV. Increasingly rising oil price and the execution of limits of fuel consumption bring much impact on SUV manufacturers. Manufacturers of low-end SUVs have suffered most from dropping sales year after year (see Graph 3.5). Outdated technologies, old models and uneven qualities will force part of these manufacturers stop production before the execution of the Phase 2 limits. The manufacturers of medium and high-end SUVs obtained more market shares in recent years via adopting energy saving technologies. However, it's too difficult for these automakers to strive for a more severe standard shortly after they staggered into the threshold of Phase 2.



Graph 3.5 SUV Sales in China Market

(Source:http://www.autoinfo.gov.cn website)

Cost

Technology upgrade will definitely drive cost up. Manufacturers of different technical maturity will undertake different costs. Information of domestic automakers from this study and related research from America show the cost to further lower 10% to 15% fuel consumption of vehicles is around RMB 3,000 to 7,000. However, cost increase will be different for automakers adopting different technologies. In addition, there're many differences between the automakers in existing technology levels, technology reserve and R&D reserve. The abovementioned cost increase is just a rough estimate for reference.

For mini-car makers, cost of technology upgrade will be huge compared with their low sales prices.

For passenger vehicles of 1.6L to 2.0L, cost of technology upgrade will increase a little for the low oil-consumption models; for JVs with higher oil-consumption models, directly introduced technologies will not cause much increase in cost; for domestic automakers with China-owned brands, cost will increase a lot since they will have to invest more for technology developing and improving.

For models of over 2.0L, as these cars are high-end products with high sales prices, the cost increase for technology upgrade will pose little influence to the high profit.

SUV sector is undergoing a run of natural selection. Only the models of high-tech and low oil-consumption could survive from the fierce competition. Currently, domestic SUV consumers pay much attention on fuel economy. For SUV manufacturers, improving fuel economy is the theme of their competition.

Others

a) Limits on oil consumption are slowed down by increasingly strict emission standards

In recent years, vehicles are causing more and more serious air pollution. China began to take the vehicle emission standard of Europe as reference, and reduced evidently China's vehicle emission after more than 10 years' effort. However, the phase-3 emission standard just implemented in China is 7 year backwards compared with Europe. Therefore China also needs more severe emission standards for vehicles. With the rapid increase of vehicle population, the emission issue is becoming more and more serious.

Before the execution of the *Limits of fuel consumption for Passenger vehicles*, automakers focused mainly on emission reduction technology innovation. Now, automakers have to meet the standards both for fuel consumption and emission reduction. While some of the emission reduction technologies conflict with energy saving technologies, so it's more difficult for automakers to launch technology upgrading.

China is going to implement the 3rd phase emission standards for vehicles and research for the 4th phase has also begun. Some automakers have started to research products for the 4th phase after they developed in advance the products that meet the 3rd phase emission standard. Thus the development and upgrade of energy saving technologies will be influenced.

Possibility of Launching More Severe Standard

As mentioned above, over 2/3 of existing passenger car models tally with the Phase 2 limits of fuel consumption and fuel economy of about 20% models is 10% lower than the Phase 2 limits. Low oil consumption has been achieved in part of automobile products, although there're still technical and cost issues. However, information integrated from this study shows that it's possible for China to launch more severe standards on fuel consumption for passenger vehicles. The limits are estimated to be lifted by 10% to 15% and be implemented after 2012 so that automakers have sufficient time to make preparation.

China Government' View on More Severe Standard for Fuel Economy

Coherence between National Macro Policies and the Standard

Energy saving is a long-term strategic guideline of China and also an urgent task. To promote energy saving in the whole society, relieve energy tense, build an energy-saving society, promote sustainable development and fulfill the goal of building an all-round well-off society, China government has issued some important regulations, policies and programs:

1) Being Coherent with the Basic State Policy of "Resource Saving"

Execution of the *Limits of fuel consumption for Passenger vehicles* is one of the important contents of resource saving and building economized society activities initiated by the State Council. In the *Notification on Key Works in the Near Future to Build an Economized Society*, the State Council pointed out that the government "will promote the execution of *Limits of fuel consumption for Passenger vehicles* and control high oil-consumption vehicles from the headwaters." Premier Wen Jiabao instructed on the "Report of *Limits of fuel consumption for Passenger vehicles* should be Implemented Strictly and Promptly" submitted by the Research Office of the State Council: "It's a good suggestion. Controlling over fuel consumption of passenger vehicles is an important measure for energy saving".

2) Being coherent with the *Medium & Long-term Special Plan for Energy Saving*

In 2004, China issued the *Medium & Long-term Special Plan for Energy Saving* (The Plan). The Plan makes comprehensive analysis on the situation of energy utilization in China and the challenges and tasks of energy saving. Also it brings forward guideline, principles and targets of energy saving, the key areas of energy saving and projects and measures to guarantee energy saving. The Plan takes transportation as a key area of energy saving and says: "According to the experiences in the US, Japan and Europe, the most effective measure to save fuel for new vehicles is to formulate and execute standards of fuel economy for vehicles and implement related systems such as fuel tax. These measures will promote automakers upgrade technologies, reduce fuel consumption, improve fuel economy and guide consumers to purchase low fuel consumption vehicles".

According to *The 11th Five-Year Plan for Development of China Economy and Society*, the energy consumption per unit GDP will be reduced by 20% and the total emission of main pollutants will be reduced by 10% during the 11th Five-Year Plan period. *Limits of fuel consumption standard for Passenger vehicles* has played an active role in improving fuel economy of vehicles and fulfilling energy saving in automobile industry and become a practical and effective measure in transportation area.

By this token, *Limits of Fuel Consumption for Passenger vehicles standard* is highly coherent with China's macro policies. Relevant administrative departments such as NDRC, MOF and State

Administration of Taxation (SAT) are pushing forward the works related to the *Study on Regulations and Policies of Fuel Economy Standards for Vehicles in China*.

Improve the Competitiveness of Automobile Industry

The execution of *Limits of fuel consumption for Passenger vehicles* further promotes technology upgrade of automobile products and encourages automakers developing and introducing fuel-efficient technologies.

Early since the formulation of the Standard, some JVs began to introduce advanced energy saving technologies. When the Standard was issued in 2004, the major JVs had completed product upgrade. And some of their products even met the Phase 2 limits in advance. In recent years, driven by the Standard, automakers with China-owned brands have launched R&D by themselves or allied foreign partners for jointly development. Apart from domestic automakers with China-owned brands, such as Chery, Geely, Brilliance, Hafei, Changhe and Southeast companies, some big automobile groups who benefited a lot from the JVs and cooperation with Chinese partners, also focus on developing China-owned brands, such as the brand of HongQi from FAW Group. After years of effort and inspired by both the Standard and the market, quality of automobiles with China-owned brands was largely improved and the gap with JV brands is narrowing.

Meanwhile, the Standard also promotes the development of engine industry.

In 2006, two years after issuing the Standard, total fuel consumption of passenger vehicles in China reduced by 10%, compared with 2002 and 2003 when the Standard was under formulation. Many automakers launch not only technology R&D, but also technology reserve. Further severe standards will accelerate the approach of China's automobile industry to the international advanced level and improve the competitiveness of China's automakers.

Suggestions on Policy Measures to Promote Formulation and Execution of New Standard of Fuel Economy

An Analysis on the Policy Measures for Fuel Economy Standard Execution in Other Countries

Many countries have made policy measures to ensure the execution of standards for fuel economy. This section will analyze the main policy measures adopted by some countries and summarize the experience for the reference of China's policy makers.

（1） America

America has worked out a series of punishment measures for fuel economy standard:

a) If automakers fail to meet the requirements of the fuel consumption standard, they must pay penal sum of US$ 5 for every 0.1 mile/gallon surpassing each car.

b) If you buy a new car with fuel consumption surpassing the standard, you, the buyer will also be punished. "Gas Guzzler Tax" is a punishment tax levied on these buyers.

c) The state government publicizes the fuel efficiency information of various models. The *Handbook of Fuel Consumption Based on Mileage* published annually by EPA and DOE publicizes the fuel consumption data of every model sold in America. Consumers could take it as a reference. A new model should label clearly the fuel consumed for 15,000 miles and the fuel efficiency information for the same model of other brands.

In a few years after the execution of CAFE, America saw obvious effect. From 1975 to 1984, fuel economy of cars was improved near 100% and trucks, over 50%. At the same time, the policy measures guided consumers purchase low oil-consumption cars. However, as the limits of CAFE have not made any changes, competitiveness of American automobile industry was impacted. In fact, to a certain extent, CAFE blocked the growth of automobile industry and technology improvement of America.

（2） Europe

Members of European Automobile Manufacturers' Association reached an inner agreement on limit of CO2 emission. The CO2 emission target is not for individual automakers but for the whole industry.

In Europe, oil price is around 3 times of that in the US. So the government of each European country will be able to guide the purchase intent of buyers' by publicizing annually the actually tested fuel consumption of each model. It's not a compulsory measure, but a market competition mechanism. According to EU's direction of 1999/94/EC, all sellers must post the fuel consumption and CO_2 emission aside the new cars being sold for the reference of the purchasers.

Although there're no compulsory measures in Europe, high fuel tax influences a lot to car buyers. In addition, as the CO_2 emission target of Europe is very low, automakers try their best to fulfill the target. Therefore the technology level of European automobile industry is lifted a lot.

（3） Japan

A series of measures have been taken to ensure the execution of the fuel economy standard:

a) Automakers are asked to report the fuel economy when new models are submitted for approval. Then Ministry of Land, Infrastructure and Transport will examine the reported information and then decide whether give approval to the models.

b) For the automakers whose products fail to meet related requirements, some punishment measures such as advising, publicizing company name and amercing will be adopted. Japan issued green environmental protection tax scheme in 2002, for cars not only meet the requirement of fuel consumption limit, but also are approved as low-emission cars, the car buyers could obtain 15,000 Yen derating of purchase tax and 50% vehicle tax in the first year (see details in the Graph below).

Graph 5.1 Derating of Vehicle Tax in Japan

(Source: clean vehicle popularization policy in Japan, 2005.3, JARI)

Vehicle Tax（29,500～111,000Yen/Year）		
Green Tax Plan（2004 and 2005）		
Fuel Economy	Emission	Tax Derating
5%over the limit of 2010	□□□□	Down by 50%
5%over the limit of 2010	□□□	Down by 25%
Meet the limit of 2010	□□□□	Down by 25%

Graph 5.2 Derating of Purchase Tax in Japan

(Source: clean vehicle popularization policy in Japan, 2005.3, JARI)

Purchase Tax（5%of the sales price）		
Special Plan for cars with high fuel economy（2004 and 2005）		
Fuel Economy	Emission	Tax Derating
5%over the limit of 2010	□□□□	Reduce 300,000 Yen
5%over the limit of 2010	□□□	Reduce 200,000 Yen
Meet the limit of 2010	□□□□	Reduce 200,000 Yen
Clean Energy Cars（2004）		
HEV（including fuel cell）、CNG、methanol and hybrid vehicles（trucks and buses）		Down by 2.7%
Hybrid passenger vehicles		Down by 2.2%

c） Ministry of Land, Infrastructure and Transport of Japan publicizes the fuel consumption of vehicles on its homepage and publishes the handbook of *Vehicle Fuel Consumption* at the end of each year.

Among the punishment measures, amercing and company name publicizing will pose great impact on automakers. To lift their position and build reputation in automobile industry, automakers accelerate the R&D and try to meet the requirements in advance. Thanks to the severe standard for fuel consumption and rational policy measures, automobiles made in Japan are quite competitive in international market.

（4） Conclusion

We can see from the above mentioned that developed countries such as America and Japan adopt the following measures to control the fuel consumption of passenger vehicles:

a) Make compulsory rules to force automakers improve fuel economy.

b) Base on the statistics of fuel efficiency and trend of new automobile technologies, bring forward fuel consumption limits of different stages for various models. At the same time, formulate uniform standard for fuel consumption test method.

c) Adopt corresponding guarantee systems, mainly the following 3 systems: report system for fuel consumption, label system for fuel consumption and publication system for actually tested fuel consumption.

d) Adopt rewards and punishment system. Punish automakers whose cars fail to meet the requirements and the buyers who purchase those cars; reward the automakers and buyers who make or purchase cars meeting the requirements.

e) Publicize standards, systems and policy measures in automobile industry and guide the consumers' purchase intent。

Practices show that the integration of the above measures accelerates technology upgrade of automobile and reduce the total fuel consumption and GHG emission.

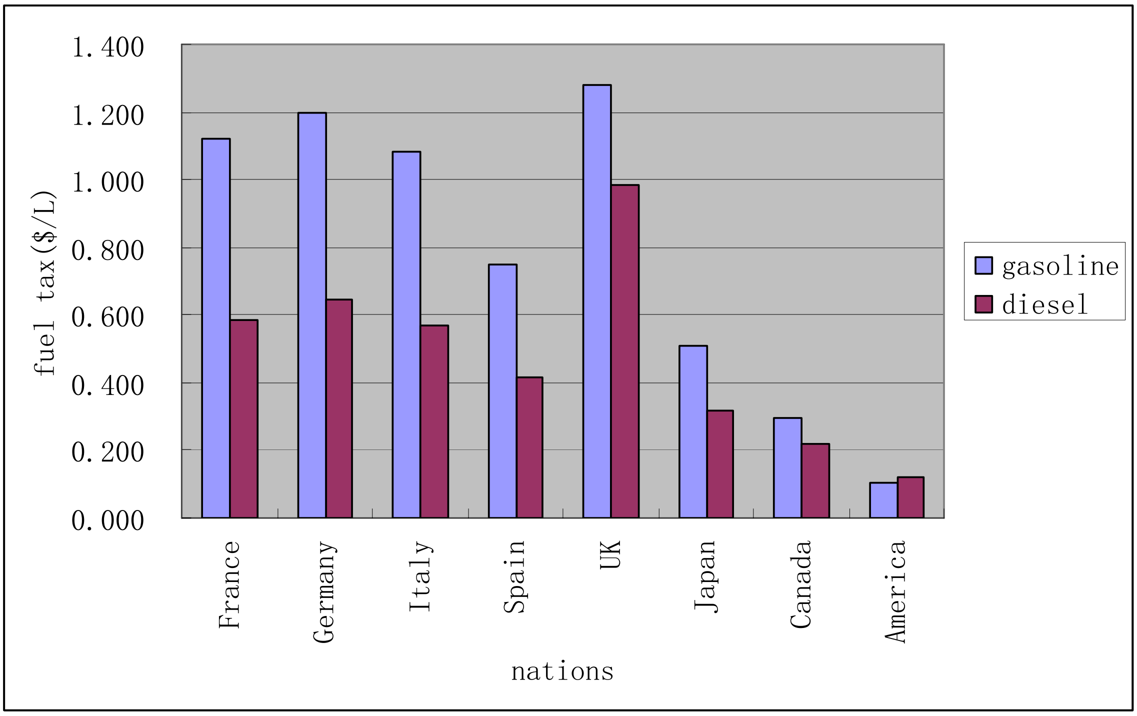
Suggestions on Policy Measures to Implement More Severe Standard for Fuel Economy in China

The integrated analysis over practices of other countries shows that rational policy measures will promote the efficient implementing of the fuel economy standards. China is going to implement the Phase 2 limits and is studying the possibility to adopt a more severe standard. The following policy measure suggestions are advanced as a reference to ensure the Standard is well implemented.

（1） Impose Fuel Tax as soon as possible

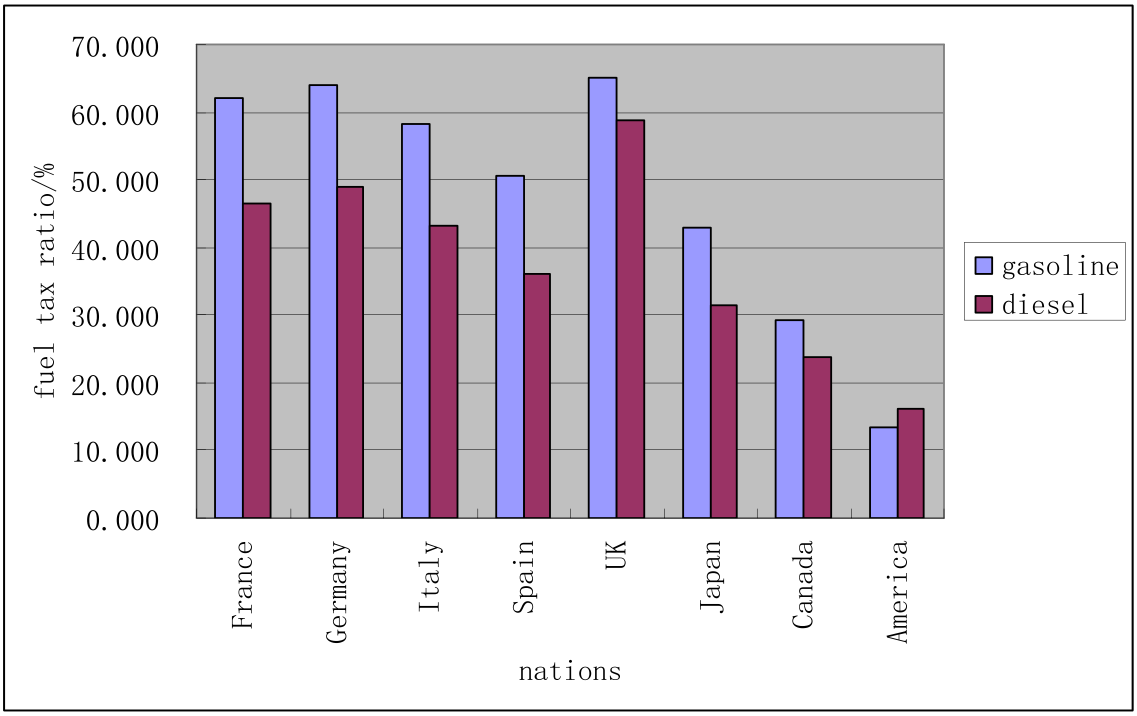
Imposing fuel tax will excite the demand for energy-saving engines and thus promote the development and application of upgraded engines.

Currently, most developed countries impose fuel tax. Graph 5.1 and 5.2 show the fuel taxes in some countries and the percentage of fuel taxes in the fuel prices.



Graph 5.1 Fuel Taxes in Various Countries (July, 2007)

(source: International Energy Agency)



Graph 5.2 Percentages of Fuel Tax in Fuel Price in Some Countries (July, 2007)

(source: International Energy Agency)

According to the experiences of the US, Japan and Europe, the most economical and effective measure for vehicles to save fuel is to formulate and execute standard for fuel economy and implement relevant systems such as imposing fuel tax. These measures will promote automakers upgrade technologies to lower fuel consumption and improve fuel economy. Also the relevant systems will guide consumers to purchase low fuel consumption cars.

To impose fuel tax has been proposed for many years in China. However, so far, only Hainan Province has been imposing fuel tax in the form of bunker surcharge and sees both economic and social benefits from the tax imposition. Considering the overall situation in China, we suggest to adopt tax system of “different tax rates for different fuels”.

（2） Implement Label system

In recent years, with the execution and publicizing of the Standard, some automakers not only provide mono-speed fuel consumption to consumers, but also provide fuel consumption data under urban, suburb and integrated driving cycles under standard experimental conditions. However, China still lack to implement a comprehensive and systematic label system.

Research on label system has been launched for some time and an integrated labeling plan has been created. The government should execute the compulsory label system as soon as possible. Experiences of developed countries show that a good label system is more effective in guiding consuming and promoting technology upgrade.

（3） Implement Incentive Measures

Effective incentive measures could accelerate the execution of fuel consumption standard and guide consumption of low fuel consumption.

The Limits of Fuel Consumption for Passenger vehicles is a compulsory standard and automakers must meet related requirements. However, for the models with excellent fuel-saving performance, China doesn’t have any incentive measures. As a result, many automobiles meet barely the requirements of the limits. To lower cost as much as possible, many automakers have not fully applied existing advanced technologies or lack enthusiasm in reducing fuel consumption. Effective incentive measures will spur automakers’ enthusiasm.

Currently, most car buyers will consider fuel consumption. However, for consumers of limousines with large displacements, they consider more about the dynamic performance, safety and comfort, which will be achieved by much higher fuel consumption. It is of great significance to take incentive measures for consumers and encourage them choose low fuel consumption cars.

We suggest taking different incentive measures to different fuel-efficient products. For example, certain percentage of derate on excise should be given to the products becoming qualified in advance; different derates on excise should be given to the products whose fuel consumption is much lower than the requirement of the Standard; different derates on purchasing tax should be given to consumers who purchase the above mentioned models; also part of incoming tax from the automakers may be returned to them if most of their products are low fuel consumption cars.

（4） Enhance I/M System for in-use Vehicles

To produce and purchase low fuel consumption cars are the basic steps to reduce fuel consumption of vehicles. However, it's also important to keep in-use vehicles e under low fuel-consumption condition. Poor maintenance will keep vehicles in high-consumption condition. Then driving a car being approved as low-consumption vehicle will make no sense. So the I/M of in-use vehicles should be enhanced.

Many countries such as America, Canada and Japan, have worked out detailed I/M procedures and issued corresponding systems. In these countries, car users must launch periodical inspection and maintenance according to related requirements. Faulted vehicles must be repaired and recorded in details. Detailed information of in-use vehicles should be available to administrative department for the convenience of management and analysis.

Currently in China, annual inspection system and spot check system are adopted for in-use vehicles. However the procedure of our annual inspection is comparatively simple and there're many issues in vehicle inspection. As a result, the actual fuel consumption of many in-use vehicles is much higher than the factory value. So I/M system must be enhanced via making and implementing more rational inspection procedure and requirements. Also the supervision over inspection institutions should be enhanced.

（5） More Severe Fuel Consumption Requirements on Alternative Energy Vehicles or Vehicles with New Dynamic System

Development of alternative energy for vehicles is another theme to build an energy-saving society. China has initiated much of related works. Some alternative energy vehicles and vehicles with new dynamic systems have been unveiled and more will be launched in near future. So， requirements on fuel consumption of these vehicles should also be underlined.

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Linking Climate Policy with Development Strategy in Brazil, China, and India

Economic Assessment of Deploying Advanced Coal Power Technologies in Chinese Context

Sponsored by the Flora and William Hewlett Foundation

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Executive Summary

At the beginning of this century, the prevalent electricity shortages resulted in rapid expansion of power capacity, especially coal power capacity. In 2006, the total installed capacity was up to 622 GW, in which thermal installed capacity was 484 GW, accounting for 77.82% of total capacity in China.[1] Coal-fired capacity took up above 95% of thermal capacity, about 460GW. IEA projected that China's coal power capacity will reach 688GW in 2015.[1] The addition will reach around 228GW in the next 9 years. When decision-makers are faced with the need for new capacity, several technology types can be considered.

Currently, in China power sector chooses Ultra Super Critical (USC) Pulverized Coal (PC) and Super Critical (SC) PC as new capacity coupled with pollutant control technology, and 300MW Circulating Fluidized Bed (CFB) as a supplement. According to national industry policy, 600MW SC and 1000MW USC units will become the standard in the coming years. Several Integrated Gasification Combined Cycle (IGCC) demonstration power plants are being built in China.[1]

One of the tools used by decision-makers is a levelized cost calculation, which incorporates all the expenses associated with a project over its lifetime. Levelized cost comparisons give investors one basis for choosing a technology. According to new capacity technology choices trends for new China generating capacity, this study is going to do levelized cost calculations for decision-makers as a reference and finding out the differences among different technology options. The technology options considered in this study include 600MW subcritical PC, 600MW subcritical PC+flue gas desulfurization (FGD), 600MW subcritical PC+FGD+ flue gas denitrification, 600MW SC PC, 600MW SC PC+FGD, 600MW SC PC+FGD+flue gas denitrification, 600MW USC PC, 600MW USC PC+FGD, 600MW USC PC+FGD+flue gas denitrification, 300MW CFB, 200MW IGCC based on multi-nozzle entrained flow gasifiger and 200MW IGCC based on dry pulverized coal entrained flow gasifier, amounting to 12 cases. The performance analysis of all the power plants is based on two units except IGCC power plants. The goal of our research is to evaluate capital cost, cost of electricity (COE) based on technological and economic level for 2006 and explore the economic gaps between IGCC and other advanced coal power technologies. There are 3 IGCC demonstration power plants being built in China during the Eleventh Five Year Plan. Two of them chose Shen-dong coal as their fuels. In order to keep on a line, we also chose Shen-dong coal as fuels for all cases. Shen-dong coal owns relatively high quality. The sulfur content of Shen-dong coal is 0.4%. It belongs to low sulfur coal. So the operating cost of FGD is also low.

COE is a function of the costs for capital, fuel, consumables, repair, labor and finance and dependent on technology, time frame, and site. Increasing environmental regulations cause plants to add more equipment (e.g., FGD systems), lose potential capacity, and lose efficiency. Advanced technologies may have a higher capital cost, and be incorporated into the facility. These technologies will reduce operating costs, thereby reducing production costs. In this study, only different technologies are considered other than time frame and site. All the technology options are considered to be built at the same time frame and site. We collected most data needed to calculate technical performance and electricity generation costs from academia, power companies, manufacturers and coal companies. The modeling of different technology options is based on comparable conditions.

In this study, net efficiency gaps between subcritical, SC and USC are small. The net efficiencies of subcritical PC (case 1, 2 and 3) are relatively high, because of the further improvements and advances in steam turbine design. These data reflect the most advanced technology level now in China. The choice of steam parameters for USC is not so high according to current industrial state. So the net efficiencies of USC PC plants (case7, 8 and 9) are a little higher than those of SC PC plants. The advantages of USC were not externalized completely. The parameters choice and design of IGCC took into account real conditions of demonstration plants and technological level. The net design efficiency for IGCC is equal to SC PC power generation technology, a little lower than USC. The reason why IGCC's efficiency is lower than USC's is total auxiliary losses for IGCC were set at higher numbers. The auxiliary losses for IGCC based on multi-nozzle entrained flow gasifier are 15.5%. The auxiliary losses for IGCC based on dry pulverized coal entrained flow gasifier are 15.8%. These data were supplied by Hangzhou Hangyang Co., LTD. China. If the total auxiliary losses are reduced to around 12%, net design efficiency for IGCC would reach 42%.

PC coupled with pollutant control technologies, CFB and IGCC can meet the SO_2, NOx and particulate matter emissions requirements. IGCC has the best environmental performances. IGCC has the ability to deeply remove sulfur after gasification. So its SO_2 emission is almost near zero, much lower than other technologies. CFB technology may realize desulfurization in the boiler. Now, in China all new power generation units are demanded to equip low NOx burners. NOx emission from Shendong coal fired PC plants with a capacity of over 600 MW is 450mg/Nm^3. Low NOx burners were adopted. So they can meet the current emissions requirement. When SNCR technology is used, NOx emissions can be further reduced to 270mg/Nm^3. CFB technology produces less NOx due to lower combustion temperature. The

NOx emission from CFB power plants is about 250mg/Nm^3. NOx emission from IGCC plants is 240 mg/Nm^3 according to current industrial technology level.

The capital cost estimates are expressed in 2006 RMB Yuan per kilowatthour. The capital costs of subcritical PC+FGD+flue gas denitrification, SC PC+FGD+flue gas denitrification, USC PC+FGD+flue gas denitrification, CFB, IGCC based on multi-nozzle entrained flow gasifier and IGCC based on dry pulverized coal entrained flow gasifier are 3762, 3942, 4137, 4566, 7433 and 8824 RMB Yuan/kW respectively. The cost of IGCC is almost twice as expensive as that of PC. In recent year, the great demand for new power plants makes manufacturers stay in a highly competitive market. This causes rapid drop in PC equipments prices. But IGCC technology is still in a testing and demonstration phase. The prices of equipments are quite high. Some equipments need to be imported. If China plans to deploy IGCC based on successful demonstration during the Eleventh Five Year Plan, economic huddles have to be overcome.

The COE not including charges for disposing pollutants of case 4 (SC), case 5 (SC+FGD) and case 6 (SC+FGD+flue gas denitrification) are respectively 261.95, 270.97, and 276.22 RMB Yuan/MWh. The COE of case 6 is 5.25 RMB Yuan/MWh higher than that of case 5, namely the addition of flue gas denitrification to the power plant results in a COE rise at 5.25 RMB Yuan/MWh. The COE of case 5 is 9.02 RMB Yuan/MWh higher than that of case 4, namely the addition of FGD to the power plant causes increase in COE at 9.02 RMB Yuan/MWh. The COE including charges for disposing pollutants of case 4, case 5 and case 6 are respectively 264.47, 272.08, and 276.93 RMB Yuan/MWh. The COE of case 6 is 4.85 RMB Yuan/MWh higher than that of case 5. The COE of case 5 is 7.61 RMB Yuan/MWh higher than that of case 4. These numbers clearly indicate that only implementation of levying charges for disposing pollutants is not enough to encourage power plants to install pollutants control equipments. Because of low levy standard, polluters prefer paying charges for disposing pollutants. The Chinese government offers a preferential price for electricity from power plants with FGD. It is 15 RMB Yuan/MWh higher than the price for electricity from power plants without FGD. Therefore, in China power plants with FGD remain competitive with other power plants. However, currently there is no incentive policy to encourage power plants to install NOx control equipments.

The COE not including charges for disposing pollutants of IGCC (case 11) is 102.8 RMB Yuan/MWh higher than that of SC PC (case 4). If charges for disposing pollutants are considered, it is 100.7 RMB Yuan/MWh higher than that of case 4. The gap is narrowed lightly. However, because of low levy standard, it is not obviously that IGCC can produce electricity more cleanly. When SC PC is coupled with pollution-control technology (case 6), the COE not including charges for disposing pollutants of IGCC (case 11) is 88.53 RMB Yuan/MWh higher than that of case 6. When charges for disposing pollutants are considered, the COE of case 11 is 88.27 RMB Yuan/MWh higher than case 6. The COE of IGCC is much higher than that of other advanced coal power technologies. There are a couple reasons for higher COE as follows. First, the capital cost of IGCC is much higher than that of other technologies. The higher capital cost is, the higher depreciation cost is. Second, due to relatively low technical level, the net efficiency of IGCC (case 11) is equal to that of case 6. So the fuel cost of IGCC is relatively higher. Repair cost is also higher than other technologies, because key technologies of IGCC are not still mature. These are main reasons why the COE of IGCC is much higher than that of other coal power technologies. From these numbers, it is clear that SC+FGD+flue gas denitrification and USC PC+FGD+flue gas denitrification units have high competition at relatively lower capital cost and higher net efficiency with other units. Therefore, in current situation IGCC has no ability to compete with other advanced coal power technologies in the market.

Because the CFB boiler technology has the ability to fire waste and other low-grade fuels in addition to various grades of coal without SO_2 and NOx control systems, it is a waste of using Shen-dong coal as the fuel. When the price of coal used in CFB is 100 RMB Yuan/tonne lower than that of coal used in conventional PC plants, CFB gains a competitive advantage over other power plants.

SC PC and USC PC power generation technology coupled with pollution-control technology can meet the requirements of emission standard. It is highly efficient, technically mature, and cost-effective. At the same time, because of its high efficiency it can reduce CO_2 emissions to some extent. From the view of efficiency, SC and USC units are good choices for power industry. IGCC power plant has a very complex system more like a chemical plant. It first gasifies fuels, such as coal converting them into gas. Then the gas powers gas turbine. The net plant efficiency has reached 45%. However, the cost of IGCC is much higher than that of other power generation technologies. So the development of IGCC is very slow around the world. In recent years, IGCC has been attracting more and more attention and support because of concerns about global warming. It is easier for IGCC to capture CO_2 at relatively low cost. Even though IGCC technology cannot compete with conventional coal-fired power generation technologies, it will show its advantage and market competitiveness once the goal of CO_2

emission reduction is set in the country. Incentive policies are needed to deploy IGCC in China. It will be a long and tough way.

1. Data Collection

We targeted typical clean coal power generation technologies and conducted data collection and investigation of their main technical parameters through literature research, interviews and other ways.

1）Annual average heat economics statistics (capacity, coal consumption, capital cost, emission, etc.) of power plants are collected.

2）Typical coal types were investigated, and Shen-dong coal was chosen to be the analyzed coal type in this project.

3）Through consultation from manufacturers in China, the data as steam parameters, steam consumption, and heat recovery system parameters of typical subcritical, SC, and USC PC plants were collected, and the parameters would be used in thermodynamic calculations of PC power plants.

4）Through consultation from manufacturers in China, main technical parameters of gas turbine combined cycle power generation system were collected, and the parameters would be used in thermodynamic calculations of IGCC.

Cost data for subcritical, SC, and USC PC units, flue gas desulfurization, flue gas denitrification, CFB, and IGCC units were gathered from various sources. Table 1.1 is a listing of sources used to compile the data presented herein.

Table 1.1 data sources

Source No.	Title	Contents
1	Shan Xi Fertilizer plant	Fixed bed gasifier (equipment, construction engineering, and installation engineering)
2	Jilin Changshan Fertilizer (Group) Co., LTD.	Fluidized bed gasifier (equipment, construction engineering, and installation engineering)
3	Yankuang Group	Entrained-bed gasifier (new coal-water slurry with opposed multi-nozzles gasifier), sysgas cleanup unit (equipment, construction engineering, and installation engineering)
4	East China University of Science and Technology	Entrained-bed gasifier, including GE, Shell, and new coal-water slurry with opposed multi-nozzles gasifier
5	Sichuan Bluestar Machinery	Gaisifier manufacture

	Co., Ltd	
6	Air Products and Chemicals (China)	Air Separation Unit (equipment, construction engineering, and installation engineering)
7	Air Liquide (Hangzhou) LTD., CO.	Air Separation Unit (equipment, construction engineering, and installation engineering)
8	Nanjing Turbine & Electric Machinery (Group) Co., LTD.	6B and 9E gas turbines, HRSG , steam turbine, auxiliary system, Control system, electric system, water treatment system, water supply system, fuel supply system, thermodynamic system
9	Harbin Boiler Company Limited	subcritical, supercritical, ultra supercritical boilers and CFB boilers
10	Shanghai Electric	subcritical, supercritical, ultra supercritical boilers and steam turbines, electric motors
11	Zhengjiang Electric Power Design Institute	Loan interest rate, loan ratio, depreciation period, depreciation residual rate, amortization of intangible assets, amortization of deferred assets
12	North China Power Engineering Co., LTD.	Loan interest rate, loan ratio, depreciation period, depreciation residual rate, amortization of intangible assets, amortization of deferred assets
13	China Huaneng Group	subcritical, supercritical, ultra supercritical PC power plants (capital, operations and maintenance costs), Construction period, Operation period, Load of first year in the operation period, Load of second year in the operation period, Annual operation hours
14	Shenhua Group	Coal price
15	Clean Environmental Protection Engineering Co., LTD.	FGD, flue gas denitrification

Through plant visits, attendance at conferences, and technology vendor and manufacturer contacts, interviews with experts, we obtained the latest information on the design, performance, and operating experience of advanced coal power plants.

The following data were collected: original equipment cost, construction engineering, installation work, market price for boiler, steam turbine, electric motor, pump, fan, electrostatic dust separator, deaerator, condenser, coal grinding machine, crushing engine, coal feeder, coal-drop, coal yard (coal storage), make-up water pretreatment, condensate treatment, condensate booster pump, cooling water, chimney, power distribution equipment, limestone, gypsum, flue gas, ash (dust), slag, slag yard, oil tank and so forth. Public works, Ancillary works, Intangible assets (invisible assets), deferred assets, design, construction management, basic preparation cost were gathered.[1]

2. General Assessment Basis

The design basis for the generation evaluations is presented as follows, including site and coal characteristics, an emission standard of air pollutants for thermal power plants and economic assessment methodology. The performance and cost data developed for this evaluation are the result of maintaining a consistent design basis throughout. Common design inputs for site, ambient, and fuel characteristics were used for each technology under consideration.

1) Site Characteristics

The plant designs utilize a common generic site with conditions typical to a south city of China. Table 2.1 lists the ambient characteristics of this site.

Table 2.1 Site Characteristics

Design Air Pressure	1atm
Design Temperature	298K
Relative Humidity	55%
Transportation	Rail access
Water	Municipal

2) Coal Characteristics

Typical coal types were investigated, and Shendong coal was chosen to be the analyzed coal type in this project for various electricity generation technologies. The coal-based plants utilize Shendong coal delivered by unit train. Limestone is delivered by car loads, which are individually handled. The coal specification is shown in table 2.2.

Table 2.2 Base Coal Analysis –Shen-dong Coal

Proximate Analysis（%，wt, as		**Ultimate Analysis（%，wt，dry**	
Moisture	10.56	Carbon	76.99
Fixed Carbon	52.52	Hydrogen	4.58
Volatile Matter	30.64	Oxygen	10.07
Ash	6.28	Nitrogen	0.94
		Sulfur	0.4
		ASH	7.02
As-Received LHV（kJ/kg）		26110	

3) The environmental performance targets:

The State Environmental Protection Administration of China (SEPA) and General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China issued an emission standard of air pollutants for thermal power plants on December 23, 2003 (GB-13223/2003). The standard was implemented on January 1, 2004 and included NOx for the first time.

The standard is divided into three period of time. It prescribes emission requirements respectively according to the operation or approval time of thermal power plant projects. Either the power plants that were put into practice or new and retrofit power plants whose environmental impact assessment reports are approved before Dec. 31, 1996 implement requirements of first period of time. New and retrofit power plants whose environmental impact assessment reports are approved from Jan. 1, 1997 to Dec. 31, 2003 implement requirements of second period of time. New and retrofit power plants whose environmental impact assessment reports are approved from Jan. 1, 2004 implement requirements of third period of time. The following tables show the emission requirements for thermal power plant.[1]

Table 2.3 SO_2 emission requirements for thermal power boiler and gas turbine unit: mg/m^3

Period of time	First Period of time		Second Period of time		Third Period of time
Implementation time	Jan. 1, 2005	Jan. 1, 2010	Jan. 1, 2005	Jan. 1, 2010	Jan. 1, 2004
Coal-fired boiler and oil fired boiler	2100 [1)]	1200 [1)]	2100 1200 [2)]	400 1200 [2)]	400 800 [3)] 1200 [4)]

1) Average value for whole thermal power plant at first period of time.

2) Before implementation of the standard, plants whose environmental impact assessment reports are approved and coal mine mouth power plants whose fuels are low sulfur (sulfur content < 0.5%) coal at non-designated acid rain control areas of western region.

3) Resource comprehensive utilization power plants burning coal refuse, low heat value<12550kJ/kg.

4) Coal mine mouth power plants whose fuels are low sulfur (sulfur content < 0.5%) coal at non-designated acid rain control areas of western region.

Table 2.4 NOx emission requirements for thermal power boiler and gas turbine unit: mg/m^3

Period of time		First Period of time	Second Period of time	Third Period of time
Implementation time		Jan. 1, 2005	Jan. 1, 2005	Jan. 1, 2004
Coal-fired boiler	Vdaf ＜10%	1500	1300	1100
	10%≤Vdaf ≤20%	1100	650	650
	Vdaf ＞20%			450
Heavy oil fired boiler		650	400	200
Gas turbine	Heavy oil fired			150
	Gas fired			80

The particulate matter emission requirement is $100mg/Nm^3$.

4) Economic Assessment Methodology

Two main terms, capital cost and COE were used to evaluate the economic performances in the study. The definitions of them are as follows.

Capital cost can be expressed as RMB Yuan per kW and is equal to total plant investment capital divided by gross generating capacity. Total plant investment capital values represent overnight construction cost plus other engineering cost, plus contingency cost and financial cost during the construction period. Overnight construction cost includes equipment cost, construction engineering, and installation engineering costs. Other engineering cost is intended to cover land use cost, preparation fee for production, exploration and design cost, operator training, joint commissioning, engineering insurance, management cost for builder and supervisor, extra cost for imported technology and equipment, and so forth. Overnight construction cost and other engineering costs are classified into three categories, including fixed assets, intangible assets (invisible assets), and deferred assets. Financial cost means loan interests during the construction. Table 2.5 shows the composition of total plant investment capital.

Table 2.5 The composition of total plant investment capital[1]

<table>
<tr><th>No.</th><th colspan="3">Items</th></tr>
<tr><td rowspan="8">1</td><td rowspan="8">Fixed assets cost</td><td colspan="2">Construction engineering cost</td></tr>
<tr><td colspan="2">Original equipment cost</td></tr>
<tr><td colspan="2">Installation engineering cost</td></tr>
<tr><td rowspan="5">Other cost</td><td>Management cost for project construction</td></tr>
<tr><td>Technical service cost</td></tr>
<tr><td>extra costs for imported technology and equipment</td></tr>
<tr><td>Site preparation</td></tr>
<tr><td>Other costs</td></tr>
<tr><td>2</td><td>Intangible assets cost</td><td colspan="2">Land use cost</td></tr>
<tr><td>3</td><td>Deferred assets cost</td><td colspan="2">Preparation fee for production</td></tr>
<tr><td>4</td><td colspan="3">Basic contingency cost</td></tr>
<tr><td>5</td><td colspan="3">Interests during construction period</td></tr>
</table>

COE is equal to depreciation cost of fixed assets plus amortization charge of intangible and deferred assets costs, plus fuel cost, and consumables cost, wage and welfare cost, repair cost, financial cost, and charges for disposing pollutants, as shown in table 2.6.

Table 2.6 The composition of COE

No.	Items
1	bought-in primary material cost
2	bought-in fuel and power cost
3	wage and welfare cost
4	repair cost
5	depreciation cost
6	amortization cost
7	financial cost
8	Charges for disposing SO_2
9	Charges for disposing NOx
10	Charges for disposing particulate matter

Operation and Maintenance (O&M) cost includes bought-in primary material cost, bought-in fuel and power cost, wage and welfare cost, repair cost and charges for disposing pollutants. The streams of expenses are expressed as a real annuity, where the payments are assumed to be for the same RMB amount in every year of the plant's life.

In 2003, State Development and Planning Committee combined with Ministry of Finance and State Environmental Protection Administration of China released managerial rules of levying standard for disposing pollutants. The rules impose a levy on pollutants emissions. 632 RMB Yuan/tonne of SO_2 and NOx, 275 RMB Yuan/tonne of particulate matter are levied by the government respectively. In this study, disposing pollutants costs were considered.[1]

The table 2.7 gives basic parameters for all technology options.

Table 2.7 Basic parameters for all technology options

Construction period	3 years	Annual operation hours	6000 hours
Depreciation residual rate	5%	Depreciation period	15 years
Amortization of intangible assets	5 years	Amortization of deferred assets	5 years
Loan rate	6.4%	Loan ratio	70%
Basic contingency cost	8%	Loan return period	15 years
Welfare and labor protection coefficient	57%	PC repair rate	2.5%
Operation period	20 years	IGCC repair rate	3.5%

In the study, the total plant capital cost (RMB Yuan/kW) values are all determined on the basis of the total plant gross power. And the COE (RMB Yuan/MWh) numbers are all based on the total net electricity generation. This will be more evident as other technologies are compared. Formation and Analysis System for Investment Project Feasibility Study is used to calculate total plant investment and COE. The system was developed based on the guidelines on investment project feasibility study issued by NDRC in 2002. These assessments compare the capital cost and COE for subcritical PC, SC PC, USC PC, CFB and IGCC on a consistent basis.

3. Pulverized Coal Power Plants

- **Process Description**

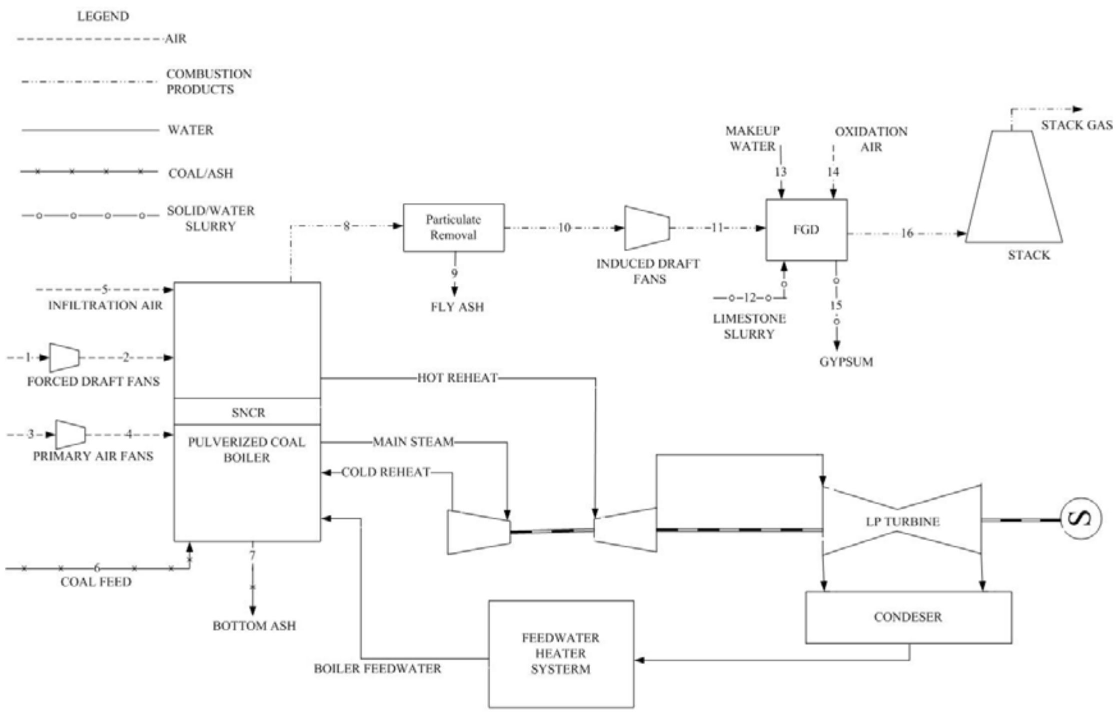


Fig. 3.1 PC power plants with wet desulphurization

The configuration of PC power plants with wet desulphurization is shown in figure 3.1. PC power station mainly consists of pulverized coal fired boiler, steam turbine, pump, FGD and other auxiliary facilities. Superheated steam with high temperature and high pressure is generated in boiler. And then steam is expanded through steam turbine to generate electricity. This kind of cycle is called Rankine cycle. The most important way to improve plant performance is to increase steam temperature and pressure. According to steam temperature and pressure, pulverized coal power plants can be divided into three types. The first is called subcritical power generation. In this kind of plants, steam is in subcritical region. If steam parameters is increased to the critical point of water (22.115MPa, 374.15□), the plant is called supercritical power generation. In fact, ultra supercritical power generation also belongs to supercritical power generation. But its steam parameters are even higher, which means higher power generation efficiency.

Coal and primary air are introduced into the boiler through the wall-fired burners. Additional combustion air, including the overfire air, is provided by the forced draft fans. The boiler operates at a slight negative pressure so air leakage is into the boiler.

Flue gas exits the boiler through the SNCR reactor and is cooled in the combustion air preheater before particulate removal. FGD inputs and outputs include makeup water, oxidation air, limestone slurry and product gypsum. The clean, saturated flue gas exiting the FGD unit passes to the plant stack and is discharged to atmosphere.

- **Calculation conditions**

According to parameters of standard units operating in China, the following conditions are shown in tables 3.1-3.4.

Table 3.1 Steam turbine parameters

	600MW subcritical plant	600MW SC plant	600MW USC plant
Live steam（MPa／℃／t/h）	16.7/538.0/1760	24.2/566.0/1660.8	25/600/1622.5
Superheated steam（hot part, and hot part, MPa／℃／t/h）	3.619/317.1/1482 3.257/538.0/1482	4.23/308.1/1414.1 3.81/566.0/1414.1	4.58/339.2/1330.8 4.12/600.0/1330.8
Heat consumption rate (kJ/kWh）	7748.2	7522	7428
Exhaust parameters (MPa)	0.0049	0.0049	0.0049
Steam rate (kg/kWh）	2.933	2.768	2.704
Feed water pump exit (℃／t/h)	271.9/1760.0	275.1/1660.8	285.7/1622.5

Table 3.2 Parameters of steam turbine bleeder heater for 600MW subcritical PC plant

		High pressure bleeder heater			Deaerator	Low pressure bleeder heater			
	Block name	H1	H2	H3	HD	H5	H6	H7	H8
Heating steam	Mass flow, t/h	119	135.9	75	75.1	70.6	45.3	50.3	57.9
	Pressure, MPa	5.526	3.51	1.648	0.7838	0.3269	0.1249	0.030154	0.0230755
Feed water	Temperature,□	270.2	242.7	202.8	169.6	136.5	106	86	63.2
dewatering	Mass flow,t/h	119	254.9	329.9		70.6	115.9	166.1	224
	Temperature,□	248.3	208.3	178.4		108.8	88.8	66	39.2

Table 3.3 Parameters of steam turbine bleeder heater for 600MW SC PC plant

		High pressure bleeder heater			Deaerator	Low pressure bleeder heater			
	Block name	H1	H2	H3	HD	H5	H6	H7	H8
Heating steam	Mass flow, t/h	94.5	130.2	68.9	88.0	85.1	40.9	46.1	48.0
	Pressure, MPa	5.80	4.10	2.08	1.01	0.382	0.110	0.0534	0.0205
Feed water	Temperature, □	273.4	251.8	214.3	180.3	142.0	102.4	83	60.6
dewatering	Mass flow,t/h	94.5	224.6	293.5		85.1	126.1	172.2	220.9
	Temperature, □	257.4	220.0	191.3		105.2	85.8	63.4	38.9

Table 3.4 Parameters of steam turbine bleeder heater for 600MW USC PC plant

		High pressure bleeder heater			Deaerator	Low pressure bleeder heater			
	Block name	H1	HD	H3	HD	H5	H6	H7	H8
Heating steam	Mass flow, t/h	111.8	51.4	60.4	51.4	53.2	58.7	60.6	63.1
	Pressure, MPa	6.82	0.95	1.95	0.95	0.534	0.265	0.104	0.031
Feed water	Temperature, □	284	177.7	211.1	177.7	154.3	129.4	100.7	69.8
dewatering	Mass flow,t/h	111.8	257.2	319.1		53.2	111.8	172.5	236.4
	Temperature, □	262.3	216.7	189.0		132.2	103.5	72.6	38.6

Wet desulphurization was applied in calculation. 95% of SO_2 in flue gas was absorbed by limestone. Gypsum produced was discharges from plant.

Thermodynamic performance of pulverized coal power plants were predicted by Aspen plus simulation. This work can be used to analyze the performance variation with steam parameters, to compare the effect of different plant configurations. With parameters listed in table 3.1-3.4, conceptual plant of subcritical steam turbine power generation section, supercritical steam turbine power generation section, ultra supercritical steam turbine power generation section were simulated. Heat balance method was used in boiler calculation. Fuel consumption was calculated based on boiler thermal efficiency, steam rate of steam turbine, etc. If FGD was applied, other three plants with sulfur removal were formed.

1) Subcritical Pulverized Coal Power Plants

This section contains an evolution of plant designs for case 1, case 2 and case 3 which are based on a subcritical PC plant. All the three cases use a single reheat 16.7MPa/538□/538□ cycle. The difference between the three cases is that case 1 is a plant with no desulphurization or SNCR NOx reduction, the wet FGD desulphurization is added in case 2 compared with case1 and the SNCR NOx reduction is added in case 3 compared with case 2.

- **Key System Assumptions**

System assumptions for Cases 1, 2 and 3 are shown in Table 3.5.

Table 3.5 Key Assumptions for Subcritical PC Plant Study

	CASE 1	CASE 2	CASE 3
Steam Parameters MPa/□/□	16.7/538/538	16.7/538/538	16.7/538/538
Coal Type	Shendong	Shendong	Shendong
Condensor Pressure（kPa）	4.9	4.9	4.9
Boiler Efficiency, %	92.9	92.9	92.9
Excess Air Coefficient	1.3	1.3	1.3
Ash Distribution, Fly/Bottom	60% / 40%	60% / 40%	60% / 40%
SO_2 Control	—	FGD	FGD
Ca/S Ratio	—	1.1	1.1
FGD Efficiency	—	95%	95%
NOx Control	LNB	LNB	LNB/SNCR
SNCR Efficiency	—	—	40%
Particulate Matter Control	Electrical precipitation	Electrical precipitation	Electrical precipitation
Electrical precipitation Efficiency	**99%**	**99%**	**99%**

- **Thermodynamic Performances**

The plant of Case 1 produces a net output of 1146 MWe at a net design efficiency of 40.2% (LHV). The plant of Case 2 produces a net output of 1128 MWe at a net design efficiency of 39.6% (LHV) and the plant of Case 3 produces a net output of 1125.6 MWe at a net design efficiency of 39.5%.

Overall thermodynamic performances for the plant are summarized in table 3.6.

Table 3.6 Thermodynamic Performances Summary for Subcritical PC Plants

	CASE 1	CASE 2	CASE 3
Gross Power (MWe)	1200	1200	1200
Total Auxiliary Losses	4.5%	6%	6.2%
Net Power (MWe)	1146	1128	1125.6
Coal Consumption (kg/hr)	392940	392940	392940
Coal Consumption Rate (Shendong Coal), g/kWh	342.9	348.4	349.1
Standard Coal Consumption Rate (g/kWh)	305.9	310.7	311.4
Net Design Efficiency (LHV)	**40.2%**	**39.6%**	**39.5%**

- **Environmental Performances**

The environmental performances for emissions of NOx, SO_2, CO_2 and particulate matter are summarized and presented in table 3.7.

Table 3.7 Subcritical PC plants Emissions

	CASE 1	CASE 2	CASE 3
SO_2 (mg/Nm^3)	759	38	38
SO_2 (g/kWh)	2.34	0.12	0.12
SO_2 (kg/hr)	2811.6	140.6	140.6
NOx (mg/Nm^3)	450	450	270
NOx (g/kWh)	1.52	1.52	0.91
NOx (kg/hr)	1828	1828	1096.8
Particulate Matter (mg/Nm^3)	40	40	40
Particulate Matter (g/kWh)	0.123	0.123	0.123
Particulate matter (kg/hr)	148	148	148
CO_2 (g/kWh)	827	827	827
CO_2 (kg/hr)	**992120**	**992120**	**992120**

For Case 2 and Case 3, SO_2 emissions are controlled using a wet limestone achieves a removal efficiency of 95 percent. The byproduct calcium sulfate is dewatered and stored on site. The wallboard grade material can potentially be marketed and sold.

NOx emissions are controlled at 450 mg/Nm^3 through the use of LNBs. For Case 3, an SNCR unit then further reduces the NOx concentration by 40% to 270 mg/Nm^3.

Particulate matter emissions are controlled using electrical precipitation which operates at an efficiency of 99 percent.

- **Cost**

The capital cost and COE of subcritical PC plants are shown in the table 3.8.

Table 3.8 Capital Cost and COE of Subcritical PC plants

	CASE 1	CASE 2	CASE 3
Capital cost (RMB Yuan/kW)	3502	3675	3762
COE (RMB Yuan/MWh)	264.31	273.41	278.66
COE including charges for disposing pollutants (RMB Yuan/MWh)	266.90	274.55	279.39

2) Super-Critical Pulverized Coal Power Plants

This section contains an evolution of plant designs for case 4, case 5 and case 6 which are based on a supercritical PC plant. All the three cases use a single reheat 24.2MPa/566℃/566℃ cycle. The difference between the three cases is that case 4 is a plant with no desulphurization or SNCR NOx reduction, while the wet FGD desulphurization is added in case 5 compared with case 4 and the SNCR NOx reduction is added in case 6 compared with case 5.

- **Process Description**

The system description is nearly identical to the subcritical PC cases and will not be repeated here.

- **Key System Assumptions**

System assumptions for Cases 4, 5 and 6 are shown in Table 3.9.

Table 3.9 Key Assumptions for Supercritical PC Plant Study

	CASE 4	CASE 5	CASE 6
Steam Parameters MPa/□/□	24.2/566/566	24.2/566/566	24.2/566/566
Coal Type	Shendong	Shendong	Shendong
Condensor pressure（kPa）	4.9	4.9	4.9
Boiler Efficiency, %	92.9	92.9	92.9
Excess Air Coefficient	1.3	1.3	1.3
Ash Distribution, Fly/Bottom	60% / 40%	60% / 40%	60% / 40%
SO_2 Control	—	FGD	FGD
Ca/S Ratio	—	1.1	1.1
FGD Efficiency	—	95%	95%
NOx Control	LNB	LNB	LNB/SNCR
SNCR Efficiency	—	—	40%
Particulate Matter Control	Electrical precipitation	Electrical precipitation	Electrical precipitation
Electrical precipitation Efficiency	**99%**	**99%**	**99%**

- **Thermodynamic Performances**

The plant of Case 4 produces a net output of 1146 MWe at a net design efficiency of 41.3% (LHV). The plant of Case 5 produces a net output of 1128 MWe at a net design efficiency of 40.7% (LHV) and the plant of Case 6 produces a net output of 1125.6 MWe at a net design efficiency of 40.6%.

Overall performances for the plant are summarized in Table 3.10.

Table 3.10 Thermodynamic Performances Summary for Supercritical PC Plants

	CASE 4	CASE 5	CASE 6
Gross Power (MWe)	1200	1200	1200
Total Auxiliary Losses	4.5%	6%	6.2%
Net Power (MWe)	1146	1128	1125.6
Coal Consumption (kg/hr)	382440	382440	382440
Coal Consumption Rate (Shendong Coal) (g/kWh)	333.7	339.0	339.8
Standard Coal Consumption Rate (g/kWh)	297.7	302.4	303.1
Net Design Efficiency（LHV)	**41.3%**	**40.7%**	**40.6%**

- **Environmental Performances**

The environmental performances for emissions of NOx, SO_2, CO_2 and particulate matter are summarized and presented in Table 3.11.

Table 3.11 SC PC plants Emissions

	CASE 4	CASE 5	CASE 6
SO_2 (mg/Nm^3)	759	38	38
SO_2 (g/kWh)	2.28	0.11	0.11
SO_2 (kg/hr)	2736.4	136.8	136.8
NOx (mg/Nm^3)	450	450	270
NOx (g/kWh)	1.48	1.48	0.89
NOx (kg/hr)	1779.2	1779.2	1067.5
Particulate Matter (mg/Nm^3)	40	40	40
Particulate Matter (g/kWh)	0.12	0.12	0.12
Particulate Matter (kg/hr)	144	144	144
CO_2 (g/kWh)	805	805	805
CO_2 (kg/hr)	**965600**	**965600**	**965600**

For Case 5 and Case 6, SO_2 emissions are controlled using a wet limestone achieves a removal efficiency of 95 percent. The byproduct calcium sulfate is dewatered and stored on site. The wallboard grade material can potentially be marketed and sold.

NOx emissions are controlled at 450 mg/Nm^3 through the use of LNBs. For Case 6, an SNCR unit then further reduces the NOx concentration by 40% to 270 mg/Nm^3.

Particulate matter emissions are controlled using electrical precipitation which operates at an efficiency of 99 percent.

- **Cost**

The capital cost and COE of SC PC plants are shown in the table 3.12.

Table 3.12 Capital Cost and COE of SC PC plants

	CASE 4	CASE 5	CASE 6
Capital cost (RMB Yuan/kW)	3683	3856	3942
COE (RMB Yuan/MWh)	261.95	270.97	276.22
COE including charges for disposing pollutants (RMB Yuan/MWh)	264.47	272.08	276.93

3) Ultra-Super-Critical Pulverized Coal Power Plants

This section contains an evolution of plant designs for case 7, case 8 and case 9 which are based on an USC plant. All the three cases use a single reheat 25MPa/600□/600□ cycle. The difference between the three cases is that case 7 is a plant with no desulphurization or SNCR NOx reduction, while the wet FGD desulphurization is added in case 8 compared with case 7 and the SNCR NOx reduction is added in case 9 compared with case 8.

- **Key System Assumptions**

System assumptions for Cases 7, 8 and 9 are shown in Table 3.13.

Table 3.13 Key Assumptions for USC PC Plant Study

	CASE 7	CASE 8	CASE 9
Steam Parameters MPa/□/□	25/600/600	25/600/600	25/600/600
Coal Type	Shendong	Shendong	Shendong
Condensor pressure（kPa）	4.9	4.9	4.9
Boiler Efficiency, %	92.9	92.9	92.9
Excess Air Coefficient	1.3	1.3	1.3
Ash Distribution, Fly/Bottom	60% / 40%	60% / 40%	60% / 40%
SO_2 Control	—	FGD	FGD
Ca/S Ratio	—	1.1	1.1
FGD Efficiency	—	95%	95%
NOx Control	LNB	LNB	LNB/SNCR
SNCR Efficiency	—	—	40%
Particulate Matter Control	Electrical precipitation	Electrical precipitation	Electrical precipitation
Electrical precipitation Efficiency	**99%**	**99%**	**99%**

Thermodynamic Performances

The plant of Case 7 produces a net output of 1146 MWe at a net design efficiency of 42.3% (LHV). The plant of Case 8 produces a net output of 1128 MWe at a net design efficiency of 41.6% (LHV) and the plant of Case 9 produces a net output of 1125.6 MWe at a net design efficiency of 41.5%.

Overall performances for the plant are summarized in Table 3.14.

Table 3.14 Thermodynamic Performances Summary for USC PC Plants

	CASE 7	CASE 8	CASE 9
Gross Power (MWe)	1200	1200	1200
Total Auxiliary Losses	4.5%	6%	6.2%
Net Power (MWe)	1146	1128	1125.6
Coal Consumption (kg/hr)	373620	373620	373620
Coal Consumption Rate (Shendong Coal) (g/kWh)	326.0	331.2	331.9
Standard Coal Consumption Rate (g/kWh)	290.8	295.5	296.1
Net Design Efficiency（LHV)	**42.3%**	**41.6%**	**41.5%**

- **Environmental Performances**

The environmental performances for emissions of NOx, SO_2, CO_2 and particulate matter are summarized and presented in Table 3.15.

Table 3.15 USC PC plants Emissions

	CASE 7	CASE 8	CASE 9
SO_2 (mg/Nm^3)	759	38	38
SO_2 (g/kWh)	2.23	0.11	0.11
SO_2 (kg/hr)	2673.3	133.7	133.7
NOx (mg/Nm^3)	450	450	270
NOx (g/kWh)	1.45	1.45	0.87
NOx (kg/hr)	1738.2	1738.2	1042.9
Particulate Matter (mg/Nm^3)	40	40	40
Particulate Matter (g/kWh)	0.118	0.118	0.118
Particulate matter (kg/hr)	140.8	140.8	140.8
CO_2 (g/kWh)	786	786	786
CO_2 (kg/hr)	**943320**	**943320**	**943320**

For Case 8 and Case 9, SO_2 emissions are controlled using a wet limestone achieves a removal efficiency of 95 percent. The byproduct calcium sulfate is dewatered and stored on site. The wallboard grade material can potentially be marketed and sold.

NOx emissions are controlled at 450 mg/Nm^3 through the use of LNBs. For Case 9, an SNCR unit then further reduces the NOx concentration by 40% to 270 mg/Nm^3.

Particulate matter emissions are controlled using Electrical precipitation which operates at an efficiency of 99 percent.

- **Cost**

The capital cost and COE of USC PC plants are shown in the table 3.16.

Table 3.16 Capital Cost and COE of USC PC plants

	CASE 7	CASE 8	CASE 9
Capital cost (RMB Yuan/kW)	3878	4051	4137
COE (RMB Yuan/MWh)	260.67	269.64	276.04
COE including charges for disposing pollutants (RMB Yuan/MWh)	263.14	270.72	276.74

4. Circulating Fluidized Bed Power Plants

This section includes plant design for case 10 which is based on a 2×300MW CFB (circulating Fluidized Bed) power plant . The plant uses a single reheat 16.7MPa/538℃/538℃ cycle.

- **Process Description**

The system description is nearly identical to the subcritical PC cases. The main difference is that CFB boiler is used.

- **Key System Assumptions**

System assumptions for Case 10 are shown in Table 4.1.

Table 4.1 Key Assumptions for CFB Power Plant Study

	CASE 10 2×300MW CFB
Steam Parameter MPa/□/□	16.7/538/538
Coal Type	Shendong
Condensor Pressure（kPa）	4.9
Boiler Efficiency, %	90
Excess Air Coefficient	1.3
Ash Distribution, Fly/Bottom	80:20
NOx Emission (mg/Nm^3)	250
SO_2 Control	Furnace Desulfurization
SO_2 Removal Efficiency	90%
Ca/S Ratio	2:1
Particulate Matter Control	Electrical Precipitation
Electrical precipitation Efficiency	**99%**

- **Thermodynamic Performances**

The plant of Case 10 produces a net output of 558 MWe at a net plant efficiency of 37.6% (LHV).

Overall performances for the plant are summarized in Table 4.2.

Table 4.2 Thermodynamic Performances Summary CFB Power Plants

	CASE 10 2×300MW CFB
Gross Power (MW)	600
Total Auxiliary Losses	7%
Net Power (MW)	558
Coal Consumption（kg/hr）	204660
Coal Consumption Rate (Shendong Coal) (g/kWh)	366.8
Standard Coal Consumption Rate (g/kWh)	327.2
Net Design Efficiency (LHV)	**37.6%**

- **Environmental Performances**

The environmental performances for emissions of NOx, SO_2, CO_2 and particulate matter are summarized and presented in Table 4.3.

Table 4.3 CFB Power Plants Emissions

	CASE 10 2×300 MW CFB
SO_2 (mg/Nm^3)	76
SO_2 (g/kWh)	0.24
SO_2 (kg/hr)	146.4
NOx (mg/Nm^3)	250
NOx (g/kWh)	0.89
NOx (kg/hr)	531.7
Particulate Matter (mg/Nm^3)	53
Particulate Matter (g/kWh)	0.17
Particulate matter (kg/hr)	102.8
CO_2 (g/kWh)	862
CO_2 (kg/hr)	**516742**

Particulate matter emissions are controlled using electrical precipitation which operates at an efficiency of 99 percent.

- **Cost**

The capital cost and COE of subcritical CFB plants are shown in the table 4.4.

Table 4.4 Capital Cost and COE of Subcritical CFB plants

	CASE 10
Capital cost (RMB Yuan/kW)	4566
COE (RMB Yuan/MWh)	305.46
COE including charges for disposing pollutants (RMB Yuan/MWh)	306.28

5. Integrated Gasification Combined Cycle

1) IGCC Power Plant Based on Multi-Nozzle Entrained Flow Gasifier

This section contains an evolution of plant designs for case 11 which is based on a 200MW IGCC power plant. The Multi-Nozzle entrained flow gasifier and GE E class gas turbine were used. This kind of gasification technology was developed by ECUST (East China University of Science and Technology).

- **Process Description**

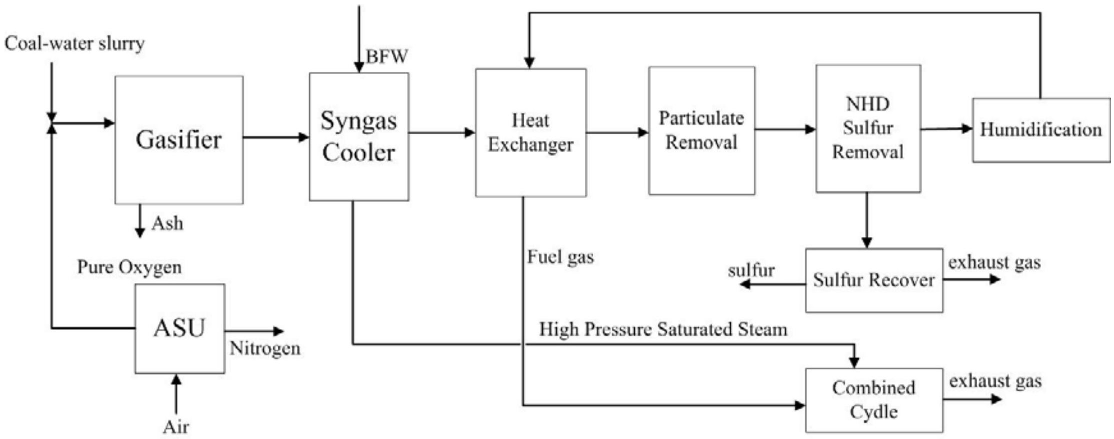


Figure 5.1 IGCC based on multi-nozzle entrained flow gasifier process flowsheet

The process flowsheet of IGCC based on multi-nozzle entrained flow gasifier power plant is presented in Figure 5.1. The system adopts the Multi-Nozzle entrained flow gasifier which is fed with coal-water slurry, and the gas cooling adopts waste heat boiler process. The gasifier is operated at the condition of 1310℃, 3.5MPa. The handling capacity of the gasifier is 1800t/d. The gasification agent is oxygen. The crude gas enters into the waste heat boiler and generates high pressure saturated steam. Then the particulate is removed from the crude gas. The temperature of the crude gas at the exit of heat recover unit is reduced to approximately 40℃. Then, the gas passes through the gas/water separate unit and sulfur removal unit, the sulfur in the gas is reduced to be less than 100ppm. The acid gas generated in the sulfur removal unit passes through the sulfur recover unit to recover element sulfur. The clean gas then has been removed sulfur would be humidified and heated, then is sent to the combined cycle unit. The combined cycle unit adopts an E-class gas turbine and a dual pressure system HRSG that has its own dearator, and the high-pressure steam parameter is 510℃/10MPa, the medium reheated steam parameter is 510℃/4MPa and the low pressure steam parameter is 260℃/0.36MPa. After the high-pressure steam which comes from the waste heat boiler of the gasifier apply work in high pressure cylinder of the steam turbine, it mixes with the mixes with the medium pressure steam generated in HRSG, and then, enters into the intermediate pressure cylinder of the steam turbine. The generating capacity of the combined cycle is 251MW.

- **Key System Assumptions**

System assumptions for Cases 11 are shown in Table 5.1.

Table 5.1 Key Assumptions for IGCC Power Plant Study

	CASE 11
Gasifier Pressure（MPa）	3.5
Carbon Conversion Rate , %	98
Steam Parameters, MPa/□/□	10/510/510
Condensor Pressure（kPa）	4.9
Gas Turbine	E-class Gas Turbine
Gasification Technology	Multi-Nozzle entrained flow gasifier
Oxygen concentration	99 vol%
Coal-Water Slurry Concentration，%	61
COS Hydrolysis	Yes
SO_2 Removal	NHD
SO_2 Removal Efficiency	99%
Particulate Matter Removal	Wet Scrubber
NOx Control	**Fuel Saturation**

- **Thermodynamic Performances**

The plant of Case 11 produces a net output of 212 MWe at a net design efficiency of 40.5% (LHV).

Overall performances for the plant are summarized in Table 5.2.

Table 5.2 Thermodynamic Performances Summary for IGCC Power Plant

	CASE 11
Coal Feed, t/d（kg/hr）	1736.1（72339）
Gross Power, MWe	251.2
Net Power, MWe	212.3
Auxiliary Losses, %	15.5
Coal Consumption Rate (Shendong Coal) , g/kWh	340.7
Standard Coal Consumption Rate, g/kWh	303.9
Net Design Efficiency, %	**40.5**

- **Environmental Performances**

The environmental performances for emissions of NOx, SO_2, CO_2 and particulate matter are summarized and presented in Table 5.3.

Table 5.3 IGCC Power Plant Emissions

	CASE 11
SO_2 (mg/Nm^3)	2
SO_2 (g/kWh)	0.01
SO_2 (kg/hr)	2.8
NOx (mg/Nm^3)	240
NOx (g/kWh)	0.57
NOx (kg/hr)	142.4
Particulate Matter (mg/Nm^3)	10
Particulate Matter (g/kWh)	0.05
Particulate matter (kg/hr)	12.3
CO_2 (g/kWh)	717
CO_2 (kg/hr)	**180000**

2) IGCC Power Plant Based on Dry Pulverized Coal Entrained Flow Gasifier

This section contains an evolution of plant designs for case 12 which is based on a 200MW IGCC power plant. The dry pulverized coal entrained flow gasifier was adopted.

- **Process Description**

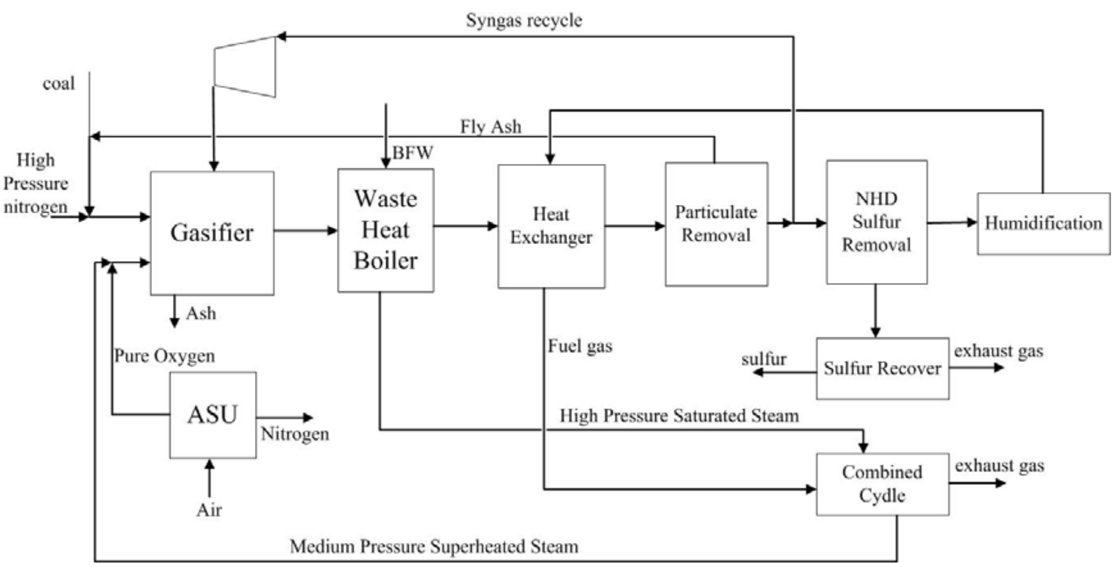


Figure 5.2 IGCC based on dry pulverized coal entrained flow gasifier process flowsheet

The process flowsheet of IGCC power plant is presented in Figure 5.2. The system adopts Shell entrained flow gasifier which is fed with dry pulverized coal, and the gas cooling adopts waste heat boiler process. The gasifier is operated at the condition of 1310℃, 2.5MPa. The handling capacity of the gasifier is 1600t/d. The gasification agent is oxygen and a small amount of superheated steam. The feed is transported to gasifer by nitrogen, and reacts with gasification agent. The high temperature crude gas is mixed with the clean gas which has been particulate removed at the exit of the gasifier, therefore the high temperature gas is chilled. The melting ash in the gas is solidified, and exhausted in the form of ash. The crude gas enters into the waste heat boiler and generates high pressure saturated steam. Then the particulate is removed from the crude gas. The temperature of the crude gas at the exit of heat recover unit is reduced to approximately 40□. Then, the gas passes through the gas/water separate unit and sulfur removal unit, the sulfur in the gas is reduced to be less than 100ppm. The acid gas generated in the sulfur removal unit passes through the sulfur recover unit to recover element sulfur. The clean gas then has been removed sulfur would be humidified and heated, then is sent to the combined cycle unit. The combined cycle unit adopts an E-class gas turbine and a dual pressure system HRSG that has its own dearator, and the high-pressure steam parameter is 510□/10MPa, the medium reheated steam parameter is 510□/4MPa and the low pressure steam parameter is 260□/0.36MPa. After the high-pressure steam which comes from the waste heat boiler of the gasifier apply work in high pressure cylinder of the steam turbine, it mixes with the mixes with the medium pressure steam generated in HRSG, and then, enters into the intermediate pressure cylinder of the steam turbine. The generating capacity of the combined cycle is 228MW.

- **Key System Assumptions**

System assumptions for Cases 12 are complied in Table 5.4.

Table 5.4 Key Assumptions for IGCC Power Plant Study

	CASE 12
Gasifier Pressure（MPa）	2.5
Carbon Conversion Rate , %	99.6
Steam Parameter, MPa/□/□	10/510/510
Condensor Pressure（kPa）	4.9
Gas Turbine	E-class Gas Turbine
Gasification Technology	Shell entrained flow gasifier
Oxygen concentration	99 vol%
Coal-Water Slurry Concentration，%	61
COS Hydrolysis	Yes
SO_2 Removal	NHD
SO_2 Removal Efficiency	99%
Particulate Matter Removal	Candle filter
NOx Control	**Fuel Saturation**

- **Thermodynamic Performances**

The plant of Case 12 produces a net output of 192MWe at a net design efficiency of 41.2% (LHV).

Overall performances for the plant are summarized in Table 5.5.

Table 5.5 Thermodynamic Performances Summary for IGCC Power Plant

	CASE 12
Coal Feed, t/d（kg/hr）	1541.7（64238）
Gross Power, MWe	228.1
Net Power, MWe	192
Auxiliary Losses, %	15.8
Coal Consumption Rate (Shendong Coal) , g/kWh	334.6
Standard Coal Consumption Rate, g/kWh	298.5
Net Design Efficiency, %	**41.2**

- **Environmental Performances**

The environmental performances for emissions of NOx, SO_2, CO_2 and particulate matter are summarized and presented in Table 5.6.

Table 5.6 IGCC Power Plant Emissions

	CASE 12
SO_2 (mg/Nm^3)	2
SO_2 (g/kWh)	0.01
SO_2 (kg/hr)	2.5
NOx (mg/Nm^3)	240
NOx (g/kWh)	0.61
NOx (kg/hr)	139.3
Particulate Matter (mg/Nm^3)	10
Particulate Matter (g/kWh)	0.05
Particulate matter (kg/hr)	12
CO_2 (g/kWh)	715
CO_2 (kg/hr)	**162590**

- **Cost**

The capital cost and COE of IGCC plants are shown in the table 5.7.

Table 5.7 Capital Cost of IGCC Power Plants

	CASE 11	CASE 12
	new coal-water slurry with opposed multi-nozzles gasifier	Shell gasifier
Capital cost (RMB Yuan/kW)	7433	8824
COE (RMB Yuan/MWh)	364.75	392.05
COE including charges for disposing pollutants (RMB Yuan/MWh)	365.20	392.53

6. Comparisons among Different Cases

1) Thermodynamic Performances

When net design efficiencies of all cases were calculated, the choices of parameters considered the current status of in-use units. Steam parameters selected for PC plant were the same as most new addition units in power sector. The parameters choice and design of IGCC took into account real conditions of demonstration plants and technological level. The figures 6.1 and 6.2 show us net design efficiency and standard coal consumption rate among Different Cases.

In this study, net efficiency gaps between subcritical, SC and USC are small. The net efficiencies of subcritical PC (case 1, 2 and 3) are relatively high, because of the further improvements and advances in steam turbine design. These data reflect the most advanced technology level now in China. The choice of steam parameters for USC is not so high according to current industrial state. So the net efficiencies of USC PC plants (case7, 8 and 9) are a little higher than those of SC PC plants. The advantages of USC were not externalized completely.

The net design efficiency for IGCC is equal to SC PC power generation technology, a little lower than USC. The reason why IGCC's efficiency is lower than USC's is total auxiliary losses for IGCC were set at higher numbers. The auxiliary losses for IGCC based on multi-nozzle entrained flow gasifier are 15.5%. The auxiliary losses for IGCC based on dry pulverized coal entrained flow gasifier are 15.8%. These data were supplied by Hangzhou Hangyang Co., LTD. China. If the total auxiliary losses are reduced to around 12%, net design efficiency for IGCC would reach 42%.

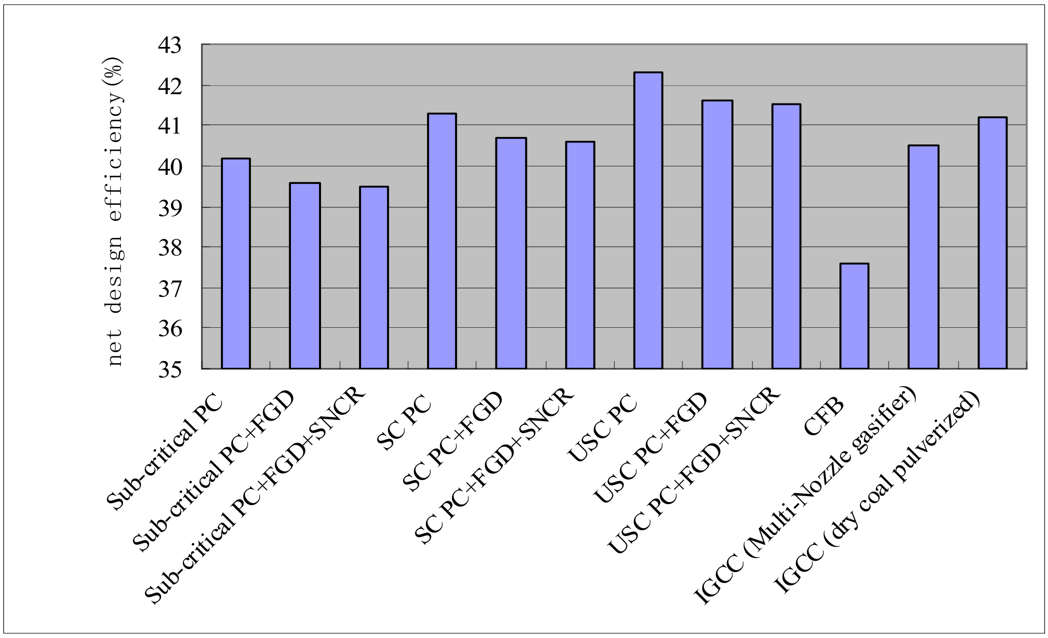


Figure 6.1 Net Design Efficiency (%)

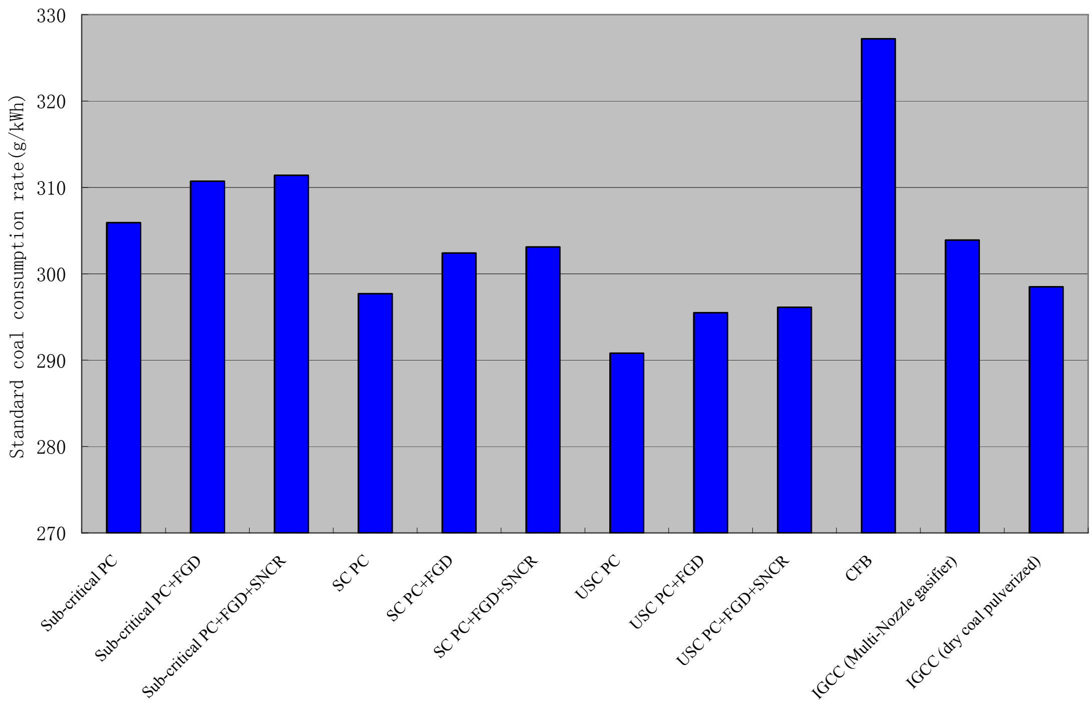


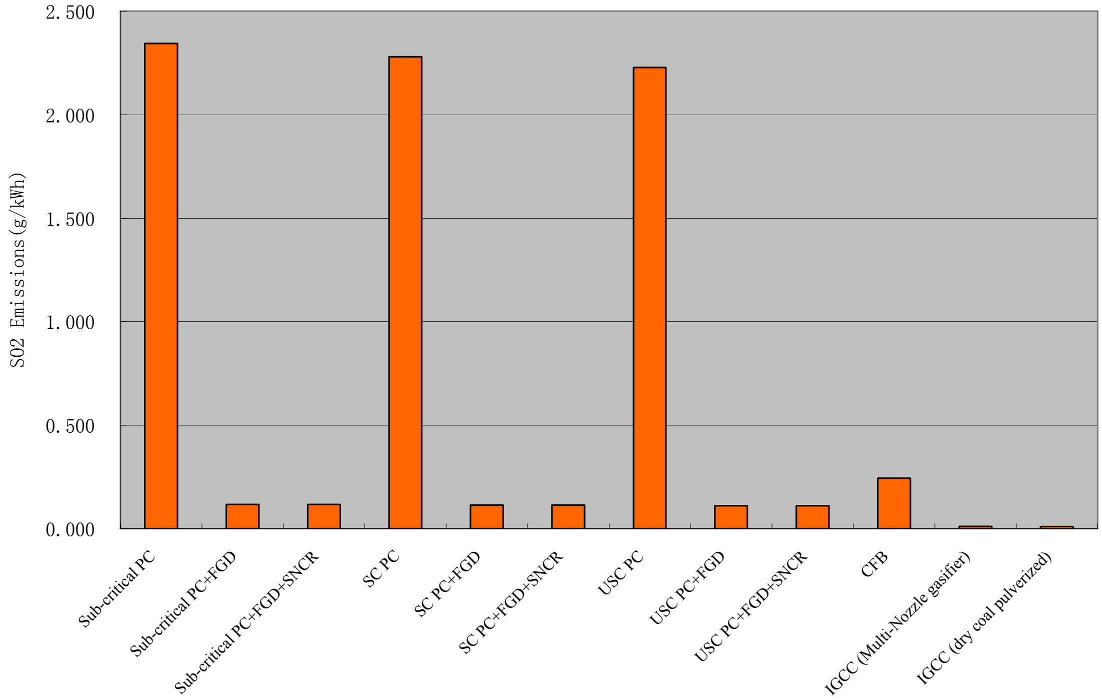
Figure 6.2 Standard Coal Consumption Rate (g/kWh)

2) Environmental Performances

PC coupled with pollutant control technologies, CFB and IGCC can meet the SO_2, NOx and particulate matter emissions requirements.

IGCC has the best environmental performances. IGCC has the ability to deeply remove sulfur after gasification. So its SO_2 emission is almost near zero, much lower than other technologies. CFB technology may realize desulfurization in the boiler.

Now, in China all new power generation units are demanded to equip low NOx burners. NOx emission from Shendong coal fired PC plants with a capacity of over 600 MW is 450mg/Nm^3. Low NOx burners were adopted. So they can meet the current emissions requirement. When SNCR technology is used, NOx emissions can be further reduced to 270mg/Nm^3. CFB technology produces less NOx due to lower combustion temperature. The NOx emission from CFB power plants is about 250mg/Nm^3. NOx emission from IGCC plants is 240 mg/Nm^3 according to current industrial technology level.



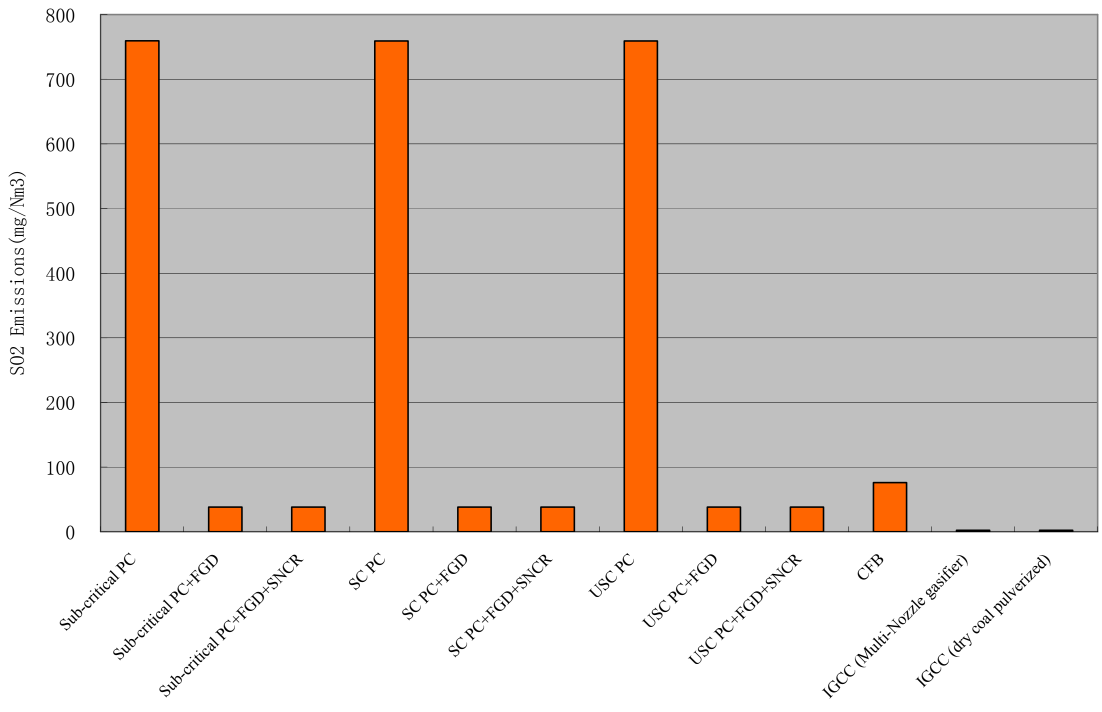
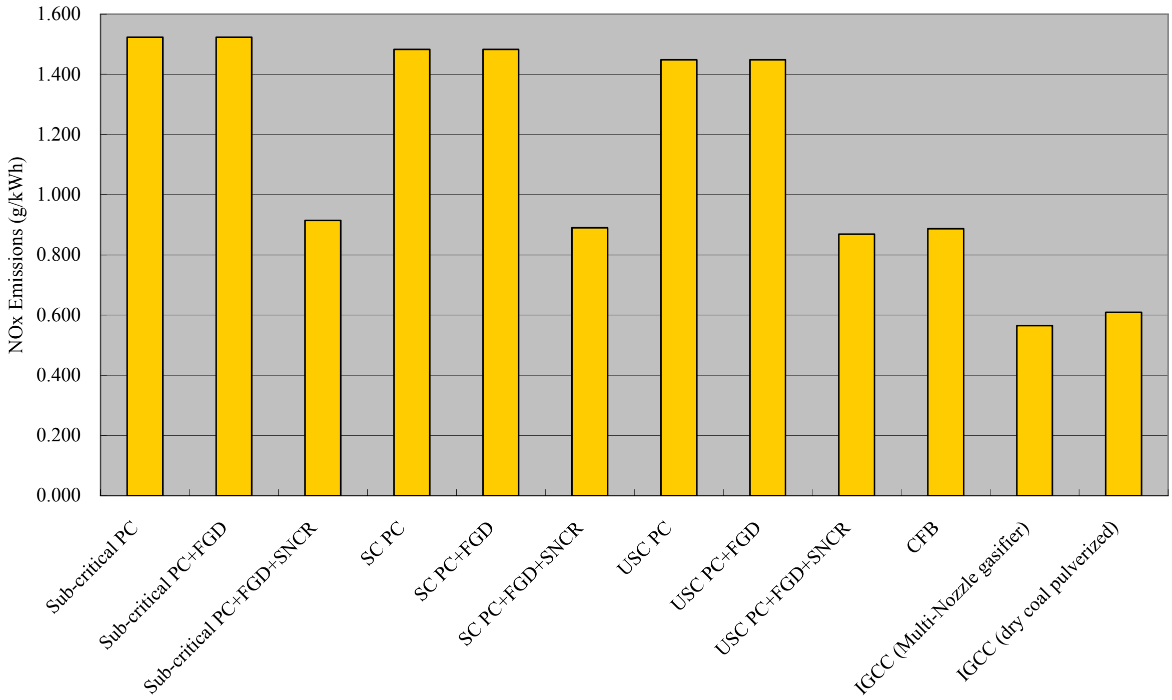


Figure 6.3 SO_2 Emissions



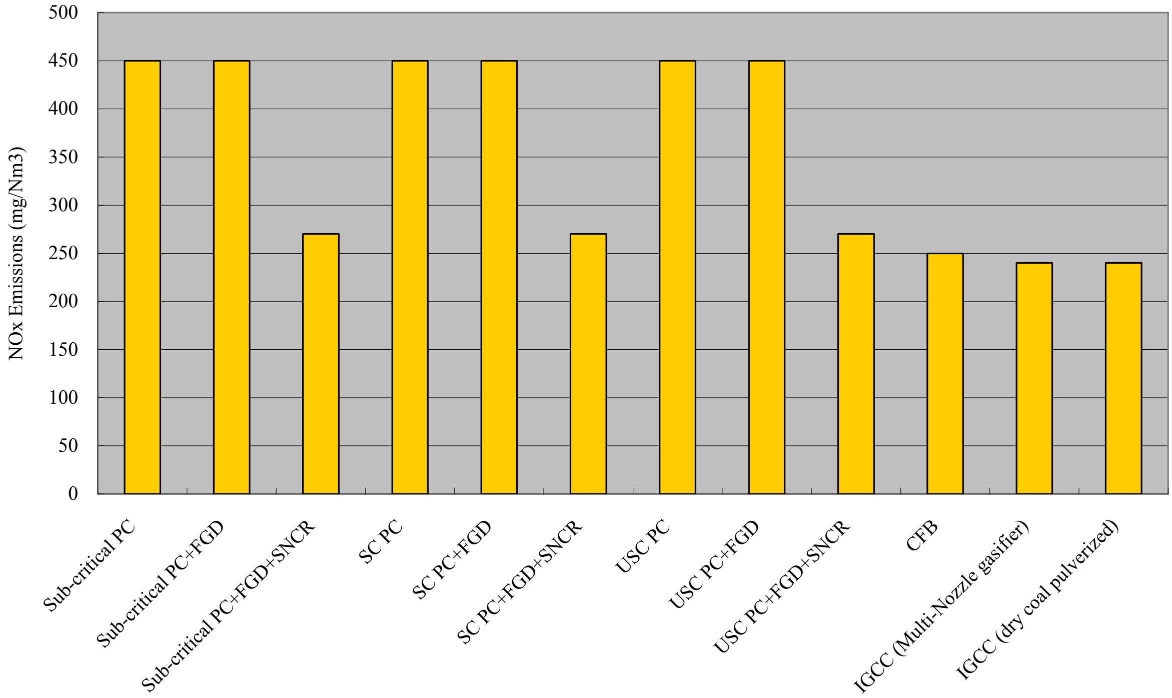
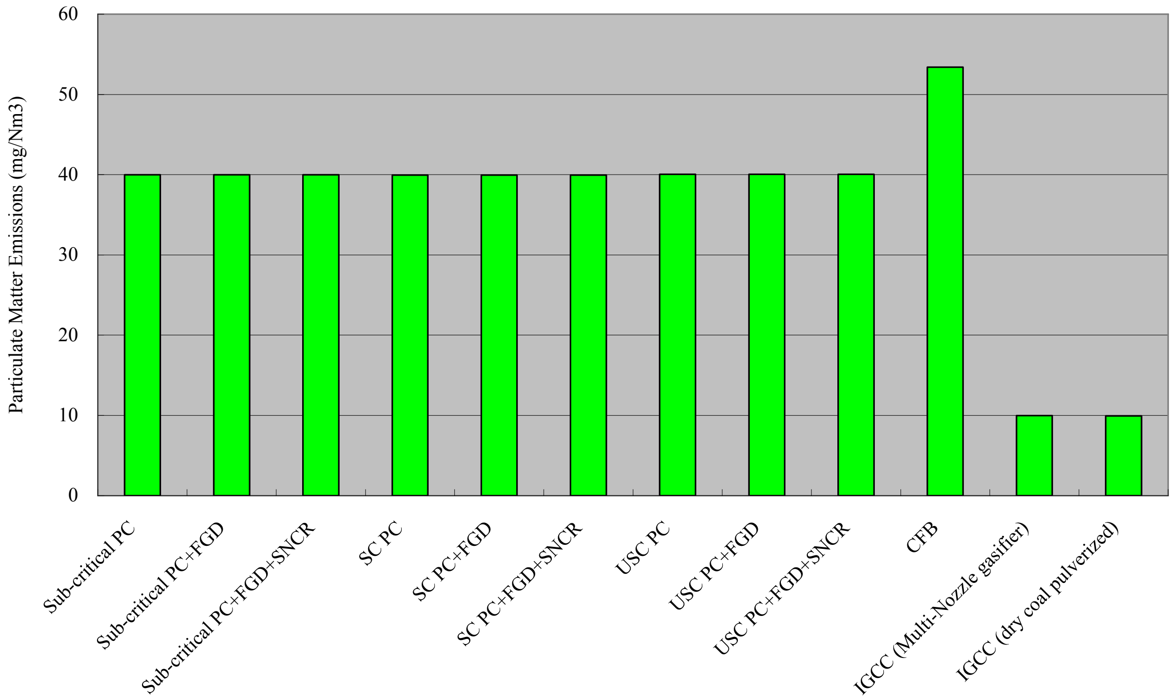


Figure 6.4 NOx Emissions



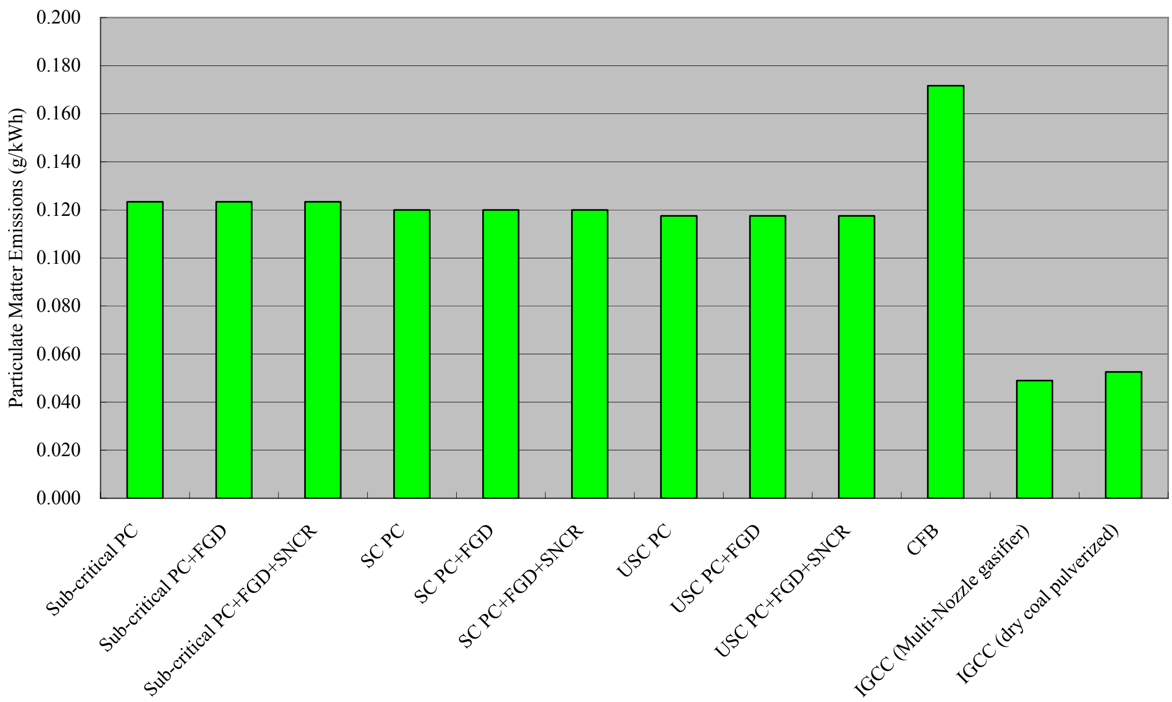


Figure 6.5 Particulate Matter Emissions

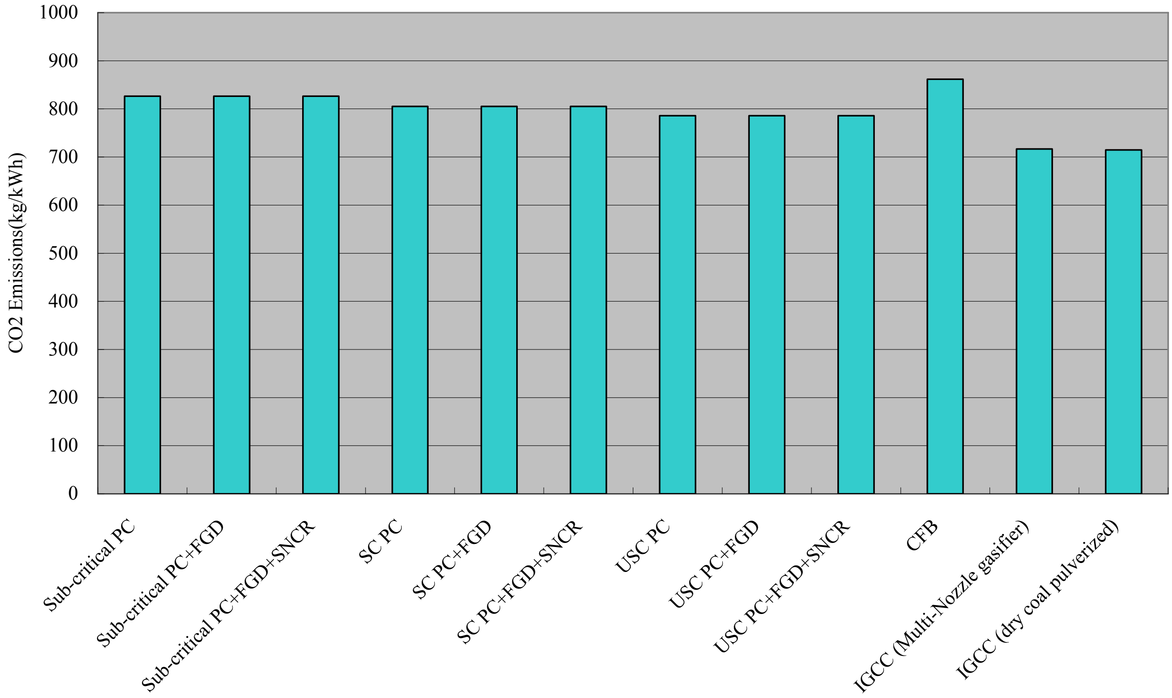


Figure 6.6 CO_2 Emissions

3) Economic Performances

The figure 6.7 shows us capital cost among different cases. The capital cost estimates are expressed in 2006 RMB Yuan per kilowatthour. The capital costs of subcritical PC+FGD+flue gas denitrification, SC PC+FGD+flue gas denitrification, USC PC+FGD+flue gas denitrification, CFB, IGCC based on multi-nozzle entrained flow gasifier and IGCC based on dry pulverized coal entrained flow gasifier are 3762, 3942, 4137, 4566, 7433 and 8824 RMB Yuan/kW respectively. The cost of IGCC is almost twice as expensive as that of PC. In recent year, the great demand for new power plants makes manufacturers stay in a highly competitive market. This causes rapid drop in PC equipments prices. But IGCC technology is still in a testing and demonstration phase. The prices of equipments are quite high. Some equipments need to be imported. If China plans to deploy IGCC based on successful demonstration during the Eleventh Five Year Plan, economic huddles have to be overcome.

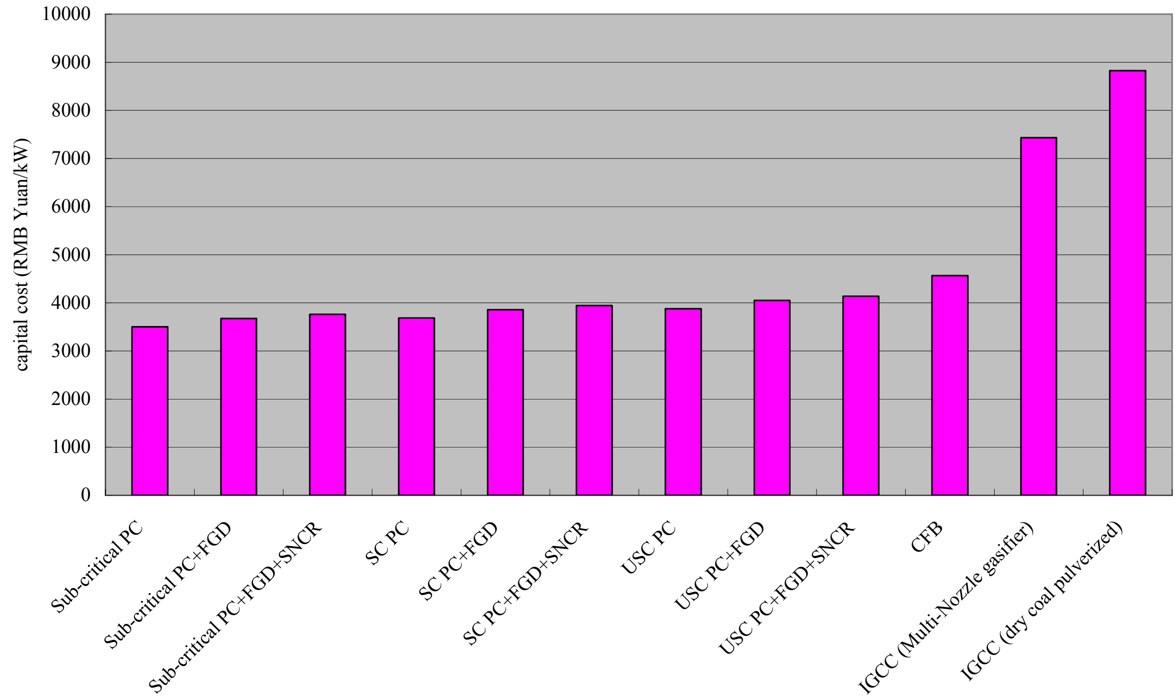


Figure 6.7 Capital Cost (RMB Yuan/kW)

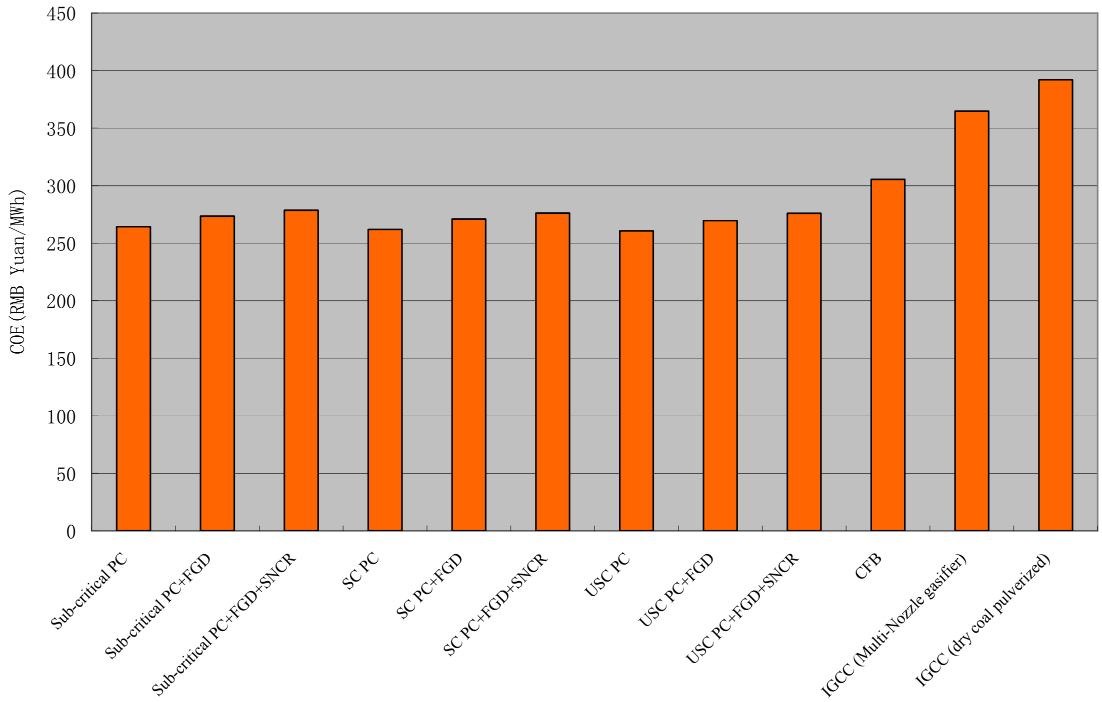


Figure 6.8 COE (not including charges for disposing pollutants, RMB Yuan/MWh)

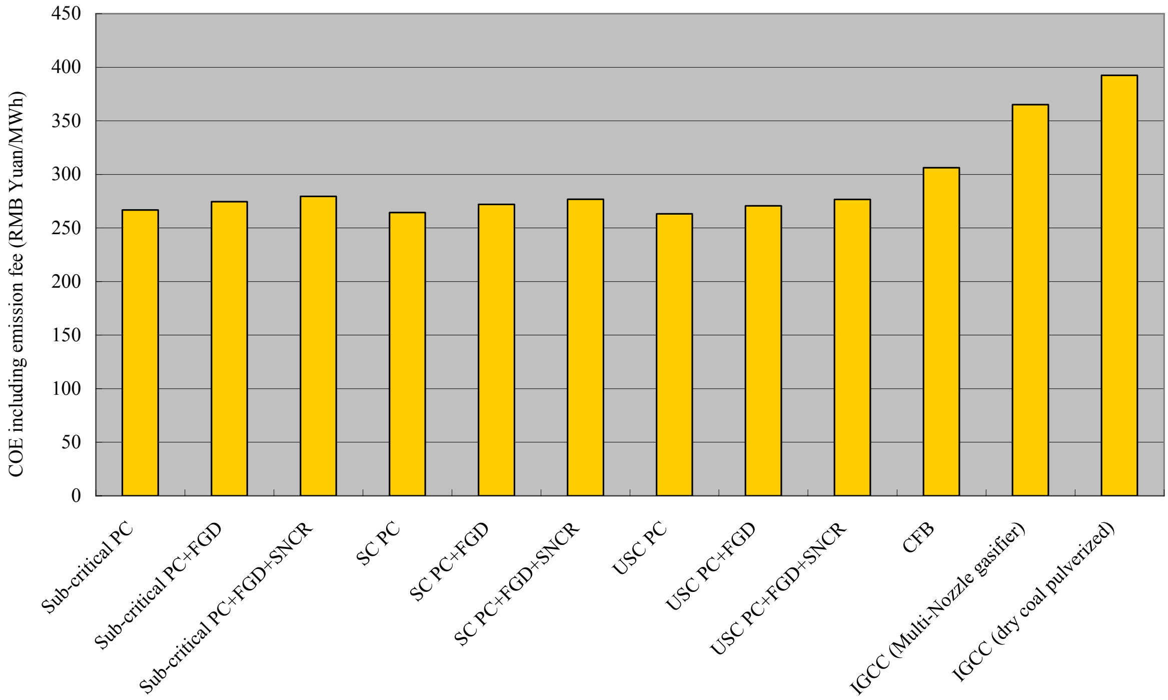


Figure 6.9 COE (including charges for disposing pollutants, RMB Yuan/MWh)

The COE not including charges for disposing pollutants of case 4 (SC), case 5 (SC+FGD) and case 6 (SC+FGD+flue gas denitrification) are respectively 261.95, 270.97, and 276.22 RMB Yuan/MWh. The COE of case 6 is 5.25 RMB Yuan/MWh higher than that of case 5, namely the addition of flue gas denitrification to the power plant results in a COE rise at 5.25 RMB Yuan/MWh. The COE of case 5 is 9.02 RMB Yuan/MWh higher than that of case 4, namely the addition of FGD to the power plant causes increase in COE at 9.02 RMB Yuan/MWh (as shown in figure 6.8).

The COE including charges for disposing pollutants of case 4, case 5 and case 6 are respectively 264.47, 272.08, and 276.93 RMB Yuan/MWh. The COE including charges for disposing pollutants of case 4 is 2.52RMB Yuan/MWh higher than the COE not including charges for disposing pollutants. The charges for disposing pollutantss of SO_2, NOx and particulate matter are 1.51RMB Yuan/MWh, 0.98RMB Yuan/MWh and 0.03RMB Yuan/MWh respectively. Adding charges for disposing pollutants makes the COE of case 4 increase 0.96 percent. The COE of case 6 is 4.85 RMB Yuan/MWh higher than that of case 5. The COE of case 5 is 7.61 RMB Yuan/MWh higher than that of case 4 (as shown in figure 6.9).

These numbers clearly indicate that only implementation of levying charges for disposing pollutants is not enough to encourage power plants to install pollutants control equipments.

Because of low levy standard, polluters prefer paying charges for disposing pollutants. The Chinese government offers a preferential price for electricity from power plants with FGD. It is 15 RMB Yuan/MWh higher than the price for electricity from power plants without FGD. Therefore, in China power plants with FGD remain competitive with other power plants. However, currently there is no incentive policy to encourage power plants to install NOx control equipments.

The COE not including charges for disposing pollutants of IGCC (case 11) is 102.8 RMB Yuan/MWh higher than that of SC PC (case 4). If charges for disposing pollutants are considered, it is 100.7 RMB Yuan/MWh higher than that of case 4. The gap is narrowed lightly. However, because of low levy standard, it is not obviously that IGCC can produce electricity more cleanly. When SC PC is coupled with pollution-control technology (case 6), the COE not including charges for disposing pollutants of IGCC (case 11) is 88.53 RMB Yuan/MWh higher than that of case 6. When charges for disposing pollutants are considered, the COE of case 11 is 88.27 RMB Yuan/MWh higher than case 6. The COE of IGCC is much higher than that of other advanced coal power technologies. There are a couple reasons as follows. First, the capital cost of IGCC is much higher than that of other technologies. The higher capital cost is, the higher depreciation cost is. Second, due to relatively low technical level, the net efficiency of IGCC (case 11) is equal to that of case 6. So the fuel cost of IGCC is relatively higher. Repair cost is also higher than other technologies, because key technologies of IGCC are not still mature. These are main reasons why the COE of IGCC is much higher than that of other coal power technologies.

From these numbers, it is clear that SC+FGD+flue gas denitrification and USC PC+FGD+flue gas denitrification units have high competition at relatively lower capital cost and higher net efficiency with other units. Therefore, in current situation IGCC has no ability to compete with other advanced coal power technologies in the market.

4) Impacts of coal price on COE

China owns relatively plentiful coal reserves, but without uniform distribution. So the coal's price varies greatly in different regions. In this study, we chose 180, 280, 380, 480, 580 and 680 RMB Yuan/tonne to calculate the COE of different technologies. The impacts of coal price on COE are shown in table 6.1.

Table 6.1 Impacts of Coal Price on COE

Price of Coal	RMB Yuan/tonne	180	280	380	480	580	680
Subcritical PC+FGD+SNCR (case 3)	RMB Yuan/MWh	139.75	174.66	209.57	244.48	279.39	314.3
SC PC+FGD+SNCR (case 6)	RMB Yuan/MWh	141.02	175	208.98	242.95	276.93	310.9
USC PC+FGD+SNCR (case 9)	RMB Yuan/MWh	143.97	177.16	210.35	243.55	276.74	309.93
CFB (case 10)	RMB Yuan/MWh	159.57	196.24	232.92	269.6	306.28	342.96
IGCC (Multi-Nozzle Gasifier) (case 11)	RMB Yuan/MWh	226.5	259.89	293.28	326.67	360.06	393.45

According to 600MW+FGD+SNCR power plant numbers, when the price of coal is or higher than 380 RMB Yuan/tonne, the COE of case 6 is lower than that of case 3; When the price of coal is or higher than 480 RMB Yuan/tonne, the COE of case 9 is lower than that of case 3. When the price of coal is or higher than 580 RMB Yuan/tonne, the COE of case 9 is lower than that of case 6. All the numbers are shown in table 6.1.

There are 3 IGCC demonstration power plants being built in China during the Eleventh Five Year Plan. Two of them chose Shen-dong coal as their fuels. The goal of this study is to explore the economic gaps between IGCC and other advanced coal power technologies. In order to keep on a line, we also chose Shen-dong coal as fuels for all cases. Shen-dong coal owns relatively high quality. Because the CFB boiler technology has the ability to fire waste and other low-grade fuels in addition to various grades of coal without SO2 and NOx control systems, it is a waste of using Shen-dong coal as the fuel. When the price of coal used in CFB is 100 RMB Yuan/tonne lower than that of coal used in conventional PC plants, CFB gains a competitive advantage over other power plants.

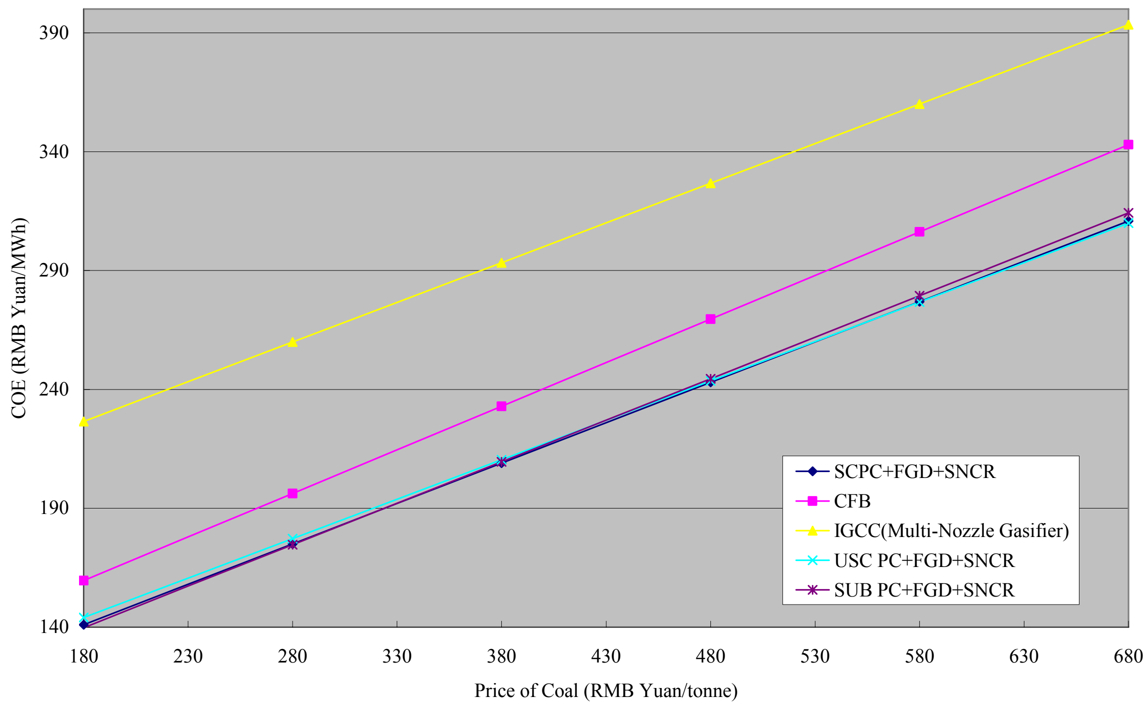


Figure 6.10 Impacts of Coal Price on COE (including charges for disposing pollutants, RMB Yuan/MWh)

SC PC and USC PC power generation technology coupled with pollution-control technology can meet the requirements of emission standard. It is highly efficient, technically mature, and cost-effective. At the same time, because of its high efficiency it can reduce CO_2 emissions to some extent. From the view of efficiency, SC and USC units are good choices for power industry. IGCC power plant has a very complex system more like a chemical plant. It first gasifies fuels, such as coal converting them into gas. Then the gas powers gas turbine. The net plant efficiency has reached 45%. However, the cost of IGCC is much higher than that of other power generation technologies. So the development of IGCC is very slow around the world. In recent years, IGCC has been attracting more and more attention and support because of concerns about global warming. It is easier for IGCC to capture CO_2 at relatively low cost. Even though IGCC technology cannot compete with conventional coal-fired power generation technologies, it will show its advantage and market competitiveness once the goal of CO_2 emission reduction is set in the country. Incentive policies are needed to deploy IGCC in China. It will be a long and tough way.

India

Development and Climate Change Benefits of Clean Energy

Nov 14, 2007

Development and Climate Change Benefits of Clean Energy

Click on heading

Contents

Preface:

This synthesis is derived from the seven separate reports, which are included in full below along with their executive summaries. Full literature citations and details of the technologies, assumptions, estimation methods, etc. are found in those reports.

SUMMARY POINTS

1. This report highlights a number of technological options for enhancing the availability of clean rural energy services using biomass and for improving the performance of the power sector, which, in turn, can lead to significant development and climate gains

2. India's CO2-eq emissions could be reduced as much as 520 million tonnes (Mt) each year (or one-tenth of coal used in power) by 2025 through vigorous pursuit of

- Improvements in coal power efficiency through the deployment of advanced generation technology
- Reductions in the large losses sustained during transmission and distribution
- Electricity-saving programs in the three end-use sectors examined here, agricultural pumping, lighting, and solar water heating

3. Rapid deployment of current biomass gasifier technologies for small industries and power generation and development and deployment of promising advanced biomass cooking technologies could reduce CO2-eq emissions by about 120 Mt, based on fossil fuel substitution calculations. This potential has not been widely recognized in the climate change literature.

4. The total potential of about 640 Mt CO2-eq/y is roughly about 18% of India's projected emissions by 2025.

5. Significant development benefits in the areas of local and national energy security, rural employment, women's and children's health, and general environmental quality can also be achieved, particularly in the biomass sector where the link between GHG emissions and damage from current inefficient usage is strongest.

6. Improvements in performance of the power sector, particularly to reduce losses and enhance billing through better management of R&D will not only save money and reduce GHGs, but will help bring the state power utilities into sustainable operation, a major development benefit.

7. There are a number of barriers to the deployment of these technologies. This is particularly important in the cases of those to be deployed at the household level where there it is not possible to rely completely on a commercial dissemination because of low incomes and high effective discount rates. To be successful, deployment strategies must be carefully designed to overcome these barriers, including development of new approaches. The report presents the preliminary outline of suggested deployment strategies.

8. International cooperation could be helpful by facilitating the availability of the relevant technologies, for assisting in program design (especially drawing on lessons from past experiences), and for building the appropriate technical and programmatic capacity.

1 INTRODUCTION

The rural energy and power sectors both lie squarely at the intersection of development and climate change in India. The use of advanced biomass energy technologies can help deliver clean energy for households and small-scale industries while reducing non-CO2-GHG emissions and increasing the efficiency of resource use. More efficient power generation, T&D, and end-use technologies can lead to significant improvements in the power system, which can help enhance the availability of power and energy security while, again, reducing GHG emissions. Thus, in both these cases, the potential for developmental and climate gains is substantial through deployment of the appropriate technologies.

Based on seven individual reports commissioned for the study (see appendix), this overview builds on a number of previous analyses of GHG mitigation options in India that have highlighted the potential of mitigation from the coal power plants as well as end-use efficiency improvements. In addition, it addresses the lack of attention to rural populations in past analyses by detailing the GHG-mitigation potential of advanced biomass energy technologies for households and small-scale industrial applications.

In addition to describing the technical options for clean biomass energy and a more efficient power sector, this report discusses the barriers to the implementation of these technologies as well as strategies for more effective deployment that overcomes these barriers. It also highlights the GHG mitigation potential and the developmental benefits of deploying these technologies.

2. PROSPECTS FOR NEW TECHNOLOGIES WITH DEVELOPMENT AND CLIMATE BENEFITS

2a Advanced biomass energy technologies for households and small and medium industries and enterprises (SMIEs)

Over 70% of the energy in rural areas (where 70% of the country's population resides) comes from biomass, which accounts for nearly a quarter of total primary energy consumption in India. Most of this biomass fuel use, however, is in low-efficiency, low-quality, energy applications, especially cooking, which produces a large amount of air pollution per unit fuel with consequent health impacts. Low-combustion efficiency also leads to significant emissions of non-CO2 GHGs such as methane and black carbon.[2] Many small and medium enterprises also depend on fossil fuels such as coal, diesel, and LPG for their energy needs. Modern bioenergy technologies, especially cleaner cookstoves and biomass gasifiers for small-scale power and thermal applications can help meet energy needs, improve the quality of life and protect the environment, while helping address climate change through cleaner combustion of biomass and replacement of fossil-fuel use.

[2] Where harvested non-renewably, biomass fuel use also leads to net CO2 emissions

Among the biomass fuels, fuelwood is the dominant fuel and its consumption is estimated to be in the range of 160-300 million tonnes (Mt) followed by 70-160 Mt of crop residue and 60-110 Mt of cattle dung.[3] Rural household cooking is the dominant end use of fuelwood accounting for an estimated 84% of the total and industrial and establishments accounting for 5%, and the rest by urban households.

Households and institutional cooking

The Indian National Sample Survey Organization reports indicate that biomass fuels are predominantly used for cooking in rural India and analysis of income-based LPG penetration in India indicates that biomass fuels will continue to provide cooking energy for a large part of the Indian population in the near-term. Currently used biomass cooking technologies (CBCTs) for households and institutions, are largely mud stoves along with some metal, cement and pottery or brick stoves, that directly burn wood, crop residues and dried animal dung. They have low thermal efficiency and significant emissions, the exposure to which has been linked to a range of health effects including child and adult respiratory disease. Approximately 400 thousand premature deaths are attributed annually to these exposures in India [Smith, et al, 2004]. CBCTs also have significant emissions of long-lived (CH_4 and N_2O) and short-lived (CO and non-methane hydrocarbons - NMHCs) greenhouse gases (GHGs). Emissions of black carbon (BC), attributed recently to CBCTs leads to significant warming of the lower atmosphere and alteration of water budgets on a regional scale, an important element of climate vulnerability especially in south Asia.

Baseline fuel use, or direct combustion of wood, crop residues and dried animal dung in CBCTs, and dung in biogas digesters is estimated at 380 MT/y. Rural penetration of LPG, currently 5%, is expected to increase six fold by 2025, offsetting biomass fuels. However, increases in population, would drive biomass fuel demand to 430 MT/y in 2025. For institutional cooking, aggregate fuel consumption estimates are not available. Fuel use data for the government sponsored mid-day meals programme for schools, show a large state-wise variation in choice of fuels (primarily LPG and firewood), with several states reporting high levels of firewood use.

Small and medium enterprises (SMEs)

There are more than 3 million small-scale industries in the organized sector and about 15 million enterprises in the unorganized sector in India. These units account for about 40% of the total industrial production and 35% of total exports. It is estimated that the small-scale industries and micro enterprises together contribute 7% to the Indian GDP.

A large number of such enterprises are highly energy consuming. Coal, biomass (wood, agro-residues), and petroleum products (furnace oil, LPG, diesel, LDO) are used for heat and power generation. In fact, it is estimated that small and medium enterprises consumed about 68 Mt of oil equivalent (Mtoe) in 2005-06 just for their thermal energy needs; about 3.5 Mt of diesel was used for power generation in SMEs in 2004-05 (and the growth rate of diesel electricity is 10.7%). Expenditure on fuels often represents a major share of their production costs. Rapidly increasing prices of commercial fuels (the diesel price in India has more than tripled in the last ten years) are reducing the profit margins of these enterprises. Hence

[3] Estimated quantities are rounded to avoid the appearance of unwarranted accuracy.

substitution of petroleum fuels with local modern biomass makes eminent sense from both an economic and an energy-efficiency perspective.

Thus, biomass energy technologies that provide clean energy services for cooking and for power and thermal-productive applications in small and medium enterprises have an enormous potential.

A critical issue in realizing the technical and economic potential of bioenergy is the sustainable supply of biomass feedstock. Estimates suggest that after excluding the land required for traditional fuelwood, industrial wood and timber production, an additional area of 24 Mha is available for energy plantations. Other estimates vary from 41-130 Mha. In addition marginal cropland and long-term fallow lands are available for plantation forestry for energy. Considering a conservative area of 35 Mha of dedicated energy plantations and a woody biomass productivity of 6.6-12 tonnes/ha-year, total (additional) woody biomass production potential is estimated to be 230-410 Mt annually.

2b Technologies for a more efficient power sector

Since the 1970s, the power sector has emerged as the major coal consumer in India. From about 9 Mt in 1960/61, the consumption by the power utilities has grown to 287 Mt in 2005/06 and is slated to continue to grow. Additionally, the coal-based captive plants associated with large industries like cement, alumina, steel etc. consume over 20 Mt annually. Coal-based thermal generation accounts for about 70% of the electricity generated by the Indian power sector in 2004-5 and, in turn, about 75% of India's coal consumption is in the power sector. Despite the impressive additions in power generation over the last six decades, there is a peak shortage (GW) of 12.3 % and an average energy (GWh) shortage of 8.1 %. Even so, more than 50% of Indian households, mostly in rural areas, still do not have any access to electricity. Consequently, the per capita electricity consumption for India is 590 kWh (2003-4), which is only 20% of the world average.

Given this context, and the central role of electricity in underpinning many aspects of economic and human development, there is a major thrust to enhance India's power sector. One scenario from the 2006 Integrated Energy Policy (IEP) report of the Planning Commission indicates that the demand by the power sector would increase from 463 Mt in 2011/12 to over 1500 Mt by 2026/27, and to over 2000 Mt annually by 2031/32. It is expected that coal would continue to be the main fuel source for the Indian power sector in the near future, with a steadily increasing portion of the total.

As a start to evaluating the potential for efficiency-enhancing technologies for the power sector, the performance of the existing power system must be understood. Indian thermal power stations currently have an average efficiency of 27.7%, with a wide variation (from 14.6 to 34.6%), which is low by global comparison. Furthermore, the average aggregate technical and commercial (AT & C) losses in the power sector accounts for about 33% of the electricity available at bus-bar (with state-wise losses varying from 17% in Tamil Nadu to as high as 65 % in Manipur). Finally, end-use efficiency in many application areas is also quite low.

It is estimated that the coal consumption in the power sector accounted for about 460Mt of carbon dioxide emissions in 2003-4 (almost half of India's total carbon-dioxide emissions) with an annual growth rate of 5.1 %. With the anticipated energy demand growth and present trend of transmission and distribution (T & D) losses, a business-as-usual scenario (assuming that the new plants would have an average operating net heat rate of 2500 kcal/kg.) suggests a coal requirement of about 1200 million tonnes (this is likely to include some coal imports) and CO2 emissions of 1740 Mt .

These data suggest that advanced technologies to improve the efficiency of coal-power generation, T&D in the power system, and end-use appliances have significant potential for improving the power sector, while reducing carbon emissions.

3 OPTIONS FOR WIN-WIN DEVIATIONS FROM CURRENT TRENDS AND BARRIERS

The following technical options are considered in this report

1. Biomass gasifiers for process heating (thermal applications)
2. Biomass gasifiers for decentralised power generation
3. Advanced biomass cooking technologies – household and institutional
4. Clean coal technologies for power generation
5. Improved accounting methodology for T & D loss reduction, distribution transformer efficiency and replacement programme, optimal distribution network planning, efficient agricultural pumping systems, innovative rural electrification programmes, efficient lighting programmes, promotion of solar water heating systems.

3a Advanced biomass energy technologies for households and small enterprises

Process heat applications in SMIEs

Biomass gasification offers a simple approach for the thermochemical conversion of biomass into a combustible gas (producer gas). Steady developments of biomass gasifier technology in India over the years have reached the point where it is able to meet a range of process heat needs for SMIEs. Some illustrative applications are listed here:

Low temperature applications:

- Water boiling: Cooking cocoons, dyeing fabric, production of magnesium chloride, etc.
- Dryers (50 – 130ºC): For farm products, food and spices (like rubber, tea, coffee, cardamom, tobacco, food and chemical products, etc).
- Boilers: Several chemical process industries, agro-processing industries, dairy industries and textile industries using low-pressure steam.

High temperature applications:

- Kilns (800–950ºC): For baking of tiles, bricks, and potteries or for heat treatment purpose (such as hardening, annealing etc).
- Furnaces (650-1600ºC): For melting metals in foundries, glass-melting industries etc.

About 5 Mt of fuel oil, 1.2 Mt of LPG and 50 million tons of coal are used to provide process heat in these enterprises (2004-05). In addition, an estimated 20 Mt of biomass (wood and agro-residues) is used in enterprises such as tea drying, brick kilns, cremations, chemical processing, bakeries, etc. Experience in recent years shows that in these industries biomass gasifiers can replace fossil fuels up to 100% and reduce fuelwood consumption by 50-60%, thus reducing dependence on fossil fuels and relieving pressure on local forests or releasing biomass for other uses.

There are a variety of fossil-fuel-fired furnaces that are ideal candidates for switching over to producer gas from biomass. Approximately 3-4 kg biomass is required to replace 1 kg of petroleum-based fuels like furnace oil, diesel and LPG), resulting in a financial payback period of 6-12 months at current fuel prices.

Power generation:

Biomass gasifier systems are also well suited to small-scale power generation, where the gasifier is coupled to an internal combustion engine which in turn drives a power generator. The IC engine can be used in a single-fuel mode, i.e., running only on producer gas, or a dual-fuel mode, i.e., running on diesel and producer gas. In recent years, almost all gasifier power is through 100% producer gas engines. At current prices, gasifier-electricity is comparable to diesel-electricity, with actual economics depending highly on local conditions. Within India, there are many opportunities for replacing diesel generation through biomass gasifier generation. Furthermore, the Rural Electrification Policy aims at providing electricity for all households by 2009 and many villages away from the power grid may be better served by local biomass gasifier systems, although there are difficulties because of the low load factor in villages (the temporal distribution of the demand is very uneven).

Household and institutional cooking

Promising advanced biomass cooking technologies (ABCTs) for household and institutional cooking include (a) advanced combustion stoves (with design innovations like a "rocket zone," or double-walled or ceramic-lined combustion chamber), (b) so-called gasifier stoves that utilize secondary combustion and (c) biogas technology using anaerobic digestion to create methane. Advanced combustion and gasifier ABCTs have the potential for about 2 times higher efficiency, 4 times reduction in emissions of particles (important from health effects perspective) and greenhouse gases regulated by the Kyoto Protocol, on a per MJ of useful energy delivered. Biomass gasifier stoves using biomass pellets/ chips as fuel are being tested by several commercial organizations, research institutes and NGOs. Typical thermal efficiencies of 30-35% have been reported and the technology shows promise.

Cattle and buffalo dung are the primary feedstock for current biogas plants, which number about 4 million at present with considerable scope for expansion. Biogas technology is particularly attractive with about 4 times higher efficiency and 20 times reduction in emissions compared to direct combustion of cattle dung. New biogas technology packages based on green vegetable feedstock and kitchen waste have been pilot tested. Plant oil stoves and ethanol stoves are two other possible ABCT options, but field data on them are very limited and not yet sufficient to consider them promising options.

Potential ABCTs for institutional and commercial cooking, which have been successfully demonstrated are: biomass gasifier stoves, advanced combustion biomass stoves and biogas plants based on dung, vegetable matter and kitchen waste. Apart from biomass energy options, Scheffler solar cookers, based on solar concentrator technology have also been used for institutional cooking. Some of these options are close to being commercialized.

Barriers to advanced biomass energy technology deployment

1. Sustained Biomass Supply:

Though land is available for biomass production for power generation. However, the barriers to the large-scale production of biomass for power generation and thermal use.

- Tenurial uncertainty for wastelands, particularly public or government lands, for private companies or power utilities, which cannot access government and community lands for producing commercial biomass.
- Absence of policy or regulatory provisions for long-term contract between farmers and biomass power utilities for sustained biomass supply from farmlands.
- Non-availability of large tracts of contiguous land limits the scale of the biomass power system largely to small-scale systems and high cost of transport for large-scale systems
- Lack of access to easy credit, financial incentives and guaranteed price for biomass feedstock to farmers. Such incentives are available for biomass power utilities and not for biomass producers.
- Absence of package of practices for high biomass yields in different agro-climatic zones.
- Lack of policies and technologies for mainstreaming biomass. Briquetting or pelletization technologies have not been developed sufficiently to produce processed biomass profitably. There is also no policy to encourage production and marketing of pelletized biomass

2. ABCT Stoves

- Both advanced combustion and gasifier stoves lack sufficient
  - R&D
  - Field testing
  - Customizing for user need.
  - Deployment of marketing techniques for widescale promotion
- The lack of strict product specifications and a testing and certification program based on well-established methodologies also impede development of suitable stoves and their dissemination..
- There are no well-established support systems through subsidies or other incentives to promote ABCTs in poor biomass-using households, which have high discount rates and low access to credit, while still being commercially sustainable.
- The current lack of availability of processed biomass fuel supplies, e.g. pellets, is a consideration, especially with options such as gasifier stoves.

3. SMIE Gasifiers:
Although gasification technology is well developed for thermal applications, there are problems yet to be overcome for power generation:

- There are technical issues relating to impurity levels in the gases (tar, particulates), engine development for 100% gas operation, and control systems for the complete power plant. Second-generation gasifiers such as the two-stage gasifier are still at the demo stage and are expensive.
- Standards for performance, safety and quality are yet to be enforced and operationalized.
- Wood is an accepted gasifier fuel at present, but consistent, verifiable and environment-friendly field performance with loose biomass such as rice husk is yet to be achieved.
- Gasifier-based electricity has been marginally cheaper than diesel electricity at present, the reasons for which are: low capacity utilization, high operating and maintenance costs and increasing biomass costs. With the current rapid increase in petroleum prices, however, gasifier electricity is becoming more attractive, especially where biomass is available at favorable prices. Thus gasifier-based power generation options need to be continuously reviewed. Although the economic viability of thermal gasifiers is well established at the prevailing costs of firewood, future efforts of mainstreaming biomass, such as pelletization, would most probably result in increased prices for biomass. Hence the relative price differential between furnace oil/LPG and pellets would decide the future economics. There also exist infrastructural barriers relating mainly to the supply chain for biomass and to the supply chain for gasifier-related services. Most gasifier manufacturers at present do not have sustained networks for supply, commissioning and servicing of gasifier systems/components. Similarly, the supply network of biomass is relatively unstructured and varies from state to state.
- Gasifier installation, commissioning and operation require trained manpower, which is scarce at present. Hence the training needs have to be addressed properly.
- The policy and regulatory barriers are related to inter-state movement of biomass, attractive tariffs for gasifier based electricity, lack of standardization, and lack of incentives or programs for development and/or import of advanced technologies (such as pelletization).

3b. Coal power for development

Advanced coal power technologies[4]

In India, power generation from coal, uses the conventional steam cycle with sub-critical steam parameters with pulverized coal combustion. Unit size variation for small power plants ranges from 30-500 MW (mean of 175 MW, mode – 210 MW). Clean-coal technologies that were evaluated include (a) Supercritical pulverised coal plants (higher pressure and temperature than sub-critical plants, leading to higher efficiency – 40-46% – and lower g/kWh emissions)[5], (b) Ultra supercritical pulverised coal plants (higher pressure and temperature than supercritical plants, leading to even higher efficiency and lower g/kWh emissions),[6] (c) Atmospheric Fluidized Bed Combustion (coal burnt in fluidized bed and then steam used in Rankine cycle; efficiency 29% to 40% and lower emissions)[7] (d) Pressurized Fluidised Bed Combustion (combination of the Rankine cycle and Brayton cycle in order to achieve higher efficiencies and reduced emissions), and (e) Integrated Gasification Combined Cycle.[8]

T&D and major efficiency options

The average aggregate technical and commercial (AT & C) losses in the power sector accounts for about 33% of the electricity available at bus-bar[9]. T & D losses include technical losses plus a high proportion as commercial losses (theft, unbilled energy, uncollected bills

Improved accounting methodology for T & D loss reduction

It is proposed to have systematic accounting (energy audits) at the sub-station level. This needs to be carried out with metering of all distribution transformers (less than 20% for most of the states at present in 2005-6). With the projected generation of electricity in the year 2025 (2528 billion kWh at bus bar) and at present loss rates, AT & C losses would amount to 834 billion kWh. We expect that bringing down the AT & C losses to a level of 25% is possible by 2025 and would contain the losses to around 630 billion kWh. This would improve the financial operation of the utilities, which is perhaps the most pressing issue at present in the Indian power sector because, without this, no sustained program of improvement is possible.

Distribution Transformer Efficiency and Replacement Programme

The number of distribution transformers (DTs) is more than 2.5 million *[4]* in India, with an aggregate capacity of 207000 MVA. DTs normally contribute around one-third of the

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[4] The effect of Indian coals (having 40-45% ash) on advanced coal technologies is analysed here using a lumped parameter simulation model to obtain the expected performance of these options.

[5] There are about 250 Supercritical PC plants operating worldwide, most of the units are of the size range 500-600 MW. At present there are no supercritical plants installed in India though several plants are in the planning and implementation stage.

[6] There are 24 ultra-supercritical units operating worldwide with units in Denmark, Germany, Japan, the Netherlands, and USA.

[7] AFBC is a commercially mature technology that has been used worldwide for over 50 years. There are two types of AFBCs:- 1) Bubbling Fluidised Bed Combustion. 2) Circulating Fluidised Bed Combustion. There are about twenty commercial Circulating Fluidised Bed Combustion (CFBC) plants around the world (ranging from 37 MW to 200MW).

[8] There are a few (about five) IGCC installations worldwide (100-350 MW range). There are no operational IGCC plants in India.

[9] Energy at bus-bar = Gross Generation – Auxiliary Consumption (GWh)

technical losses under optimal network configuration and loading. It is estimated that the capacities of more than 90% of the total DTs in India range between 10 to 315 kVA Owing to the growing energy demand and the need of rural electrification, DT market in India is expected to grow with an annual rate of around 10%. Therefore energy savings is possible through the use of more efficient DTs.

Optimal Distribution Network Planning

The length of low voltage distribution lines in India is more than 3.9 million kilometers, which is more than 60% of the total line length. This has led to suboptimal network configuration leading to a high length of distribution lines served by a single DT that varies from 0.7 km (average DT capacity 55 kVA) in Uttar Pradesh to more than 9 km (average DT capacity 415 kVA) in Uttaranchal. The mean value of low tension (LT) distribution lines length for the country is around 3 km per DT (average DT capacity 130 kVA) There are no minimum standards set for LT DT lines served by a DT and without a timely DT replacement programme which leads to overloading of both lines and DT and causing high rate of feeder tripping and outages It is estimated that the distribution transformer efficiency and optimal network planning options would result in a reduction of AT&C losses by 5%

Efficient Agricultural Pumping System

There are more than 14.1 million agricultural pumpsets, which consumed around 25 % (87,000 GWh) of the total electricity generation, in India (2003-4). The tariff for agricultural consumption is subsidised and is usually based on the HP (horsepower) pumpset rating (i.e.) connected load instead of the actual consumption. Improper sizing of pipes for pumping operation, quality of foot valves and other accessories are important aspects to be considered for efficiency improvement.

It has been estimated that by improving the pump efficiency standards and using improved pump designs would result in around 15% energy savings. Appropriate pump pipe sizing and standard upgrades have the potential of around 20% energy savings *[9]*.

The losses in agricultural energy consumption can be reduced by more than 35% through systematic audits, retrofits, pump and piping sizing. The existing average efficiency of motor-pumpsets is about 20%, A DSM programme focusing on efficient agricultural pumping can enhance this average to 30% in 2025

Innovative Rural Electrification Programmes

More than 56% of households in India are not electrified. Rural power distribution is characterized by low electricity usage densities and dispersed load and consequently high line losses and high transaction costs against the actual revenue generated. To take care of low load densities electricity usages, optimal distribution network planning, implementation of High Voltage Distribution System (HVDS), energy efficient transformers and electric devices would drive the future electrification and expansion of rural network.

Efficient Lighting Programmes

Lighting load accounts for 17% of the installed capacity of India. Efficiency programmes and innovative schemes for the replacement of incandescent bulbs by Compact Fluorescent Lights (CFL) and Fluorescent Tube Lights (TFL) by efficient TFL are considered. Replacing a 60 W incandescent bulb by a 15 W CFL would result in a nominal 75% power saving.[10] Similarly, replacing an ordinary TFL (56W) with energy efficient TFL 5 tube light (28W) would result in a nominal 50% saving. The higher initial capital cost and the high consumer discount rates for these options results in relatively few adoptions. A study for Maharashtra revealed that there is a potential of 2335 GWh in energy saving and peak demand reduction of 703 MW in rural area, and a potential of 2121 GWh in energy savings and peak demand reduction of 663 MW [2004-5]. The electricity savings achievable through an efficient lighting programme is 150 Billion kWh in 2025 .

Adoption of Solar Water Heating Systems

Solar water heating is an option that can reduce the morning peak demand significantly. In many urban areas (Pune, Bangalore), there are already a large number of residential installations. Although such systems are reliable and economically viable (payback periods 3-4 years), the actual installed capacity is only a small fraction of the national potential (2% of the estimated potential). The CO_2 savings compared to electric heating is 0.87 kg of CO_2 per kWh of electricity saved. The annual electricity savings potential has been estimated to be around 12.2 BU for 60 million sq. m. of collector area, which amounts to around 10.5 Mt of CO_2 savings annually (2005-6). The annual electricity savings in 2025 through this option is estimated to be 20 Billion kWh (assuming a diffusion curve with a fraction of the potential being achieved)

Barriers to deployment of technologies for a more efficient power sector

1. Sustained coal supply

- There are concerns about the capability of coal mining companies to deliver the amount of coal that will be needed if the power sector expands as planned. The contribution from existing mines and projects is expected to start declining in the next decade and the projected increase in output of the new projects to 178 Mt in 2011/12 and 363 Mt in 2011/12 seems to be impractical. At the same time, socio-political concerns relating to land acquisition for this projected increase (3000 sq km with a 730 sq km component of forest land displacing 850,000 persons) will add another layer of complexity.
- There also are concerns about the total coal reserves available in the country, although this is more of an issue for the longer term rather than the next 20 years. Further investigations on this topic are critical (and already underway in the country).
- Coal imports may become increasingly important over the next few decades for both the reasons mentioned above.

2. Clean Coal Technologies

- The Indian power sector, particularly at the state level, has inadequate exposure to advanced clean coal technologies.

[10] Actual savings would be less, of course, because of "take back," i.e., consumers react to the lower cost of energy services by increasing usage somewhat as well as taking some of the benefit in lower costs.

- The indigenous efforts at technology development and research and development have been limited. India's experiment with IGCC in the 1980s was not followed up with a technology development program.
- There are relatively few active research groups working on advanced coal and clean coal technologies in India.
- The international technologies developed for IGCC have not been tried with Indian coals.
- The investments in R & D have been low and there is an absence of a concerted technology development mission. In 2000 the Prime Ministers office and the Principal Scientific Adviser to the Government established a committee consisting of BHEL and NTPC to decide a strategy for establishing an IGCC plant of 100 MW. Though they commissioned studies and recommended the setting up of a plant, this has not yet been operationalised.
- There are no incentives for utilities and generation companies to invest in more capital-intensive clean coal technologies, particularly under conditions of negative profit.
- There is no incentive provided by regulatory authorities for clean coal technologies.

3. T&D and major efficiency options

- Electricity is subsidized for low usage residential and agricultural customers for equity reasons. In addition, a significant part of electricity usage is not accounted for, which makes it difficult to monitor consumption.
- Low electricity usage densities entail high transaction costs making it economically not viable without subsidy.
- There is a lack of documentation and consolidation of best practices for distributing power in rural areas effectively..
- The operating areas of utilities are large and there are not mechanisms to ascertain sub-station demand, shortages. Lack of accountability at the substation is an issue.
- As the tariff is based on HP rating for agricultural pumpsets, there is no motivation for energy-water use efficiencies. In addition, *lack of metering* encourages power pilferages.
- There are no utility data on transformer loading, losses from which valuable parameters can be extracted on its performance and hence for planning.
- State Electricity Boards, Distribution companies are supply focused and have little or no experience on DSM and energy efficiency techniques.
- There is a lack of information about the true transaction costs for efficiency programmes.
- The significant extent of 'commercial' losses (theft) is a barrier to the commercial operation of electricity supply companies and makes returns on investments in power distribution uncertain.
- High initial capital cost and high consumer discount rates for solar water heaters and efficient lighting is a hurdle to their adoption.

4. DEVELOPMENT AND CLIMATE BENEFITS OF ADVANCED ENERGY TECHNOLOGY DEPLOYMENT

4a. Development benefits

The main development benefit of all the energy options discussed here is providing access to higher quality energy to the rural poor. The second most important benefit is an increase in energy security at all levels, from villages to the nation.

Biomass gasifiers

The use of biomass gasifiers for small power generation would result in installation of about 6500 MW by 2025. The operation and maintenance of these plants would result in the creation of approximately 130 thousand local jobs . The electricity generated is likely to result in the creation of village enterprises and improve the average income of these areas. This will have a positive impact on the education as well as provide access to entertainment. The main benefit of using biomass gasifiers for thermal applications would be in reducing the operating cost of the industry and improve the profitability. This would result in a reduced consumption of about 7 MT of fuel oil and LPG and some 17 MT of coal (2024-25). These would reduce the dependence on imported crude oil and improve the energy security. The creation of a market for biomass fuels is likely to stimulate the rural economy.

ABCTs

More than 60% of Indian households do not have access to convenient cooking fuels, with even higher percentages in rural areas and among the poor . The main advantage of this option would be provision of this access. Indoor air pollution from CBCTs has an adverse health impact. The adoption of ABCTs will improve the health of rural women and children and do so at a cost per life-year saved within accepted ranges for health expenditures in a country at India's level of development. The reduction in the future LPG demand for cooking that would result from providing a higher quality energy service using biomass will reduce investments in oil supply infrastructure. This will also be beneficial for energy security.

Clean Coal Technology

The main development benefit would be the reduced coal consumption. In view of the constraint of coal availability, the reduction of annual coal consumption in 2025 by 10% or more (100 million tonnes) would result in extending the coal reserves, thereby enhancing energy security, and reducing coal imports. The disadvantage would be the higher capital investments required. Another advantage would be the reduced NOx and particulate emissions with consequent lower health impacts from outdoor air pollution exposures and lower damage from acid precipitation.

T&D and major efficiency options

Improving the accounting methodology for T & D loss reduction will improve the financial position of the utilities. This is critical for attracting investments in this sector. An estimated 200 Billion units can be reduced from AT&C losses in 2025. This is not likely to actually reduce the total demand, as it is only a reduction of theft. This would result in additional revenue of about Rs 500 Billion (in present prices) and would help in eliminating the annual deficit of the power utilities. This will enable more accurate estimation of savings and costs of energy efficiency and demand side management programmes. Options for distribution transformer efficiency and HVDS would reduce losses, improve voltages and reduce the cost of supply. These measures are also likely to improve the supply availability and reduce outages. The agricultural pumpset efficiency, efficient lighting and solar water heating programmes reduce the energy requirement in 2025 by about 5200 Billion units. The system peak requirements would be reduced and this would result in a reduction of about 110,000 MW of future capacity (Capacity saving of Rs 4400 Billion at present prices). This would facilitate the provision of access to un-electrified households and remote villages.

4b. Climate Change Benefits

Biomass gasifiers

The installed capacity of diesel power plants in 2004-05 was 7195 MW with a generation of 13,400 GWh and estimated diesel consumption of 3.48 Mt. Regression analysis of the last 10 years' data showed that the average annual growth rate of diesel installed capacity is 6.4% and the growth rate of diesel electricity is 10.7%. The installed capacity, energy generation and diesel consumption for the year 2025-26 can then be estimated as about 26,300 MW, 114,000 GWh, and 30 million tons respectively. The fuel consumption savings and emission reduction estimates for both industrial thermal energy production and diesel power generation are summarized in Table 1.

Table 1. Emission reduction with different gasifier technology penetration rates

Emission reduction scenarios	CO_2 emissions (million tons)	Surplus biomass requirement (million tons)	Surplus biomass availability (million tons)
Year 2004-05	141		158
Year 2024-25 BAU	280	202	239
Year 2024-25 Scenario-I Gasifier penetration to reduce consumption 25% in furnace oil, LPG, wood using & 10% in coal using and captive diesel generation	245	58	
Year 2024-25 Scenario-II Gasifier penetration to reduce consumption 50% in furnace oil, LPG, wood using & 25% in coal using and captive diesel generation	199	111	

ABCTs

Evaluation of ABCTs for fuel savings and GHG emissions reduction indicates the potential for substantial gains. For example, consider a 50%:50% technology-mix of ABCT:CBCT for household applications in 2025, whereby 50% cooking energy from current CBCTs (wood and crop residues), is provided by advanced stoves and gasifier stoves, and 50% cooking energy from direct CBCT combusted dung is supplied by biogas digesters.

- Estimated biomass use under such a scenario is 306 MT/y in 2025 (compared to the projected 430 MT/y under a business as usual CBCT mix), because of energy efficiency improvements, comprising a 29% reduction in biomass fuel use.

The current Indian national communication to the UNFCCC allocates only 35 MT CO_2-eq/y of methane emissions to residential biomass energy using its standard methods in which global warming potentials (GWP) are calculated on a 100-y time frame for only 3 combustion-related GHGs -- CO2, methane, and N2O ("Kyoto" GHGs) -- and assumes that all the biomass fuel in India is harvested renewable, i.e., there are no net CO2 emissions. Nevertheless, the scientific literature makes it clear that several short-lived species (CO, NMHCs, black carbon aerosols) also contribute to warming and that some fraction of Indian biomass fuel is not harvested renewably. Thus, calculations using UNFCCC methods result in highly conservative (low) estimates of true GHG benefits.

Using the published emission factors (summarised in Table A1) and published GWPs for pollutants discussed above, we project Indian GHG emissions from household biomass combustion based on three emissions scenarios, for 2005 and 2025 for the business as usual and 50%:50% end-use energy delivery by a mix of ABCT:CBET described above, and LPG substitution by ABCT combusted biomass fuels.

- Scenario I – Kyoto GHGs only and all fuel harvested renewably: Reduction of 36 MT CO_2-eq y^{-1}.
- Scenario II – All GHGs and BC – all fuel harvested renewably: Reduction of 134 MT CO_2-eq y^{-1}.
- Scenario III – Fossil CO2 offset by 1 MTy-1 LPG substitution using ABCT combusted biomass fuels: Reduction of 3.1 MT fossil-CO_2 y^{-1}.

Although the total reduction is greater under a full accounting of GHGs, the 38% using Method I is greatest among the three because the baseline increases as more GHGs are included.

Clean Coal Technologies

A strategy for aggressive adoption of supercritical power plants and advanced coal technologies would result in the new plants would have an average operating net heat rate of 2200 kCal/kWh. The coal requirement reduces to less than 1100 Mt resulting in an annual saving of 100 Mt of coal and a saving of 150 Mt of carbon dioxide.

Table 2: Energy, coal, and GHG savings from advanced coal generation

Year	Electricity Generation (Billion kWh)	Electricity at BusBar (Billion kWh)	Peak Demand (GW)	Installed Capacity (GW)	Coal (MT)	Coal Based generation (Billion kWh)	CO2 (MT)
2003-4	633	592	89	131	318	443	461
2025 (using existing heat rates)	2704	2528	412	542	1450	2028	2109
2025 BAU*	2704	2528	412	542	1198	2028	1736
2025Adv**	2704	2528	412	542	1093	2028	1584

* The 2025 BAU scenario assumes an average operating heat rate of 2500 kCal/kWh.

** The advanced technology scenario assumes an average operating heat rate of 2200 kCal/kWh

T&D and major efficiency options

In 2003-4, the electrical energy available at the bus-bar was 592 billion kWh and the estimated AT & C losses were 195 billion kWh as shown in Table 3. An extrapolation of the energy used at the bus bar (based on 8% growth per year and falling electricity GDP elasticities as assumed in the Planning Commission's IEPC) results in a requirement of 2528 billion kWh and AT & C losses (considering power sector operation to be similar to the present) computed to be 834 billion kWh.

The impact options considered have been quantified as shown in Table 3. In the case of energy accounting a reduction of AT & C losses to a level of 25% is reasonable. It is expected, however, that the major part of this improvement would result in a reduction of pilferages, which in turn would assist in increase in revenue generated by improving billing efficiency. Significant saving of nearly 12% is possible by increase of efficiencies in agricultural pumping systems.

Table 3: Impact options for CO_2 saving for the year 2025 from T&D and Efficiency

<table>
<tr><th>Year</th><th colspan="2">[1] Energy at Bus-bar (BU)</th><th>[2] AT & C losses (33%) (BU)</th><th colspan="2">[3] CO_2 Emission (Million Tonnes)</th></tr>
<tr><td>2003</td><td colspan="2">592</td><td>195</td><td colspan="2">519</td></tr>
<tr><td>2025</td><td colspan="2">2528</td><td>834</td><td colspan="2"></td></tr>
<tr><th></th><th>Energy at Bus-bar (BUs)</th><th>Key Options</th><th>Saving Potential (BUs)</th><th>CO_2 emission savings (Million Tonnes)</th><th>% CO_2 emission savings</th></tr>
<tr><td rowspan="4">2025</td><td rowspan="4">2528 BU</td><td>[a] Energy Accounting/ improved collection/ billing efficiency</td><td>200</td><td colspan="2">Nil</td></tr>
<tr><td>[b] Efficient Distribution Transformer</td><td rowspan="2">125</td><td rowspan="2">103</td><td rowspan="2"></td></tr>
<tr><td>[b] Line Losses/ Pilferages</td></tr>
<tr><td>[c] Efficient Agricultural Pumping System</td><td>225</td><td>185</td><td></td></tr>
<tr><td></td><td></td><td>[d] Efficient Lighting</td><td>150</td><td>123</td><td></td></tr>
<tr><td></td><td></td><td>[e] Solar Water Heating</td><td>20</td><td>16</td><td></td></tr>
</table>

Assumption for calculations

[1] Energy at bus-bar = gross generation – auxiliary consumption; auxiliary consumption = 6.5% of gross generation

[2] Energy losses calculated as a percentage of energy available at bus bar

[3] Share of thermal generation projected to be 75% of gross generation in 2025

[a] Improvement of collection and billing efficiency> 90%, % AT & C loss reduction to 25%

[b] Improvement in DT efficiency and line loss reduction, % AT & C loss reduction by 5%

[c] Improvement of agricultural pumping efficiency to 40%, assuming share of agricultural consumption to be constant at 25% of the total for the year 2025

[d] 6% savings from efficient lighting is being assumed for India [8]

e Potential estimated by model developed in [9] 2005-6

5. STRATEGIES FOR DEPLOYEMNT

5a. Advanced biomass energy technologies

Biomass Gasifiers

The strategy for biomass gasification technologies should consist of mainstreaming technology and an emphasis on those biomass forms that are suitable for use in gasification such as pellets and wood chips. The gasifier manufacturers are quite fragmented at present and need to act jointly to evolve networks for supply and service of gasifier systems and components. Entry of well-known engineering firms would help in improving the product quality. Involvement of financing agencies would also help in building up the confidence levels of potential users in a new technology. An exercise of formulating and adhering to quality, performance and safety standards would have to be carried out prior to, or simultaneously with, the mainstreaming efforts. The role of Bureau of Indian Standards (BIS) and Ministry of Non-conventional and Renewable Energy would be critical in such exercises.

The strategy for mainstreaming of sized or standardized biomass fuel would involve many players including farmers, NGOs, small entrepreneurs (for producing commercial biomass), dealers etc on one side, and government bodies at district, state and central level on the other. The movement of sized biomass should be allowed freely and there should be incentives such as tax breaks so that the price of biomass to the user is affordable. Attempts also should be made to achieve long-term sustainability of the biomass supply network by ensuring adequate profits to all network members. Again, entry of large corporations might be beneficial.

Substantial applied and engineering research would have to be mounted to develop second-generation gasifiers that are capable of producing low-impurity gases. Simultaneously, efforts to design and make efficient and pollution-free dedicated producer gas engines need to be strengthened.

ABCTS

Retargeting subsidies for cooking energy: The Government of India continues to administer prices for domestic liquefied petroleum gas. As a result, domestic LPG prices are substantially lower than the real market price for LPG. The under-recoveries on account of administered LPG prices added up to over Rs 28,000 crore (US $7 billion) during 2006-7, which is about 1% of the nation’s GDP, nearly as much as the entire public expenditures on health. With recent rises in international oil prices, this subsidy is rising further. The present LPG subsidy system, which delivers a subsidy of Rs 1200-1500 per household per year, largely benefits the urban non-poor. A strong case has been made for withdrawal of this subsidy and retargeting to economically weak sections. LPG is currently used by 5% of rural households, with its penetration limited by factors other than affordability. Therefore, retargeting the LPG subsidy must include clean cooking energy options, other than LPG, to reach a significant fraction of the rural population. The money made available from better targeting of the LPG subsidy, should be used for a national initiative for advanced biomass energy technologies for micro-scale cooking applications. The main features of this initiative could be:

1. *Targeted technology development:* Some of the priority areas of the technology development programme would be: development of direct combustion advanced stoves, fine-tuning of gasifier stoves, field testing and development of non-dung based biogas plants, testing and development of machinery for pelletizing and briquetting. A technology development programme with clear time bound goals is needed. The

programme should aim at bringing together all the available expertise in academic, public, NGO and private sectors.

2. *Subsidy to end-users:* A capital subsidy of 50% on all ABCTs for domestic applications, needed to overcome the capital cost barrier. At the current prices, this would result in a 50:50 cost-share between the user and subsidy provider, with cost to each of around Rs 500 for an advanced stove, Rs 1500 for a gasifier stove and Rs 6000 for a biogas plant. In addition, a fuel subsidy may be required for very poor households, for purchase of processed biomass fuel, perhaps using low-cost “smart cards.”
3. *Enterprise development:* Providing interest subsidy, along with technical support, to facilitate development of enterprises for (a) manufacturing, installing and servicing ABCTs, and (b) supplying processed fuel e.g. pellets for gasifiers. Monetising reductions in GHG emissions through carbon finance routes must be integrated into enterprise development. Quick gains and capacity building, through a targeted programme for ABCTs in institutional and commercial cooking would be very useful for a larger effort focusing on households.
4. *Testing, quality control and certification:* One of the main reasons for the success of the Chinese improved cookstoves programme is attributed to the effective monitoring and quality control components. Thus, testing, quality control and certification should be an important element of the new initiative.

5b. Power sector technologies

Clean Coal Technologies

There is a need to support the establishment of prototype clean coal technologies (at least one plant each of CFBC, PFBC and IGCC). This can be done based on competitive bidding with the joint involvement of indigenous companies and foreign suppliers. This has to be supported by a multi-institutional research initiative to provide the necessary analytical and experimental support. For the super-critical plants India’s strategy should be to build a number of plants and then assess their performance vis-à-vis the sub-critical plants.

For the advanced clean coal technologies a critical assessment of the prototypes and performance after a period of about 5 years should result in a commercial deployment strategy. A clean coal fund can be established or an incentive provided for a higher efficiency or reduced emissions. Innovative financing mechanisms may be explored with government support to defray the higher initial capital cost of these plants.

T&D and major efficiency options

In order for the electricity sector to be viable, it is essential that the AT & C losses are reduced significantly. This can be achieved by a combination of improved accounting methodologies (where quantification of sub-station wise electricity usage and comparison with billed amounts can be used to determine the T & D losses for each substation and therefore help estimate norms) and metering of distribution transformers coupled with an energy audit framework and public availability of sub-station wise loss data. This would facilitate the adoption of distribution transformer efficiency and replacement programme, optimal network planning and agricultural motor pump efficiency programmes.

A program to deploy more efficient DTs would involve two components:

a. Replacement and refurbishments of lowest efficiency DTs with energy efficient DTs, which would involve energy auditing at DT level to assist in identifying high loss DTs where systematic replacement programme could be implemented based on cost benefit analysis. Particular attention must be paid to states that have high rural and agricultural consumption (based on load factors) with a consequent reduction in distribution line lengths. This would require a framework for optimum transformer selection based on data on region-wise loading and load concentration/ spread.
b. Standardization of efficiencies and to initiate mandatory minimum efficiency standards to promote use/ installations of efficient DTs with demonstrated benefits.

For optimal distribution network planning and maintaining a standard values of LT lines length as per DT capacity in rural and urban areas would require a program to systematically reduce the LV/ HV line length ratio by the implementation of High Voltage Distribution System (HVDS) in future network installation and upgrading wherever practicable. This would result in a reduction of the average DT capacity and therefore LV lines length per DT.

For improving the efficiency of agricultural pumping systems, standards should be laid out for optimum pipe sizing for minimum overall cost of pumping (including capital and running cost). Existing standards are sub-optimal and voluntary which are most of the times not followed by manufacturers and farmers. Policy formulation to introduce incentives to farmers for efficient pumping use can help in reduction of theft and overuse of pumps. This can be realized by metering of pumpsets and subsidized tariffs being based on actual energy consumption rather than on connected load. Agricultural feeder separations, metering of pumpsets, efficiency standards on new installations are elements of an efficient agricultural pumping programme.

Innovative Demand Side Management (DSM) programmes for efficient lighting and Solar Water Heaters can help in widespread adoption and result in significant energy and CO2 savings. An efficient lighting program, for example, could provide reduced capital cost options through large-scale procurement and provide the possibility and installment payments in utility bills [e.g. [11]BELP]. To be successful, such DSM programmes would need utilities to set up separate DSM cells with realistic budgets and energy saving (megawatt generation) targets. Monitoring and verification of DSM programmes and public reporting of actual performance would help in building cost-effective DSM programmes. An analysis of different rural electrification models can help identify a few options that may be replicable and address the issue of cost recovery.

6 CONCLUSION

India's development strategy needs significant increases in energy services. At present India accounts for 17% of the world's population and consumes only about 4-5% of the world's primary energy use. As India develops (current GDP growth rates of 9% per year), the energy sector is projected to expand (power installed capacity from 130 GW in 2004-5 to about 540GW in 2025). The development goals are providing access to convenient energy sources

[11] *BESCOM Efficient Lighting Program*

for the poor (almost 50% of the population). At present coal and biomass are the two main fuel sources in the energy mix.

The technical options identified and analyzed in this study -- clean biomass, clean coal power, improved T&D, and efficiency -- offer the possibility of significant progress towards key developmental goals while offering significant climate benefits. As summarized in Table 4, taken together these options would result in a reduction of GHG emissions by ~640 MT CO_2-eq/y in 2025 under our most optimistic deployment scenarios (~18 % of India's emissions in the BAU scenario).

In addition, deployment of these advanced technologies offers a range of direct development benefits, which are summarized in Table 5. Although the GHG benefits are somewhat larger in the power sector, the development benefits are concentrated in the biomass arena because the inefficient use of current technologies leading to economic loss, resource constraints, environmental impacts, and ill-health among women and children.

Reaping the benefits from these win-win options requires strategically-targeted programs that take into account the various barriers that impede the deployment of these technologies. This report has discussed specific approaches and outlined key programmatic elements that could help advance the deployment of these various energy technologies so as to deliver the development and climate benefits of clean energy to India's citizenry and economy.

Table 4: Potential 2025 fuel and GHG savings from Win-Win options for biomass fuel and power system efficiency in India

All Compared to Business as Usual in 2025	Direct Fuel/Energy Savings				GHG Savings (MT CO_2-eq/y)	Compared to all Indian emissions (%)
	Biomass (MT)	Petroleum Fuels (MT)	Coal (MT)	Electricity (BU)		
BIOMASS						
SMIE (Scenario–II)*	5	14	17		81	2.2
ABCT (Scenario-I)	124				36	1.0
Subtotal	129	14	17		117	3.2
COAL POWER						
Coal power generation			100		153	4.1
Power T&D				125 BU	103	2.7
Ag pumping				225 BU	185	4.9
Lighting				150 BU	123	3.3
Solar water heating				20 BU	16	0.4
Subtotal**			100	520 BU	~520	14.4
TOTAL	129	14	117	520 BU	~637	17.6

* The replacement of fossil fuels by biomass-using technologies will require ~110 MT of biomass. Thus the net biomass use in this scenario will increase by 105 MT.

** Total is less than sum because of overlaps in savings

Table 5. Summary of Development Benefits from Clean Energy Options

Option	Development Benefit	Effects / Impacts	Quantification (in 2025)
Advanced Biomass Cooking Technologies	Health (+++)	Reduction in respiratory and other diseases of women and children	90 million households (5 member family)
	Economic (Household) (-+)	Initial capital expenditure for new stove (-), which can be reduced by smart subsidies More time for women to engage in other economically productive activities	Rs. 1500 per stove of ~ 7 y lifetime (~ the current household subsidy per year for LPG)
	Economic (Society) (++)	Reduction in annual amount paid as subsidy for LPG	Per I MT/y of LPG substituted will need 4.3 million ABCTs. Savings of Rs. 6.45 billion /y in LPG subsidy.
	Access / Equity (++)	Convenient clean fuels for rural poor; reduction of burden of fuelwood collection for women and children	90 million households (5 member family)
	Energy Security (+)	Reduction of demand for LPG, conservation of biomass resources.	Savings of 124 million tonne of biomass/year. Each MT/y of LPG substitution will need 4.3 MT/y of biomass, available from savings.
	Employment (++)	Enterprise development for gasifier stove, processed-fuel industries, biogas construction and maintenance	*Employment for 150,000 persons

Biomass Gasifiers	Economic (SMIE) (++)	Reduced energy bill	
	Energy Security (+)	Reduction of oil consumption	Scenario-II: Fuel savings Coal: 17 million tons/year Biomass: 5 million tons/year Petroleum fuels:14 million tons/year
	Employment (++)	Creation of biomass markets, jobs for equipment manufacture, supply, maintenance, biomass supply, transport, pelletization	*Total: Employment for 900,000 persons (300,000 employment for gasifier manufacturer and operation and 600,000 employment in biomass production, processing, supply chain and after sale service)
	Access / Equity (-?)	Possible reduction in access for cooking fuel for poor households due to biomass markets	
	Others	Reclamation of degraded lands (+) Land availability for food (-)	
Clean Coal	Energy Security (+)	Conservation of existing coal reserves	100 million tonne of coal annually saved
	Economic (--) Economic (++)	Additional capital investment, technology development cost Annual savings in fuel cost	
	Local Environmental (+)	Reduced NOx, SOx, particulate emissions	
T & D and Efficiency	Economic (++)	Improved revenue of utilities Deferred capacity addition	Rs. 500 billion additional 110,000 MW
	Equity / Access (+)	Reduced power shortages, availability of power for new connections	520 billion units savings
	Employment (+)	Jobs for energy efficiency, pump rectification, transformer audit	
	Same benefits as Clean Coal	By reducing demand for coal power, the same kinds of benefits as found under Clean Coal occur	

* Does not include employment generated in biomass collection and biomass plantations.

India Topic Reports

1. *Review of Indian Mitigation Studies*
2. *Indian National Biomass Fuel Resources and prospects*
3. *Biomass Gasification Prospects in India*
4. *Advanced Biomass Technology*
5. *Indian National Coal Resources and Prospects*
6. *Advanced Technologies for Coal Power Generation*
7. *Power Transmission &Distribution and End-Use Efficiency*

Development Benefits of Clean Energy in India Review of Literature on GHG Mitigation Potential in India

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Review of Literature on GHG Mitigation Potential in India

1. Introduction

Considerable research has been carried out on the various issues related to the climate change. These include several collaborative efforts- some of the significant ones that have been coordinated by the Ministry of Environment and Forests include the climate change studies supported by the Asian Development Bank, the ALGAS (Asian Least-Cost Greenhouse Gas Abatement Study) supported by the Global Environment Facility (GEF), the climate impact assessment study conducted under the Indo-UK collaborative project and the latest is the Initial National Communications (INC) to the UNFCCC supported by the GEF.

This chapter reviews the literature related to the GHG mitigation potential in India, focusing on studies that have estimated the GHG emissions reduction potential from various sectors and worked out the economics of mitigation, the co-benefits including that on the local environment, human health, value of carbon CERs and the uncertainties in these estimates. There are barriers involved in the formulation and implementation of the various sectoral policies, including financial, economic, technical and institutional and this chapter reviews the literature on this important issue. Based on this review, we draw the key conclusions on this topic. Further, the study aims to provide a critique of the existing highlighting the research areas to be pursued. Since some of the literature consists of figures that have been updated by the authors, this study reviews the latest work. Each section summarizes the major literature in a table format for comparative purposes. An extensive survey of literature is presented in the Bibliography.

2. Review of literature

2.1 India's GHG estimates- Base case scenario

Substantial work has been done by researchers on estimating Indian emission inventories of different gases and years (Mitra, 1991; ALGAS, 1998; Garg et al., 2001 a,b; Reddy and Venkataraman, 2002; Garg and Shukla, 2002; Mitra and Bhattacharya, 2002; Garg et al., 2002; Mondal et al., 2004; PCRM, 2002). India has submitted the Initial National Communication (INC) to UNFCCC in June 2004 including inventory of CO2, methane and N_2O using many domestic emission factors (INC, 2004). The emissions inventory reported to the UNFCCC (INC 2004) is a considerable improvement over similar studies, especially ALGAS 1998, in terms of providing a more comprehensive reporting of sources and sinks, using a wider emission factor database representing country specific circumstances, and following a bottom up approach (Sharma et al 2006). We present the estimated emissions in different studies for the main GHGs- CO_2, CH_4 and N_2O in Table 1. The Table also highlights the major conclusions drawn in these studies.

Table 1: India's GHG estimates- Base case scenario

Study (context)	Methodology	Estimates			Key conclusions
		CO_2	CH_4	N_20	
Garg et al 2006 (Multi gas and multi sector analysis)	Uses IPCC methodology*, taking India-specific emission factors; default is IPCC emissions factors	849 MT in 1995; 1229 MT in 2005	18.85 MT in 1995; 20.08 MT in 2005	0.185 MT in 1995; 0.253 MT in 2005	• Profile of GHGs Rapid growth in CO_2 emissions (52% in 1985 to 71% in 2005); Share of CH_4 emissions declining • Growth of GHGs, especially CO_2, faster than local pollutant emissions
Shalini et al 2006 (Assessment and mitigation of CO2 emissions from cement industry in India)	Uses a system dynamics model based on the dynamic interactions among a number of system components	Direct emissions 80.5 MT in 2000; 396.89 Mt by 2020 Indirect emissions## 2.24 MT in 2000; 11.87 MT in 2020			Integrated mitigation scenario comprising population stabilization by 2020, energy management policies and structural management policies can reduce CO_2 emissions from cement industry by 42% by 2020
Garg et al 2004b (Estimates future CH_4 and N_2O emissions and the mitigation flexibility)	Uses GIS interfaced AIM/ Enduse model		18.63 MT in 2000; 24.36 MT in 2030	0.308 MT in 2000; 0.807 MT in 2030	• Slow growth in CH_4 emissions (1.8% per annum) since main the contributors- enteric fermentation and rice cultivation- grew below 1% per annum. • Greater than 5% growth in N2O emissions annually due to rapid growth in the use of synthetic fertilizer (main contributor)
INC 2004 (India's national communication to the UNFCCC)	Uses IPCC (1996 Guidelines) Tier I, II and III approaches depending upon the quality and reliability of activity data and the emission coefficient	817 MT in 1994	18.08 MT in 1994	0.178 MT in 1994	
Shukla et al 1999a (Analyses emissions from the electric power sector in India)	Uses a least cost LP model for analyzing scenarios for the power sector in India till 2015	92 MT in 1995 217 MT in 2015			• Carbon emissions rise two and a half times by 2015
ALGAS 1998 (Analyses emissions from 11 Asian countries)	MARKAL model	585 MT in 1990	18.47 MT in 1990	0.255 MT in 1990	On a CO2 equivalent basis • CO2 emissions account for 53% of the total emissions • CH4 and N2O contribute 39% and 8% respectively;

*$\text{Emissions}_{Gas} = \sum_{source\_cat} \text{Activity data}_{source\_cat} \times \text{Emission factor}_{Gas,\, source\_cat}$

$Q_{CO2} = C\rho\eta$

Where Q_{CO2} is the amount of carbon dioxide emitted (MT); C is the carbon fraction of the fuel; ρ is the amount of fuel consumed in the particular year (MT per annum); η is the combustion efficiency of the fuel.

Arises from fossil fuel combustion during transportation of material to the industry and finished product cement to the market

2.2 Sectoral contributions of GHG emissions

Several studies have been undertaken to estimate the sectoral contribution of the different GHGs. These studies have estimated that coal consumption in large point sources as the major contributor to CO2 emissions (major contributor among them being the power plants), while the agriculture services are a major contributor to CH4 and N2O emissions. The estimates from the major studies are shown in Table 2.

Table 2: Sectoral Contributions of GHG emissions

Study	CO_2	CH_4	N_2O	Policy conclusions
Garg et al 2006 (Multi gas and multi sector analysis)	• 52% from power generation in 2005 (7.7% CAGR between 1985-2005) • Cement sector CAGR was 6.5% between 1985-2005 • Two-third contribution from coal use	83% from agriculture sector in 2005, of which • 53% from livestock-related activities, • 20% from rice-paddy cultivation • 10% from biomass burning	80% from agriculture sector, of which • 60% was from use of synthetic fertilize • 12% each from agri residue burning and indirect soil emissions • 3% from manure management	• Targeting coal usage in LPS for CO_2 emissions • Developing less methane intensive paddy varieties more feasible than improving digestibility of animal feed • N_2O emissions from agri activities are widely dispersed; requires substantial mitigation efforts
Raghuvanshi et al 2006 (Estimates CO_2 emissions from coal combustion in power plants)	• Coal use- contributes about 70% of CO2			Technically feasible and economically viable options available for CO2 reduction from coal use
INC 2004 (India's national communication to the UNFCCC)	Estimates for 1994 • 81,7% from energy consumption • 12.2% from industrial activity • 0.046% from LULUCF	Estimates for 1994 • 16.01% from energy use • 78.38% from agriculture • 0.05% from waste	Estimates for 1994 • 84.83 from agriculture • 0.06% from energy • 0.05% from industrial activity	
Garg et al 2004b (Estimates future CH_4 and N_2O emissions and their mitigation flexibility)		• 65% from agriculture and livestock	• More than 90% from agriculture and livestock	• Considerable efforts required for mitigation, since emission sources are widely dispersed • Mitigation offers synergies with sustainable development objectives
Garg et al 2002a (Analyses the LPS emissions for India)	65% from LPS, of which • 47% from power • 6% from steel • 9% from cement • 2% from fertilizer • 0.09% from sugar • 0.37% from paper	• 9% from LPS	• 6% from LPS	• LPS emissions growing faster than national average • LPS provide focused opportunities for targeted CO_2 mitigation • Abatement measures in 50 LPS addresses 50% of CO2 emissions
Bandhopadyay et al 1996 (Analyses the CH_4emission sources and mitigation options)		• 4.0 Tg/yr from paddy fields in 1992 • 8.05 Tg/yr from livestock		Controlling emissions from • Paddy fields: Control irrigation water • Livestock include, increasing the intake of the animal, modifying the composition of diet, eliminating protozoa in rumen, improving fibre digestion efficiency etc
Parikh and Gokam 1993 (Analyses CO_2 emissions in the Indian economy and alternate mitigation options)	Direct sectoral analysis (1983-84) • 33% from power sector • 9.8% from iron and steel Analysis by final demand (1983-84) • 22% attributed to construction sector • 8.6% to food crop			Policy options to reduce CO2 emissions include • Improving construction efficiency by optimizing the use of construction material • Implementing construction technologies that use energy- efficient materials

2.3 Alternate scenarios for CO_2 emissions

Modeling exercises for developing alternate scenarios of future CO2 emissions has over a decade of experience. Studies have developed scenarios using different modeling framework and under different assumptions. Rana and Shukla (2001), while using the Edmonds-Reilly-Barnes model (ERB) model, worked with one reference scenario and a few emission mitigation scenarios wherein imposition of carbon taxes at various levels were varied and its impact on future carbon emissions was studied. The PEW Center on Global Climate Change has developed six scenarios in its study of the electric power sector of India (Shukla et al., 1999). Another set of scenarios analyzed in one of the emissions studies using the Asia-Pacific Integrated (AIM) End-use and Market Allocation (MARKAL) models (Garg et al., 2003a) are the economic growth scenarios and environmental scenarios. Another study (Ghosh, 2000) explores the implications of specific intervention scenarios on the long-term technology strategy for power sector and related carbon emissions. The scenarios considered are local and global environmental interventions, demand side management for electricity and grid integration & regional co-operation.

Table 3: Alternate scenarios for CO_2 emissions

Study	Scenarios	Assumptions	Results
Shalini et al 2006 (Assessment and mitigation of CO2 emissions from cement industry in India)	• Sc. I: Population growth rate is expected to reach zero in 2020 and beyond • Sc. II: Population growth rate is expected to stabilize by 2012	a) Variations in production according to demand and supply b) 25% of power demand in cement plants from 2010 is from RETs c) Improvements in thermal energy efficiency d) 30% of thermal energy generated is from waste heat recovery e) Combination of b, c, d	Sc. I: CO2 emissions in 2020 would reach 322.22 MT Sc. II: CO2 emissions in 2020 would reach 313.87 MT(20.92% reduction from base case)
Shukla et al 2003 (Presents Indian emission scenarios following IPCC scenarios)	• Termed IA1 (high growth), IA2 (BAU), IB1 (Sustainable development, IB2 (Self-reliance) • Draws mainly from the IPCC SRES methodology	Assumptions on • Market integration (Extent of liberalization, globalization and integration with the world markets) • Nature of governance (centralization v/s decentralization)	• Carbon emissions grow from 261 Mt in 2000 to 841 Mt by 2030 in IA1 scenario • The least emissions in 2030 are in the IB1 scenario at 560 Mt
Parikh and Gokam 1993 (Analyses CO_2 emissions in the Indian economy and alternate mitigation options)	Sc. I: Reducing the use of coal or oil by conserving the same amount of energy Sc. II: Fuel substitution i.e. oil for coal	Sc. I: Saving 107GJ of energy using the two fuels Sc. II: 10% coal is substituted by equivalent amount of oil or 13.5% of oil is substituted by an equivalent amount of coal	Sc. I: • 13.5% reduction in oil usage vis-à-vis 10% usage in coal • If energy saved from coal usage, it would save 6 Mt C vis-à-vis 2.18 Mt C if energy saved from oil use • Marginal cost of additional carbon saving from coal as opposed to oil is Rs. 1150/tC (US1$=Rs10 in 1983-84) • Divergence between energy conservation and GHG reduction policies Sc. II: • 12mt of coal requirements; cuts 3mt of oil requirements, • Saves Rs. 10.500 bn in imports vis-à-vis 8.7mt C • Relative price, global regimes determinant of policy choice

Different ministries of the Government of India have also developed scenarios for future, which have been used in short-term and long-term policymaking. These include Hydrocarbon Vision 2025, Planning Commission five-year plan documents, Technology Information Forecasting & Assessment Council (TIFAC) reports on Technology Vision 2020 for seventeen sectors, Electric Power Surveys, Railways vision 2050, National Highways plan, Auto Fuel Policy (Mashelkar et al., 2002), and a few state level plans like Delhi 2021. Although, these studies have not been used for emission projections, they provide useful information on key driving forces.

2.4 Options for mitigation of CO_2 emissions, estimated potential and costs

Given the dominance of coal in CO2 emissions in India, we reviewed the literature on the different coal technologies and its operations in India. Table 4 presents a comparative picture of these technologies and its operations in India.

Table 4: Comparison of Coal Technologies' characteristics

Technology	Maturity of technology	Capital cost ($/kW)		Overall cycle efficiency	Operations in India
		Year 2000	Year 2015		
Sub-cr PC	Completely proven	1000	925	Limited (33-35 percent) by steam conditions	Most commonly used technology in India
Super-cr PC	Substantially proven	1150	1045	High (37-39 %), further increase depends on materials development	Few pilot projects under NTPC
AFBC	Proven at small scale (less than 200 MW only)	1470	1340	Relatively low (33 percent), but supercritical steam conditions will raise efficiency.	Used for captive power generation, with unit capacity around 40MW
PFBC	Limited experience	1215	1105	Inherently less good than IGCC (40 %)	Not being used
IGCC	Limited experience	1480	1350	High (45 %), further increase as gas turbines improve	Pilot projects • Coal based IGCC by BHEL on 6.2 MW pilot plant at Trichy • Collaboration between NTPC and BHEL for setting up a 100 MW IGCC demonstration plant based on Indian coal at NTPC Auraiya plant

* All cost figures in this table are in 1998-99 prices
Source: WB, 1997; IEA, 1996; Shukla et al 1999a

The Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS), projected energy-sector carbon emissions of at least 688 million tons in 2030, nearly three times the current level. Forestry-related emissions would reach 21 million tons of carbon by 2020 and about 29 million tons by 2030. They evaluated several mitigation options, which are summarized in Table 5.

Table 5: Details of GHG mitigation options

Description	Investment cost	GHGs emissions reduction	Cost effectiveness, $/tCO2
Clean coal			
Cogeneration	900 $/KW	1.50 kg/kWh	10
Combined cycle	818	0.96	54
ISTIG	947	0.76	77
PFBC	1894	0.18	503
IGCC	1578	0.23	340
PCSCB	1202	0.18	342
Coal washing	11 $tpa	0.125	179
Renewables			
Small hydro	1950 $/KW	1.3 kg/kWh	88
Wind farm	1405	1.3	257
Biomass power	710	1.6	102
Solar thermal	3730	1.3	592
PV	5952 $/kWp	1.6	541
Renewables for agriculture			
Gasifier			
-agro based	760 $/KW	1.6 kg/kWh	119
-wood based	694	1.6	115
Wind			
-shallow well	1157	1.6	173
-deep well	2149	1.6	176
PV pump	8598 $/kWp	1.6	1602
Industry (Cost cutting options)			
Diesel cogen	1022 $/KW	0.75 kg/000 t of steam	Base case: No diesel Cogeneration
Heat pumps	330 $/kW th	0.06-0.12 kg/kg of steam for coal fired boilers 0.04-0.08 kg/kg for oil fired	No heat pump
High efficiency motors	109 $/KW	2% energy saving	Standard motor
Waste heat recovery	61000 $/recuperator	0.03 kg/kWh (av); 44 kg/t of steel	No waste heat recovery
Transport			
CNG car	10965 $/unit	0.017 kg/pkm	4500
CNG bus	31000	0.41	12
MRTS	1.4 billion $	-	-
BOV 3-W	2444 $/unit	-	-
2-W 4 stroke	1156	0.0014 kg/pkm	30000
Domestic lighting			
CFL	8 $/unit	6.49 Tg/year	
36 W fluorescent	0.9	0.09	

Note: In the table cost effectiveness represents the total investment to abate a unit of CO2. However the investment is indicative of the total investment and not incremental investment.

The conclusions drawn in the ALGAS 1998 report are as follows: a) carbon abatement is primarily achieved through fuel switching and to some extent through more efficient but expensive technology choice; b) in the power sector, the priority options are hydroelectric sector, gas based generation, and wind energy capacity increase, c) in the agriculture sector, faster introduction of efficient pumps are essential and d) in the household sector, mitigation comes through an increase in the use of CFLs and efficient fans.

The IPCC report on Climate Change Mitigation (IPCC 2001) provides a detailed view of the literature on mitigation options. The mitigation scenarios assessed in the IPCC reports suggest that the type, magnitude, timing and costs of mitigation depend on different national circumstances and socio-economic and technological development paths and the desired level of GHG concentration stabilization in the atmosphere. Development paths leading to low emissions depend on a wide range of policy choices and require major policy changes in areas other than climate change. The various approaches discussed for mitigation are as follows -

- Technologies and practices for end-use energy efficiency in buildings, transport and manufacturing industries.
- Efficiency improvement in energy supply and conversion technologies.
- Low-carbon energy supply systems.
- Methane and nitrous oxide emissions reduction in agriculture.
- Process changes to reduce emissions of fluorinated gases
- Biological mitigation by conservation of existing carbon pools, sequestration by increasing the size of carbon pools, and substitution by sustainable biological products.

- Social learning and innovation.
- Demographic changes.
- Policy measures ranging from command and control to market instruments

Another study shows (Chandler et al 2002) that the growth of energy-related carbon dioxide emissions in India was reduced over the last decade by an estimated 111 million tons.[46] The key factors in these reductions have been economic restructuring, local environmental protection, and technological change. These drivers have been mediated through economic reform, enforcement of existing clean air laws by the nation's highest court, and renewable energy incentives and development programs funded by the national government and foreign donors. In 2000 alone, energy policy initiatives reduced carbon emissions growth by 18 million tons—about 6 percent of India's gross energy-related carbon emissions. The contribution of different areas of energy reforms in emissions mitigation is shown in the following figure.

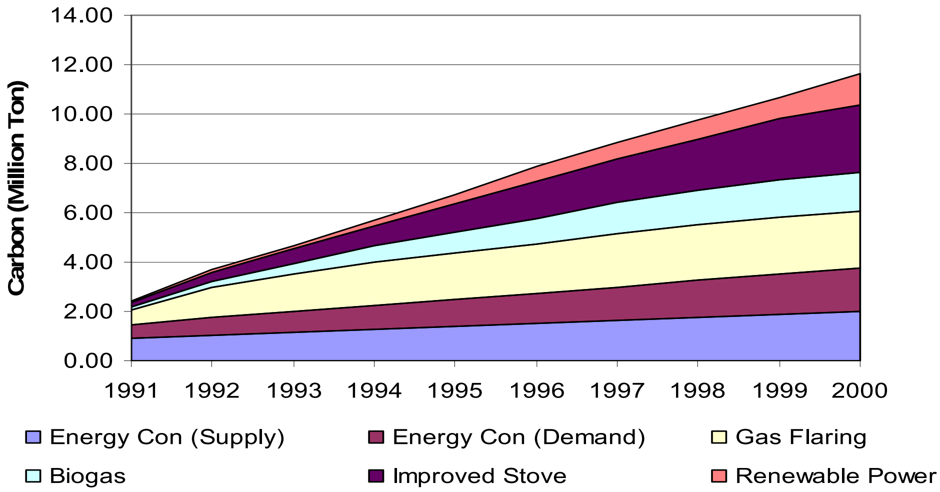

Figure 1: Emissions mitigation in India's Energy Sector, 1991-2000

Table 6 presents a summary of other studies have looked at the CO2 mitigation options in India.

Table 6: Options for mitigation of CO_2 emissions, estimated potential and costs

Study (context)	Mitigation options	Estimated mitigation potential	Estimated costs
Raghuvanshi et al 2006 (Estimates CO_2 emissions from coal combustion in power plants)	From power plants Supply side options like efficiency improvements, clean coal technologies and renewable energy	Supply side options in power plants • Combined Cycle with PFBC- 8%; IGCC- 9%; IGCC with hot gas cleaning- 16% • 43% reduction by substituting gas for coal • 12% decrease if plant works at design efficiency	
Zhang et al 2004 (Studies issues related to setting of baselines in the Indian and Chinese power sector)	Lowering carbon intensity by • Substituting coal • Adopting advanced coal-fired generation technology	• Fuel mix key driver to lowering carbon intensities • Use of coal generation units larger than 100 MW has led to efficiencies of scale Between fuel switches and increasing energy efficiency, the former accounts for 70 to 80% of carbon savings in case studies	$34-$339
Purohit et al 2007a (Techno-economic evaluation of biogas based water pumping system in India)	Biogas driven dual fuel engine for water pumping systems	Net annual CO_2 emissions mitigation potential for systems with rated capacities of 15, 20 and 25 m^3 is 14%, 15% and 18% respectively	
Purohit et al 2007b (Assesses CDM	Bagasse cogeneration	Annual CO2 emissions mitigation potential using regional baseline is 28MT State-wise mitigation potential:	

potential of bagasse cogeneration in India)		Uttar Pradesh (about 10 MT), Maharashtra (4.6 MT), Tamil Nadu (3.6 MT), Karnataka (3.3 MT), Andhra Pradesh (1.7 MT) etc		
Purohit et al 2006 (Assesses CDM potential of SPV pumps in India)	SPV pumps	Maximum mitigation potential- more than 214 Mt annually		
Shukla et al 2006a (Comprehensive report to the MoEF on GHG emissions in India)	Option	MT of carbon (2000-2012)		($/ton of carbon eq.)
	Demand side energy efficiency	45		0-15
	Supply side energy efficiency	32		0-12
	Electricity T&D	12		5-30
	RETs	23		3-15
	Fuel switching (from coal to gas)	8		5-20
	Forestry	18		5-10
Garg et al 2004a (Assesses the carbon capture and storage (CCS) potential in India, focusing on the LPS)	CCS from LPS 2010-2030	CO2 capture potential (Pg-CO2)		Average capture, transportation and storage cost around US$ 60 to 70/t-CO_2 using existing technologies,
		At 80% system efficiency	At 90% system efficiency	
	Top 5 LPS	3	3.4	
	Tops 10 LPS	6.1	6.8	
	Top 20 LPS##	9.9	11.2	
Parikh and Parikh 2004 (Studies the CDM policy in India, its potential in few sectors and the key concerns)	Increasing construction efficiency	Potential to educe 21% of CO_2 emissions from cement industry		
Kroeze et al 2004 (Evaluates the potential of different GHG mitigation options)	• End-use efficiency improvements • Fuel switches • Efficiency improvements of existing and new plants	Options to reduce GHG from power plants	Reduction in 2020 GHG emissions (% of BAU)	
		End use efficiency improvements a) Cement, iron & steel, aluminum b) Other industries c) Residential sector d) Commerce e) Agriculture Total	a) 3% b) 14% c) 12% d) 11% e) 5% Total 45%	
		Renewable use is 47% higher than in BAU,	14%	
		Natural gas use is doubled compared to BAU	14%	
		Nuclear electricity generation of 252PJ (12 PJ in BAU scenario)	6%	
		Efficiency of existing power plants increased by 5% and new power plants established with efficiency of 42%	9%	
		Heat production is maximized that also increases electricity production in coal based cogeneration	4%	
		The difference between the gross electricity production and end use is reduced by 1/3rd to 9% of the gross electricity production	6%	

It may be noted that these estimates relate to total investment and not incremental investment from base technology.
20 top LPS comprise of power and steel plant

2.5 Alternate scenarios of CO_2 mitigation

Studies have developed scenarios to estimate the potential mitigation opportunities. Some of the major ones are discussed in Table 7.

Table 7: Alternate scenarios of CO_2 mitigation

Study (Context)	Methodology	Scenarios and assumption	Estimated mitigation potential		Estimated costs
Sathaye et al 2006 (Estimates the cost of reducing carbon emission using combined cycle units in place of coal power plants in India)s	Cost of reduced carbon emissions= ¼ (Cost of electricity generation from combined-cycle power plants - Cost of electricity generation from coal plants)/(Carbon emissions from coal power plants	Studies 8 proposed power projects- 4 using LNG and 4 coal-based plants Base case assumptions b) Capital costs as in the PPAs c) 14% discount rate and 80% PLF for all plants d) Oil price $24/barrel e) Carbon content for coal (25.8 kg C/GJ) and LNG (15.3 kg C/GJ) across power plants and over time. Alternate Scenarios a) Lower capital costs (US levels) b) Lower capital costs and lower price of domestic natural gas (instead of LNG use) c) Improving heat rate (US levels) d) Combining of a, b, c	CO2 emissions from • Coal based plants: 0.29 KgC/kWh • Combined cycle plants: 0.125 KgC/Kwh		Base case Avg. cost of reduced carbon emissions in India= $144/tC • Capital, fuel costs, O&M costs and heat rates are significantly higher in India than in the US for CCGT plants; these parameters are only slightly higher in India for the mature technology of coal power plants. Alternate scenarios Costs of reduced carbon emissions a) 18% decline b) Lowers costs c) 27% decline d) In a mature market the cost of reduced carbon emissions is only $6/tC
Shukla et al 2006a (Comprehensive report submitted to the MoEF on GHG emission in India)	Uses integrated modeling framework	Stabilization scenarios	Kyoto regime (2000-2012)	Medium term (2000-2030)	
		750 ppmv	3%	5%	
		650 ppmv	7%	11%	
		550 ppmv	10%	17%	
Shalini et al 2006 (Assessment and mitigation of CO2 emissions from cement industry in India)	Uses a systems dynamics model	Sc. I: Energy management scenario in the base case	% reduction of CO2 emissions over BAU in 2020		
		a) 25% of power for cement plants from RETs after 2010	2.8%		
		b) Increased thermal energy efficiency up to 2.9 Gj/tonne of clinker produced	4.95%		
		c) 30% of thermal energy used is from waste heat recovery	10%		
		d) Integration of a, b and c	16%		
		Sc. II: Structural management scenario, where share of blended cement is increased #	11.63%		
		Integrating Sc. I and Sc. II	26.37%		
Parikh and Parikh 2004 (Studies the CDM policy in India, its potential in few sectors and the key concerns)	Uses a multi-sector inter-temporal model in a activity analysis framework	GHG reduction from cement sector till 2015 Sc. I: BAU (8% growth) Sc. II: High growth (12%) Two energy efficiency improvements (EEI) cases for both the scenarios	• BAU growth rate and conservative EEI- 10% reduction • BAU growth rate, vigorous EEI measures- 27.5% reduction • Process-generated emission in Sc. II is around 60% higher than that in BAU.		
Kroeze et al 2004 (Evaluates the	Uses RAINS-ASIA model	Options with largest technical potential to reduce GHG from power plants	Reduction in 2020 GHG emissions		

potential of different GHG mitigation options)		Sc. I: Mixed options scenario (BPT1), combining technical options and stakeholder views	47%	
		Sc. II: Efficiency improvement preferred (BPT 2)	53%	
		Sc. III: Preference for fuel switch (BPT3)	53%	
		Sc. IV: Theoretical maximum potential to reduce BOT2 and BPT3 (BPT4).	77%	
Halsnaes et al 2001 (Study provides a detailed analysis of thee environmental choices for the transport sector)	Least cost methodology	Case of 2-stroke 3-Wheelers in Delhi Sc. I: Local pollutant abatement measures Sc. II: GHG abatement measures Sc. III: 'Least cost' local program with add-on GHG abatement measures	Sc. I Total GHG emissions increase by 42% Sc. II. Reduces CO_2 eq. emissions by nearly 5%; Total local weighted pollutants reduced by 38%	• Opportunity cost of forgoing Sc. I more than the benefit in terms of damage cost avoided ($30 / tCO2 eq. vis-à-vis $10 t/ CO2 eq) • Not implementing Sc.I would forgo local benefits worth $7.6 million per year • In Sc. III,, annual decline of 66,000 tons of CO2 eq.; • Difference in annual net benefit between Sc.I and SC.III is around $4.8 million/person
Shukla et al 2002 (Assesses the impact of energy system responses to global carbon market signals on power sector RETs)	Uses an integrated bottom-up modeling framework	Mitigation scenarios over cumulative baseline emissions- • Low mitigation (5%) • Medium mitigation (15%) • High mitigation (25%) Assumption: High potential for RETs in a climate change regime since a) They contribute to global sustainability through GHG mitigation b) They conform to national priorities	Power sector CO_2 mitigation potential across different scenarios is 55% to 70%, where a) Biomass and cogeneration- 60-80% (Offers cheap mitigation opportunities and potential easiest to realise) b) Wind share- 10-15%. (Most wind sites having high potential get tapped in early years; exploitation of more difficult sites in later periods results in low capacity utilisation and slowing down of mitigation opportunities). c) Solar share- 3-6%	Investment shares of the different RETs across the mitigation scenarios is as follows: a) Biomass and cogeneration- 25%-40% b) Wind- 20-25% c) Solar- 20-33%
Shukla et al 1999a (Reviews the electric power sector in India in the context of policies to bridge demand-supply gap and reduce the CO2 emissions from coal consumption)	Uses a least-cost LP model	I: Market reform- Assumes competition and access to global finance and technology II: Efficient technology- Technology RD, technology transfer and local capacity building III: Local environment control- Strict local pollution control, emission standards, clean fuel and technology choices IV: Sustainable development- Environmental integrity, consumption changes, dematerialization and cooperation V: Growth scenarios- Assumptions of economic growth rate	• Significant CO_2 reductions in scenarios II and IV, namely 22 and 35% in 2015 over the projected baseline emissions in that year	• Capital costs of around $8bn by 2015 in Sc. II due to higher efficiencies, improved capital utilization rates and reduced power demand • Capital cost in Sc. IV is around $9bn by 2015 mainly due to reduced power demand and improved technologies.

t45% PPC (Portland Pozzolana cement), 16% PSC (Portland Slag Cement) and 2% zeolite blended Portland cement

2.6 Carbon Abatement Cost Estimates for India

A study (Chandler et al 2002) further shows that India has potential for substantial GHG mitigation at a relatively low price. In the short run, till the Kyoto Protocol period, substantial potential of mitigation of carbon, methane and nitrous oxides exist at costs below $30 per tonne of carbon equivalent (or $8 per tonne of carbon dioxide equivalent). In the long run, the results of the modeling exercises show that India, between 2005 and 2035, could supply cumulative 5 billion tonne of carbon equivalent mitigation from the energy options at price below $10 per tonne of carbon equivalent (Figure 2) (Shukla et al 2004; Garg et al 2003, Nair et al 2003).

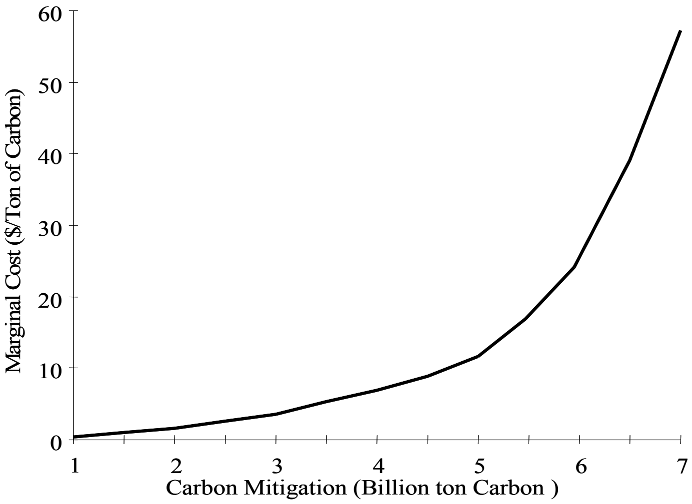

Figure 2: Carbon mitigation supply curve for India for the period 2005-2035

The literature on carbon abatement costs in India has been summarized in Table 8.

Table 8: Carbon Abatement Cost Estimates for India

Study	Modeling approach	Scenario period	Assumptions: Carbon tax rate; % reduction	Qty of carbon reduction (Mt)	Abatement cost (US$1995/tC)	Income (or welfare) change (%)
Shukla 1996	Op-down: SGM CGE Model	1995-2030	Stabilization At I* 1990 emission levels At 2*`1990 level (20% reduction from baseline)	580 380	412 64	6 (2030) (GNP) 3 (2030) (GNP)
Shukla 1999a	Bottom-up MARKAL	2005-2035	20% reduction of cumulative emissions 30% cumulative reduction		10 (PV) 45 (PV)	
Shukla 1999b	Bottom-up MARKAL	2015	6.5% reduction from 2015 baseline		112 (PV)	
Gupta and Hall 1997	Bottom-up: Various engineering studies Top-down: *Sui generies* Keynesian macro model	1990-2020	4.5-5.7% emissions reduction in 2020 24% average reduction- 2007-2020		6.1 108	2.3 (2020) 8.0 (avg.loss)
Fisher-Vanden et al 1997	Top-down: SGM	1990-2030	2030 emissions 1* 1990 level 2*1990 level 3*1990 level	580 380 180	412 61 9.4	2030 GDP loss 6.3 2.9 0.1
Mongia et al 1991	Multi sector LP model	2005 2025	17.6% reduction 22.4% reduction	60 150	10.4 54	
ALGAS 1998	Bottom-up: MARKAL	2020	10% reduction 20% reduction		3.15 ** 11 **	
Chattopadhyay and Parikh 1993	Power sector alone; comparative static	1989-90	5% reduction 10% reduction 15% reduction		96 # 113 # 148 #	
Reddy and Parikh 1997	Bottom-up: DSM in electricity sector only	1995-2010	280 mn tones of cumulative emissions		49..5 **	
Khanna and Ziberman 1999	Power sector alone; comparative static	1990-91	10%		160#	Welfare gain: 8.4
Bitzer et al 1992	CGE model: incorporates CO2 and CH4	1990-2040	20% reduction in radiative forcing		14.5	6 (GDP loss in 2025)

Notes: ** Average cost; # Marginal cost
Source: Bussolo M and O'Connor D 2001

One important difference in the assumptions underlying the results in Table 9 is the treatment in the baseline of extant energy system inefficiencies. In cases where those inefficiencies are incorporated in the baseline, the potential is much greater for low- or negative-cost emissions reductions. If, on the other hand, the baseline is already an "efficient" one, then even minimal abatement measures are likely to incur positive costs (Halsnaes, 1996). The study by Bussolo and O'Connor (2001) itself compares their tax rates, which reflect the costs, to those in the studies given in the Table 7. The comparison shows that for CO2 abatement up to around 10-15 per cent from baseline levels, abatement costs vary in the $5-150 range per tC. The figures in this study fall within this range up to 10 per cent abatement, but thereafter they become significantly higher because it incorporates efficiency assumptions in the baseline, making their method comparable to those yielding abatement cost estimates toward the upper end of the range.

There is a fundamental assertion that carbon mitigation costs are lower in developing countries as compared to that in the developed countries. This assertion has been questioned in a paper by Sathaye and Phadke (2006)), where they estimate the cost of reducing emissions through the use of combined cycle units in place of coal power plants in India (the different scenarios and costs are summarized further in Table 6). They have used the data of power plants proposed by independent power producers and estimated the cost of carbon reduction to be \$144/t C. They conclude that whole the domestic coal plants have attained the technological maturity; the same is not true for the combined cycle units. In fact, the capita, fuel and other costs are all higher for these units as compared to these costs in the US. As the combined cycle technology matures, the cost differential may narrow in the future to as low as \$6/t C.

2.7 Implications of mitigation options

2.7.1 Co-benefits

Heller & Shukla (2003) argue the case for mainstreaming by an inclusive strategy that promotes the climate cause through innumerable economic development actions that happen daily and everywhere, rather than following the current climate strategy that marginalizes the climate cause by pursuing exclusive climate centric actions. A study by Dave et al 2007 analyzes how development pathways can be made more climate-friendly without adversely affecting the priorities of socio-economic development. The paper includes different case studies on this aspect. Some of the important conclusions from these cases are as follows:

Case 1- Co-benefits of local and GHG mitigation: One of the case studies mentioned in this paper estimates the co-benefits of conjoint GHG and local pollutant emissions market in the electricity sector. The modeling assessment, presuming the CO_2 price of \$5 per ton and identical SO_2 trajectory as in the BAU, shows that mitigation costs for the 25 year period would be lower in the conjoint market by \$400 million compared to under the two separately operating markets. Besides, the conjoint market would deliver 520 million tons of additional CO_2 mitigation and thereby add \$2.6 billion to the carbon revenues.

Case 2- Regional co-operation: Analysis of regional cooperation among the SAARC countries (Nair et. al, 2003; Shukla and Nair, 2003), shows significant direct, indirect and spillover benefits via economic efficiency, energy security, water security and environment. The economic value of these benefits, over the 20 year period 2010-30, would be US\$319 billion, nearly 1 percent of the region's GDP for the entire period. These would increase the economic growth for the entire region by 1% each year, sustained over the 20-year period, benefiting the region where largest number of world's poor resides. Besides the direct development benefits, South Asian regional cooperation would accrue significant climate and local air quality benefits. The cumulative carbon saving for the period 2010-30 would be 1.4 billion tons of carbon (or 5.1 billion tons of CO_2. The energy changes would also reduce loads of SO_2 in the region by nearly 2.5 million tons of SO_2 emissions each year, a 30% decline. In addition, balanced hydro development would yield spillover benefits, prominent among which would be the enhanced water supply, flood control and rational water management.

Sathaye et al 2006 have mentioned some strategies that promote sustainable development with GHG emissions reduction. These measures include a) adopting cost-effective energy efficient technologies in electricity generation, transmission, distribution and end-use can reduce costs and local pollution, while also reducing GHG emissions; b) Shift to renewables can enhance sustainable energy supply, reduce local and GHG emissions; c) Adoption of forest conservation, reforestation, afforestation and sustainable forest management practices can contribute to conservation of biodiversity, watershed protection, rural employment generation, increased income to forest dwellers and carbon sink enhancement; d) Efficient, fast and reliable public transport systems such as metro railways can reduce urban congestion, local pollution and GHG emissions; e) Adoption of participatory approach to forest management, rural energy, irrigation water management and rural development in general can promote sustained development activities and ensure long-term GHG reduction or carbon sink enhancement and f) Rational energy pricing based on long run marginal cost principle can level the playing field for renewables, increase the spread of energy efficient and renewable energy technologies and the economic viability of utility companies ultimately leading to GHG emission reduction.

While sustainable development has gained prominence, there is also a growing consensus on the need to promote mitigation measures that would generate developmental co-benefits. The GHG mitigation options also have significant implications, including co-benefits, which need to be estimated since they could play a crucial role in the decision-making process regarding the adoption of any mitigation strategy. A study by Shukla 2007 analyses the role of biomass energy in aligning development and climate policies. Biomass energy technologies are capable of providing a renewable, sustainable and cleaner energy source, while having potential multiple dividends like local employment, land restoration, soil conservation and afforestation which are vital to achieving national development targets and commitment to Millennium Development Goals (MDG). The long-term techno-economic analysis presented in the paper shows nearly a tenth of India's electricity could be economically supplied by biomass electricity technologies by the year 2035. The study shows the economic advantages that would accrue, to the household as well to national economy, if bio-energy policies and development policies such as for employment, water and land-use are synergized.

The study by Garg et al 2004a, which assesses the carbon capture and storage (CCS) potential in India, point out the co-benefits of this strategy. The use of CCS would not only enhance the recovery of coal-bed methane, but injecting the captured CO2 in dry and oh-the-verge-dry oil wells would enhance the oil recovery process.

A study by Bussolo and O'Connor (2001) estimates the synergies of reducing CO2 emissions growth, in terms of the ancillary benefits. The ancillary benefits are defined in terms of reduced mortality and morbidity due to reduced particulate concentrations and are juxtaposed against the welfare costs of CO2 abatement through a tax to arrive at the level of "no regrets" abatement. The study also incorporates regional detail that allows a more differentiated analysis of climate policy, further beyond a national level study. The benefits are estimated at 334 lives saved per million tonnes of carbon abated (or $58/ton of carbon emissions reduced in monetary terms). The study estimates that just for accruing ancillary benefits, CO2 emissions could be reduced by at least 17-18% over the baseline in the year 2010 without any net cost. The analysis also finds that abatement costs are relatively low and ancillary benefits high in North and East-Northeast.

2.7.2 CDM Potential

Studies have looked to estimate the CDM potential of the different mitigation options. Purohit et al 2006 have estimated that the annual CER of SPV pumps in India could be 50,000-1,00,000 by 2012 and 0.25-0.75 million by 2020. With respect to bagasse cogeneration Purohit et al 2007b has estimate the annual CER volume to be 20-26 mn by 2012. Based on the technical potential, the potential CERs from wind power generation is estimated to be 82.5 million t/CO2 equivalent annually (Parikh et al 2005). Results of some other studies are highlighted below in Table 9.

Table 9: CDM Potential

Study (Context)	Scenarios/technologies	CERs potential	Revenue generated (Other positive implications)
Shukla et al 2006a (Comprehensive report submitted to the MoEF on GHG emissions in India)	Power supply technologies	TCO2/MW/Year	Revenue per year (@5$/tCO2)
	Wind power	2000	10000
	Biomass power	5400	27000
	MSW[1] power	5400	27000
	Gas	3600	18000
	Coal (retrofit)[2]	400	2000
	Coal (Advanced)[3]	800	4000
Kishore et al 2004 (Paper studies the potential of biomass resources in India, focusing on the case for biomass based technologies under CDM)	Assumptions about the power plant e) Capacity- 500 KW f) Aux cons & Dist losses- 20% g) PLF- 75% h) Fuel price- Rs.900/t i) Sale price of elec- Rs.2.50/KWh j) Sale price of CERs- $5/tCO2 k) Each unit of biomass power displaces 1kg of CO2 Case I: Biomass based power project feeding into the grid Case II: Biomass based power project for off-grid applications	Case I: 2600/annum Case II:1120/annum[4]	IRRs (without CDM)- 15% IRR (with CER proceeds) Case I: 18% Case II: 16%

[1]Municipal solid waste;
[2]5% efficiency improvement over base coal technology (Base case coal plant operating for 6000 hours/year emits 1800 tons of C);

[3] 10% efficiency improvements over base coal technology (Base case coal plant operating for 6000 hours/year emits 1800 tons of C)
[4]This is because unlike in Case I, where the biomass power replaces existing or proposed grid that would have coal-based electricity, in Case II, since the village is not electrified, it is assumed that the biomass power would replace kerosene for lighting and diesel for water pumping.

Table 10: CO_2 reduction from existing CDM projects (as of August 2003)

Project name	Project description	Total GHG reduction (tCO2 eq)*
Biomass based (bagasse)# cogeneration power plant, Karnataka	Biomass cogeneration in sugar mill; 26 MW	696,167
Suzzlon Wind Project	Wind 15 1-MW turbines; 15 MW	360,000
Tamil Nadu Wind Project	Wind; 170.85 MW Turbines; 14.45 MW	308,030
Enercon Wind Farm		2,000,000
Tamil Nadu Biomass Project	Biomass; 18MW	800,000
Biomass project, Maharashtra	Biomass, agricultural wastage power plant; 7.5MW	378,000
Kalpataru Biomass Project, Rajasthan	Three biomass plants, on mustard crop residues; 20 MW	1,150,000
OSIL waste heat power project	10 MW waste heat recovery	314.404

Source: Parikh and Parikh 2004

The total CERs generated add up to 5.41 million tonnes of CO_2 equivalent. Since these CERs are calculated over the lifetime of the plants (i.e., ten years) the reduction in GHG emissions is only 0.06 % of India's emissions. The total value of the CER credits at US$3 per tonne of CO_2 is $16.23 million dollars over the lifetimes of the projects.

2.7.3 Other implications

The consequences of alternate CO2 emission reduction strategies on economic development have been analyzed in a paper by Murthy et al 2006. Two scenarios are considered: Scenario I: Cumulative reduction scenario (1990-2025)- with 10% reduction (C10), 20% reduction (C20) and 30% reduction (C30); Scenario II: Annualized reduction scenario- with 10% reduction (A10), 20% reduction (A20) and 30% reduction (A30). The implications of this study are a) GDP and per capita consumption fall relatively less in Sc. I as compared to Sc. II- For instance, in C30 it is 4.06 % compared to BAU vis-à-vis 10% loss in the A30 case; b) A dynamically optimum approach would reduce burden. The study also provides a quantitative assessment of the foreign capital required to offset the welfare loss- a) In Scenario I, the capital flow is around $145 bn. during the whole period, b) In Scenario II, the magnitude of cash flows increase by three-fold to $278 billion, c) In Scenario II, the capital flows required in the initial years is very high (about 70% of GDP) and thus infeasible and d) The minimum value for any CDM project should be $14/tC

2.8 Options for mitigation of CH_4 and N_2O

Garg et al 2004b study the mitigation opportunities for CH_4 and N_2O emissions under different scenarios (Table 11 and 12).

Table 11: Technology share profile for CH_4 mitigation in India (in fraction)

Sector	Technology	Type	2010		2020		2030	
			Medium	**Strong**	**Medium**	**Strong**	**Medium**	**Strong**
MSW	CH4 recovery	Existing	0.004	0.01	0.02	0.06	0.07	0.13
		Innovative	0	0.002	0.03	0.05	0.08	0.18
	Waste to electricity	Existing	0.001	0.003	0.02	0.05	0.06	0.11
		Innovative	0	0.001	0.01	0.03	0.06	0.12
	Waste reduction to organic fertilizer	Existing	0.02	0.05	0.11	0.17	0.18	0.26
		Innovative	0	0.02	0.05	0.14	0.08	0.23
	Waste segregation for material reuse and recycle	Existing	0.01	0.02	0.06	0.14	0.12	0.25
CBM recovery	Degasification and pipe injection	Existing	0.005	0.02	0.06	0.10	0.15	0.18
	Catalytic oxidation	Innovative	0	0.01	0.02	0.07	0.08	0.14
Enteric fermentation	Improved digesters for animals	Existing	0.005	0.01	0.02	0.04	0.05	0.10
		Innovative	0	0.004	0.03	0.05	0.06	0.14

Note: Medium and strong mitigation scenarios envisage 5% and 10% cumulative emission mitigation, respectively, over the reference scenario for the period 2000–2030.

Table 12: Technology Shares for N_2O mitigation in India (in fraction)

Sector	Technology	Type	2010		2020		2030	
			Medium	**Strong**	**Medium**	**Strong**	**Medium**	**Strong**
Synthetic fertilizer use	CAN fertilizer in crops with aerobic conditions	Existing	0.02	0.05	0.08	0.14	0.2	0.25
		Innovative	0	0.02	0.03	0.09	0.1	0.2
	Ammonium fertilizer in wetcrops	Existing	0.01	0.02	0.07	0.15	0.15	0.26
		Innovative	0.01	0.02	0.06	0.09	0.12	0.2
Soil emissions	Use of nitrification inhibitors	Existing	0.01	0.05	0.09	0.17	0.18	0.25
		Innovative	0.01	0.02	0.07	0.09	0.12	0.18
HNO3 production	NSCR use	Existing	0.01	0.03	0.13	0.19	0.23	0.28
		Innovative	0	0.02	0.08	0.11	0.18	0.27

Note: Medium and strong mitigation scenarios envisage 5% and 10% cumulative emission mitigation, respectively, over the reference scenario for the period 2000–2030.
CAN: Calcium Ammonium Nitrate; NSCR: Non-selective catalytic reduction

Shukla et al 2006 have analyzed the mitigation potential of CH_4 and N_2O emissions assuming a 750 ppmv post-Kyoto regime (Table 13).

Table 13: CH4 and N20 mitigation options, potential and costs

Greenhouse gas	Mitigation options	Mitigation potential (2002-2012) (MT)[1]	Long-term marginal cost ($/ton of carbon equivalent)[1]
CH4	Enhanced cattle feed	0.66*	$5-30**
	Anaerobic manure digesters	0.38*	$3-10**
	Low methane rice varieties [2]	Marginal**	$5-20
	Cultivar practices[2]	Marginal**	$0-20
N2O	Improved fertilizer application[2]	Marginal**	$0-20
	Nitrification inhibitors[2]	Marginal**	$20-40

1.All numbers, except when explained otherwise, are based on modeling exercises reported in Rana and Shukla 2001, Ghosh et al 2001 and Garg and Shukla 2002
2. These options have considerable potential in the long run, but in the short time frame of the Kyoto Protocol, these can be harnessed only marginally. These programs need grassroots implementation, which is slow, as compared to focused projects that are quick to implement such as the energy projects. The preparation to harness the program based options, such as awareness and capacity building at grassroots levels, is vital to realize their potential in the post-Kyoto period.
* Estimates are based on ALGAS 1998; ** Estimated based on discussion with Indian experts

2.9 Barriers and Operational Strategies related to mitigation options

While studies have established the GHG mitigation potential in the Indian context, but there are several barriers that exist in the formulation, implementation and widespread dissemination of these mitigation strategies (Table 14). Some of these barriers are specific to a particular strategy, but there are constraints including capital requirements, lack of government support, technical barriers etc that are common to most of the mitigation strategies.

Table 14: Barriers and operational Strategies related to mitigation options

Study (Context)	Barriers	Operational strategies
Purohit et al 2007a (Techno-economic evaluation of biogas based water pumping system in India)	Related to biogas based power • Unavailability of sufficient feedstock to regularly operate even the lowest size biogas plant • Biogas based water pumping systems are financially less feasible, though they rank high on economic performance parameters (tangible/ intangible benefits)	• Explore opportunities for community sized biogas plants for end uses like cooking, water pumping, lighting • Large scale dissemination would also address the financial constraints • State support is crucial in the initial phase of dissemination
Purohit et al 2007b (Assesses the CDM potential of bagasse cogeneration in India)	Related to bagasse cogeneration Large scale dissemination is hindered by • High upfront costs prevents • Technical barrier • Financial drawbacks • Poor institutional framework • Short-sighted electric utility policies, and maybe • Low environmental concern	
Purohit et al 2006 (Assesses the CDM potential of SPV pumps in India	Related to SPV pumps • High capital costs prevents large scale dissemination; • Socio-environmental costs are not internalized; thus consumers do not face real costs for conventional pumps	• Strong government support, in the form of subsidies, might help in overcoming barriers to some extent • CDM could be a n important tool to facilitate dissemination
Raghuvanshi et al 2006 (Estimates CO_2 emissions from coal combustion in power plants)	Related to power sector RETs • Site specific resource variability • Load uncertainty, • System selection/sizing • Incomplete assessment of options. • Need for system analysis/load forecasting and software/modeling	

Kishore et al 2004 (Studies the potential of biomass resources in India)	Related to biomass use • Carbon abatement costs of biomass based technologies is low, but they are not technologically mature • Difficulties in collection and processing of biomass • Low-end use efficiency of conventional devices using biomass based fuels	• Need to emphasize on a basket of energy technologies in the govt. programs, rather than a single technology to deliver energy services • Presently biomass is harvested unsustainably; efficient utilization of biomass will enhance the sink facility of forests
Shukla et al 2002 (Assesses the impact of energy system responses to global carbon market signals on power sector RETs)	Related to RETs for power sector • High investment required • Lack of R&D focus has impeded a reduction in the technology costs. • Non-internalization of socio-environmental externalities in energy pricing reduces competitiveness • Risk perceptions of private investors • Low reliability of the devices, lack of remunerative tariffs for RET-generated electricity, and a lack of consumer-desired features	• Promoting decentralized use through incorporating renewable energy strategy into development programs. • Increase in private participation and industry collaboration in R&D • International cooperation in R&D and technology transfer mechanisms • Improved reliability of technologies and introduction of consumer-desired features • Promoting economic instruments such as Green Pricing Schemes for renewable electricity with tradable renewable energy certificates • Enhancing competitiveness by internalizing socio-environment externalities in energy service pricing
WB 1997	Technical barriers include Super-cr PC: Fuel flexibility, gas clean-up, efficiency and build-up time AFBC: Scale, efficiency an ash disposal PFBC: Scale, efficiency, ash disposal, N_2O emissions, higher gas inlet temperatures and gas turbine performance IGCC: Availability, flexible operation and scale	Development needs include Super –Cr PC a) High temperature corrosion resistant material b) Furnace and final superheat tubing materials c) More modular construction AFBC a) Increase in furnace size b) Introduction of supercritical steam conditions c) Identification of clean-up options for flue gas PFBC a) Increase in furnace size b) Introduction of supercritical steam conditions c) Identification of clean-up options for flue gas d) Topping systems/advanced PFBC IGCC a) Increase in gasifier maintenance intervals b) Better performance of gas turbines c) Simplified design d) Reduction of time between shut-down and back-on-load e) Utilization of smaller gas turbines

2.10 Uncertainty levels

The discussion on uncertainty regarding GHG emissions primarily focus on methodology, estimates, emissions coefficients etc.

Related to methodology

A study by Kumar et al 2004 showed that methane emissions from landfills calculated by the default IPCC methodology were higher than an alternate method, namely the triangular method. The national level methane emission from solid waste disposal sites using the default methodology varies from 263.02 Gg in year 1980 to 502.46Gg in year 1999 and the methane emissions using triangular pattern of gas generation indicates that the methane emissions vary between 119.01Gg in 1980 and 400.66 Gg in 1999. One major reason for this was that the IPCC methodology assumes that all potential methane is released in the year that the waste is disposed off. The triangular method provides a time-dependent emission profile that reflects the true pattern of the degradation process over time.

Related to emission factors

A study by Garg and Shukla 2002b shows that uncertainty levels related to CO_2 emissions from fuel combustion could be around 10%, while for N_2O it could range from 30-70%. Similarly the uncertainty levels in CH_4 estimation from coal mining and biomass could be around 30% and 35% respectively. Methods to reduce uncertainty include further research for quantifying emissions transport sector, measurement of carbon content of various coal types and their oxidation rates, statistical analysis, measuring indigenous emission coefficients etc.

Related to particular statistical value

The study by Bussolo and O'Connor 2001 highlights the uncertainties related to the estimations. For instance, while calculating the ancillary benefits, the value of statistical life chosen becomes important. Different studies place different values to this parameter. Taking these into consideration, the study does a sensitivity analysis which shows that a 12-13 per cent abatement rate in 2010 would seem to be a safe target for a risk-averse Indian climate policy maker — safe in the sense that, up to that rate, ancillary benefits would most probably exceed economic costs.

3. Key Conclusions

3.1 Aligning development, clean energy and climate policies

- Millennium Development Goals

The UN Millennium Development Goals include an undertaking to 'integrate the principles of sustainable development into country policies and programs and reverse the loss of environmental resources' Many actions for climate adaptation and mitigation that can be integrated with and incremental to projects that already are occurring for developmental reasons should be designed as incremental or adjunct to projects that are justified for economic development purposes. Climate-friendly development pathways and national sustainable development goals, like conservation of resources and human capacity enhancements, are complementary. In fact, cascading effects of development along a sustainable pathway could reduce emissions and also moderate the costs of adverse impacts of climate change. And progress toward basic development goals, such as poverty reduction and elimination of hunger would enhance adaptive capacity of poor due to improved food security, health security and enhance their resilience to cope with risks from uncertain and extreme events.

- Conjoint policies

Policymakers have focused on measures for local air quality management. These measures could have significant impacts on GHG emissions too if conscious decision is taken to align the policies. For instance, several policy initiatives have been taken in the transport sector such as investments in enhanced road quality, metro railway in large cities, and conversion of fleet of public vehicles to CNG in Delhi. While these measures have achieved significant reductions in SO_2, NO_x, and particulate emissions, but they would have also co-benefits in terms of GHG emission reduction and at lower costs than policies solely for GHG emissions mitigation.

GHG emission reductions have also been a side impact to general energy policies in India including energy conservation and efficiency programs, advanced coal technology, incentives for renewable energy technologies, and to investment in water conservation practices, resource recycling and afforestation and land restoration. India's national communication to the UNFCCC mentions the climate-friendly contribution of legal, institutional and financial reforms like the enactment of Energy Conservation Act, 2001 and Electricity Act 2003; establishment of regulatory authorities; rationalization of tariffs and reductions of subsidies to fossil energy and electricity (INC, 2004). Therefore, a good opportunity exists to align development, local air quality management and climate change policies that would not only reduce costs but also achieve multiple dividends.

- South-South Co-operation

Regional co-operation is a key principle for addressing the issues of aligning policies. It has high potential to sustain economic growth through rational deployment of region's human and natural resources. The South Asian region comprising of Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka holds quarter of the global population. The countries have diverse energy resource endowments - coal in India, gas in Bangladesh, hydro potential in Himalayan nations of Bhutan and Nepal and strategic location of Pakistan for the transit routes linking South-Asia with the vast gas and oil resources of Central Asia and the Middle East. Maldives and Sri Lanka, as small island nations face energy security and scale economy concerns. The cooperation initiatives, like South Asia Free Trade Agreement (SAFTA) could deliver substantial direct, indirect and spill-over benefits via economic efficiency, energy security, water security and environment. Efficient energy trade in South-Asia would thus yield direct economic benefits due to energy efficiency gains resulting from improved fuel and technology choices.

- Financing

There are a variety of national and international financial mechanisms that could be deployed to help shift development pathways toward more sustainable climate solutions. In many cases, the adoption of non-climate policies with ancillary climate benefits would create a context in which the commercial development of lower GHG emitting systems could be financed through regular private investment channels. In other cases, there may be a need for one-time incremental resources from public or private sources outside the developing economy to provide start-up costs, defray initial risks, or install know-how that would lead, once embedded, to a commercially sustainable economic activity or sector. In still further cases, the changing national or local demands for new quality goods and services, along with the enhanced domestic capacity to finance it, may combine with ongoing external transfers to compensate for incremental value of the global public good component.

- Institutional

The process of aligning development, clean energy and sustainable development policy requires coordinated efforts from related Ministries and departments. Currently, there is a lack of multi-level and multi-sectoral co-ordination among the concerned ministries, which not only creates high transaction costs, but also prevents implementation of conjoint policies that would optimize costs, thereby creating high transaction costs for the society. Each ministry and department looks at the problem in an independent manner and gives its own recommendations, and rarely is there any feasibility study that looks at the issue in its entirety. Therefore, there is need for a co-coordinating mechanism to cover the institutional constraints in policy formulation and implementation.

3.2 GHG mitigation opportunities and barriers

The key conclusions that can be drawn from the survey of literature are as follows:

- Targeting the large point sources (LPS) offers focused opportunities for CO_2 emission mitigation. The major LPS include power plants, iron & steel plants and cement plants.

- The mitigation potential in the power and cement sector is as follows::
    - o Studies on the power sector show the potential of switching fuels (from coal to gas), use of clean coal technologies (CCTs) and renewable energy technologies (RETs). In power generation. While CCTs and RETs have considerable potential in terms of carbon mitigation, there are barriers, especially in terms of their cost effectiveness vis-à-vis other options. With respect to RETs, biomass has high mitigation potential

    - o Studies on the cement sector call for improving energy efficiencies in production and reducing use of energy-intensive materials

- Controlling CH_4 and N_2O from agriculture poses a high implementation challenge due to the dispersed nature of the activities; yet at the same time, measures such as improved farming practices, more efficient utilization of synthetic fertilizers could promote sustainable practices

- The costs of mitigation options vary substantially depending on the assumptions of the mitigation scenarios and the nature of the CDM opportunities. Some of the major conclusions that can be drawn from the studies are as follows:
    - o With respect to RETs and CCTs, there is need for further R&D efforts to reduce the technology costs. Besides, the issue of energy pricing has to be addressed to enhance their competitiveness
    - o The role of global cooperative mechanisms and the domestic government would influence the costs and choice of mitigation options
    - o Studies are also questioning the assertion that carbon mitigation costs in developing countries are lower than in developed countries, since new technology costs in a nascent market are often higher in these countries. This implies that to the extent project-based activities, e.g., under CDM, rely on new technologies to reduce carbon emissions, their incremental costs may be higher in developing countries.

- The barriers to penetration of several mitigation options are primarily the high capital costs, the technology is immature and sufficient government support is not forthcoming in terms of energy pricing, providing finance, favorable policies etc.

4. Summary and critique of literature

Table 15 presents a critique of the existing literature on GHG mitigation options.

Table 15: Summary and critique of literature

Focus	Issues addressed	Literature and research gaps
Indian GHG emissions calculations	Estimating national emissions inventory	• Regional and sectoral emission inventory estimates; • Assessment of India specific emission coefficients
Indian GHG emissions mitigation potential	• Research on mitigation options • Research on global cooperative mechanism to reduce GHG emissions	• Integration of local and global environmental mitigation strategies in the context of the present thrust on controlling local air pollution • Assessment of GHG mitigation potential of developmental policies • Not many studies doing a detailed analysis of GHG mitigation potential from different sectors
Economics of GHG mitigation	Literature focusing on costs of carbon mitigation	• Detailed cost-benefit analysis of GHG emissions mitigation options
Co-benefits of GHG emissions mitigation	Implications of carbon mitigation on national parameters including growth, welfare etc	• Detailed studies of incremental impacts of GHG mitigation • Estimating benefits in terms of local impacts
Barriers	• Substantial work on barriers related to RETs • CDM potential in overcoming financial barriers	• Institutional coordination requirements over short, medium and long terms • Implementation mechanisms that ensure sustained financial government support

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Development Benefits of Clean Energy in India

Biomass for Energy; Resource Assessment in India

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Executive summary

Biomass energy accounts for nearly a quarter of total primary energy consumption in India and further it accounts for over 70% of rural energy consumption pattern. Biomass resources for energy consist of fuelwood, crop residue, vegetable oil and cattle dung. Biomass use as energy is characterized by low efficiency of use, use for low quality energy applications such as cooking, shortages and environmental degradation. However, modern bioenergy technologies, such as biomass combustion and gasification for power, biodiesel and ethanol as liquid fuels and biogas as gaseous fuel for cooking, provide opportunities for meeting energy needs, improving the quality of life and protecting the environment, including addressing climate change. The critical issue in realizing the technical and economic potential of bioenergy is the sustainable supply of biomass feedstock; woody biomass, leaf biomass, vegetable oil seeds and cattle dung. In this report biomass resource supply issues are addressed focusing on the current supply of biomass fuels, potential for sustainable supply of biomass for energy, the barriers to realizing the full potential of bioenergy, along with listing of the co-benefits, such as local socio-economic and local and global environmental benefits.

Current Biomass Energy consumption: There are limited recent estimates and the values vary according to studies. Among the biomass fuels, fuelwood is the dominant fuel and its consumption is estimated to be in the range of 162 to 298 million tonnes (Mt) followed by 67 to 156 Mt of crop residue and 64 to 114 Mt of cattle dung. Rural household cooking is the dominant end use of fuelwood accounting for 84% of the total and industrial and establishments accounting for 5%, and the rest by urban households.

Renewable and Non-renewable S***ources of Fuelwood***: Supply of crop residue and cattle dung is sustainable since they are by-products. Sources of supply of fuelwood and the extent of renewable supply are less understood and contentious. According to National Forestry Action Programme and Forest Survey of India, sustainable supply of fuelwood from forests is only about 8% and private plantations and trees account for the dominant share of almost 50% and project a deficit of 86 million tonnes, which is assumed to come from non-sustainable extraction from forests leading to forest degradation. According to another detailed estimate, non-sustainable supply from felling of trees in forests accounted only for 19 million tonnes. The rest of woody biomass came from lopping of trees and fallen twigs from forests (51 Mt), tree plantations (40 Mt) and trees outside forests and plantations (108 Mt). Thus a dominant part of woody biomass fuel consumed is likely to come form sustainable sources, particularly from out side the forests.

Area Under Forests and Changes in Area: Area under forests in India is estimated to be around 64 Mha (million hectares) and area under forest cover (including trees outside the forests) is estimated to be 77 Mha (23.5% of geographic area), which included short rotation plantations, homestead gardens and agro-forestry systems. According to Forest Survey of India estimates, based on periodic monitoring using remote sensing techniques, the area under

forests has not only stabilized but has increased in the recent years. However, it is not clear how much of the area under forest cover estimated (77 Mha) consists of natural forests and afforested plantation areas on degraded forest and private lands, since India has implemented a large afforestation programme.

Afforestation Programme: India has implemented one of the largest afforestation programmes in the world, since 1980 when social forestry programme was launched. During the period 1980 to 2005 about 34 Mha have been afforested at an annual rate of 1.32 Mha. This included community woodlots, farm forestry, avenue plantations, agro-forestry, apart from forest plantations. The afforestation programme is largely dominated by plantations of Eucalyptus, Acacia, Casuarina, Teak, etc, largely commercial species, aimed at meeting fuelwood, industrial wood and timber requirements.

Carbon Stocks in Indian Forests and CO_2 Emissions: National studies conducted over the years showed that the total stock of carbon in forests is 8.5 to 9.5 GtC (giga tonnes of carbon) and according to the latest estimate made by FAO, it is 10 GtC. The carbon stocks in Indian forests do not seem to have declined significantly. The CO_2 emissions and removal estimates made using the IPCC Guidelines for the year 1994 showed that the emissions were nearly offset by removals. Thus the carbon stock in Indian forests has nearly stabilized or increasing due declining deforestation rates and large-scale afforestation.

Land Available for Biomass Feedstock Production. India has a large human and livestock population density and a large percentage of population depends on land-based activities such as agriculture and animal husbandry. Rural communities also depend on forests and non-forest lands for fuelwood for cooking and for livestock grazing. According to Remote Sensing technology based assessments of wastelands (or degraded lands) by NRSA (National Remote Sensing Agency) and considering only potential land categories suitable for plantation forestry, an area of 41 to 55 Mha is estimated to be available for biomass production for energy. Another study estimated that about 12 Mha is adequate to meet the incremental fuelwood, industrial wood and timber requirement projected for the year 2015 over the consumption level during 1995. Thus even after excluding the land required for traditional fuelwood, industrial wood and timber production, an additional area of 24 Mha is available for energy plantations. Other estimates vary from 41 Mha to 130 Mha. In addition marginal cropland and long-term fallow lands are available for plantation forestry for energy.

Sustainable Biomass Production Potential for Energy: Considering a conservative area of 34.6 Mha of dedicated energy plantations and a woody biomass productivity of 6.6 to 12 tonnes/ha/year, total woody biomass production potential is estimated to be 228 to 415 Mt annually. The total power generation potential at 1 MWh/tonne of woody biomass is 228 to 415 TWh. This accounts for 36 to 66% of the total power generated during 2005 in India. Thus the biomass power has a large potential to meet the energy needs sustainably. According to another study the lifecycle cost of power generation form biomass combustion and gasification is economically attractive compared to large coal-based power generation.

Biomass production potential for biomass power generation

Land category	Area in Mha	Biomass productivity t/ha/year	Total biomass production for energy (Mt/year)
Short rotation energy plantation[a]	34.6	6.6 (without genetic improvement and fertilisers)	228
		12 (with genetic improvement and fertilizer)	415
Short rotation energy plantation[b]	24.0	6.6 (without genetic improvement and fertilisers)	158
		12 (with genetic improvement and fertilizer)	288

Notes: [a] Assuming no increase in area under crops (compared to 1995)
[b] Assuming 10 Mha increase in area under crops

Barriers to Sustained Biomass Supply: It was shown earlier that land is available for biomass production for power generation. However, technical, financial and policy barriers limit the large-scale production of biomass for power generation. Some of the barriers are as follows:

- Tenurial uncertainty for wastelands, particularly public or government lands, for private companies or power utilities, which cannot get access to government and community lands for producing commercial biomass.
- Absence of policy or regulatory provisions for long-term contract between farmers and biomass power utilities for sustained biomass supply from farm lands.
- Lack of access to easy credit, financial incentives and guaranteed price for biomass feedstock to farmers. Such incentives are available for biomass power utilities and not for biomass producers.
- Absence of package of practices for high biomass yields in different agro-climatic zones.
- Non-availability of large tracts of contiguous land limits the scale of the biomass power system largely to small-scale systems and high cost of transport for large-scale systems.

Modern Biomass Energy Options and Potential: Modern bioenergy technologies provide a large potential to meet energy needs in a sustainable way. The technologies include; biomass combustion and gasification for power generation, liquid fuels (Biodiesel and Ethanol) and gaseous fuel (biogas). The dominant biomass based energy option is for power generation using woody biomass, largely from dedicated energy plantations. Thus the potential land available for woody biomass feedstock production and sustainable biomass production and biomass power generation potential is assessed. The liquid and gaseous fuels are briefly discussed.

Spread of Biomass Power in India: India has a large renewable energy promotion programme with several financial and policy incentives. According to the latest report of Ministry of New and Renewable Energy Sources, the total installed capacity of biomass combustion and gasification is 738 MW compared to a potential of over 20,000 MW. Thus despite the large potential for biomass power and incentives from the Government of India, the rate of spread of biomass power technology is low. This is due to several barriers, including non-availability of sustained biomass feedstock supply.

Biomass for Ethanol and Biodiesel Production: Ethanol production requires use of good agricultural lands for growing sugarcane and maize, which may not be feasible in India given the demand for land for producing food grains. Biodiesel production from perennials crops such as *Jatropha, Pongamia pinnata* and other tree species is also currently being explored in India.

Co-benefits of biomass production for energy: **Biomass production for power and similarly for liquid fuels in degraded or marginal lands has the following co-benefits:**

- Reclamation of degraded lands, which are subjected soil erosion and degradation due absence of vegetation cover.
- Carbon sequestration in degraded lands in standing vegetation and soil.
- Local employment and income generation from biomass production practices, harvesting, transportation and processing.
- Promotion of biodiversity, if adequate sustainable production practices, such as a mix-of species and leaving a fraction of land fallow for natural forest succession, are adopted.

Sustained biomass production for power generation has several local and global co-benefits apart from supplying biomass feedstock for power generation for meeting the growing demand for power in India sustainably.

Policy options to promote sustainable biomass production for energy: Sustainable biomass supply is a critical barrier to bioenergy technologies. Some of the potential policy, financial and institutional options are as follows:

- Legal and institutional support for long-term supply arrangements between farmers and bioenergy utilities along with assured price for biomass feedstock production
- Development of package of practices for high and sustained yields for different agro-climatic and soil conditions especially for short-rotation plantations
- Access to credit for biomass feedstock producers, though in principle a few programmes are available, but in reality credit is not easily accessible to the farmers
- Development of biomass feedstock markets to promote easy access to surplus biomass from different locations
- Removal of regulations on biomass feedstock transportation
- Development of software to assess the land requirements and linking biomass production capacity with bioenergy utility capacity

Biomass for Energy; Resource Assessment in India

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1. Introduction

Biomass energy accounts for nearly a quarter of total primary energy consumption in India and further it accounts for over 70% of rural energy consumption pattern (Ravindranath and Hall, 1995 and Ravindranath et al, 2000). Biomass consists of fuelwood, crop residue and cattle dung. Traditional biomass use as energy is characterized by low efficiency of use, shortages and environmental degradation. However, modern bioenergy technologies such as biomass combustion and gasification for power, biodiesel and ethanol as liquid fuels and biogas as gaseous fuel for cooking provide opportunities for meeting energy needs sustainably, improving quality of life and protecting environment, including addressing climate change. The critical issue in realizing the technical and economic potential of bioenergy is the sustainable supply of biomass feedstock; woody biomass, crop residues, leaf biomass, vegetable oil seeds, and cattle dung. In this report, biomass resource supply issues are addressed focusing on the current supply of biomass fuels, potential for sustainable supply of biomass for energy, the barriers to realizing the full potential of bioenergy and policies to over come the barriers, along with listing of the co-benefits, such as local socio-economic, and local and global environmental benefits.

2. Biomass Consumption

2.1 Biomass Fuel Consumption According to Types of Biomass Fuels: There are limited recent estimates of biomass fuel consumption and the estimates are varied (Table 1). Among the biomass fuels, fuelwood is the dominant fuel and its consumption is estimated to be in the range of 162 to 298 million tonnes (Mt) followed by 37 to 156 Mt of crop residue and 64 to 114 Mt of cattle dung over the recent years.

Table 1 Fuelwood, crop residue and cattle dung consumption (Mt)

Year	Fuel wood	Crop Residue	Dung	Reference
1978-79	94	37	83	NCAER, 1981
1995	298	156	114	Ravindranath & Hall, 1995
1996	214	67	64	Sarma et al, 1998
1996	162			Planning commission, 1999
2010	381	132	98	Sarma et al, 1998

2.2. End Uses of Fuelwood: Biomass fuels, particularly fuelwood dominates rural energy use (Ravindranath et al, 2000). Rural household cooking is the dominant end use of fuelwood accounting for 84% of the total consumption, followed by industrial establishments accounting for 5%, and the rest by urban households (Table 2).

Table 2 End uses of biomass (Mt)

Year	Household	Bricks	Cottage industries	Industrial establishments, Rituals, hotels	Reference
1995	252 (rural) + 30 (urban)	6		10	Ravindranath and Hall, 1995
1996	162	NA	25	14	FSI, 1996
2000	180	NA	NA	40	CSE, 2000

3. Renewable and Non-renewable Sources of Fuelwood and Crop Residue

3.1 Sources of Fuelwood: Source of fuelwood is a very controversial issue, especially the contribution of forest source and its impact on forest degradation and deforestation. Fuelwood is obtained from multiple sources namely, forests, tree plantations, trees on common lands, farm trees, avenue trees, and homestead gardens. Further, fuelwood is obtained by felling whole trees or by cutting branches non-sustainably or sustainably without damaging the trees by gathering fallen branches and twigs. Sources of fuelwood are given in Table 3. Forests account for 31% (Ravindranath and Hall, 1995) and 40% (NFAP, 1999) of the fuelwood and the rest comes from non-forest sources. According to NFAP (1999), sustainable supply of fuelwood from forests is only about 8% (or 14 Mt) and private plantations and trees account for the dominant share of almost 50%. A deficit of 86 million tonnes is projected, which is assumed to come from non-sustainable extraction from forests leading to forest degradation. According to another detailed estimate (Ravindranath and Hall, 1995) non-sustainable sources, from felling of trees in forests, accounted only for 19 million tonnes. The rest of woody biomass came from lopping of trees and fallen twigs from forests (51 Mt), tree plantations (40 Mt) and trees outside forests and plantations (108 Mt). Thus dominant part of fuelwood is estimated to come from sustainable sources, particularly from outside the forests.

Table 3 Sources of fuelwood (Mt)

Year	Source	Forest	Farm forestry, common land and other resources	Plantations
1995	Ravindranath& Hall, 1995	71	98	60
1996	FSI, 1996	103	21	77
1999	NFAP, 1999	70	23	79

Annual biomass production from forest area in different states is provided by FSI (2003), according to which total biomass production is 93 Mt or 1.2 t/ha/year (Table 4). It is not clear how much of this biomass production is extracted as fuelwood**.**

Table 4 Biomass growing stock and production of wood (2003)

	Forest area (sq km)	Growing stock (Million Cu. m)	Annual production (Mt)
Andhra Pradesh	63821	372.49	7
Arunachal Pradesh	51540	555.43	11
Assam	27018	251.57	5
Bihar	6473	20.46	0.4
Chhattisgarh	59772	245.44	5
Delhi	85	1.44	0.03
Goa	1224	5.10	0.1
Gujarat	19113	83.79	1.6
Haryana	1558	2.37	0.05
Himachal Pradesh	37033	339.42	6.5
Jammu & Kashmir	20230	246.85	5
Jharkhand	23605	96.93	2
Karnataka	43084	356.79	7
Kerala	11268	129.77	2.5
Madhya Pradesh	95221	216.99	4.2
Maharashtra	61939	216.65	4
Manipur	17418	111.07	2
Meghalaya	9496	73.61	1.4
Mizoram	16717	59.71	1.1
Nagaland	8629	55.02	1
Orissa	58136	291.36	6
Punjab	3084	11.08	0.2
Rajasthan	32488	31.96	0.6
Sikkim	5841	33.12	0.6
Tamil Nadu	22877	183.56	3.5
Tripura	6293	13.51	0.25
Uttar Pradesh	16826	164.27	3.2
Uttaranchal	34662	429.59	8.2
West Bengal	11879	126.07	2.4
A. & N.Islands	7171	51.61	1
Chandigarh	34	0.57	0.02
D. & N. Haveli	204	3.69	0.07
Total	774740	4781.29	92.923

Source: FSI (2003)

3.2 Sources and Quantity of Crop Residue: Crop residues can be classified as (i) primary residues (paddy straw, sugarcane top, maize stalks, coconut empty bunches and frond, palm tree frond, etc.) and, (ii) Secondary residues (paddy husk, bagasse, maize cob, coconut shell, coconut husk and coir dust). The residue production varies from crop to crop. Rice husk, a by-product of rice milling, accounts for 20% of paddy. Unlike the cereals whose residue is largely used as cattle feed, crops such as red gram, cotton, rapeseed, mustard, mulberry and plantation crops produce woody (ligneous) residues (Table 5).

The dominant end uses of crop residues in India are as fodder for cattle, followed by fuel for cooking and thatch material for housing. India has a large cattle population of 294 million and the estimated total quantity of residues utilized as fodder is 301 Mt in 1997 (Ravindranath et al, 2005).

Ligneous and hardy crop residues namely, rice (husk), maize (cobs) and stalks of red gram, cotton, mulberry, coconut fronds and shells are mainly used for fuel purpose. About 44 Mt of sugarcane bagasse is used as fuel in sugar mills, and in small-scale crude rural sugar producing units. Next to sugarcane bagasse, cotton plays a vital role as an energy source, contributing 50 Mt. Rice husk and straw together contribute 23 Mt as fuel. Apart from red gram, rape seed, mustard and other residue consumption values are given in Table 5.

Out of the total residue production of 407 Mt only 191 Mt was used as fuel during 1997. Apart from sugarcane bagasse and rice husk, other crop residues are used as fuel for cooking. Crop residue used as fuel for cooking was 142 Mt during 1997, which is close to the estimate of 156 Mt made by Ravindranath and Hall (1995).

Table 5 Crop residue production and use as energy

		1997			**2010**		
Crops	**Type of residue**	**Total residue production (Mt)**	**Quantity used as fuel (Mt)**	**Energy used as fuel PJ**	**Total residue production (Mt)**	**Quantity used as fuel (Mt)**	**Energy used as fuel PJ**
Rice	husk	27	5	65	36	6	78
Rice	straw	112	18	234	173	21	273
Red gram	Waste	14	13	176	11	9	126
Other pulses	Shell+Waste	17	9	112	17	8	117
Ground nut	Waste	21	4	56	28	4	56
Rape seed & mustard	Waste	14	14	182	24	24	312
Other oil seeds	Waste	18	18	247	27	27	364
Cotton	Seeds+ Waste	50	50	750	56	56	840
Sugar cane	Bagasse+Leaves	111	44	704	186	76	1216
Coconut, arecanut	Fronds	20	16	256	28	23	322
Total		407	191	2782	585	255	3704

Source: Ravindranath et al, 2005

3.3 Dung production and use as energy

India has the largest bovine population of 294 million as estimated in 1996-97 and is projected to increase to 321 million in 2010. Total dung production was estimated to be 669 Mt during 2003 (Table 6). Out of 669 Mt of total (fresh) dung production, 250 Mt was used as fuel, largely for cooking in 2003. India has a large biogas production programme for meeting the cooking energy needs. Total dung utilization for biogas was estimated to be 30 Mt in 2003 (Table 6). Thus, a large potential of dung for biogas production is yet to be utilized.

Table 6 Dung production and use as energy
(fresh weight in Mt/year)

	1997	**2003**	**2010**
Total dung production	659	669	730
Dung directly utilized as fuel	185	250	340
Dung utilized in biogas plants	22	30	99
Total use	207	280	439

Source: Ravindranath et al, 2005

4. Area under Forests and Changes in Area

The Forest Survey of India has been periodically estimating the forest cover in India since 1987 using remote sensing techniques. Area under forests in India (Table 7) is estimated to be around 67 Mha (million hectares) and area under forest cover (including trees outside the forests) is estimated to be 77 Mha, which included forests, plantations, homestead gardens and agro-forestry systems. However, it is not clear how much of the area under forest cover estimated (77 Mha) consists of natural forests and afforested plantation areas on degraded forest and private lands, since India has implemented a large afforestation programme.

According to the Forest Survey of India (FSI), "all lands, more than one hectare in area, with a tree canopy density of more than 10 percent is defined as Forest". The total forest cover of India according to the latest State of Forest Report 2003 is 67.82 Mha and this constitutes 20.64 percent of the geographic area. The distribution of area under very dense, dense and open forest is given in Table 7. Dense forest dominates by accounting for about half of the total forest cover. The tree cover (which includes forests of less than one hectare) is 9.99 Mha (3.04 percent). The total area under forest and tree cover is 77.82 Mha, which is 23.68 percent of the geographic area (Table 7).

Table 7 Status of forest cover in India (2003)

Tree crown class	**Area (Mha)**	**Percent geographic area**
Very dense forest (>70%)	5.13	1.56
Dense forest (40 to 70%)	33.93	10.32
Open forest (10 to 40%)	28.78	8.76
Mangroves	0.45	0.14
Total forest cover	**67.83**	**20.64**
Tree cover	9.99	3.04
TOTAL	**77.82**	**23.68**
Forest cover according to FAO	***67.7***	**-**

(Source: FSI, 2005 and FAO, 2005)

According to the Forest Survey of India estimates, the area under forests has not only stabilized but has increased in the recent years (Figure 1). The forest cover reported for the year 1987 was 64.08 Mha and according to the latest assessment for the year 2003, the forest cover is 67.83 Mha. This indicates an increase in forest cover of 3.75 Mha over a period of 15 years (Figure 1). It can be observed from Figure 1 that the forest cover in India has nearly stabilized and further it is increasing marginally over the years. In the recent estimates, FSI has included the tree cover, in addition to forest cover. The area under tree cover reported is also marginally increasing (Figure 1).

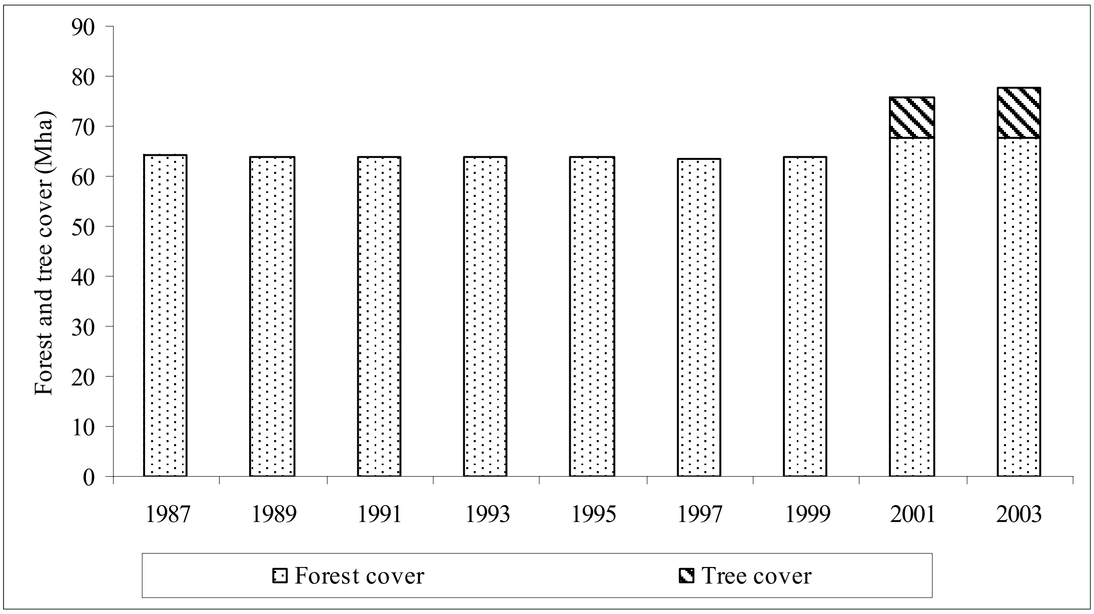

Figure 1: Trends in area under forest and tree cover
(Source: State of Forest Reports of FSI)

5. *Afforestation Programme*

India has implemented one of the largest afforestation programmes in the world, since 1980 when social forestry programme was launched. Figure 2 presents the progress of afforestation in India for the period 1951 to 2005. It can be seen from Figure 2 that the cumulative area afforested in India during the period 1980 to 2005 is about 34 Mha at an average annual rate of 1.32 Mha. This includes community woodlots, farm forestry on farm lands, avenue plantations and agro-forestry. The afforestation programme is largely dominated by plantations of Eucalyptus, Acacia, Casuarina, Teak, etc., largely commercial species, aimed at meeting the fuelwood, industrial wood and timber requirements. Afforestation and reforestation in India is being carried out under various programmes namely;

- Social forestry initiated in early 1980s
- Joint Forest Management Programme initiated in 1990
- Afforestation under National Afforestation and Eco-development Board (NAEB) programmes since 1992
- Private farmer and industry-initiated plantation forestry

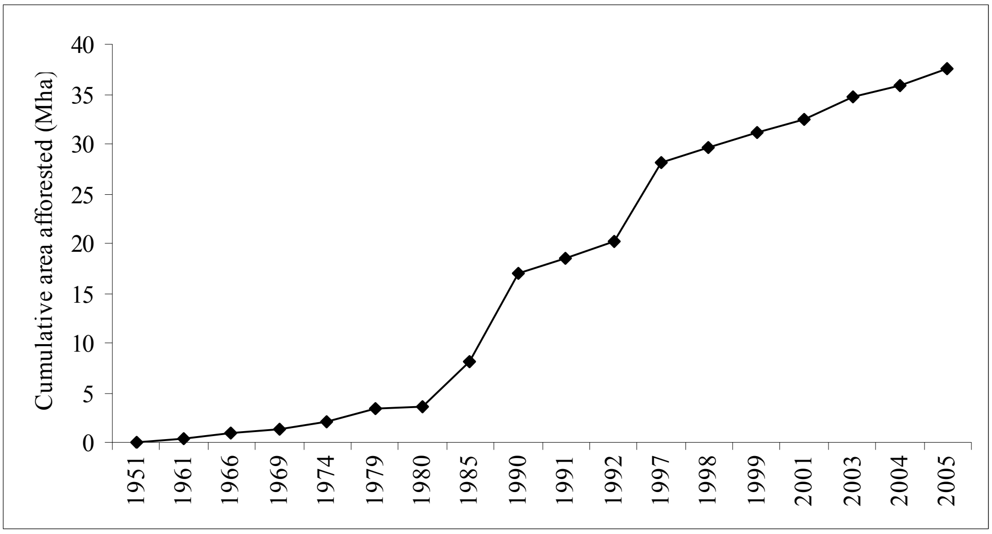

Figure 2: Cumulative area afforested during 1951 to 2005
(Source: http://www.envfor.nic.in/nfap/table-geographic-area.html)

The plantations raised under various afforestation programmes provide fuelwood, industrial wood, construction poles, and timber, though the actual quantities for different end uses are not available. Estimates provided earlier in Table 3, showed that about 60 to 79 Mt of fuelwood is obtained from tree plantations.

6. Carbon Stocks in Indian Forests

Carbon stocks in forests and plantations depend on growth, accumulation and loss due to extraction and disturbance. Estimates for the forest carbon stocks, including biomass and soil carbon from various studies is given in Figure 3. According to an earlier estimate the biomass carbon stock in Indian forests was 7940 MtC during 1880 and this study does not provide soil carbon estimates. Further estimates for 1980 showed that forest biomass carbon stock had declined by nearly half over a period of 100 years. Estimates of forest carbon stock including biomass and soil carbon for the year 1986 are in the range of 8.58 to 9.57 GtC. According to a latest estimate by FAO for 2005, total forest carbon stock is 10 GtC. Thus, the carbon stocks in Indian forests have not declined, and in fact seem to have increased, over a period of 20 years (1986 to 2005). Forest soil carbon accounts for over 50% of the total forest carbon stock. Thus the carbon stock in Indian forests have nearly stabilized or increasing due to decline in deforestation rates and large afforestation.

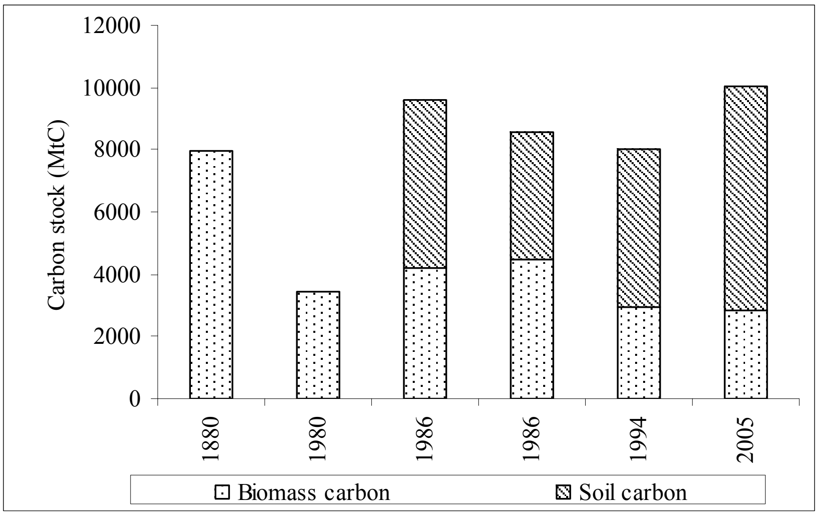

Figure 3: Trends in carbon stock estimates for Indian forests (compiled by Ravindranath, *et al.,* 2007)

7. Land Available for Biomass Feedstock (Energy Crop) Production

India has a large human and livestock population density and a large percentage of population depends on land-based activities such as agriculture and animal husbandry. Rural communities also depend on forests and non-forest lands for gathering fuelwood for cooking and livestock grazing. The population of India is growing at over 2%, annually, leading to increased demand for food grains, fibre, dairy products etc. Thus the area under crops is expected to increase. However, the area under crops seems to have stabilized for decades. Further, area under food grains has fluctuated between 126 Mha during 1980 to 124 Mha during 2004 (Figure 4). Thus area under food grains has not increased, despite increase in human population in the recent decades. When non-crop land categories with potential for biomass fuel production are considered, it can be observed from Figure 4, that the area under these categories has remained unchanged or changed only marginally.

Based on a recent Remote Sensing technology based assessment of wastelands (or degraded lands) by NRSA (National Remote Sensing Agency) and considering only potential land categories suitable for plantation forestry, an area of 41 Mha is estimated to be available for biomass production for energy (Table 8).

A study by Sudha *et al* (2003) estimated that about 12 Mha are adequate to meet the incremental demand (over the consumption during 1995) of fuelwood, industrial wood and timber requirement projected for the year 2010. Further, it assumed that the current needs (of 1995) would be met from existing sources. Thus even after excluding the land required for traditional fuelwood, industrial wood and timber production, an additional area of 29 Mha is available for energy plantations. Other estimates vary from 41 to 130 Mha (Table 8). In addition, marginal cropland and long-term fallow lands are available for plantation forestry for energy. Thus more than 50 Mha is likely to be available for dedicated production of energy crops.

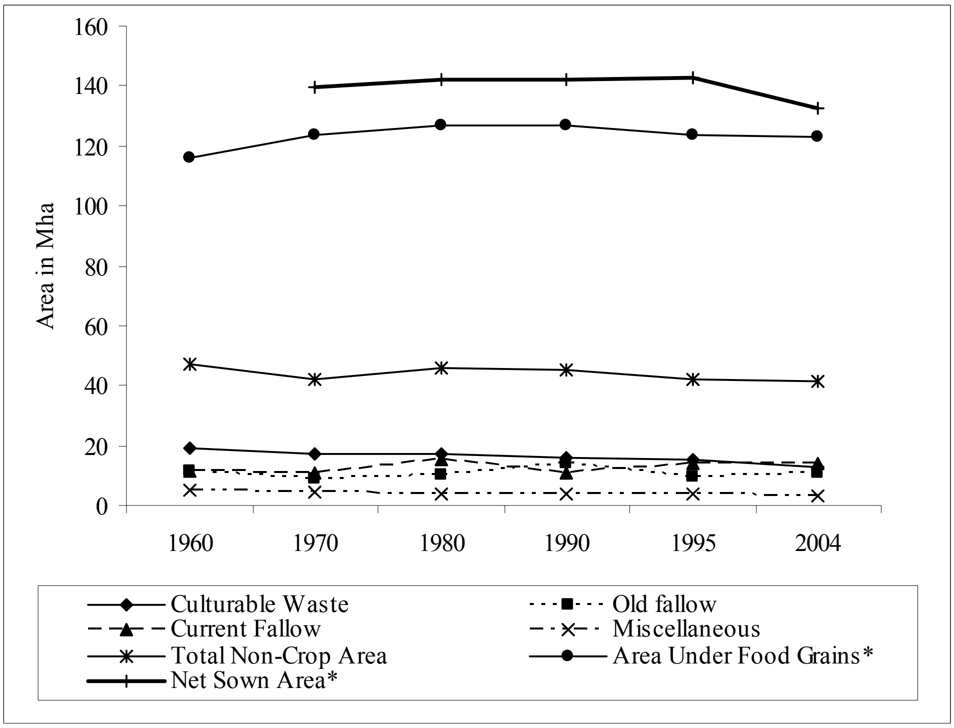

Figure 4. Trends in area under crops, food grains and wasteland (degraded land availability) in India

Table 8. Land available for biomass production for energy

Study	Land categories and land availability (Mha)	Total area (Mha)
Degraded land quoted in Planning Commission (1992)	Degraded forest—36, Degraded non-forest—94	130
Chambers et al. (1989) Land available for tree planting	Cultivated land—13, Strips and boundaries—2, Uncultivated, degraded land—33, Degraded forest land—36	84
Kapoor (1992) Land available for tree planting	Agricultural land—45, Forest land—28, Pasture land—7, Fallow land (long and short)—25, Urban land-1	106
Ministry of Agriculture (1992)	Forest land with < 10% tree crown cover—11, Grazing land—12, Tree groves—3, Culturable land—15, Old fallow—11, Current fallow—14	66
Sudha and Ravindranath (1999)	Cultivable land under agro-ecological zones—26.1, Land not suitable for cultivation---13.6, Pasture land-2.9	42.6
Ravindranath et al (2001)	Short Rotation (SR) - 38.2, Long Rotation (LR) – 14.0, Forest regeneration – 11.0,	63.2
NRSA (1995)	Forest degraded land—16.27, Wasteland—38.11, Other category—11.07	65.45
NRSA (2004)		55.2
NRSA (2005)		41.0

8. Biomass Energy Options and Potential

Traditional use of biomass for energy is largely for heating purpose, in activities such as cooking, heating water, and brick making. Traditional biomass use for energy is characterized by low efficiency of use, drudgery and environmental degradation. Modern bioenergy technologies overcome these limitations and provide a large potential to meet energy needs in an efficient and sustainable way. The modern bioenergy technologies include;

- biomass power through combustion and gasification
- liquid fuels (Biodiesel and Ethanol)
- gaseous fuel (biogas)

The dominant biomass based energy option is for power generation using woody biomass largely from dedicated energy plantations (Ravindranath et al, 2000). Therefore, the potential for sustainable biomass production and biomass power generation is assessed. The liquid fuels are also briefly discussed.

8.1. Biomass Power Generation: Biomass power generation depends on land availability, sustainable biomass production and energy conversion efficiency. Land availability estimates were provided in Table 8. Only degraded or wastelands identified by National Remote Sensing Agency are considered for woody biomass feedstock production. Considering a conservative area of 34.6 Mha of dedicated energy plantations and a woody biomass productivity of 6.6 to 12 tonnes/ha/year, Sudha *et al* (2003) estimated the total woody biomass production potential to be 228 to 415 Mt annually, as shown in Table 9. The total annual power generation potential, at 1 MWh/tonne of woody biomass, is estimated to be 228 to 415 TWh (Table 9). This accounts for 36.5% to 66.5% of total power generated during 2006 (623.3 TWh) in India. Thus the biomass combustion and gasification technology for power generation has a large potential to meet the power needs sustainably. According to another study the lifecycle cost of power generation from biomass combustion and gasification is economically attractive compared to large coal-based power generation (Ravindranath et al, 2006). Even if a lower area of 24 Mha is considered, sustainable biomass feedstock production potential is estimated to be in the range of 158 to 288 Mt annually (Table 9).

Table 9. Biomass production and biomass power generation potential

Land category	Area in Mha	Biomass productivity t/ha/year	Total biomass production for energy (Mt/year)	Power generation in TWh / year
Short rotation energy plantation[a]	34.6	6.6 (without genetic improvement and fertilisers)	228	228
		12 (with genetic improvement and fertilizer)	415	415
Short rotation energy plantation[b]	24.0	6.6 (without genetic improvement and fertilisers)	158	158
		12 (with genetic improvement and fertilizer)	288	288

Source: Sudha *et al*, 2003

Notes: [a] Assuming no increase in area under crops (compared to 1995)

[b] Assuming 10 Mha increase in area under crops

8.2 Bio-diesel Production: Given the rising price of petroleum fuels, India has embarked on a large programme to produce vegetable oil and convert it to bio-diesel for substituting petroleum fuels. Both shrubs such as Jatropha and tree based vegetable oil production systems are being pursued. The Planning Commission (2003) has estimated the potential for producing bio-diesel (Table 10). Considering an area of 14 Mha, bio-diesel production using Jatropha option is estimated to be in the range of 20 to 48 Mt. If tree-based farming is considered the bio-diesel potential is estimated to be about 20 Mt annually.

Table 10 Bio-diesel production potential

Land category	Area (Mha)	Options	Oil seeds production (Mt/year)	Vegetable oil extracted Mt/year	Bio-diesel[3] (Mt/year)
Fallow land / wasteland, avenues, railway line, boundary of lands, row crops, etc.	14	*Jatropha curcas* [1]	70[a] (low yield)	21	20
			168[b] (high yield)	50	48
		Tree based [2] (Karanja or *Pongamia pinnata*)	70	21	20

Planning Commission (2003)
[1]*Jatropa production*
[2] *Oil seed yield of karanja tree (Pongamia pinnata) is 5 tonnes/ha/year.*
[3] *Seeds have 40% oil out of which 30% can be successfully extracted. 1.05 kg of seeds is required to produce 1 kg of biodiesel.*
[a]*low oil seed yield of Jatropha curcas at 5 tonnes/ha/year*
[b]*high oil seed yield at 12 tonnes/ha/year*

8.3. Ethanol Production: Ethanol is produced by fermentation route using sugarcane as well as maize. India has initiated a plan to blend petroleum fuel with ethanol for automobiles. Potential for producing ethanol is given in Table 11. With the current area under sugarcane and maize, about 21 Mt of ethanol could be produced annually. If additional area of 14 Mha of fallow land could be brought under sugarcane, about 54 Mt of ethanol could be produced annually. Conversely if maize is grown, about 22 Mt of ethanol could be produced. However, there are limitations in using high quality land and irrigation water for producing sugarcane or even maize for Ethanol production. This would lead to conflict with food production. Ethanol could at best be a by-product of the sugar industry.

Table 11. Ethanol production potential in India

Land category	Options	Area (Mha)	Production Mt/year	Ethanol Mt/year
Cropland (Current area)	Sugarcane[1]	5.5 (current area)	385	21.2
	Maize[2]		27.5	8.6
Fallow land	Sugarcane	14.0 (additional area)	980	54.1
	Maize		70	22.0

"Committee on development of biofuel"-Report. Planning Commission, India, 2003, http://www.truthabouttrade.org/article.asp?id=6702
[1]yield of sugarcane @ 70 t/ha,1 liter of ethanol per tonne of sugarcane.
[2] yield of corn @ 5 t/ha and @ 400 liters of ethanol per tonne of corn.

8.4 ***Biomass for Ethanol and Biodiesel Production***: Ethanol production requires use of good agricultural lands for growing Sugarcane, Sorghum and Maize, which may not be feasible in India given the demand for land for producing food grains. Biodiesel production form perennial crops such as *Jatropha, Pongamia pinnata* and other tree species is also currently being explored in India. Vegetable oil seeds or sugarcane production for liquid fuels is limited by availability of suitable lands.

9. Spread of Biomass Power in India

India has a large renewable energy promotion programme with several financial and policy incentives. Biomass power is one of the most important programmes promoted by the Ministry of New and Renewable Energy Sources. The biomass power potential is conservatively estimated by Ministry to be 16,881 MW, where as other estimates show a potential of 57,000 MW (Ravindranath *et al*, 2000). According to the latest report of this Ministry, the total installed capacity of biomass combustion and gasification systems is 542 MW in addition to 45 MW of non-bagasse cogeneration (Table 12). Thus despite the large potential for biomass power and multiple incentives from the Government of India, the rate of spread of biomass power technology is low. This is due to several barriers, including non-availability of sustained biomass feedstock supply, which are discussed in the following sections.

Table 12. Bioenergy Technology- Spread, Potential and

Sources	Medium-term estimated potential (projected to year 2032)	Cumulative Achievements (as on June 2007)
Bio-power (Agro residues and Plantations)	16,881	542.80 MW
Waste to energy	2,700	43.45 MW
Family type biogas plants	**12 Million**	**4 Million**

Source: MNRE (2007).

10. Financial assessment of biomass production options for energy

Financial assessment of biomass production options for energy is carried out using discount cash flow techniques. Eucalyptus, the most preferred species, plantation is considered to assess the financial viability for biomass production for energy. Financial analysis carried out by Sudha *et al* (2003) is reported here. Financial analysis was aimed to assess biomass production of two options; plantations with no improvement in genetic stock and no fertilizer application which is the current practice and with genetic improvement plus fertilizer application for high yields. Eucalyptus plantations are usually harvested after 8 years rotation and 2 additional rotations of 8 years each are considered from the planted Eucalyptus. Hence, the financial assessment has been carried out for a period of 24 years encompassing all the three rotations.

Cost effectiveness: The investment and the life cycle costs are considered for assessing the cost effectiveness. The investment or plantation establishment costs include nursery, land preparation, planting and aftercare in the initial 2-3 years. The life cycle costs include all costs over the 24 years period. The land value for raising the plantations is also included, at the rate of Rs.500 ha/year. The present value (PV) of establishment costs and life cycle costs are given in Table 13. The Net present value is Rs. 15,670 and Rs.40,424 at a discount rate of 12% for the option of plantation with no treatment and with genetic improvement plus fertilizer applications, respectively. This indicates that the investment in bioenergy plantation is profitable at a discount rate of 12%. The internal rate of return for the investment is 19.8% and 26.2% for the two options. It can be seen that though the initial investment cost is higher for establishing plantations with genetic improvement plus application of fertilizer compared to the other option, the net income is also higher due to the higher productivity.

Table 13. Financial analysis of Eucalyptus plantations for bioenergy at 8 years rotation with 3 rotations, using 12% discount rate

	With no genetic improvement and fertilizer	With genetic improvement plus fertilizer applications
Woody biomass productivity (t/ha/yr)	6.6	12.0
Present value of life cycle costs (Rs)	21,756	27,623
Present value of returns (Rs.)	37,426	68,048
Net present value(Rs.)	15,670	40,424
Internal rate of returns	19.8	26.2
Benefit–cost ratio	172	246

Source: Sudha *et al* (2003)

11. Barriers to Sustained Biomass Supply

It was shown earlier that land is available for woody biomass production for power generation. Further, financial analysis has shown that biomass production for energy at market prices is also financially viable and profitable. However, studies have shown that lack of sustainable biomass supply is a major barrier to spread of biomass power systems in India (Ravindranath and Hall, 1995 and Ravindranath et al, 2000 and Usha and Ravindranath, 2002) However, technical, financial and policy barriers limit the large-scale production of biomass for power generation. Some of the barriers are as follows:

- Tenurial uncertainty for wastelands, particularly public or government lands, for private companies or power utilities and further, industry or utilities cannot get access to government and community lands for producing biomass.
- Absence of policy or regulatory provisions for long-term contract between farmers and biomass power utilities for sustained biomass supply from farm lands to biomass power utilities
- Lack of access to easy credit, financial incentives and guaranteed price for biomass feedstock to farmers and such incentives are available for biomass power utilities and not for biomass producers.
- Absence of package of practices for high biomass yields in different agro-climatic zones.
- Long-gestation period in producing biomass (a minimum of 3 to 5 years for harvesting).
- High transportation costs for large-scale biomass power generation systems, since large contiguous tracts of degraded lands are not available for biomass feedstock production in India.

12. Policy options to promote sustainable biomass production for energy: Sustainable biomass supply is a critical barrier to bioenergy technologies. Some of the potential policy, financial and institutional options are as follows:

- Legal and institutional support for long-term supply arrangements between farmers and bioenergy utilities along with assured price for biomass feedstock production

- Development of package of practices for high and sustained yields for different agro-climatic and soil conditions especially for short-rotation plantations
- Access to credit for biomass feedstock producers, though in principle a few programmes are available, but in reality credit is not easily accessible to the farmers
- Development of biomass feedstock markets to promote easy access to surplus biomass from different locations
- Removal of regulations on biomass feedstock transportation
- Development of software to assess the land requirements and linking biomass production capacity with bioenergy utility capacity

13. Co-benefits of Biomass Production for Energy

Biomass production for power and similarly for liquid fuels in degraded or marginal lands has the following co-benefits:

- Reclamation of degraded lands, which are subjected to soil erosion and degradation due absence of vegetation cover
- Carbon sequestration in degraded lands in standing vegetation and soil
- Greenhouse gas emission reduction, if bioenergy is used to substitute fossil fuel energy
- Promotion of biodiversity, if adequate sustainable production practices, such as a mix-of species and leaving a fraction of land fallow for natural forest succession, are adopted
- Local employment and income generation from biomass production practices, harvesting, transportation and processing
- Improved socio-economic conditions and quality of life, if access to modern bioenergy is provided to rural communities, such as biogas for cooking and biomass power for lighting and mechanical applications.

Sustained biomass production for power generation has several local and global co-benefits apart from supplying biomass feedstock for power generation for meeting the growing demand for energy in India sustainably.

14. Conclusions

India has a large potential for modern bioenergy, particularly biomass power and biogas. India has also initiated large programmes to promote biomass combustion and gasification for sustainable biomass power, with a number of policy and financial incentives. However, compared to the large potential, the rate of spread of biomass power programme is insignificant. One of the critical barriers is the absence of sustainable biomass feedstock supply.

The present analysis has shown that degraded or wasteland is available for producing biomass. Biomass production for energy is financially viable. Even taking a conservative estimate of land availability of 34 Mha, it is possible to produce biomass to generate 228 to 415 TWh of electricity, accounting for 36 to 66% of total power generation (during 2006). There are barriers to spread of biomass production for energy; biomass power, bio-diesel and Ethanol. There is a need to overcome the barriers to sustainable biomass production and supply to biomass power utilities. Legal and institutional support for long-term supply arrangements between farmers and bioenergy utilities along with assured price for biomass feedstock production is necessary. Development of package of practices for high and sustained yields for different agro-climatic and soil conditions especially for short-rotation plantations is critical for sustainable biomass supply.

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Development Benefits of Clean Energy in India

Biomass Gasification Prospects in India

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V.V.N. Kishore, Sanjay Mande

The Energy Resources Institute

Report COP-13
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Executive Summary

Biomass Gasification Prospects in India

1. Introduction

Biomass is an important energy source, contributing 14% of the world energy (Woods and Hall, 1994). Improvements in biomass energy production and conversion technologies (Johansson et al, 1993), rising global environmental concerns like climate change, deterioration in air quality due to the use of fossil fuels (Shukla, 1996), and national concerns about energy security are leading to a renewal of interest in biomass globally.

Organized production of wood fuels (through commercial or co-operative sector) and modernized conversion at appropriate scale economies have potential to make biomass a competitive commercial fuel vis-à-vis fossil fuels (Ahmed 1994 and Ravindranath 1993).

2. Identification and elaboration of biomass gasifier applications with most promising win-win opportunities

Growing experience of modern biomass technologies such as biomass gasification has potential to penetrate in two segments:

1. *Process heat applications in SMiEs (Small and Micro Enterprises)*
2. *Small Power generation: Decentralized/captive*

2.1 Process heat applications in SMiEs

There are more than 3 million small-scale industries in the organized sector and about 15 million enterprises in the unorganized sector. These units account for about 40% of the total industrial production and 35% of total exports. It is estimated that the small-scale industries and micro enterprises together contribute 7% to GDP in Indian economy (Srinivas 2000).

A large number of enterprises in the small-scale sector are highly energy consuming. Coal, biomass (wood, agro-residues), petroleum products (furnace oil, LPG, diesel, LDO) are used for heat generation. Expenditure on fuels often takes a major share of their production costs. Rapidly increasing prices of commercial fuels (the diesel price in India has more than tripled in the last ten years) are reducing the profit margins of these enterprises. Hence substitution of petroleum fuels with modern biomass makes eminent sense.

The thermal energy needs of SMiEs can be categorized as follows:

Low temperature applications:

- Water boiling: Cooking cocoons, dyeing fabric, production of magnesium chloride, etc.
- Dryers (50 – 130ºC): For farm products, food and spices (like rubber, tea, coffee, cardamom, tobacco, food and chemical products, etc).
- Boilers: Several chemical process industries, agro-processing industries, dairy industries and textile industries using low-pressure steam.

High temperature applications:

- Kilns (800–950ºC): For baking of tiles, bricks, and potteries or for heat treatment purpose (such as hardening, annealing etc).
- Furnaces (650-1600ºC): For melting metals in foundries, glass-melting industries etc.

2.2 Power generation:

The recently announced Integrated Energy Policy (MoP 2006a) states that sustained growth of 8% is required through 2031 to increase the generation capacity from 160,000 MW to 800,000 MW. However, gap between supply and demand is likely to continue, thus perpetuating dependence on captive power generation. Rural Electrification Policy (MoP 2006b) aims at providing electricity for all by 2009. Owing to the small scales of such plants, biomass gasifier based systems can become logistically and economically viable.

A recent survey of gasifier manufacturers found that 75% of gasifiers offered commercially were downdraft, 20% were fluid bed (including circulating fluid bed), 2.5% were updraft and 2.5% were of other types (Knoef 2000). In India, atmospheric downdraft or updraft gasifiers are prevalent because of the lower initial costs. Elaborate gas cleaning is not required for thermal applications, but engine applications need gas with low contaminant levels.

An estimated 20 million tonnes of biomass (wood and agro-residues) is used in enterprises such as tea drying, brick kilns, cremations, chemical processing, bakeries, etc. In these industries, induction of biomass gasifiers can help in reducing fuel consumption by 50-60%, thus reducing possible deforestation or releasing biomass for other uses.

There are a variety of fossil fuel-fired furnaces that are ideal candidates for switching over to producer gas from biomass. Approximately 3-4 kg biomass is required to replace 1 kg of petroleum-based fuels like furnace oil, diesel and LPG), resulting in a pay back period of 6-12 months at current prices of biomass.

At current prices of diesel, gasifier-electricity is comparable to diesel-electricity, with actual economics depending highly on local conditions. It can, however, be stated that there would be many opportunities for replacing diesel generation through biomass gasifier based generation.

3. Estimated potential saving in terms of GHG emissions from specific opportunities against accepted published baseline through 2025

Indian industries use a variety of fuels for process heat requirements viz firewood and agro-residues, coal, fuel oil (or furnace oil), LDO (light diesel oil), HSD (high speed diesel), naphtha, natural gas, LPG (liquefied petroleum gas). Here an effort has been made to estimate thermal energy requirements in Indian industry, with a view of replacing different fossil fuels with renewable biomass and quantitative estimates of different GHG emissions calculated using IPCC default emission factors for BAU scenario of continued use of fossil fuel and alternate scenarios of varying deployment of biomass gasifier systems.

We followed two different methods for estimating fuel consumption figures and projections. The first method used a MARKAL model employed in preparing the National Energy Map of India (TERI 2006), with business as usual (BAU) scenario. The second method used available CMIE data for consumption of different petroleum fuels and assuming certain fractions for heat generation where explicit fraction is not known (based on discussions with senior officials of Indian Oil Limited). In both the methods, the following large industries are not considered either because the quantities consumed are too large to be replaced by biomass, or because the fuel is used as feedstock. These industries are: iron & steel, cement, pulp and paper, caustic soda and soda ash, aluminum, textiles and fertilizers. The MARKAL model gives projections of all fossil fuels except firewood, which is used primarily in micro enterprises and unorganized industries. Specific wood consumptions and estimates of annual consumption levels are available from a limited amount of field data for selected small enterprises such as brick and tile making, food drying, textile dyeing, bakeries, sericulture, cremations etc.

There is considerable variation in the estimates of crop residues for current production, future projections and fractions available for gasification. Ravindranath estimated the residue production figures as 626.5 and 840.6 million tons (air dry) for the years 1996-97 and 2010-11 respectively (Ravindranath 2005). These figures yield an annual growth rate of 2.12%, which is close to the projected agriculture GDP growth rate. The biomass atlas prepared by CGPL at IISc Bangalore from *Taluka* level assessments of MNRE gives lower values for biomass production. It takes major states into account but does not include all states. It also gives estimates of biomass available for energy production, based on current use patterns of biomass for other applications such as fodder. The different estimates of biomass are shown in Table 1.

Table 1. Biomass availability estimates

Year	Biomass estimates (million tonnes)		
	Ravindranath	Biomass atlas IISC	
		Production	Surplus**
1996-97	626.5		
1998-99	653.4*	546.4	139.4
2004-05	741.0*	619.0*	157.9*
2010-11	840.6	701.2*	178.8*
2024-25	1127.3*	938.0*	239.2*

Notes:
* Projections based on 2.12% annual growth (same as Ravindranath's two year values)
** Surplus biomass fraction assumed constant as given in biomass atlas of IISc for year 1998-99

The fuel consumption estimates and the corresponding emissions obtained from the modeling exercise are shown in Table 2. It is apparent that the highest contribution to CO_2 in 2026-27 comes from coal burning, followed by, fuel oil, naphtha, LDO, LPG and natural gas. Discussions with oil specialists indicated that fuel oil is burnt also for captive power generation and only about 50% goes for general trade for process heat. Also, naphtha is being phased out due to its high cost. LDO consumption goes mainly for low speed engines and very little goes for burning. The model predictions thus seem to be on the higher side. The estimates based on different fuel consumption data from CMIE and with projections based on past 5-15 years data are summarized in Table 3, which includes wood fuel consumption as well as diesel consumption for captive power generation also. As noted earlier, use of wood seems to decline, and hence its use is assumed to be constant through 2025. Values of biomass required to substitute fossil fuels completely are also shown in the table, assuming a replacement value of 3.64 kg wood for 1 kgoe.

Table 2. Industrial thermal energy needs: Markal Model projections

Year	Fuel consumption (million tons of oil equivalent)							
	Coal	Diesel	Fuel oil	LDO	Naphtha	Gas	LPG	Total Industrial thermal
2001-02	19.9	4.5	8.4	1.4	8.3	4.7	1.2	48.5
2006-07	30.3	4.9	12.2	2.1	12.0	5.0	1.8	68.2
2011-12	48.0	4.7	17.6	3.0	17.5	5.2	2.7	98.7
2016-17	75.1	3.4	25.4	4.4	25.31	5.5	3.8	142.9
2021-22	117.8	0.0	36.6	6.3	36.7	5.8	5.3	208.5
2026-27	183.4	0.0	52.9	9.2	53.2	6.1	7.2	312.0

Year	GHG emissions (million tons of CO_2)							
	Coal	Diesel	Fuel oil	LDO	Naphtha	Gas	LPG	Total Industrial thermal
2001-02	78.9	13.9	27.5	4.5	25.5	11.1	3.1	164.5
2006-07	119.9	15.1	39.5	6.5	36.9	11.6	4.8	234.3
2011-12	190.3	14.6	56.9	9.4	53.6	12.2	7.1	344.0
2016-17	297.5	10.6	82.2	13.6	77.7	12.8	10.1	504.5
2021-22	466.6	0.0	118.7	19.7	112.6	13.5	14.0	745.1
2026-27	726.4	0.0	171.5	28.5	163.2	14.3	19.1	1123.0

3.1 Prospects of biomass gasification for power generation

The number of unelectrified (or unelectrifiable) villages was hovering around 25000 for many years. The planning commission transferred these remote villages to MNRE for electrifying through renewable energy. Revised estimates of such villages, including 'de-electrified villages' and village hamlets varied between 125000 to 250000. Also, MNRE came up with the VESP activity recently, in which gasifier-based small power assumed significance. However, with the launching of the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), most of the remote villages are planned to be served through grid, and the number of remote villages left for MNRE are only about 6000. The Ministry of Power (MoP) has a target of electrifying all households by 2012. By all these considerations, the prospects of deploying gasifier systems for village electrification seem to decrease considerably. The prospects of substituting captive power plants with gasifier-based systems, however, remain good.

Table 3 Industrial process heat and captive power generation: BAU scenario for fuel consumption, CO_2 emissions, and biomass required for completely replacing fossil fuel

	Fuel Consumption[f] (million tons)		Emissions[g] in million tons for 2004-05				Emissions[g] in million tons for 2024-25				Biomass required[h] (million tons)		Annual growth rate[i]
	2004-05	2024-25	CO2	CH4	N2O	CO2 equiv	CO2	CH4	N2O	CO2 equiv	2004-05	2024-25	
Furnace Oil[a]	5.0	8.3	15.464	0.000599	0.000120	15.514	25.389	0.001002	0.000200	25.922	14.73	24.61	2.6% tenth plan
LPG[b]	1.2	5.6	3.479	0.000055	0.000006	3.482	16.827	0.000267	0.000027	16.840	4.53	21.92	8.2% 10^{th} plan
Coal[c]	50.5	68.9	109.787	0.001161	0.001741	110.351	149.859	0.001584	0.002376	150.629	99.16	135.35	1.6% during 1990/91-2004/05
Biomass[d]	20.0	20.0	0.0	0.010037	0.001338	0.626	0.0	0.010037	0.001338	0.626			Assumed constant
Total thermal			128.7	0.011852	0.003204	130.0	192.5	0.012889	0.003941	194.017	118.42	181.88	
Diesel for[e] captive power	3.5	26.8	11.104	0.000450	0.000090	11.141	85.307	0.003454	0.000691	85.594	20.10	154.46	6.36% & 10.7% in capacity & generation during 1990/91-2004/05
TOTAL			139.834	0.012	0.003	141.113	277.832	0.016	0.005	279.611	138.52	336.34	(Thermal + power)
Surplus biomass availability (million tons)											157.86	239.22	IISc Biomass atlas projections (refer table 1)

Notes:
a Furnace oil for industry and other industries only
b LPG for commercial use only
c Coal for other industrial use
d Fuelwood for SMiEs for heat applications in unorganized sector
e Diesel consumption for DG set captive power generation
f fuel consumption data from CMIE-Energy 2006
g Emissions based in IPCC default emission factors
h biomass required fro completely replacing fossil fuels use
i annual growths from last 5-15 years data taken for projections

The installed capacity of diesel power plants in 2004-05 was 7195 MW with a generation of 13403 GWh and estimated diesel consumption of 3.48 million tons. Regression analysis of the last 10 years' data showed that the average annual growth rate of diesel installed capacity is 6.36% and the growth rate of diesel electricity is 10.7%. The installed capacity, energy generation and diesel consumption for the year 2025-26 can then be estimated as 26310 MW, 114025 GWh and 29.65 million tons respectively. The fuel consumption and emission scenarios for both industrial thermal energy production and diesel power generation are summarized in Table 4.

Table 4. Emission reduction with different gasifier technology penetration rates

Emission reduction scenarios	CO_2 emissions (million tons)	Surplus biomass requirement (million tons)	Surplus biomass availability (million tons)
Year 2004-05	141.1		157.9
Year 2024-25 BAU	279.6	201.9	239.2
Year 2024-25 Scenario-I Gasifier penetration to reduce consumption 25% in furnace oil, LPG, wood using & 10% in coal using and captive diesel generation	245.1	58.1	
Year 2024-25 Scenario-II Gasifier penetration to reduce consumption 50% in furnace oil, LPG, wood using & 25% in coal using and captive diesel generation	198.9	110.7	

3.2 Emerging scenarios for modern biomass

Biomass is currently being considered for several competing energy uses such as pelletising, cogeneration, power generation through combustion, industrial process heat, gasification and ligno-cellulosic ethanol. The ethanol route is still at the lab/demo stage, but considering the global research efforts for making it economically viable, it may soon become attractive. Pelletization and use of pellets for heating applications is growing steadily in Europe, and is likely to find its way in India also. The BP pellet stove is an example. If pellets get mainstreamed, there will be a corresponding demand for pellet stoves, gasifier stoves and gasifiers in general. Biomass gasifiers have long suffered from use of non-standard fuels; hence pelletization could just be the answer for mainstreaming gasifiers in commercial and industrial applications. Thus, pelletization and ethanol production can well be the prime competitors for biomass use in future.

4. Development/Co-benefits of biomass gasification

Biomass gasification has the following co-benefits:

- Local employment and income generation
    - During mainstreaming sustainable supply of processed biomass (production, harvesting, processing and transportation)
    - For manufacturing of gasifier systems and sub-components (spare parts)
        - Manufacturers, entrepreneurs
        - Local Service Providers for system installation, commissioning
        - Operation and maintenance of the systems

- Improved working conditions (less smoke exposure)
- Enhanced profitability of enterprises due to reduced fuel cost, improved productivity, product quality and processing rates
- Reduced dependency on import of petroleum products, hence better energy security
- Improved socio-economic conditions and quality of life due to access to modern bioenergy to remote rural communities for lighting and mechanical applications
- Enhanced sustainable biomass production has associated local and global environmental benefits due to increased green cover.

5. Barriers to achieve the projected savings of GHG emissions

Technological: While the technology of gasification is well developed for thermal applications, there are problems yet to be overcome for power generation. These are related to impurity levels in the gases (tar, particulates), engine development for 100% gas operation, and control systems for the complete power plant. Second generation gasifiers such as the two-stage gasifiers are still at the demo stage and are expensive. Further, standards for performance, safety and quality are yet to be enforced and operationalized. Wood is an accepted gasifier fuel at present, but consistent, verifiable and environment-friendly field performance with loose biomass such as rice husk is yet to be achieved.

Financial: The economic viability of thermal gasifiers is well established at the prevailing costs of firewood. Future efforts of mainstreaming biomass, such as pelletization, would most probably result in increased prices for biomass, hence the relative price differential between furnace oil/LPG and pellets would decide the future economics. Other benefits such as energy security and carbon trading might outweigh economic benefits in future and hence the overall prospects of pellet gasification replacing fossil fuels for thermal applications are bright. The same, however, cannot be said about power generation through gasification. Gasifier based electricity is at best marginally cheaper than diesel electricity at present, the reasons for which are: low capacity utilization, high operating and maintenance costs and increasing biomass costs.

Infrastructural, policy and regulatory: The infrastructural barriers relate mainly to the supply chain for biomass and to the supply chain for gasifier related services. Most gasifier manufacturers at present do not have sustained networks for supply, commissioning and servicing of gasifier systems/components. Similarly, the supply network of biomass is relatively unstructured and hazy and varies a lot from state to state. Also, gasifier installation, commissioning and operation require trained manpower, which is scarce at present. Hence the training needs have to be addressed properly. The policy and regulatory barriers are related to inter-state movement of biomass, attractive tariffs for gasifier based electricity, lack of standardization, and lack of incentives or programs for development and/or import of advanced technologies (such as pelletization).

6. Basic strategy elements for overcoming the various barriers

The strategy for achieving emission reductions through use of biomass gasification technologies should consist of several sub-strategies. These include 1) strategy for mainstreaming technology and 2) strategy to mainstream those biomass forms that are suitable for use in gasification such as pellets and wood chips. The former strategy mainly involves private sector players who would have to evolve networks for supply and service of gasifier systems and components. A huge exercise of formulating and adhering to quality, performance and safety standards would have to be carried out prior to, or simultaneously with, the mainstreaming efforts. The role of Bureau of Indian Standards (BIS) and MNRE would be critical in such exercises. The gasifier manufacturers are quite fragmented at present and would gain by forming associations and acting jointly. Entry of well-known engineering firms would definitely help in improving the product quality. Involvement of financing agencies would also help in building up the confidence levels of potential users in a new technology.

The strategy for mainstreaming of sized or standardized biomass would involve many players including farmers, NGOs, small entrepreneurs (for producing commercial biomass), dealers etc on one side, and government bodies at district, state and central level on the other. The movement of sized biomass should be allowed freely and there should be incentives such as tax breaks so that the price of biomass to the user is affordable. Attempts also should be made to achieve long-term sustainability of the biomass supply network by ensuring adequate profits to all network members. Again, entry of large corporates might be beneficial.

Substantial applied and engineering research would have to be mounted to develop second-generation gasifiers that are capable of producing low-impurity gases. Simultaneously, efforts to design and make efficient and pollution-free producer gas engines from scratch should be initiated.

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Biomass Gasification

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1.0 Introduction

Biomass has provided energy since millennia. Before the use of fossil fuels became widespread, biomass, in the form of wood, was the predominant energy source for heating, cooking and, sometimes with prior conversion to charcoal, for industrial processes such as smelting. Recently, the rapid increase in fossil fuel use contributed to the decline in the share of biomass in total energy, however biomass still remains an important energy source contributing 14% of the world energy (Woods and Hall, 1994).

Fossil fuels, with their higher energy density and portability, rapidly replaced wood in countries with ready access to them. In most industrialized countries, however, biomass sources rarely merit mentioning in official energy statistics, Sweden and Austria being notable exceptions with biomass components of 9% and 10% respectively. Finland also obtains a significant amount of its energy supply from biomass. In developing countries, biomass remains a fuel of major importance; especially in rural areas with average use of around 38% of national energy consumption in India but in some countries this figure rises to 90% (Brian Price, 1998).

Wood fuels, including charcoal, are the most prominent biomass energy sources in developing countries, where a substantial use of biomass energy continues in the rural area and among urban poor. Most biomass energy in developing countries is homegrown or collected by the households and is not traded. The incomplete combustion of biomass in the traditional stoves contributes not only to the energy inefficiency, but also to substantial emissions of pollutants, which can cause severe health damage (Smith and Thorneloe, 1992).

Since long, the biomass energy use has been confined to traditional sectors. Lately however, several factors have contributed to a renewal of interest in biomass energy globally. The chief among them are – the improvements in biomass energy production and conversion technologies (Johansson et al, 1993), rising global environmental concerns like climate change and acid rain, and deterioration in air quality due to the use of fossil fuels (Shukla, 1996). The concerns about sustainable development have also led to a fresh look at biomass energy as a renewable, sustainable and environmentally benign energy source.

The rural energy crisis, such as in India, emanating from the low purchasing power of rural poor and the shortages of commercial fossil fuels have made the policy makers in developing countries to reconsider the biomass as a long-term and viable energy alternative for rural areas. Biomass energy has drawn the attention of developing country policy makers due to its multiple advantages like–the accessibility in rural areas where commercial fuels and centralized electric grid are not available, employment generation in energy plantations and rural industries, saving of foreign exchange spent on oil imports and, restoration of deforested and degraded lands by energy plantations (Shukla 1997 and Reddy et al. 1997).

These advantages, together with more efficient and versatile biomass electricity generation technologies, have led to the transition of re-emergence of biomass as a competitive and sustainable energy option for the future. Another reason for the renewed interest in biomass is the commercial viability of biomass in niche applications and closing in of the technological and economic gap with the fossil energy. The cheapest biomass resources, the waste products from wood or agro-processing units, are available at competitive costs. However, their supply is limited. The plantation-grown fuels are more expensive, but their supply costs are improving. Organized production of wood fuels (through commercial or co-operative sector) and modernized conversion at appropriate scale economies therefore have potential to make biomass a competitive commercial fuel vis-à-vis fossil fuels (Ahmed 1994 and Ravindranath 1993).

Economic reforms have opened the doors for competition in energy. Long-term penetration of biomass energy shall depend on the cost of delivered energy as well as reliability of technologies. Future of biomass energy lies in its use with modern technologies such as biomass gasification which can give convenience of gaseous fuel by converting it into producer gas through gasification in gasifier reactor and can help in harnessing potential in three segments:

- Process heat applications in agro-based industries generating waste as by-product
- Electricity generation, and
- Cooking energy in domestic-commercial sectors (through charcoal/briquettes)

First two segments will be dealt here in this B-2 section while the cooking energy is being covered separately under B-3 section of the study.

2.0 Evaluation of gasification options

2.1 Biomass gasification: An overview of technology

Thermo-chemical biomass gasification is a process of converting solid biomass fuel into gaseous combustible form (called producer gas) by means of partial oxidation carried out in a reactor called gasifier at elevated temperatures. Application of gasifier assumed significant importance and attention during World War II due to scarcity of petroleum products. By the end of world war in 1942 more than million vehicles were in operation using gasifiers through out the world. However, after the end of war they were largely decommissioned as petroleum products once again became widely available at cheap rates. The energy crisis in 1970s brought renewed interest in gasification. The technology was perceived as a relatively cheaper option in developing countries having sufficient sustainable biomass for small scale industrial as well as power generation applications. Gasification of biomass looks simple in principle and many types of gasifiers have been developed. Production of gaseous fuel from solid fuel offers easy handling, better control on combustion and possibility of using it in internal combustion engine for shaft power or electricity production makes gasification very appealing especially for small decentralized options. However biomass fuel used in gasifier varies widely in its physical and chemical properties and makes the gasifier reactions complicated to design.

2.1.1 Principle of gasification:

Biomass gasification is a process of converting solid biomass fuel into gaseous combustible gas (called producer gas) through a sequence of complex thermo-chemical reactions. In the first stage partial combustion of biomass to produce gas and char occurs along with generation of heat. This heat is utilized in drying of biomass to evaporate its moisture as well as for pyrolysis reactions to bring out volatile matter and provide heat energy necessary for further endothermic reduction reactions to produce producer gas which mainly consists of mixture of combustible gases such as CO (carbon monoxide), hydrogen (H_2) and traces of methane (CH_4) and other hydrocarbon. Normally air is used as gasifying agent, however use of oxygen or steam can producer rich higher calorific value gas but due to cost implications is not usually preferred.

2.1.2 Modes of biomass gasification

Gasification of solid biomass fuels to convert them into more ease/convenient to use cleaner producer gas fuel can be achieved through various modes: either by partial oxidation to give a mixture of carbon monoxide, carbon dioxide, hydrogen and methane with nitrogen if air is used as the oxidant, or by steam or pyrolytic gasification. Table 1 summarizes the main products in each case.

Table 1. Various gasifier operation modes

Gasification mode	Comments
Partial oxidation with air	Gives low heating value gas (~5MJ/Nm^3) with main gas components of CO, CO_2, H_2, CH_4. N_2 and tar. Presence of tar can arise problems in combustion, particularly in turbine.
Partial oxidation with oxygen	Gives medium heating value gas (~10-12 MJ/Nm^3) with main gas components of CO, CO_2, H_2, CH_4 and tar (no N_2). For some niche applications cost of using oxygen can be compensated by better quality gas with higher heating value.
Steam (pyrolytic) gasification	Gives medium heating value gas (~15-20 MJ/Nm^3) with main gas components of CO, CO_2, H_2, CH_4 and tar. Process occurs in two stages: primary reactor produces gas and char and char and sand is passed to second reactor where char is burned with air to reheat sand which is then re-circulated in first reactor to provide heat of reaction. Gas heating value is maximized due to higher methane and hydrocarbon in gas but over all efficiency drops de to loss char in second reactor.
Pressure gasification	Typically operates under 15-20 bar pressure. Both operating and capital costs are higher for pressurized operation which to some extent balanced by compactness. Liquid feeding as bio-oil has significant operational and economic advantages over solid biomass feeding. Normally oxygen is used as gasifying agent.
Oxygen gasification	Use of oxygen (normally with pressure operation) gives higher reaction temperatures resulting in lower tar levels in gas. Absence of oxygen also makes system compact (small) and gas quality is also higher for both power generation and for liquid fuel synthesis. However use of oxygen is quite cost and energy intensive for its procurement, and also for taking additional measures needed to mitigate hazards in its handling and use.

Source: Bridgewater and Maniatis 2004

2.1.3 Gasification reactions

A complete understanding of the various complex reactions occurring in a gasifier has not been possible so far. However, the following reactions explain the process of gasification fairly well.

$C+O_2 \Rightarrow CO_2$+393 800 kJ(kilojoules)/kg mole (combustion)

$C+H_2O \Rightarrow CO+H_2$ – 131 400 kJ/kg mole (water gas)

$C+CO_2 \Rightarrow 2CO$ – 172 600 kJ/ kg mole (Boudouard reaction)

$CO+H_2O \Leftrightarrow CO_2$+H2+41 200 kJ/kg mole (water shift reaction)

$C+2H_2 \Rightarrow CH_4$+75 000 kJ/kg mole (methane reaction)

It is generally observed that for effective gasification, the ER (equivalence ratio viz. ration of actual air supplied to stoichiometric air requirement for ideal complete combustion) should be in the range of 0.2 - 0.4. Below an ER value of 0.2, pyrolysis predominates the process and above an ER value of 0.4, combustion predominates. In a real gasifier, however, the composition of the gas dependent on the gasifier design and other several operating factors such as the temperature distribution in the fuel bed, average gas residence time, and the residence time distribution. These in turn dependent upon the mode of air entry, dimensions of the gasifier, and the quantum of heat loss to the surroundings.

2.2 Gasifier Reactor Types

While the various reactors used for biomass gasification can be classified in many different ways, the density factor (ratio of dense biomass phase to total reactor volume) is a simple and effective method of classification. Thus, gasifiers can be classified as:

- Dense phase reactors
- Lean phase reactors

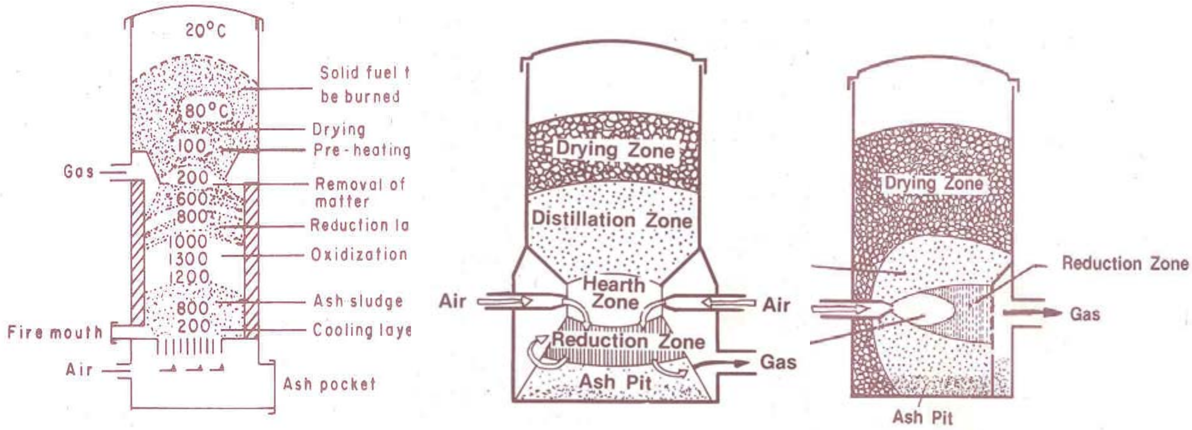
In dense phase reactors such as fixed bed reactors (updraft, downdraft, cross-draft, etc.) the biomass or feedstock occupies maximum reactor volume with typical density factors of around 0.3—0.8. On the contrary in lean phase reactors such as fluidized bed reactors biomass occupies very little reactor volume – to the order of 0.05—0.2.

2.2.1 Dense Phase Reactors

These are the most common gasifier types having a long history and were the first to be produced commercially due to the advantage of simplicity in construction as well as operation. One of the important characteristics of these reactors is that they have fairly distinct reaction zones within the reactor such as drying, pyrolysis, combustion, and reduction. However, the relative position of these zones varies with the fuel characteristics and operating conditions.

Depending on air and gas movement these can be classified as (Figure 1a,b,c):

- Updraft or co-current gasifiers
- Downdraft or counter-current gasifiers
- Cross draft gasifiers



(a) Updraft gasifier (b) Downdraft gasifier (c) Cross draft gasifier

Figure 1 Types of dense phase gasifiers

In the counter-current moving bed reactor, also called the updraft gasifier, the air flows counter to the downward fuel flow and enters into the gasifier from below the grate and flows in the upward direction within the gasifier. An updraft gasifier has distinctly defined zones for partial combustion, reduction, and distillation (Figure 3a). The gas produced in the reduction zone leaves the gasifier reactor together with the pyrolysis products and the steam from the drying zone. The resulting combustible producer gas is rich in hydrocarbons (tars) and, therefore, has a relatively higher calorific value. Therefore, it is more suitable for thermal applications, such as direct heating in industrial furnaces, as it gives higher operating thermal efficiencies.

In the cocurrent moving bed reactor or downdraft gasifier, the air enters at the middle level of the gasifier above the grate and the resulting mixture of air and gas flows down cocurrently through the gasifier reactor. All the decomposition products from the pyrolysis and drying zones are forced to pass through the oxidation zone (Figure 3b). This leads to thermal cracking of the volatiles resulting in reduced tar content in the producer gas (therefore preferred for engine applications). Compared to the updraft gasifier the disadvantages of a downdraft gasifier are the higher gas outlet temperature and the lower thermal efficiency. The starting ignition time required for downdraft gasifiers is lower as compared to updraft gasifiers but is still perceived to be long as it is in the range of 15—20 minutes. It also has relatively better load following capability (ability to quickly extend the partial combustion zone to produce the requisite higher gas quantity).

2.2.2 Lean phase reactors

In lean phase gasifiers, distinct reaction zones do not exist like in dense phase reactors. All the reactions viz. drying, oxidation, pyrolysis, and reduction take place effectively in the same region. Among the lean phase reactors, the most commonly used reactor types are the fluidized bed and entrained flow reactors. Recently, other reactor designs like cyclonic reactors are being developed and tested.

Tables 2 and 3 give typical operational data and the producer gas composition and quality in different gasifier reactors.

Table 2 Typical operational data for different types of gasifiers

	Downdraft	Updraft	Fluidbed	
			Conventional	Circulating
Grate energy release, GJ/h.m^2	1.5 – 4	2.5 – 5	6 – 9	40
Offgas temperature, °C	600 – 800	75 – 150	650 – 850	800 – 900
Oils and tar, kg/kg dry feed	0.001 – 0.01	0.05 – 0.15	0.01 – 0.05	-
Char loss, kg/kg dry feed	0.02	0.01 – 0.02	0.02 – 0.05	-

Table 3 Producer gas characteristics from different gasifiers

Gasifier reactor type	Gas composition, dry, vol %					HHV	Gas quality	
	H_2	CO	CO_2	CH_4	N_2	MJ/m^3	Tars	Dust
Fluid bed air-blown	9	14	20	7	50	5.4	Fair	Poor
Updraft air-blown	11	24	9	3	53	5.5	Poor	Good
Downdraft air-blown	17	21	13	1	48	5.7	Good	Fair
Downdraft oxygen-blown	32	48	15	2	3	10.4	Good	Good
Multi-solid fluid bed	15	47	15	23	0	16.1	Fair	Poor
Twin fluidized bed gasification	31	48	0	21	0	17.4	Fair	Poor

2.3 Status of biomass gasification technology

The recent survey of gasifier manufacturers around the world found that 75% of gasifiers offered commercially were downdraft, 20% were fluid bed (including circulating fluid bed), 2.5% were updraft and 2.5% were of other types (Knoef 2000).

The ranges of gasifier technologies along with their respective efficiency range are given in Figure 2. It can be observed that for applications in developing countries like India where majority of applications are for small scale (upto megawatt capacity) and decentralized in nature, atmospheric downdraft gasifiers are more attractive in spite of its lower efficiency.

There can be large market for these in both developing and developed economies. While there may be still some problem of effective removal of tar and particulates considerable progress has been made in managing these gasifiers under field conditions. Atmospheric updraft air gasifiers have some application areas in larger capacity (specially where large quantities of gas can be immediately burnt in hot conditions to get process heat) despite its higher tar content as it gives relative more flexibility than downdaft gasifier with regard to fuel size and moisture content. Therefore these two types of fixed bed gasifiers are more in use in developing countries like India.

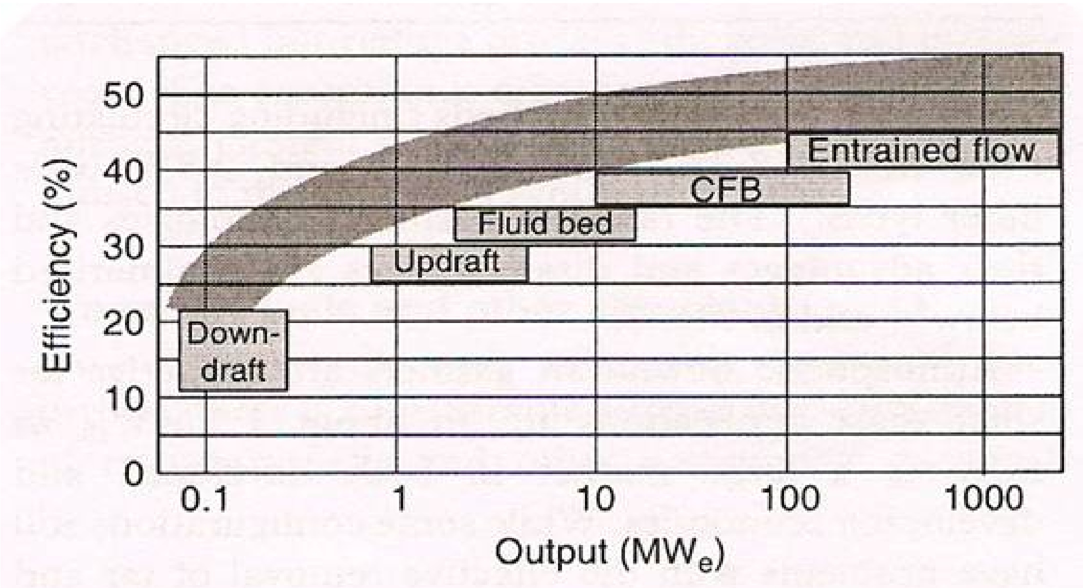


Figure 2. Relationship between technology scale and efficiency
(Source: Brigdwater 2006)

Fluidized bed gasifiers have proved quite reliable in developed countries for large-scale operations from few MW to several hundred MW with loose biomass handling with lot of sophistication and automation. Pressurized fluidized bed systems (either circulating or bubbling) are considered to have limited short-term market because of complexities in its installation and operation and higher costs due to pressurized vessels and only very large gasification systems for processing millions of tonnes of biomass a year can consider using pressurized oxygen blown gasifiers.

However, in developing countries like India where majority of applications are for small scale (upto megawatt capacity) and decentralized in nature, atmospheric downdraft gasifiers are more attractive in spite of its lower efficiency. There can be large market for these in both developing and developed economies. While there may be still some problem of effective removal of tar and particulates considerable progress has been made in managing

these gasifiers under field conditions. Atmospheric updraft air gasifiers have some application areas in larger capacity (specially where large quantities of gas can be immediately burnt in hot conditions to get process heat) despite its higher tar content as it gives relative more flexibility than downdraft gasifier with regard to fuel size and moisture content. Therefore these two types of fixed bed gasifiers are more in use in developing countries like India. No elaborate gas cleaning is normally required for thermal applications while gas has to be cooled (to improve engine volumetric or breathing efficiency) and cleaned thoroughly (to minimize damage to engine and maintenance requirement) for engine or power applications.

3.0 Gasifier for process heat in SMiEs in India

Small-scale industries play a significant role in the Indian economy. There are more than 3 million small-scale industries in the organized sector and about 15 million enterprises in the unorganized sector (Srinivas 2000). These units account for about 40% of the total industrial production and 35% of total exports. It is estimated that the small-scale industries and micro enterprises together contribute 7% to Gross Domestic Product (GDP) in Indian economy (SIDBI 2002).

A large number of enterprises in the small-scale sector are highly energy consuming. Coal, coke, charcoal, biomass, diesel and furnace oil are the major fuels used in this sector. Expenditure on fuels takes a major share of their total expenditure. In recent years, the prices of fossil fuels have been increasing steadily. For example, the diesel price in India has more than tripled in the last ten years.

Fuel wood, charcoal and other biomass fuels are used in small and medium-scale industries such as textile processing, brick making, lime production and food processing industries. Many of these industries use outdated and energy inefficient devices. Given the impacts of increasing population, economic growth, industrial production, the demand for wood and biofuel is expected to increase. One of the important aspects of sustainable harnessing of biomass as energy source is through its efficient conversion and by increased end use utilization efficiency. Biomass gasifier based thermal appliances can facilitate more efficient use of traditional fuels in small and medium scale industries.

3.1 Thermal energy needs of SMiEs

Thermal energy need of an enterprise varies over a wide range of temperatures (from ambient upto metal melting temperature of 1500-1600ºC) depending upon the type of industry, type of application and type of process adopted for given application. In general the thermal energy needs of SMiEs can be categorized as follows:

3.1.1 Low temperature applications:

Water boiling:

Majority of small scale unorganized enterprises need process heat in the form of boiling water which in turn can be used for cooking food, cocoons, etc or for dyeing fabric, etc. Even some large industrial applications such as magnesium chloride production is basically boiling bittern to evaporate water to get fine $MgCl_2$ flakes as finished product. Here temperature requirement are lower i.e. upto boiling point of liquid however capacity varies from very small pot of few litre capacity for cooking food, to medium size applications like dyeing or large scale cooking (with vessels of 100-200 litre capacities) to very large size pots like $MgCl_2$ production (having 8-10ft diameter)

Dryers:

This is another low temperature (temperature requirement 110 – 130ºC), which is used to remove moisture (drying process) from variety of farm products, food and spices (like rubber, tea, coffee, cardamom, tobacco, food and chemical products, etc).

Boilers:

In several chemical process industries, agro-processing industries, dairy industries and textile industries and even on tiny scales in tyre retreading, cooking, low-pressure steam is used in SMiEs. Here also since most of the steam boilers in SMiEs are non-IBR type they operate with low steam pressures and therefore temperatures. However fuelwood (in many cases furnace oil, diesel or LPG is also used as fuel) input to boiler varies from few kg/hr to quintals/hr depending on tiny to large sized boilers.

3.1.2 High temperature applications:

Kilns:

In several industries various types of kilns are used for baking of tiles, bricks, and potteries or for heat treatment purpose (such as hardening, annealing etc). Normal temperature requirements for such applications are in the medium range viz. 800–950ºC).

Furnaces:

This application requires high temperature range (1500-1600ºC) for melting metals in foundries, glass-melting industries etc. Relatively lower temperature requirements (~650-1000ºC) are theirs in furnaces for alloys in non-ferrous, or scrap melting-reusing (such as copper, aluminum, lead industries).

In order to meet energy demand, all industries burn fuel in one form or the other. As per the estimate about 28% of the enterprises use firewood, 8% of the enterprises use charcoal and a large population of enterprises uses fossil fuel as the main source of energy.

Fossil fuels such as coal, and petroleum-based fuels such as kerosene and diesel, are generally used in urban areas due to their easy access and difficulty of using biomass due to their smoky operation. Hence, a large proportion of urban SMiEs depend on such fossil fuels for energy despite their rising prices.

3.2 Assessment of traditional technologies for thermal energy needs

This section presents an assessment of traditional/conventional technologies still being used by various SMiE clusters for their thermal energy needs. Since the technology varies significantly from cluster to cluster, depending on product and process requirement, here effort is made to discuss the common categories from the selected niche market clusters of SMiEs.

3.2.1 Traditional stoves and ovens

This is one of the most common technology/device commonly used in many SMiEs in which large stoves, ovens are used essentially for boiling water (or chemicals/solvents in some cases). Examples include silk reeling units, textile dyeing, chemical process industries, large scale cooking, etc. It can be single pot or multi pots. Wood logs are burned in these stoves while some smaller units also go for locally available loose biomass. In many cases like puffed rice units, charkha silk reeling ovens where high power levels or instantaneous variation in power levels are required, loose biomass is still preferred (and in some cases like puffed rice making supplementary fuels like used tyre strips are burnt) over solid fuel in spite of the fact they are more polluting resulting in poor working conditions. Normally, it is observed through several energy audits, that operating thermal efficiencies of these ovens is quite low of the order of 5-15% and major share (almost 30-50%) is due to hot flue gases.

3.2.2 Open firing

Still age-old open fire stoves (with large opening of combustion chamber) are being used for various applications in SmiEs. For example in many drying applications fuel is burned in open *bhatti*s and hot flue gases are used for drying of produce. In arecanut processing units (in costal Karnataka, Kerala and Assam) and large-cardamom curing chambers (*bhatti*s) (in north eastern state of Sikkim) produce is spread over wire mesh or bamboo mats and firewood logs are burnt in open fire below it. The operating efficiency of such drying systems is very low of the order of 3-12% depending on construction of *bhatti* structure due to substantial heat loss from large opening of combustion chamber through radiation mode. Open fire of the wood logs also makes the entire local environment too smoky causing health hazard. Uncontrolled fire of open fire results in poor quality produce (charring or blackening of product and over un-uniform drying).

3.2.3 High temperature closed kilns/furnaces

These are relatively little advanced/special SMiE applications in which the enclosed space is heated to very high temperatures of the order of 600-1200ºC depending on process requirements. The chamber needs to be highly insulated with thick firebricks walls. Common usages in this category include metal melting (copper, aluminium, steel), steel re-rolling, baking ovens (ceramic tiles, pottery, bakeries), kilns (lime, plaster of paris, brick). Normally fossil fuels such as coal, diesel, furnace oil, natural gas etc are used apart from biomass in some cases. The operating efficiencies of traditional furnaces is quite low (below 15-20%) and thermal mass and hot flue gases contribute to major fraction of heat losses.

3.3 Gasifier thermal systems for biomass using industries

Most of the biomass-consuming industries are located in rural or peri-urban areas. An estimated 20 million tonnes of biomass is used in traditional and rural enterprises. Table 4 gives specific fuel consumption in few selected SMiEs.

Table 4 Firewood consumption in industries/enterprises in India

Industry	Specific firewood consumption (approximate)	Total firewood consumption per annum (estimated)
Cremations	300-500 kg per body	4-5 million tonnes
Tea drying	1-2 kg per kg dry tea	0.5-1 million tonnes
Large Cardamom curing	7-10 kg per kg dry cardamom	0.05-0.07 million tonnes
Small Cardamom curing	14-16 kg per kg dry cardamom	0.1 million tonnes
Silk reeling	17-25 kg per kg silk	0.15 million tonnes
Ceramic tiles	0.5 kg/tile	0.2 million tonnes
Brick making	0.3-1.5 kg per brick	9 million tonnes
Rubber sheet smoking	1 kg (per kg fresh latex)	0.06 million tonnes
Tobacco leaf curing	4-10 kg per kg cured tobacco	0.4 million tonnes
Dyeing & fabric printing of sarees & cloth	0.2 kg per m of cloth	1.87 million tonnes
Road tarring	23 tonne per km	0.37 million tonnes

Table 4 Firewood consumption in industries/enterprises in India

Industry	Specific firewood consumption (approximate)	Total firewood consumption per annum (estimated)
Vanaspati ghee	0.67 kg per kg ghee	0.63 million tonnes
Fish smoking	0.2-1.6 kg/kg	0.02 million tonnes
Lime making	0.5-2.0 kg per kg limestone	100 tonnes
Distilleries	0.2 kg/liter	0.6 million tonnes

Source: Srinivas, S.N., Biomass consumption in unorganised enterprises in India, Wood Energy News, Vol. 11 No. 2, June 1996.

3.3.1 Gasifier selection sizing and cost economics for biomass using industries

In India for thermal applications fixed grate gasifiers (both downdraft and updraft) are used. Choice of gasifier and fuel combination so far is quite mixed and almost all combinations are being tried, manufactured and sold in the market by various manufacturers. However updraft gasifiers are recommended where one has to have little more fuel flexibility compared to downdraft gasifier with regard to its size and moisture content. Updraft gasifers are normally used when gas is not required to be carried over long distance and is to be burnt immediately on production. Also as mentioned earlier down draft gasifiers are used where more clean gas is required (like food processing industry) where slight exposure of gas can damage the product adversely. Also as mentioned earlier downdraft gasifiers are preferred for smaller (upto 1 MWth level) and updraft gasifiers are preferred for large capacities. Also in remote area application and requiring quite steady consistent gas output rate for longer durations (such as drying) natural draft gasifier can be sized accordingly.

In traditional biomass using industry induction of biomass gasifier can help in reducing fuel consumption by 50-60% in most cases or improve efficiency by more than 100% (double). Table 5 gives fuel cost reduction details using gasifier system.

The gasifier size can be calculated based on study of present energy use pattern and process requirements. Figure 3 gives quick monogram to estimate the gasifier size required for solid (biomass/coal) using industries based on following assumption:

- Approximately 60% reduction in heat input rate required while using gasifier system for replacing traditional system
- Gas calorific value (1100 kcal/Nm^3)
- Specific gas production rate (2.5Nm^3/kg biomass)

Table 5. Fuel cost reduction due to gasifier in traditional biomass using industry

Fuel	Price (Rs/kg)	Wood/kg fuel	Wood price (Rs/kg)	Wood cost (Rs/kg fuel)	Fuel cost reduction (%)
Fuelwood	1.5	0.5	2.0	1	33%

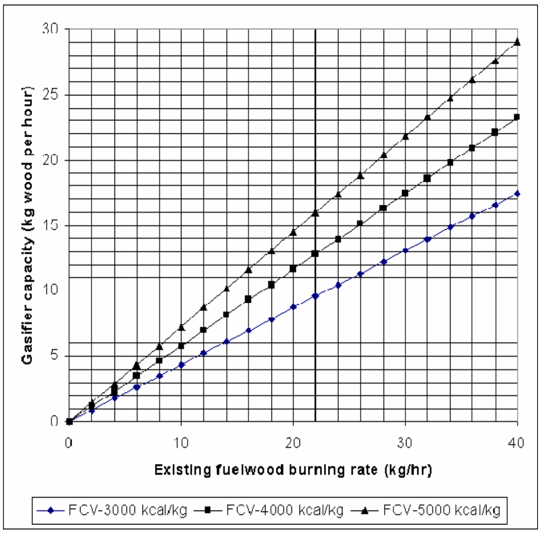


Figure 3 Gasifier sizing for replacing solid fuels

3.4 Gasifier thermal systems for fossil fuel using industries

With continued rising prices of fossil fuels coupled with their scarcity (quota) in open market many SMiEs are facing serious problems in controlling fuel cost and as a result keeping competitive pricing for existence in the market. Gasification technology offers them a option to have all benefits of gaseous fuels using comparatively cheaper solid biomass fuel. Even some larger units are considering switchover to biomass fuel as there is even possibility of getting additional income/revenue through CER/VER as biomass being carbon neutral renewable energy fuels against polluting fossil fuel.

There are a variety of fuel-fired furnaces that are ideal candidates for switching over to producer gas from biomass. Some typical furnaces are:

Forging furnaces

There are about 300 forging units widely spread in India. The forging furnace is used for preheating billets and ingots to attain a 'forge' temperature maintained at around 1200 to 1250°C. Forging furnaces use an open fireplace system and most of the heat is transmitted by radiation. The typical loading in a forging furnace is 5 to 6 tons, with the furnace operating for 16 to 18 hours daily.

Re-rolling mill furnaces

There are over 2000 re-rolling units widely dispersed in the country. The furnaces may be batch or continuous pusher type or steel reheating furnace with operating temperatures of about 900-1200°C.

Fired heaters

Direct-fired process heaters provide heat energy directly to an industrial process without the use of steam or a heat exchanger to heat fluids or solids. Direct-fired process heaters exist in a variety of forms to serve a variety of functions. Examples of industries that use this technology are the food, textile, paper, printing, chemical, rubber, plywood and plastic industries. The food industry uses direct fired process heaters to cook soups, fry, and sterilize; the textile industry uses direct fired process heaters for washing, scouring, and singeing; and the chemical industry uses direct fired heaters to heat liquids.

Dryers

Dryers are used in manufacturing processes by various industries to remove liquid (s) from wet solid. Examples of industries that use dryers are the paper, cardboard, wood and lumber, textile, ceramic, tobacco, plastic, paint, food, and pharmaceutical industries.

Out of various type most easy to switch over is one with indirect heat transfer as here the product is not in direct contact with gases.

Kilns

Primarily the stone and clay industries use kilns to melt and heat different substances. Examples are the gypsum, vitreous china-plumbing fixture, brick and structural clay, and concrete industries. The five above mentioned industries use kilns specifically designed for their needs.

Ovens

Ovens are used by the industry for low temperature (ranging between 20 to 370 degree Celsius) cooking, baking, curing, or to vulcanize (a treatment that stabilizes and adds elasticity) rubber or plastic. The food industry uses ovens to bake bread, cookies, crackers, pretzels, while the rubber and plastic industries use the lower temperature heat produced in ovens in the production of tires, footwear, hosiery, and rubber belts (e.g., fan belts). In general, ovens are direct fired. In a direct-fired oven the heat is generated through combustion of the fuel. Indirect fired ovens are prevalent for applications that may get contaminated with particulate matter in the products of combustion.

Small Boilers

Small sized baby boiler, used at present in many small industries such as food processing and chemical can be retrofitted easily to burn producer gas. Installation of the gasifier helps in replacing the oil, coal or burning biomass for raising steam. As gasifiers are not covered under IBR, it may be favored by the small firms, which are not so comfortable with IBR.

3.4.1 Gasifier sizing and cost economics for replacing fossil fuels

Here also both updraft and downdraft gasifiers can be used easily. For indirect heat transfers (which may require frequent cleaning of heat exchangers) down draft gasifiers are preferred due to relatively cleaner gas with less impurities (tar and particulates) deposition of which not only affects heat transfer effectiveness but also adds difficulty in maintaining. Lager gasifier can be updraft especially where gas is to be burnt immediately at higher temperatures (as burning of gas at temperatures above its condensation adds to calorific value of gas).

In traditional fossil fuel using industry switching over to biomass-based gasifier has major economic incentive with payback periods of as low as 2-3 months depending on investment and fossil fuel price. Table 6 gives the fuel cost reduction details for various fossil fuels by switching over to biomass based gasifier system. Figure 4 gives the quick monogram to estimate appropriate gasifier size (capacity) based on prevailing fossil fuels of different heating values like Furnace oil, diesel, LPG etc. based on following assumptions:

- No change in system efficiency (same)
- Gas calorific value (1100 kcal/Nm^3)
- Specific gas production rate (2.5Nm^3/kg biomass)

Table 6. Fuel cost reduction with fuel switching for various fossil fuels

Fuel	Price (Rs/kg)	Wood/ kg fuel	Wood price (Rs/kg)	Wood cost (Rs/kg fuel)	Fuel cost reduction (%)
Kerosene	20	3.5	1.5	5.25	74
Diesel	38	4	1.5	6.00	83
LPG	25	4	1.5	6.00	76

Note: neglecting small electrical power (0.25-1hp) required for blower

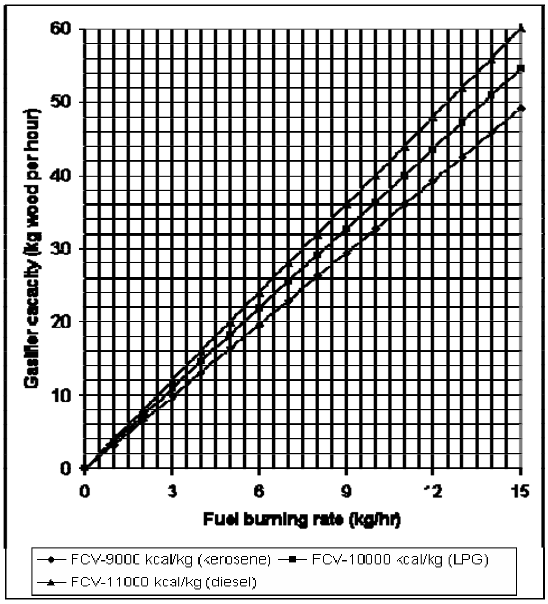


Figure 4 Gasifier sizing for replacing different fossil fuels

Table 7 gives hourly monitory saving for gasifiers of various capacities used to replace different fossil fuels.

Table 7. Monetary savings by replacing fossil fuels with biomass gasifier system

Fuel	Price (Rs/kg)	Hourly reduction in fuel cost (Rs/hr)			
		10 kg/hr	20 kg/hr	40 kg/hr	100 kg/hr
Kerosene	20	42	84	169	421
Diesel	38	73	145	290	725
LPG	25	48	95	190	475

Note: neglecting small electrical power (0.25-1hp) required for blower

4.0 Gasifier based for power generation in India

India has an installed generating capacity of nearly 124 GW gigawatts in March 2006 (CEA 2006). The current annual gross electricity generation in utilities is about 617 BU (billion units). The demand for power was, however, higher and the country experienced supply shortage of 8.4% and peaking shortage of 12.3% in 2005/06. The overall electricity generation in country, which was 513 BU in 2001/02, has risen to 617 BU1 in 2005/06 at a CAGR (compound annual growth rate) of 4.7%.

Captive power generation has shown an increasing trend over the years. According to CEA (Central Electricity Authority), the all-India installed capacity in captive plants increased to 19 102.57 MW. The contribution of diesel, and gas in the total capacity of captive power plants was 7126.86 MW (37.31%), and 2866.40 MW (15.01%), respectively. The electricity generated from captive generating units during 2004/05 was 71.41 BU; the contribution of diesel and gas generation was 12039.86 MU (16.86%) and 15052.05 MU (21.08%) respectively. Recently announced (August 2006) IEP (Integrated Energy Policy) (MoP 2006a) states that sustained growth of 8% is required through 2031 to increase the generation capacity from 160,000 MW to 800,000 MW. Though coal would remain dominant source emphasis is also given for other options like nuclear, hydro, and renewable sources of energy. Rural Electrification Policy (MoP 2006b) aims at providing electricity for all by 2009 and quality and reliable power (minimum lifeline consumption of 1 unit per day per household) by 2012.

With easy availability of biomass residues in India, there exists a tremendous potential for biomass gasifier-based systems for power generation applications. The potential for biomass utilization in general and biomass gasification in particular indicates that, even taking into account the demand for fodder, etc., the biomass available in the country (excluding animal residues) can optimistically support electrical power plants aggregating to a total of 21,000 MW. For using wood 1 MW can be generated from a 3 ha (hectare) energy plantation. Due to accelerated activities in agricultural sectors and agro processing industries and through harnessing sustainable energy plantation on wasteland the explorable potential is as high as 50 000 MW. The sugar industry alone is capable of producing over 5 000 MW of surplus power through bagasse-based co-generation systems.

4.1 Grid Connected gasifier based power generation

In India, generally biomass combustion based large size (few megawatt and above) power plants and bagasse based cogeneration plants are grid connected to supply surplus power to the grid. There was one gasifier based pilot demonstration grid connected plant at gasifier manufacturing facility of ASCENT. Recently one MW gasifier based power plant based on IISc gasifier design has been commissioned near Coimbatore in Tamil Nadu.

For grid interaction dual fuel operation of gasifier for power generation is easier as diesel governor system takes care of fluctuating load to maintain the frequency. In case of 100% producer gas operation governor operation with tar-laden producer poses major maintenance problem and maintaining frequency and synchronization are major barriers for grid interaction.

There for so far gasifier based power generation is used for saving upto 75-85% diesel by duel fuel operation of existing captive diesel genset or for decentralized power generation for remote village electrification.

4.2 Decentralized gasifier based power generation

Biomass gasifiers are ideal for decentralized applications of power generation in rural areas, where it is either too expensive to extend the grid, or the power demand is low. Agro residues as well as biomass from agro-processing industries – such as tobacco waste and cashew-processing units – could be used for power generation using the biomass gasifier. The viability of gasifier power plants is strongly linked to the supply mechanisms of biomass. In many states of India, on account of the poor quality of the grid and its low reliability, industries are forced to switch over to their own captive power generation using diesel. Considering the relatively stable and low price of biomass, it makes a good option to couple these generator sets with gasifiers. Dual-fuel (gasifier and diesel) operating electric power generators thus offer a great potential for fuel saving and decentralized power generation. However, focus has recently shifted to developing biomass power plants that do not consume diesel for operation, and operate solely on producer gas.

At the moment, biomass gasifier systems are being implemented in the country under different schemes of MNRE. These are VESP (Village Energy Security Programme), RVE (Remote Village Electrification) Programme, and biomass energy and cogeneration (non-bagasse) in industrial and urban areas. RVE Programme is the national-level scheme that aims to achieve national electrification targets within the stipulated time frame. The objective of the RVE Programme is to provide electricity through non-conventional energy sources to remote un-electrified census villages and hamlets, where grid connectivity is either not feasible or not cost-effective.

5.0 Estimated potential saving in terms of GHG emissions (from specific opportunities against accepted baseline through 2025)

Indian industries use a variety of fuels for process heat requirements. These fuels can be listed as coal, HSD, Fuel oil (or furnace oil), LDO, naphtha, natural gas, LPG, firewood, and agro-residues. Some of the petroleum based fuels such as naphtha and natural gas are also used as feedstock. An estimate of thermal energy requirements in different segments of Indian industry, with a view of replacing fossil fuels with renewable biomass or solar energy has not been made in recent years. Once quantitative estimates of different fuels are made, GHG emissions can be calculated using IPCC default emission factors. The potential savings in terms of GHG emissions can then be estimated from specific opportunities such as deployment of biomass gasification technologies or solar thermal technologies.

We followed two different methods for estimating fuel consumption figures and projections. The first method used a MARKAL model employed in preparing the National Energy Map of India [TERI 2006], with business as usual (BAU) scenario. The second method used available CMIE data for consumption of different petroleum fuels and assuming certain fractions for heat generation. The assumptions for these fractions are based on discussions with senior officials of Indian Oil Limited (IOL). In both the methods, the following large industries are not considered either because the quantities consumed are too large to be replaced by biomass, or because the fuel is used as feedstock. These industries are: Iron & Steel, Cement, Pulp and paper, Caustic soda and Soda ash, Aluminum, Textiles and Fertilizers. The MARKAL model gives projections of all fossil fuels except firewood, which is used primarily in micro enterprises and unorganized industries. Specific wood consumptions and estimates of annual consumption levels are available from a limited amount of field data for selected small enterprises such as brick and tile making, food drying, textile dyeing, bakeries, sericulture, cremations etc. These are then projected for future. It should however be noted that wood or biomass consumption for industries is steadily declining due to factors such as difficulty of obtaining wood due to Supreme court ruling prohibiting cutting of trees and transportation of wood fuel and increased availability of petroleum fuels in general and natural gas in some regions. Specifically, process heat requirements for tea industry in the northeast are now almost exclusively met by natural gas instead of fuel wood a few years ago; many bakeries and *halwais* have shifted to LPG or diesel; and electrical or diesel based crematoria are now becoming common in many cities.

There is considerable variation in the estimates of crop residues for current production, future projections and fractions available for gasification. Ravindranath estimated the residue production figures as 626.5 and 840.6 million tons (air dry) for the years 1996-97 and 2010-11 respectively (Ravindranath 2005). These figures yield an annual growth rate of 2.12%, which is close to the projected agriculture GDP growth rate. It should also be noted that the net-cropped area is constant at about 140 m ha, but the gross cropped area is increasing at an annual rate of about 0.4% from 168.6 m ha in 1996-97 to 178.2 m ha in 2010-11. The MARKAL model also gives an annual growth rate of 0.43%. The higher growth rate for residue production would thus have to be attributed to increased fertilizer use, better irrigation and better pesticide management. The biomass atlas prepared by CGPL at I I Sc Bangalore from Taluka level assessments of MNRE gives lower values for biomass production, but include woody biomass such as eucalyptus. It takes major states into account but does not include all states. It also gives estimates of biomass available for energy production, based on current use patterns of biomass for other applications such as fodder. The different estimates of biomass are shown in Table 8.

Table 8. Biomass availability estimates

Year	Biomass estimates (million tonnes)		
	Ravindranath	Biomass atlas IISC	
		Production	Surplus**
1996-97	626.50		
1998-99	653.35*	546.42	139.36
2004-05	740.98*	618.99*	157.86*
2010-11	840.60	701.19*	178.83*
2024-25	1127.26*	937.99*	239.22*

Notes:

* Projections based on 2.12% annual growth (same as Ravindranath's two year values)

** Surplus biomass fraction assumed constant as given in biomass atlas of IISc for year 1998-99

Source: http://lab.cgpl.iisc.ernet.in/CropReport/Default.aspx accessed on 15 September 2007

The fuel consumption estimates and the corresponding emissions obtained from the modeling exercise are shown in Table 9. It is apparent that the highest contribution to CO_2 in 2026-27 comes from coal burning, followed by, fuel oil, naphtha, LDO, LPG and natural gas. Discussions with oil specialists indicated that fuel oil is burnt also for captive power generation and only about 50% goes for general trade for process heat. Also, naphtha is being phased out due to its high cost. LDO consumption goes mainly for low speed engines and very little goes for burning. The model predictions thus seem to be on the higher side. The final estimates for fuel consumptions and emissions, which include wood fuel consumption, also are shown in Table 10 and Table 11 for the base year 2004-05 and projections for the year 2024-25 respectively. As noted earlier, use of wood seems to decline, and hence its use is assumed to be constant through 2025. Values of biomass required to substitute fossil fuels completely are also shown in the table, assuming a replacement value of 3.64 kg wood for 1 kgoe. Table 12 gives the emission reduction scenarios under following two scenarios considered:

Scenario-I

Gasifier penetration to reduce consumption

- 25% in furnace oil, LPG, wood using &
- 10% in coal using and captive diesel generation

Scenario-II

Gasifier penetration to reduce consumption

- 50% in furnace oil, LPG, wood using &
- 25% in coal using and captive diesel generation

Table 9. Industrial thermal energy needs: Markal Model projections

Year	Fuel consumption (million tonnes of oil equivalent)							
	Coal	Diesel	Fuel oil	LDO	Naphtha	Gas	LPG	Total Industrial thermal
2001-02	19.93	4.47	8.47	1.44	8.32	4.72	1.18	48.54
2006-07	30.26	4.87	12.18	2.08	12.04	4.96	1.80	68.19
2011-12	48.04	4.70	17.57	3.02	17.46	5.20	2.67	98.65
2016-17	75.12	3.40	25.37	4.38	25.31	5.47	3.81	142.86
2021-22	117.81	0.00	36.63	6.34	36.67	5.76	5.30	208.52
2026-27	183.41	0.00	52.93	9.19	53.17	6.09	7.22	312.01
Year	GHG emissions (million tonnes of CO2)							
	Coal	Diesel	Fuel oil	LDO	Naphtha	Gas	LPG	
2001-02	78.92	13.88	27.45	4.47	25.54	11.09	3.12	164.47
2006-07	119.87	15.12	39.47	6.45	36.94	11.64	4.76	234.25
2011-12	190.29	14.58	56.94	9.36	53.57	12.22	7.05	344.01
2016-17	297.51	10.55	82.22	13.58	77.67	12.84	10.08	504.45
2021-22	466.61	0.00	118.72	19.67	112.55	13.53	14.01	745.10
2026-27	726.42	0.00	171.51	28.52	163.16	14.30	19.08	1122.99

Table 10 Industrial process heat and captive power generation: for base year 2004-05 fuel consumption, emissions, and biomass required for completely replacing fossil fuel

	Fuel Consumption[f] (million tons)	Emissions[g] in million tons for 2004-05				Biomass required[h] (million tons)
		CO2	CH4	N2O	CO2 equiv	
Furnace Oil[a]	5.0	15.464	0.000599	0.000120	15.514	14.73
LPG[b]	1.2	3.479	0.000055	0.000006	3.482	4.53
Coal [c]	50.5	109.787	0.001161	0.001741	110.351	99.16
Biomass [d]	20.0	0.0	0.010037	0.001338	0.626	

Total thermal		128.7	0.011852	0.003204	130.0	118.42
Diesel for [e] captive power	3.5	11.104	0.000450	0.000090	11.141	20.10
TOTAL (Thermal + power)		139.834	0.012	0.003	141.113	138.52
Surplus biomass availability (million tons) IISc Biomass atlas projections (refer table 8)						157.86

Notes:
a Furnace oil for industry and other industries only
b LPG for commercial use only
c Coal for other industrial use
d Fuelwood for SMiEs for heat applications in unorganized sector
e Diesel consumption for DG set captive power generation
f fuel consumption data from CMIE-Energy 2006
g Emissions based in IPCC default emission factors
h biomass required fro completely replacing fossil fuels use

Table 11 Industrial process heat and captive power generation: BAU scenario 2024-25 for fuel consumption, emissions, and biomass required for complete replacing fossil fuel

	Fuel consumption[f] (million tons)	Emissions[g] in million tons for 2004-05				Biomass required[h] (million tons)
		CO2	CH4	N2O	CO2 equiv	
Furnace Oil[a]	8.3	25.389	0.001002	0.000200	25.922	24.61
LPG[b]	5.6	16.827	0.000267	0.000027	16.840	21.92
Coal [c]	68.9	149.859	0.001584	0.002376	150.629	135.35
Biomass [d]	20.0	0.0	0.010037	0.001338	0.626	
Total thermal		192.5	0.012889	0.003941	194.017	181.88
Diesel for [e] captive power	26.8	85.307	0.003454	0.000691	85.594	154.46
TOTAL (Thermal + power)		277.832	0.016	0.005	279.611	336.34
Surplus biomass availability (million tons) IISc Biomass atlas projections (refer table 8)						239.22

Notes:
a Furnace oil for industry and other industries only (annual growth rate 2.6% tenth plan)
b LPG for commercial use only (annual growth rate 8.2% tenth plan)
c Coal for other industrial use (annual growth rate 1.6% during 1990/91-2004/05)
d Fuelwood for SMiEs for heat applications in unorganized sector (assumed constant)
e Diesel consumption for DG set captive power generation (annual growth rate 6.36% & 10.7% in capacity & generation during 1990/91-2004/05
f fuel consumption data from CMIE-Energy 2006
g Emissions based in IPCC default emission factors
h biomass required fro completely replacing fossil fuels use
i annual growths from last 5-15 years data taken for projections

Table 12. Emission reduction with different gasifier technology penetration rates

Emission reduction scenarios	CO_2 emissions (million tons)	Surplus biomass requirement (million tons)	Surplus biomass availability (million tons)
Year 2004-05	141.1		157.9
Year 2024-25 BAU	279.6	201.9	239.2
Year 2024-25 Scenario-I			
Gasifier penetration to reduce consumption 25% in furnace oil, LPG, wood using & 10% in coal using and captive diesel generation	245.1 (Saving of 34.5)	58.1	
Year 2024-25 Scenario-II			
Gasifier penetration to reduce consumption 50% in furnace oil, LPG, wood using & 25% in coal using and captive diesel generation	198.9 (Saving of 80.7)	110.7	

6.0 Development/Co-benefits of biomass gasification

Biomass gasification has the following co-benefits (Table 13):

- Local employment and income generation

- o During mainstreaming sustainable supply of processed biomass (production, harvesting, processing and transportation)
- o For manufacturing of gasifier systems and sub-components (spare parts)
  - ▪ Manufacturers, entrepreneurs
  - ▪ Local Service Providers for system installation, commissioning
  - ▪ Operation and maintenance of the systems

- ➢ Improved working conditions (less smoke exposure)
- ➢ Enhanced profitability of enterprises due to reduced fuel cost, improved productivity, product quality and processing rates
- ➢ Reduced dependency on import of petroleum products, hence better energy security
- ➢ Improved socio-economic conditions and quality of life due to access to modern bioenergy to remote rural communities for lighting and mechanical applications
- ➢ Enhanced sustainable biomass production has associated local and global environmental benefits due to increased green cover.

Table 13 Development co-benefits of biomass gasification

Development Benefit	***Effects / Impacts***	***Quantification (in 2025)***		
Economic (SMIE) (++)	Reduced energy bill			
Energy Security (+)	Reduction of oil consumption	Fuel	Scenario I	Scenario II
		Furnace Oil	2.07	4.13
		LPG	1.41	2.82
		Coal	6.89	17.23
		Biomass	2.50	5.00
		Diesel	2.68	6.69
Employment (++)	Creation of biomass markets, jobs for equipment manufacture, supply, maintenance, biomass supply, transport, pelletization	300000 direct employment for gasifier manufacturer and operation and 600000 indirect employment in biomass production, processing, supply chain and after sale service		
Access / Equity (-?)	Possible reduction in access for cooking fuel for poor households due to biomass markets			
Others	Reclamation of degraded lands (+) Land availability for food (-)			

7.0 Way forward at the government level

Promotion of biomass gasification in India had been initiated as early as 1980s through activities of the then DNES (currently MNRE). Support was initially through R&D projects, documentation of literature and limited capital subsidies. Later the activities supported by MNES expanded to

- Creation of Gasifier Action Research Programs/Centers (GARP / GARC)
- Creation of Project Investigators' Committee for Coordination of Projects (PICCOP)
- Highly subsidized type testing services for new manufacturers
- 100% subsidy for demonstration projects
- R&D projects tailored to the capabilities and competencies of various institutes

Through another initiative, a taluka level assessment of biomass availability was undertaken for the entire country, and all data/reports generated were handed over to I I Sc Bangalore to prepare a biomass atlas that can be used by prospective industries and entrepreneurs. Details of this atlas are available at http://cgpl.iisc.ernet.in/GISResourceMaps.htm . The national biomass atlas takes inputs from various sources and provides estimates of availability of different biomass resources. However, biomass movement across the borders of a district or state has not been taken into account, hence the atlas has a limited utility.

These initiatives, together with the efforts of individual entrepreneurs and R&D institutes such as TERI, helped in establishing biomass gasifiers as viable alternatives for heat and power applications. Starting with just a handful of entrepreneurs making gasifiers in 1980s, there are currently over 30 recognized gasifier manufacturers in the country and gasifier applications are spreading out to other countries such as Sri Lanka, Myanmar, Thailand and Uganda. Also, very small power (10 kW_e) gasifiers for remote village electrification, which were considered economically and technically unviable earlier, are now being installed through an MNRE program called Village Energy Security Program (VESP). However, there had been some lacunae in MNRE project/program implementation as outlined below.

- Though a large number of gasifier systems exist as per records, there is no mechanism or felt need to document field experiences. A lot of 'informal' knowledge is, however, available through field personnel, visits to specific installations etc, but such information is not quantifiable and carries some personal biases. Reasons for failure or success (technical, economical, logistic, social etc) are rarely collected, analyzed and documented.

- Testing of gasifier systems was always a contending issue. At present there is no agency to test and certify gasifier systems. A preliminary meeting was held at Bureau of Indian Standards (BIS) to formulate standards, but no significant progress has been made since then. Lack of manufacturing, performance and safety standards allows for poor quality installations and subsequent failures.
- The issue of sustainable biomass supply for gasifier systems has never been debated with the seriousness it deserves. Most operating gasifiers depend on purchased firewood, and both the quality (moisture, presence of bark etc.) and price of firewood show considerable fluctuations. This is probably the most important reason for failure (from performance as well as O&M points of view) or short-lived operation of many gasifier systems. Emphasis was largely on wood or wood-like material (such as stalks, coconut shells, mulberry sticks etc.). However, long-term performance with the mythical "wood-like material" is extremely scarce. There had been considerable talk about "powdery biomass" or loose biomass, but this research had been confined to laboratory demos. In spite of recent successes and mainstreaming of biomass pelletisation in Europe, pellets are not considered as a realistic option in India as yet. Similarly, machines for harvesting of biomass or for preparing wood chips on a suitable scale have neither been developed nor re-engineered in the country.
- The important question of mainstreaming of gasifier systems has never been debated in the concerned circle of players. Manufacturers of gasifier systems were, and still are thought of as the prime movers for mainstreaming. However, most manufacturers are essentially fabricators, and gasifier making is a side activity for them. Many of these are happy supplying equipment to whoever orders it, but they are neither interested nor well equipped to do marketing, further product improvisation or risk taking. The added disadvantage is that the intended users of gasifiers are micro or rural enterprises, who are known to be difficult customers (wanting to buy things very cheap, not paying agreed amounts on time, looking for subsidies etc). The other important aspect of mainstreaming, namely financing, is not in place. The financing arm of MNRE, IREDA, did give loans to gasifier installations earlier, but due to poor recoveries it stopped financing gasifiers. The marketing or mainstreaming strategies for gasifier systems thus have to be innovative and will have to evolve through

discussions with all stakeholders including the concerned central and state government departments.

Considering the long and varied experience the country had in development and promotion of biomass gasifier systems, the way forward at the government level can be formulated as follows for different categories of applications.

Gasifier stoves and small capacity thermal gasifiers:

Considering the large potential these devices have for being sold in large numbers, the government should facilitate a number of actions.

1. Help create a sustainable supply chain for both equipment and services in the retail market. There can be a large number of local manufacturers or fabricators to supply gasifiers in a state. Inter-state transport adds to both transportation cost and taxes, hence the need for state level suppliers. Examples of similar devices that are in the retail market are kerosene stoves, LPG stoves, baby boilers, water heaters etc. Creation of an ISI mark for stoves and gasifiers will definitely help in small entrepreneurs and manufacturers take up fabrication of biomass gasifiers. TERI has tried the concept of Local Service Providers (LSPs) in Rajasthan, which can be extended to other states. It has also tried, through one of its licensees, the concept of ESCO to supply both sized biomass and maintenance services to a few end users in Bangalore. This can be tried out in other places and for other end-users. The local governments can facilitate such an activity by providing tax breaks, linkages for financing and for biomass supply.
2. Help create a sustainable supply of gasifier-friendly biomass feed stock which includes sized and dried wood, biomass pellets made from leaves, municipal waste etc, sized lantana, corncobs, mulberry sticks etc. Such biomass materials can be made available in 10 to 50 kg bags at a cost plus or even subsidized price. The biomass can be stocked with retailers (just like charcoal packs sold in supermarkets in developed countries) who stock stoves/gasifiers. Significant efforts would, however, be required to make sized biomass available in retail markets. Biomass sold in such a manner should also be subjected to some quality standards related to moisture content, ash content, calorific value and bulk density so as to create some degree of uniformity among different fuels. A large number of players such as entrepreneurs, tree farmers, rural based NGOs etc would have to be brought into the large network that would

facilitate biomass growth, collection, processing, storage and transport through capacity building exercises, financing, tax concessions etc. Mainstreaming of sized/processed biomass will necessarily be a parallel process to mainstreaming of this class of gasifier systems.

Large, industrial sized thermal gasifiers:

Examples in this category include rubber drying, steel re-rolling, manufacture of plaster of paris (POP), crematoria etc. These systems are more complex, have a high initial cost and require large quantities of biomass for daily operation (1.5-15 tons per day). Hence quality of fabrication, ease of operation and maintenance, safety standards, financing, sustainable biomass supply…all become very crucial. The government can definitely play an important role in facilitating adherence to quality standards and in organizing hassle-free financing. The issue of sustainable supply of biomass is more complex. Firewood should not be encouraged for such applications (except probably cremations) unless there is a clear supply chain, such as tree farmers tying up with industry. In the special case of crematoria, the gasifier system should be seen as an energy saving device and municipal corporations should facilitate supply of sized wood at the cremation site itself. This can be done as a small enterprise also. Considering the huge amount of firewood spent on cremations in India (~3 million tons per year) and the huge savings offered by gasifier system (more than 70%), the government should consider subsidizing gasifier-based crematoria. Biomass briquettes made from agro residues would be the most preferred alternative, especially when biomass is replacing furnace oil or diesel. Considering the oil savings obtainable through replacement with biomass, the briquetting industry should get a lot of encouragement through R&D funding, tax breaks etc.

Decentralized Power gasifiers for Rural Electrification:

These are located in remote rural areas that do not, and are not likely, to have access to electricity in near future. The capacities are necessarily small (10-20 kW_e) as the load is mainly limited to lighting for about 5 hrs. Even if small loads are added in due course, they would be day time loads and hence would not call for a fresh capacity addition. Examples in this category are the VESP of MNRE and the rural electrification program of NTPC. Biomass supply is not seen as a problem at present as many villages are located in forest areas and the quantum of biomass needed (about 2.5 tons per month) is not considered as threatening for deforestation. In addition, programs such as VESP plan to grow the required amount of biomass on wastelands or panchayat lands. Solar photovoltaic systems were, and are still a favored option because of ease of installation and maintenance, but these are expensive and are not amenable to productive use applications such as flour mill, oil mill etc. Gasifier systems, on the other hand, operate at a very low load factor (if used only for lighting) and are eminently suitable for load addition without extra investment.

The real issues related to technology, economics, social acceptance, biomass sustainability etc. would come to the fore during the current phase of implementation of VESP and NTPC programs. It would thus be premature to suggest a way forward in this category of gasifier systems. However, based on the preliminary first hand knowledge gathered during execution of a few projects, the following observations and suggestions can be made.

- The program should build up a strong social component by involving grass root NGOs right from the design stage. Financial allocations should be made to keep the social component alive and vibrant so that the economic and social benefits of the program can be maximized to the extent possible.
- The program should be integrated with other ongoing programs of the government such as the Rojgar Yojana etc. so that available funds for income generation can be channelized so as to maximize benefits to the target population. For example, supply of biomass for the power plant and regular operation and maintenance of the plant can be made eligible under minimum employment guarantee scheme. Also, programs such as installing IT kiosks or rural telephones should give preference to villages in which rural electrification projects are going on. A lot of planning and integration among different government agencies would be required for this.
- The program currently requires a lot of training of local youth on operation and maintenance issues. The training can be expanded to include village level self-help groups or NGOs and to cover aspects of electricity-based income generation, biomass cultivation, indoor air pollution and health and entrepreneur development.
- The gasifier systems currently being installed require a lot of maintenance due to high amounts of tar and particulates, wear and tear of engines etc. These can be considerably reduced by improving the technology and by introducing suitable instrumentation and control systems. R&D funds should thus be made available for continuous improvement of the power generation system.

- Though the rural people welcome introduction of electricity for lighting enthusiastically in the beginning, they soon start comparing gasifier electricity to grid electricity. They start demanding power throughout the night or for appliances such as fans. Considerable discussion and brainstorming would be needed, involving the beneficiaries, program managers, NGOs and government agencies to resolve this problem effectively.
- The current rural electrification programs have a very high subsidy component. Ways and means of replacing subsidies with soft loans should be discussed sooner rather than later. Concepts such as Rural Independent Power Producers (RIPPs) could be debated so that a few plausible solutions evolve in future.
- Preliminary calculations show that, with suitable load factors and biomass costs, gasifier electricity (delivered costs) can compare reasonably well with grid electricity. This and other related aspects of rural electrification should be debated thoroughly at the highest policy making level so as to realize the future prospects and benefits of Distributed Power Generation and/or Micro Grids as strong contenders for centralized grid system.

Biomass gasifier power plants for use by enterprises/industry

Examples in this category include power gasifiers installed in rice mills, tea estates, etc. with capacity range of 100-1000 kW_e. Many such systems are reported to be operating in West Bengal, Tamil Nadu, Karnataka and other states. The operation and maintenance issues of these systems, such as engine breakdowns, wastewater disposal, safety aspects etc are seldom known, except to those who made site visits. Rice husk based power gasifiers make eminent techno-economic sense. However, the technology has not been thoroughly evaluated and substantiated through field data so far, though there are strong claims from manufacturers. The first task would thus be a thorough survey of existing systems and collection of performance and field data, followed by analysis of technical and operational problems. An R&D program can then be initiated, if necessary, to find suitable solutions pertaining to use of loose biomass.

<u>Grid-connected gasifier systems:</u>

There are very few examples in this category (probably only one existing and a few coming up in the BERI project). Gasifier systems are, however, integrated into existing diesel grids, for example, in Sunderbans islands. At present gasifier systems are seen as too small in capacity to be grid integrated. In Indian grids, power plants of 10MW and above are considered grid-worthy and many decentralized systems based on wind, small hydro, biomethanation, cogeneration and biomass power (combustion) are already grid connected. A 10 MW gasifier power plant does not seem to have any special economic advantages compared to the combustion system. In fact, the steam turbine mode via the combustion route is well standardized in terms of design, operation, maintenance and costs. The biomass combustion power plants, however, attracted criticism that the requisite biomass is not available for sustainable operation. Biomass gasifier systems in the range of 500-1000 kW are currently believed to be feasible for grid connection. The biomass requirements (500-1000 tons per month) are thought of as feasible (in comparison with combustion based plants), especially if tied up with agents supplying prosopis juliflera and similar fast growing species. The economics of such plants are especially attractive, as they can operate with a high power factor, besides providing electricity to needy rural areas. In addition, the waste heat from engines can be used for crop drying, desalination or cold storage operations (via the absorption or adsorption route), in which case the economics would be even more attractive.

The way forward in this category is essentially to brainstorm the pros and cons of grid interactive gasifier systems in terms of technology, economics, energy independence, resource utilization, social benefits etc.

8.0 Way Forward in the Private Sector

In the context of biomass gasification, the private sector can be classified as a) manufacturers, b) service providers and biomass suppliers, and c) users. These categories will be discussed separately.

Manufacturers: Most gasifier manufacturers in India are small entrepreneurs in terms of turnover, bidding capacity etc. For example, a recent World Bank bid for supply of gasifier systems for Uganda got only two applications. Only a few have technical back-up support from R&D institutions and the rest try to develop hardware on their own or try to "re-engineer" technology. While manufacturers in other renewable energy areas such as wind and photovoltaic have associations of their own, gasifier manufacturers do not have a common platform to dialog or to share information. And large and reputed thermal engineering firms such as Thermax have not entered the field yet. On the other hand, large multinationals, especially those that make gas engines have started showing interest in gasifier systems recently. As the gasifier market is still dominated by subsidies and adherence to L1 (preference for lowest bidder) culture, many suppliers try to cut corners in materials, resulting in compromise in quality or system life.

The way forward for the gasifier manufacturers is thus to come together on a common platform and discuss ways and means to sort out problems of technology, quality control, government support etc.

Gas engines or turbines are a crucial part of the complete package for power generation. Engine manufacturers have been shying away from giving guarantees on engine performance for producer gas operation, but this situation is changing. Also, some entrepreneurs with expertise on engines are now offering services for conversion of diesel engines to 100% producer gas operation or for maintenance of producer gas engines. Almost all leading engine manufacturers such as Kirloskars, Greaves and Cummins claim to supply engines for producer gas operation, though in reality only a few have been tested for performance over long periods. In view of the emerging interests of the engine manufacturers, it seems highly desirable that they also share a common platform of the gasifier manufacturers to address the issues of gas quality, life of engine parts, servicing of engines and future R&D needs for development of engines tailored to use producer gas.

Service providers and biomass suppliers: This group of private players consists of agents acting on behalf of manufacturers, consultants, briquetting manufacturers, tree farmers, financing companies and NGOs. These play a crucial role in the overall mainstreaming and sustainable operation and maintenance of gasifier systems. As of now, there had not been many attempts to bring together these groups so as to highlight their roles, or to discuss means of integrating them at a regional or state level. A few training programs for groups consisting of manufacturers, LSPs and possible entrepreneurs had been conducted by TERI in Delhi, Rajasthan and Karnataka, and it is being increasingly felt that there is a need to conduct many such awareness and training programs. There is also a need to conduct initiation and awareness programs especially for possible biomass suppliers, NGOs and forest officials at regional and state levels. This initiative would have to be taken jointly by manufacturers and institutes working towards promotion of biomass gasifier systems.

Users: The best way to classify the users of thermal gasifiers is by industry category or by cluster. For example, there can be a category of users doing aluminum melting or those involved in mid-day meals etc. A large number of user groups in various states is already identified by TERI in an SDC funded project, especially for the states of Rajasthan and Karnataka. The way forward for this category of users is to first sensitize them on issues of environment, energy security, and economic advantages of gasifier systems. Such sensitization is best done around a demonstration cum awareness program. However, such programs should be well planned and gasifier manufacturers and marketing people should go with well-packaged offers for prices, financing, biomass linkages and maintenance services. In special cases, users can also influence government policies for promotion of gasifier systems in a particular sector. This has happened, for example, in the rubber drying industry, leading to formulation of a subsidy package for gasifiers by the Rubber Board in Kerala.

The users of power in remote villages have special training requirements covering many social issues apart from technology, maintenance and economic issues. For example, it has to be shown that overall economic benefits, creation of livelihoods, improvement of quality of life etc. would have to be balanced against opting for free electricity which may not be available when needed or in quantities required. The way forward is thus a massive program for sensitization at village or sub-regional level involving farmers, village leaders etc.

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Development Benefits of Clean Energy in India Advanced Biomass Energy Technology for Cooking

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Biomass Energy Technologies for Cooking
Executive Summary

Introduction: Biomass fuels are presently estimated to supply cooking energy to about half the world's households. The Indian National Sample Survey Organization reports indicate that biomass fuels are predominantly used for cooking in rural India and analysis of income-based LPG penetration in India indicates that biomass fuels will continue to provide cooking energy for a large part of the Indian population in the near-term. Currently used biomass energy technologies (CBETs) for micro-level cooking applications (households and institutions), are largely mud stoves along with some metal, cement and pottery or brick stoves, that directly burn wood, crop residues and dried animal dung. They have low thermal efficiency and significant emissions whose exposure has been linked to health effects including respiratory and heart ailments, tuberculosis and blindness [Smith and Mehta, 2003]. CBETs also have significant emissions of long-lived (CH_4 and N_2O) and short-lived (CO and non-methane hydrocarbons - NMHCs) greenhouse gases (GHG) [Zhang et al., 2000]. Emissions of black carbon (BC), attributed recently to CBETs [Venkataraman et al., 2005] leads to significant warming of the lower atmosphere and alteration of water budgets on a regional scale, an important element of climate vulnerability especially in south Asia.

Baseline fuel use, or direct combustion of wood, crop residues and dried animal dung in CBETs, and dung in biogas digesters is estimated at 380 MT y^{-1} [Habib, 2005]. Rural penetration of LPG, currently 5%, is expected to increase six fold by 2025 [Planning Commission, 2006], offsetting biomass fuels. However, increases in population, would drive biomass fuel demand to 430 MT y^{-1} in 2025 [Planning Commission, 2006]. For institutional cooking, aggregate fuel consumption estimates are not available. Fuel use data for the government sponsored mid-day meals programme for schools, show a large state-wise variation in choice of fuels (primarily LPG and firewood), with several states reporting high levels of firewood use.

Promising Advanced biomass energy technologies (ABETs): Promising ABETs for household cooking include (a) direct combustion advanced stoves (with design innovations like a "rocket zone," or double-walled or ceramic-lined combustion chamber), (b) gasifier stoves and (c) biogas technology. Direct combustion and gasifier ABETs have the potential for about 2 times higher efficiency, 4 times reduction in emissions of particles (important from health effects perspective) and greenhouse gases regulated by the Kyoto Protocol, on a per MJ of useful energy delivered (see Table A1 in the Appendix). Biomass gasifier stoves using biomass pellets/ chips as fuel are being tested by several corporate organizations, research institutes and NGOs. Typical thermal efficiencies of 30-35% have been reported and the technology shows promise. Biogas technology is particularly attractive with about 4 times higher efficiency and 20 times reduction in emissions compared to direct combustion of cattle dung. Cattle dung is the feedstock for the existing 4 million biogas plants. New biogas technology packages based on green vegetable feedstock and kitchen waste have been pilot tested. Detailed field testing results are required for estimating the potential of new biogas technology packages and gasifier stoves. Plant oil stoves and ethanol stoves are two other possible ABET options, however, experience and data on them is very limited and is not sufficient to consider them as promising options at this point of time. Except dung-based biogas technologies, all the other ABETs need substantial R&D, field testing and customizing for user need. There is also need for strict product specifications and a testing and certification programme based on well established methodologies.

Potential ABETs for institutional and commercial cooking, which have been successfully demonstrated are: biomass gasifier stoves, direct combustion biomass stoves and biogas plants based on dung, vegetable matter and kitchen waste. Apart from biomass energy options, Scheffler solar cookers, based on solar concentrator technology have also been used for institutional cooking. Some of these options are close to being commercialized.

Potential for fuel savings and GHG emissions reduction: Evaluation of ABETs for fuel savings and GHG emissions reduction indicates the potential for substantial gains. For example, consider a 50%:50% technology-mix of ABET:CBET for household applications in 2025, whereby 50% cooking energy from current CBETs (wood and crop residues), is provided by advanced stoves and gasifier stoves, and 50% cooking energy from direct CBET combusted dung is supplied by biogas digesters.

- Estimated biomass use under such a scenario is 306 MT y^{-1} in 2025 (compared to the projected 430 MT y^{-1} under a business as usual CBET mix), because of energy efficiency improvements (see Table A1), comprising a 29% reduction in biomass fuel use.
- An illustrative scenario is considered, of interest to energy security and offsetting LPG imports with clean biomass fuels. Current LPG consumption in India is around 11 MTy-1 with LPG imports of 2.5 MTy^{-1}. Offsetting 1 MT y^{-1} of LPG consumption, would need 4.3 MTy^{-1} of ABET combusted biomass fuels, available readily based on the current biomass availability calculations.

The current Indian national communication to the UNFCCC allocates only 35 MT CO_2-eq y^{-1} of CH_4 emissions to residential biomass energy. Global warming potentials (GWP) calculated on a 100-y time frame, for long-lived GHGs, short-lived species like CO and NMHCs [IPCC, 2001], and more recently for BC aerosols [Bond and Sun, 2005] provide a framework for integrated assessment of the climate impact of technologies based on their emissions of GHGs and aerosols. Using the published emission factors summarised in Table A1 and published GWPs for pollutants discussed above, we project Indian GHG emissions from household biomass combustion based on three emissions scenarios, for 2005 and 2025 for the business as usual and 50%:50% end-use energy delivery by a mix of ABET:CBET described above, and LPG substitution by ABET combusted biomass fuels.

- Scenario I – Kyoto GHGs only and all fuel harvested renewably: Reduction of 36 MT CO_2-eq y^{-1}.
- Scenario II – All GHGs and BC – all fuel harvested renewably: Reduction of 134 MT CO_2-eq y^{-1}.
- Scenario III – Fossil CO2 offset by 1 MTy-1 LPG substitution using ABET combusted biomass fuels: Reduction of 3.1 MT fossil-CO_2 y^{-1}.

Strategy for ABET promotion:

Currently, clean cooking energy for the rural population is entirely excluded from government policies and programmes in the energy, environment and health sectors, representing the biggest barrier in the promotion of ABETs. The National Programme on Improved Cookstoves (NPIC) has been withdrawn a few years back and support for biogas programme has seen a cutback. Recent market-based pilot initiatives by corporate organizations and NGOs on clean biomass cooking energy show promise, but suffer from limited geographical coverage and reach. The current thrust of Government policies and programmes for rural energy, during the ongoing 10^{th} five year plan and proposed 11^{th} five year plan, is overwhelmingly focused towards building electricity infrastructure.

Targeting subsidies for cooking energy: The Government of India continues to administer LPG prices for domestic liquefied petroleum gas. As a result, domestic LPG prices are substantially lower than the real market price for LPG. The under-recoveries on account of administered LPG prices added up to over Rs 28,000 crore (US $ 7 billion) during 2006-7 [ET, 11 September 2007]. The present LPG subsidy system which delivers a subsidy of Rs 1200-1500 per household per year, largely benefits the urban non-poor. A strong case has been made for withdrawal of this subsidy [PC, 2006] and retargeting to economically weak sections. LPG is currently used by 5% of rural households, with its penetration limited by factors other than affordability. Therefore, retargeting the LPG subsidy must include clean cooking energy options, other than LPG, to reach a significant fraction of the rural population. The money made available from better targeting of the LPG subsidy, should be used for a national initiative for advanced biomass energy technologies for micro-scale cooking applications. The main features of this initiative could be:

5. *Targeted technology development:* Some of the priority areas of the technology development programme would be: development of direct combustion advanced stoves, fine-tuning of gasifier stoves, field testing and development of non-dung based biogas plants, testing and development of machinery for pelletizing and briquetting. A technology development programme with clear time bound goals is needed. The programme should aim at bringing together all the available expertise in academic, public, NGO and private sectors.
6. *Subsidy to end-users:* A capital subsidy of 50% on all ABETs for domestic applications, needed to overcome the capital cost barrier. At the current prices, this would result in a 50:50 cost-share between the user and subsidy provider, with cost to each of around Rs 500 for an advanced stove, Rs 1500 for a gasifier stove and Rs 6000 for a biogas plant. In addition, a fuel subsidy is required for very poor households, for purchase of processed biomass fuel.
7. *Enterprise development:* Providing interest subsidy, along with technical support, to facilitate development of enterprises for (a) manufacturing, installing and servicing ABETs, and (b) supplying processed fuel e.g. pellets for gasifiers. Monetising reductions in GHG emissions through carbon finance routes must be integrated into enterprise development. Quick gains and capacity building, through a targeted programme for ABETs in institutional and commercial cooking would be very useful for a larger effort focusing on households.
8. *Testing, quality control and certification:* One of the main reasons for the success of the Chinese improved cookstoves programme is attributed to the effective monitoring and quality control components. Thus, testing, quality control and certification should be an important element of the new initiative.

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Appendix

Table A1: Emissions factors in g of pollutant emitted per MJ energy delivered

Cooking technology/fuels	**Emission factors (g MJ delivered $^{-1}$)**							**Efficiency (%)**
	CO_2	**CH_4**	**N_2O**	**CO**	**NHMC**	**PM**	**BC**	
CBET /wood[a,b,c]	520.6 ± 20.1	2.44 ± 1.3	0.07 ± 0.03	30.8± 10.2	4.0.± 0.8	0.9± 0.4	0.2 ±0.02	18±7
CBET / dung[a,b,c]	880.3 ± 41.09	7.0 ± 7.0	0.3 ± 0.01	35.2 ±15.1	24.1± 3.8	1.08±0.4	0.08	13±3
CBET / crop waste[a,b,c]	677.1 ± 74.7	5.73 ± 5.5	0.08 ± 0.04	37.8± 10.1	10.6 ±5.5	2.5 ± 1.9	0.4±0.3	11±2
Anaerobic digester /biogas	142	0.10	0.01	0.19	0.06	0.05	0.01[e]	55
Gasifier /wood	275[d]	0.30[d]	0.06[d]	5.0[d]	0.3[d]	0.20[d]	0.08[f]	38
Direct combustion ABET / wood[e]	275[d]	0.30[d]	0.06[d]	5.0[d]	0.3[d]	0.20[d]	0.08[f]	38
Gas burner / LPG	118	0.002	0.006	0.6	0.7	0	0	57

[a]from Smith et al. [2000]
[b]from Venkataraman et al [2005]
[c]from Habib et al. [2005]
[d] Uma, 2004
[e] assumed same as gasifier
[f] from measured PM and BC/PM ratios in Venkataraman et al. [2004]

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Advanced Biomass Energy Technology for Cooking

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Executive Summary

1.0 Background and issue/problem introduction:

Biomass fuels are presently estimated to supply cooking energy to about half the world's households. An estimate of long-term trends in global biomass fuel use indicates stable global use from 1850-1950 (at about 1200 MT per year) and increasing, only after 1950, in response to population growth in the developing world, to 2460 MT per year during 2000 [Fernandes et al., 2007]. The Indian National Sample Surveys [e.g. NSSO, 2005] indicate predominant biomass fuel use for cooking energy in rural households, with 76% using firewood and chips, 11% using dung and 5% liquefied petroleum gas (LPG). Analysis of the penetration of LPG [Ailawadi and Bhattacharya, 2006; Bhattacharya, 2006] shows significant (~50%) use only in states with per capita income above Rs 50,000. Further, even high income rural households continue to use substantial amounts of firewood. This indicates that factors other than income, possibly including reliability of the fuel-supply chain and competing expenditures on capital household goods, will retard the substitution of biomass fuels by fossil fuels, for a large part of the Indian population in the near-term.

Currently used biomass energy technologies (CBETs) for micro-level cooking applications (households and institutions), are largely mud stoves along with some metal, cement and pottery or brick stoves, that directly burn wood, crop residues and dried animal dung. They have low thermal efficiency and lead to significant emissions of pollutants [Smith et al., 1983; Ahuja et al., 1987; Smith, 1987; Joshi et al., 1989; Gupta et al., 1998; Oanh et al., 1999; Smith et al., 2000a; Zhang et al., 2000; Venkataraman and Rao, 2001; Oanh et al., 2002] with acute (e.g. CO) and chronic (e.g. PM) toxicity and mutagenicity [Smith et al., 1983; Venkataraman et al., 2002; Mukherji et al., 2002; Mudway et al., 2005]. Studies have established links between exposure to the smoke particles and respiratory and heart ailments, tuberculosis and blindness [Smith and Mehta, 2003; Smith, 2000; Smith et al., 2000b]. CBETs also have significant emissions of long-lived (CH_4 and N_2O) and short-lived (CO and non-methane hydrocarbons - NMHCs) greenhouse gases (GHG) [Zhang et al., 2000] like CH4 and N2O, which are addressed under the Kyoto Protocol. Additionally, CO and non-methane hydrocarbons (NMHCs), products of incomplete combustion (PICs), also have significant greenhouse effects [Smith et al., 1993; IPCC, 2001]. Emissions of black carbon (BC), attributed recently to CBETs [Venkataraman et al., 2005; Roden et al. 2006] and modelling studies [Bond et al, 2004a; Streets et al., 2003]. Aerosol BC leads to warming of the lower atmosphere [Ramanathan et al., 2001; 2007] and could significantly influence water budgets on a regional scale [Chung et al., 2002; Menon et al., 2002; Ramanathan et al., 2005], an important element of climate vulnerability especially in south Asia.

Therefore, there is need to examine advanced biomass energy technologies (ABETs) for micro-scale cooking applications, in terms of their potential to deliver higher thermal efficiencies and lower emissions of pollutants with effects on local to global scales. Here we summarise key analysis that will be included in the report on the potential benefits of such interventions to energy savings and co-benefits to health effects and climate change mitigation, and assess the barriers to their widespread diffusion.

1.1 Status/history of technological developments and current programs / policies

India has seen two large national programmes related to household cooking technologies - the National Programme on Improved Cookstoves (NPIC) during 1985-2002 and the National Programme on Biogas Development (NPBD). The NPIC promoted the dissemination of about 30 designs of “improved” cookstoves [RWEDP, 1993]. Stoves were constructed of materials like dried mud, metal, pottery or ceramic materials. The emphasis was on use of materials and skills available in rural India and on production at the cheapest cost. Stove design and testing were carried out by Technical Back-up Units (TBUs) located in various universities and government-run laboratories. A standard laboratory test method was specified for thermal efficiency and emissions measurement [CIS 1315-Z, Part I, 1991]. On this basis, most stoves had a power output of 0.7-1.5 kW (Table A1 in the Appendix), with thermal efficiencies typically higher (20-30%) burning wood, lower (15-20%) burning dried animal dung (Figure A1), and erratic (5-20%) burning crop residues like mustard stalks. Later independent studies, measured emissions from these stoves (in g pollutant emitted per kg of fuel burned and per MJ of useful heat input) [Ahuja et al., 1987; Joshi et al., 1989; 1991; Zhang et al., 2000] and revealed that NPIC “improved” stoves often had higher emissions than traditional stoves. Actual efficiencies of both traditional and “improved” stoves depended on a host of factors such as (a) type of fuel used, (b) cooking conditions, e.g., indoor or outdoor placement of the stove, and (c) age of the stove and (d) cooking practice, e.g. rate of fuel feeding [Ahuja et al., 1987; Joshi et al., 1989; 1991]. Evaluators of the NPIC [e.g. Kishore and Ramana, 2002] concluded that the programme was only marginally successful in achieving its objectives of reduction in firewood consumption, reduction of deforestation and reducing drudgery for women and children. In several regions the users modified the cookstoves or abandoned them.

One of the main reasons for user dissatisfaction was that designs did not pay sufficient attention to ease of cooking, smoke removal and adequate heat rate, which were user priorities. High subsidy, inadequate emphasis on awareness and local capacity building and a general lack of a commercial approach resulted in poor replicability and sustainability after the end of the programme.

Biogas technology has a long history in India. After independence, Khadi and Village Industries Corporation (KVIC) did pioneering work on development and dissemination cattle dung biogas plants. In 1981, a National Project on Biogas Development (NPBD) was launched. Out of the total potential for around 12 million household biogas plants, till date around 4 million household biogas plants have been installed. The construction of the biogas plants peaked in the initial years of the biogas programme, and during last decade, around 100,000 to 150,000 biogas plants have been constructed every year. Different evaluation studies to evaluate the performance of the programme have shown overall functionality rate of 60-88% [Winrock, 2004] for the installed biogas plants. Field performance studies show that a typical 2 m^3 household biogas plant, replaces around 1700 kg of firewood or around 188 kg of LPG [Pal et. al 2000]. MNRE has proposed construction of 1 million biogas plants during the XI th five year plan period, which is a moderate increase over the target for the Xth five year plan [MNRE, 2006]. Currently, a capital subsidy ranging between 25-33% is provided for the construction of biogas plants. During recent years, some new biogas plant designs to utilize kitchen waste, green vegetable material have also been developed.

1.2 Current programmatic approaches/policies:

After executing a large National Programme on Improved Cookstoves the Ministry of New and Renewable Energy (MNRE) terminated this programme a few years ago. The initiative was left to the state governments to continue improved cookstoves programme, which only a few states have done. However the field is dynamic with new stakeholders like Shell Foundation, Philips, BP energy and their collaborators in promoting cleaner stoves based on market principles. Though not many details are available about the number of cookstoves disseminated so far, the Shell Foundation programme targets installation of 10 million cookstoves in India and other developing countries [Smith, 2007]. The biogas programme for household cooking continues to be sponsored by MNRE.

2. Technological options at the micro (for a single industry or household) level

2.1 Options with greatest practical potential in the near-to-medium term

Promising Advanced biomass energy technologies (ABETs): Promising ABETs for household cooking include (a) *gasifier stoves* and (b) *biogas or anaerobic digester technology* and (c) *direct combustion ABETs*, or stoves that directly burn biomass fuels.

Gasifier stoves using wood-chips as fuel and an electric blower [Reed and Larson, 1996], has been developed for outdoor cooking. This has been modified for use in those many developing-country areas through reliance on natural draught [Mukunda et al., 1998] and more recently on forced draught [Bhattacharya and Leon, 2004; Andersen et al., 2007 – boiling point; China compendium]. These stoves deliver 1-3 kW of power with an efficiency of 35-40% (Table A2 in the Appendix). Gasifier stoves have been introduced recently in field operation in developing countries, including a market-based pilot programme in the People's Republic of China [Luo, 2005], and in Sri Lanka [Wijeywardene, personal communication, 2006], where they have found some acceptance among users. A national stove contest in China recently highlighted a number of such stoves being sold around the country [Ref].

Biomass gasifier stoves are being tested by several corporate organizations, research institutes and NGOs e.g. Philips, Bharat Petroleum Limited (BPL), the Shell Foundation, The Energy and Resources Institute (TERI), the Indian Institute of Science (IISC), and Appropriate Rural Technology Institute (ARTI) in India [e.g. Philips, 2007; BPL, 2007; Raman, 2007]. Detailed performance data is not available in public domain. Typical thermal efficiencies of 30-35% have been reported. Very limited lab testing indicates the potential for significant decrease in GHGs and health damaging pollutants, but this needs to be verified through robust lab and field testing programmes. However, the need for standardising currently used biomass into chips or pellets for gasifier-stoves is an important barrier to their widespread dissemination and is discussed in a following section.

Anaerobic digesters for methane production (or *biogas plants*) using animal dung as a feedstock have been disseminated in several parts of India as well as many other parts of the world [Dutta et al., 1997]. Currently, for example, there is a large successful program to promote household biogas plants in Nepal [ref]. Biogas has the distinct co-benefits of maintaining or enhancing the fertilizer value of the dung and, where social norms permit, serving to reduce the pathogen risks of human waste. Limitations to the widespread adoption of family-size biogas digesters (or biogas plants) include the requirement of a large quantity of feedstock (about 40 kg slurry with dung from 2-3 large animals), long digestion time (about 40 days), a large size (about 4000 litres), and the charging and disposal of a large quantity of water and slurry (80 to 100 litres/day). Other operational problems include the low gas production rate in winter in large parts of India, and competition from auxiliary uses of cattle dung for plastering walls and floors of rural homes. Economic barriers to the widespread adoption of biogas include its high first cost and large area required for the plant. However, new designs of biogas digesters have been innovated to reduce the digestion time and increasing the specific methane yield, leading to reduced plant size and cost for a given gas output [Yadvika, 2005]. Other developments in biogas technology relate to use of alternate feedstock, consisting of starchy or sugary material derived from waste-grain or non-marketable fruit, or leafy biomass, or co-digestion of crops with dung, in shorter digestion time and smaller capacity biogas plants [Jagadish et al., 1998; ARTI, 2004; Umetsu et al., 2006; Lehtomaki et al., 2007]. Studies are also being carried out on recycling water from the digested slurry toward slurry drying for more convenient use as dung [Kohli, personal communication, 2006]. Such advances in biogas technology, to optimise performance and enable the use of multiple feedstock, offer the potential for its more widespread adoption.

Direct-combustion ABETs or stoves that directly burn biomass fuels, would probably find the highest user acceptance as no change in fuel is required. However, such stoves need design innovations that can reliably result in cleaner burning and higher thermal efficiency. Most stoves disseminated under the Indian NPIC were not statistically different in performance from the three-stone fire or simple U-shaped stove, but two stoves with insulated combustion chambers showed superior thermal efficiency. Thermal efficiency is the product of combustion efficiency (related to complete burning of evolved fuel gases) and heat transfer efficiency (related to transfer of the released heat to the cooking vessel and its contents). Achieving high combustion efficiency requires high temperature in the flame region, for which insulating the combustion zone and providing controlled air-flow at a low volume rate and a high velocity into the flame region is required. Providing a double-walled or ceramic/pottery-lined combustion chamber for insulation and a short tapering pipe (sometimes called “rocket” zone) following the flame region are innovations that have been tried in stoves developed for other regions [Still, 2007]. Increasing heat transfer efficiency requires maintaining a high temperature difference between flue gases and the cooking vessel and a high velocity of flue gases forced to flow close to the vessel. This is typically achieved by using a skirting around the cooking vessel, with a gap of the correct size to create a high velocity of gases but not restrict air flow through the flame region. Such innovations have been tried in some stove prototypes in Brazil and Uganda, but are yet to be adapted for Indian user needs.

Plant oil stoves and ethanol stoves are two other possible ABET options. A plant oil stove prototype has recently been developed [Stumpf and Muhlbauer, 2002; Bosch-Siemens, 2007]. As plant oils are significantly more viscous and have lower flash points that kerosene, innovations have been made to heat the oil prior to spraying through a nozzle and passing it through a vapouriser to enable complete vapourization. Field tests in the Phillipines (with coconut oil) and in Guatemala were proposed in 2004. However, no test information is available on performance and emissions characteristics. Some prototypes of ethanol and ethanol-gel stoves have been built and tested in India and Nigeria [UTRIA, 2004 ESD paper; HEDON 2004; Rajvanshi et al., 2007]. The Indian stove uses low concentration ethanol (50%) and the Nigerian stove an ethanol-gel to minimize risks of explosion from ethanol in flammability. The economics of the fuel are not favourable to LPG or kerosene, which are subsidized in India as cooking fuels [Rajvanshi et al., 2007]. The limited experience and data on these technologies, is not sufficient to consider them as promising options at this point of time. Except dung-based biogas technologies, all the other ABETs need substantial R&D, field testing and customizing for user need. There is also need for strict product specifications and a testing and certification programme based on well established methodologies.

Institutional cooking generally refers to cooking of food for a group of about 25 or more persons in hospitals, hotels, community centers, religious places, hostels, prison, etc [Tripathi et al., 1999]. Potential ABETs for institutional cooking, which have been successfully demonstrated are: biomass gasifier based cooking systems, direct combustion biomass stoves and biogas plants based on dung, vegetable matter and kitchen waste. The overall thermal efficiency of the institutional gasifier systems is reported to be 35-40% [Tripathi et. al 1999]. A financial analysis of biomass gasifier institutional cooking systems in the range of 17.5 to 291 kWth showed that these systems are always better compared to coal based systems and better compared to LPG in the large capacity range [Tripathi et al, 1999]. Biomass gasifier systems ranging up to 600 kWth capacity have been used for cooking mid-day meals for schoolchildren, cooking food for devotees in religious institutions [Mande and Kishore, 2007]; the study reports firewood savings of the order of 50-70%. Improved cookstoves using biomass briquettes as fuel have been used in schools to replace LPG stoves and have resulted in fuel cost savings of 50% [Akshay Urja, 2005]. Several biogas plants with a capacity to treat 1-5 tons per day capacity of waste materials – kitchen waste, vegetable matter, garden waste, etc have been installed to supply biogas for cooking in institutions [Kale, 2005] Apart from biomass energy options, Scheffler solar cookers, based on solar concentrator technology have also been used for institutional cooking. Several of these options are now available commercially.

2.2 Technological status and performance

Since the technologies disseminated in the NPIC, were not statistically different from traditional cooking devices, in terms of efficiency or emissions, we treat them together to develop the baseline for performance of current biomass energy technologies (CBETs) for household cooking (Table 1).

Table 1: Emissions factors in g of pollutant emitted per MJ energy delivered

Cooking technology/fuels	Emission factors (g MJ delivered $^{-1}$)							Efficiency (%)
	CO_2	CH_4	N_2O	CO	NHMC	PM	BC	
CBET /wood[a,b,c]	520.6 ± 20.1	2.44 ± 1.3	0.07 ± 0.03	30.8± 10.2	4.0.± 0.8	0.9± 0.4	0.2 ±0.02	18±7
CBET / dung[a,b,c]	880.3 ± 41.09	7.0 ± 7.0	0.3 ± 0.01	35.2 ±15.1	24.1± 3.8	1.08±0.4	0.08	13±3
CBET / crop waste[a,b,c]	677.1 ± 74.7	5.73 ± 5.5	0.08 ± 0.04	37.8± 10.1	10.6 ±5.5	2.5 ± 1.9	0.4±0.3	11±2
Anaerobic digester /biogas	142	0.10	0.01	0.19	0.06	0.05	0.01[e]	55
Gasifier /wood	275[d]	0.30[d]	0.06[d]	5.0[d]	0.3[d]	0.20[d]	0.08[f]	38
Direct combustion ABET / wood[e]	275[d]	0.30[d]	0.06[d]	5.0[d]	0.3[d]	0.20[d]	0.08[f]	38
Gas burner / LPG	118	0.002	0.006	0.6	0.7	0	0	57

[a]from Smith et al. [2000]
[b]from Venkataraman et al [2005]
[c]from Habib et al. [2005]
[d] Uma, 2004
[e] assumed same as gasifier
[f] from measured PM and BC/PM ratios in Venkataraman et al. [2004]

Values are shown for each technology-fuel system as a mean and one standard deviation around it. Baseline emission factors of pollutants from CBETs [Smith et al., 2000a, b; Zhang et al, 2000; Habib, 2005; Venkataraman et al., 2005] are derived in g of pollutant emitted per MJ of useful energy delivered. Larger values for CO_2 reflect the conversion of a large fraction of the fuel carbon to CO_2 during combustion. The CO/CO_2 ratio is the traditional measure of combustion efficiency or extent of "clean" combustion [Edwards et al., 2003, 2004]. While emissions from various ABETs described above are yet to be measured, very limited measurements are available for gasifier stoves [Uma, 2004] and biogas burners [Smith et al., 2000a, b] (Table 1) of GHGs and particulate matter. Black carbon emission factors for the biogas and the gasifier stove are derived from their measured particle emission factors [Smith et al., 2000a; Uma, 2004] and ratios of BC to particle mass, in particulate emissions, respectively, from a kerosene stove [Habib, 2005] and a sawdust packed-bed stove [Venkataraman et al., 2004], which operates like a gasifier. We therefore caution that the BC emission factors used here are indicative of emissions from these technologies, needing confirmation through direct measurement.

Baseline thermal efficiency of CBETs ranges 10-16%, lowest for the direct combustion of dried animal dung. Direct combustion and gasifier ABETs have the potential for about 2 times higher efficiency, 4 times reduction in emissions of particles (important from health effects perspective) and greenhouse gases regulated by the Kyoto Protocol, on a per MJ of useful energy delivered (Table 1). Biomass gasifier stoves using biomass pellets/ chips show typical thermal efficiencies of 30-35%. Biogas technology is particularly attractive with about 4 times higher efficiency and 20 times reduction in emissions compared to direct combustion of cattle dung. In comparison, the thermal efficiency of LPG stoves is 57%, with low emissions of the products of incomplete combustion.

2.3 Biomass needs

While the traditional cookstoves can generally accept a large variety of biomass fuels, several of the ABETs require processed fuels. Most of the biomass gasifier based cooking systems either require cut fire wood (up to a few inch size) , briquettes or pellets. Most of the household biomass gasifier stoves which are being tried require biomass pellets. Thus dissemination of biomass gasifier cooking systems requires developing the processed biomass fuel chain.

India has more than 200 biomass briquetting plants producing around 0.5 million tons of biomass briquettes [Akshay Urja, 2005]. These briquetting plants use a variety of agro-residues as raw materials for the production of briquettes. Gujarat (ground–nut shell and bagasse), Maharashtra (bagasse and saw dust), Karnataka (groundnut and coffee husk), north-west India (mustard stalk and groundnut shell) are the important briquette manufacturing regions in the country. The typical cost of production of briquettes is around Rs 2000 – 2500 per ton and the average selling price ranges from Rs 3000 -4000 per ton [A R Khatter, personal communication]. A machine to produce pellets has been recently developed; it can produce pellets having diameter ranging from 8 to 25 mm. These pellets have been found suitable for use in household gasifier stoves.

2.4 Economic feasibility and benefits over status quo

Annualized cost of various cooking technologies is presented in table 2. The method used and major assumptions made for calculating annualized cost are presented in Appendix A.

Table 2: A comparison of annualized cost of cooking energy per household

	Capital cost (US$)	Fuel Price (US$/kg)	Annualized cost for cooking (US$/household)
Traditional stoves	1.25	0.025	30
Improved combustion stoves	25	0.025	23
Gasifier stoves	75	0.075	64
Family biogas	300	0.0	47
LPG (subsidised)	64	0.49	65
LPG (non-subsidised)	64	0.8	100

The analysis shows that:

- Though the capital cost of acquiring a good improved combustion stove is almost 20 times that for a traditional stove, fuel savings results in lower annualized cost of energy for an improved combustion stove.
- The other two ABET options i.e. biogas and gasifier stoves have higher annualized cost for cooking compared to improved combustion stoves. In case of a biogas plant the capital cost is higher compared to all other options, while, in case of gasifier stoves the fuel (biomass pellets) cost is significant (Rs 3-4/kg).

- The annualized cost of all the ABET options are less compared to the annualized cost of the subsidized LPG cooking option. If the subsidy for LPG is not considered, the economic attractiveness of ABETs increases significantly.

3. Potential benefits/risks of new technologies at micro level
3.1 Energy savings/substitution

Biomass fuel use for household cooking is India has been estimated largely by the energy-survey approach, which gives per capita biomass fuel consumption [e.g. the Rural Energy Data Base, Joshi et al., 1992; Sinha et al., 1998 and IREP, 1992], combined with assumed population of users [Streets and Waldhoff, 1998; Reddy and Venkataraman, 2002; Streets et al., 2003; Bond et al., 2004; Smith et al., 2000]. Uncertainties in this approach include relatively small samples and their ability to represent large populations, as well as the magnitude of the user population itself. More recently, a methodology based on food consumption statistics and end-use energy needed for cooking was combined with recent surveys of household fuel user populations [Habib et al., 2004] to estimate cooking biomass fuel use. This method was based on food consumption statistics (F_{ij}, kg per capita per day) in each state i, for each of four cooking processes j available from National Sample Surveys [NSS, 2001] both for rural and urban regions (Figure A2 in Appendix). This was combined with the specific energy required for food preparation (EM_{jk}, MJ kg^{-1} of food cooked) for various cooking processes j, using different fuels k [Verhaart, 1982; Islam, 1984; Mukunda et al., 1988; Ravindranath and Ramakrishna, 1997].

The total cooking energy consumption for India for 2000 was 6325 PJ with rural population using about 84%. This reflects both the large rural population and the use of low efficiency biofuel cooking devices. Also, cooking energy consumption from biofuels in India was predominant 92% (5825 PJ) with a minor contribution 8% (500 PJ) from fossil fuels. Total biomass fuel consumption was estimated as 379 (247-584) Tgy^{-1} resulting in a biomass fuel mix of 74:16:10% of fuelwood, dung-cake and crop waste, respectively (Table A2 in the Appendix). National fuelwood consumption was 281 (192-409) Tgy^{-1} and largest among biomass fuels in all regions (Figure 1). The high biofuel consumption in northern and eastern regions reflects higher per capita food consumption and significant use of dung-cake and crop waste compared to the western and southern regions.

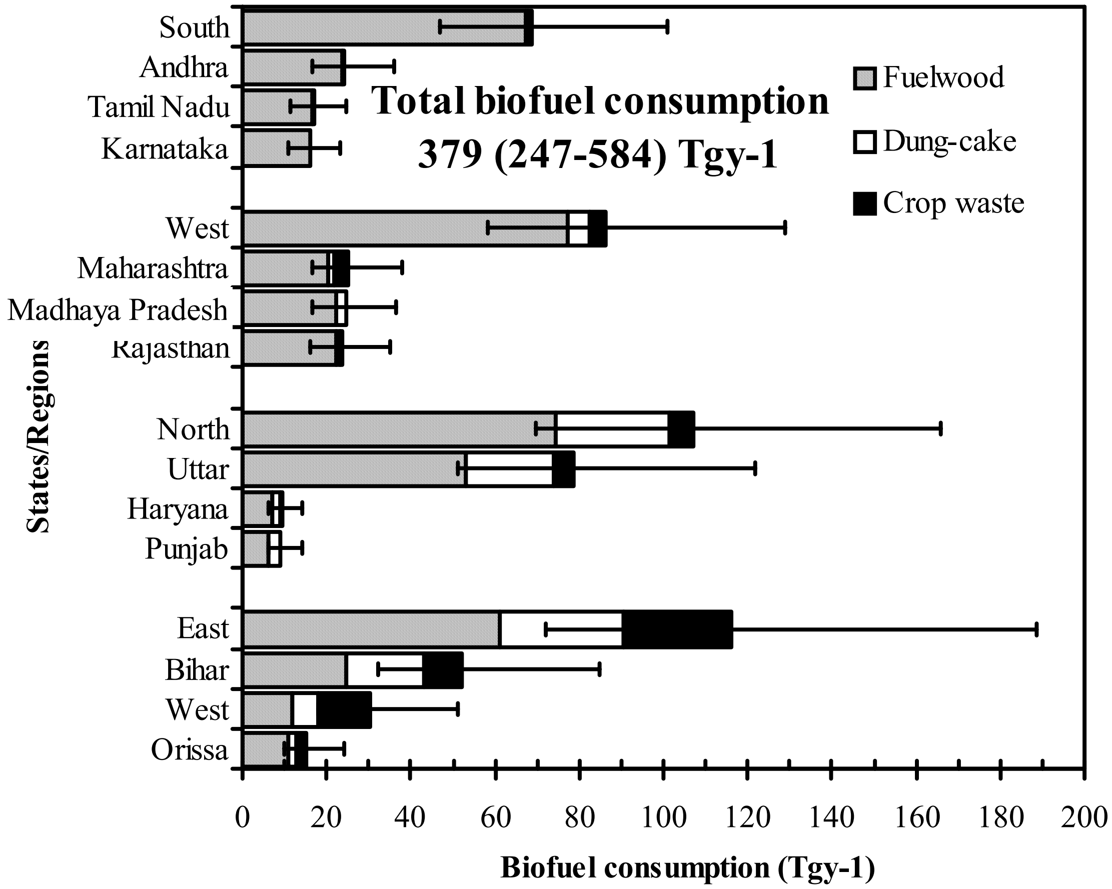

Figure 1. Biofuel consumption for cooking in major states and regions of India showed high fuelwood consumption in all regions, large dung-cake and crop waste consumption in northern and eastern states, error bars were estimated at 95% CI.

The end use energy approach [Habib et al., 2004] gives estimates lower than previous studies (compared in Table A3 in the Appendix), which all used per capita consumption from the REDB related energy use surveys [Joshi et al., 1992; Sinha et al., 1998], and assumed various user populations [Streets and Waldhoff, 1998; Reddy and Venkataraman, 2002; Streets et al., 2003; Bond et al., 2004]. It compares well with a more recent estimate of Smith et al. [2000], which uses per capita biofuel consumption from a different compilation of surveys [IREP, 1992]. New information from the National Family Health Survey [NFHS, 2001], incorporated by Habib et al. [2004], indicated that about 60% of India's population used fuelwood, while dung and crop residues accounted for only 6% each, with the balance (28%) using fossil fuels (coal, LPG, and kerosene). However, households use multiple fuels depending on their availability – for instance, after harvest, crop residues are used extensively till they are exhausted, after which they revert to using wood. Many households use multiple cooking devices such as kerosene or LPG stoves, in addition to biomass stoves, and the NSS does not adequately capture this information, leading to uncertainty in the fuel use estimates, discussed by Habib et al. [2004].

Evaluation of ABETs for fuel savings is based on a mix of ABET:CBET supplying 50%:50% end use energy for household applications in 2025, whereby 50% cooking energy from current CBETs (wood and crop residues), is provided by advanced stoves and gasifier stoves, and 50% cooking energy from direct CBET combusted dung is supplied by biogas digesters.

Table 3: Current (2005) and projected (2025) use of biomass fuels in currently used and advanced biomass energy technologies (CBETs and ABETs) for household cooking.

Cooking technology/ fuel	2005	2025	2025	2025
	Current fuel use	Projected fuel use (business as usual cooking technologies)	Projected biomass fuel for 50:50 ABET/CBET mix	End-use energy from BET-fuel categories
	($MT\ y^{-1}$)	**($MT\ y^{-1}$)**	**($MT\ y^{-1}$)**	**(% end use energy supply)**
CBET/wood	280.6	318.2	159.1	50% wood
CBET/dried cattle manure	61.6	69.9	34.9	50% cattle dung
CBET/crop residue	36.4	41.3	20.6	50% crop residue
Anaerobic digester /biogas	0.6	0.7	22.9	50% cattle dung
Gasifier / wood or crop residue	0	0	34.3	25% each wood and crop residue
Direct-combustion ABET / wood or crop residue	0	0	34.3	25% each wood and crop residue
Biomass subtotal	**379**	**430**	**306**	
Illustration for LPG substitution by biomass	**Current import ($MT\ y^{-1}$)**	**Projected import ($MT\ y^{-1}$)**	**Biomass needs for 1 MTy^{-1} LPG substitution**	
Gas burner /LPG	2.5	??	4.3	NA

Estimated biomass use under such a scenario is 306 MT y^{-1} in 2025 (compared to the projected 430 MT y^{-1} under a business as usual CBET mix), because of energy efficiency improvements (see Table 1) of the gasifier or ABET stove over CBETs and of the anaerobic biogas digester over direct combustion of dried dung. This would yield an overall 29% reduction in biomass fuel use. The savings by fuel category are 97 MT y^{-1} fuelwood, 15 MTy^{-1} crop residues and 12 MT y^{-1} dry animal dung.

An illustrative scenario is considered, of interest to energy security and offsetting LPG imports with clean biomass fuels. Current LPG consumption in India is around 11 MTy-1 with LPG imports of 2.5 MTy-1 (ref?). The ABET offset of LPG is most likely to occur in institutional cooking, with some accompanying offset in household cooking. Offsetting 1 MT y-1 of LPG consumption, would need 4.3 MTy-1 of ABET combusted biomass fuels, available readily based on the current biomass availability calculations.

3.2 Achievable GHG reductions from deployment of ABETs

Here we calculate GHG mitigation for the scenario of 50% end-use energy supply by ABETs in 2025 discussed in the previous section. The following issues are factored into the estimate:

- "Renewable" harvesting of biomass fuels is estimated to lead to equivalent CO2 uptake from the atmosphere during biomass growth, as that released during biomass combustion, leading to zero net CO2 emissions. Current estimates (see section B1) indicate that most biomass fuel is harvested renewably, largely from outside dense forest areas. Therefore, we will project emissions with the assumption that all biomass is 100% renewable (no net CO2 emissions).

- CBETs lead to significant emissions of greenhouse gases (GHG) including CH_4 and N_2O, which are addressed under the Kyoto Protocol, and have a larger greenhouse effect than CO_2, with CH_4 having a shorter and N2O a longer atmospheric lifetime (Table 4). Global warming potential (GWP) [IPCC, 2001] was proposed to assess the relative effects of pollutants, with dissimilar lifetimes, during a specified time after emission (20 y, 100 y or 500 y). It is defined as the net change in radiation entering Earth's atmosphere, during the specified time horizon, following instantaneous release of a global warming pollutant compared to that of the same emitted mass of CO_2. Among the many products of incomplete combustion (PICs) that have a greenhouse effect, the Kyoto Protocol covers only CO_2, CH_4 and N_2O and uses GWPs calculated on a 100-y time frame. While GWP is widely accepted for these long-lived GHGs, which are well-mixed in the global atmosphere, it has also been calculated for more short-lived PICs like CO and NMHCs (Table 4).

Table 4: GWPs and lifetime of pollutants emitted from biomass fuel combustion in CBETs

Species	**Lifetime Years**	**Global warming potential (GWPs)**	
		20 yr	**100 yr**
Direct acting			
Carbon dioxide (CO_2)[1]	~100	1	1
Methane (CH_4)[1]	12	62	23
Nitrous oxide (N_2O)[1]	114	275	296
Black carbon (BC)[3]	2.4-8.4 days	2000	680
Organic carbon (OC)[3]	5-8 days	-250	-75
Indirect GHGs[4]			
Carbon monoxide (CO)[1]	~1 month	10	3
Non-methane hydrocarbons (NMHC)[2]	A few days	4.9	1.7

[1]IPCC [2001]; [2]IPCC [1990], [3]Bond and Sun [2005], [4]These are not GHGs themselves, but chemically react in the atmosphere to extend the lifetime of methane, a powerful GHG.

- Emissions of aerosol black carbon (BC), another important climate change agent, have been recently attributed to CBETs, especially in east and south Asia and Africa through measurements [Venkataraman et al., 2005; Habib, 2005; Roden et al. 2006] and modelling studies [Bond et al, 2004a; Streets et al., 2003]. Recently, the concept of GWP has been extended to BC aerosols [Bond and Sun, 2005; Forster 2007]. While this index does not directly capture BC effects on regional water budgets described earlier, it provides a framework for integrated assessment of the climate impact of technologies based on their emissions of both GHGs and BC. Despite its very short lifetime compared to CO_2, the 100 year GWP for BC is estimated as 510-680 [Bond and Sun, 2005; Forster et al., 2007], with the two studies in reasonable agreement given the large uncertainties in these calculations. We adopt the value of Bond and Sun [2005] in this study (Table 4).

The current Indian national communication to the UNFCCC allocates only 35 MT CO_2-eq y^{-1} of CH_4 emissions to residential biomass energy [UNFCCC, 2005]. Using the published emission factors summarised in Table 1 and published GWPs for pollutants discussed above, we project Indian GHG emissions from household biomass combustion based on three emissions scenarios, for 2005 and 2025 for the business as usual and 50%:50% end-use energy delivery by a mix of ABET:CBET described above:

- Scenario I – Kyoto GHGs only and all fuel harvested renewably: Reduction of 36 MT CO_2-eq y^{-1}.
- Scenario II – All GHGs and BC – all fuel harvested renewably: Reduction of 134 MT CO_2-eq y^{-1}.
- Scenario III – Fossil CO2 offset by 1 MTy-1 LPG substitution using ABET combusted biomass fuels: Reduction of 3.1 MT fossil-CO_2 y^{-1}.

Table 5: Estimated Indian emissions of global warming pollutants (MT CO_2 eq y^{-1}) in 2005 from currently used biomass energy technologies for cooking.

Cooking technology/fuels	Emissions (MT CO_2 eq y^{-1})						100% renewable biomass (CH_4 and N_2O)	100% renewable biomass (all GHGs, BC)
	CO_2	**CH_4**	**N_2O**	**CO**	**NHMC**	**BC**		
CBET /wood	378.6	40.7	16.6	67.3	4.9	114.5	**57**	**244**
CBET / dung	63.3	10.6	5.7	8.0	2.7	5.0	**16**	**32**
CBET / crop waste	44.2	8.6	1.5	7.4	1.2	14.9	**10**	**33.6**
Anaerobic digester /biogas	0.9	0.014	0.018	0.004	0.001	0.041	**0.03**	**0.1**
Gasifier / wood or crop residue	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**
Direct combustion ABET / wood or crop residue	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**
Total	**487**	**60**	**24**	**83**	**9**	**134**	**84**	**309.7**

Table 6. Estimated Indian emissions of global warming pollutants (MT CO_2 eq y^{-1}) in 2025 from projected fuel use and currently used biomass energy technologies (business as usual scenario).

Cooking technology/fuels	Emissions (MT CO_2 eq y^{-1})						100% renewable biomass (CH_4 and N_2O)	100% renewable biomass (all GHGs, BC)
	CO_2	CH_4	N_2O	CO	NHMC	BC		
CBET /wood	429.4	46.1	18.8	76.4	5.6	129.8	**65**	**276.7**
CBET / dung	71.8	12.0	6.4	9.1	3.1	5.7	**19**	**36.3**
CBET / crop waste	50.1	9.8	1.7	8.4	1.3	16.8	**12**	**38.1**
Anaerobic digester /biogas	1.0	0.016	0.020	0.004	0.001	0.046	**0.04**	**0.1**
Gasifier / wood or crop residue	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**
Direct combustion ABET / wood or crop residue	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**
Total	**552**	**68**	**27**	**94**	**10**	**152**	**95**	**351.2**

Table 7. Estimated Indian emissions of global warming pollutants (MT CO_2 eq y^{-1}) in 2025 from projected fuel use, and a 50:50 supply of cooking energy from a mix of currently used and advanced biomass energy technologies.

Cooking technology/fuels	Emissions (MT CO_2 eq y^{-1})						100% renewable biomass (CH_4 and N_2O)	100% renewable biomass (all GHGs, BC)
	CO_2	CH_4	N_2O	CO	NHMC	BC		
CBET /wood	214.7	23.1	9.4	38.2	2.8	64.9	**33**	**138.4**
CBET / dung	35.9	6.0	3.2	4.5	1.5	2.8	**9**	**18.1**
CBET / crop waste	25.1	4.9	0.9	4.2	0.7	8.4	**6**	**19.0**
Anaerobic digester /biogas	7.98	0.13	0.16	0.03	0.01	0.37	**0.3**	**0.7**
Gasifier / wood or crop residue	58.5	1.4	4.1	3.2	0.1	11.7	**6**	**20.4**
Direct combustion ABET / wood or crop residue	58.5	1.4	4.1	3.2	0.1	11.7	**6**	**20.4**
Total	**401**	**37**	**22**	**53**	**5**	**100**	**59**	**217.1**

This represents a 30-38% reduction in GHG emissions in 2025, for the 50%:50% end-use energy delivered by a mix of ABET:CBET. Scenario I, which accounts for CH_4 and N_2O mitigation by ABETs, would offer 36 MTy^{-1} of CO_2-eq emissions reductions. Scenario III illustrates an additional fossil-CO_2 offset of 3.1 MTy^{-1} per 1 MTy^{-1} LPG substitution using ABCT combusted biomass fuels. These carbon reductions can be monetized under the Kyoto Protocol CDM framework, at the prevailing market price of carbon, through development of projects frameworks that address the verification and reporting protocols required under CDM.

The total 134 MTy^{-1} of CO_2-eq mitigated, in terms of reduction in emissions of all PIC-GHGs and BC by ABETs under Scenario II, represents the actual achieved mitigation of global warming pollutants from ABET deployment. Since PIC-GHGs and BC have a larger global warming effect than CO_2, addressing emissions mitigation of global warming pollutants in total, would target "dirty combustion" energy technologies, whose substitution by clean energy technologies would have large benefits to indoor and local / regional air quality and related health effects. Therefore these pollutants need to be addressed within policy frameworks related to post-Kyoto climate change agreements or rural energy or public health programmes.

3.3 Health effects of emissions from biomass fuel combustion in CBETs

Aerosol health effects are evidenced by toxicological and epidemiological studies which are increasing the certainty that exposures to small combustion particles of combustion origin pose significant health risk globally. Close to 3 million premature deaths are now attributed to aerosol exposures in occupational, indoor, and outdoor environments from combustion sources, mainly fossil and biomass fuels and tobacco (passive smoking). Combustion aerosol, thus, is by far the largest environmental source of ill-health in the world, far exceeding that of poor water and sanitation for example. Most of the impact occurs in developing countries, a significant fraction in young children. To quantify the burden of disease (premature death and illness) from various risk factors. Such assessments, e.g., the Comparative Risk Assessment (CRA) study of the World Health Organization [Ezzati et al., 2004] are presently made using particle mass as a measure of health effects. Fine particles predominate in combustion emissions, and represent a small fraction of the particle mass, but dominate particle number and surface area concentration. Fine particles deposit less in the upper respiratory tract and more in the deep lungs than do larger particles. Higher numbers increase the probability of contact with lung tissue and transport across the lung epithelium into the interstitium. Toxicological studies indicate that fine particles can be highly oxidizing, thereby inducing inflammation in macrophages and lung tissues. Very high concentrations can overwhelm the macrophage removal system, especially when subjects are compromised.

Nearly all research and policy related to the health risk of ambient (outdoor) air pollution focuses on urban areas. Most of Asia, however, still breathes in rural areas and will do so for some decades to come. Research in the climate change and acid precipitation communities, including satellite observations, make it clear that there are significant sources of combustion particles outside of cities including agricultural burning, small industries, solid-fuel-burning households, pollution from cities, and industries forced from cities. The few measurements done indicate that particle concentrations in densely populated rural areas, such as the four largest river valleys of India and China where the majority of the national populations reside, can be quite significant. The resulting health impacts must also be significant, but essentially no health-oriented research has focused on this issue. With the growing recognition of the climate impact of combustion aerosols, there is need for additional emphasis on the co-benefits in climate and health protection that can be gained from efforts to improve combustion and otherwise control aerosol emissions and resulting human and atmospheric exposures. Some pioneering work has been done, but the scale of the co-benefits clearly warrants substantial additional measurement, modeling, and policy work in this arena.

3.4 Economic/poverty alleviation

Widespread use of ABETs has the potential to generate a large number of new employment opportunities in rural areas, these are:

- Employment and entrepreneurship opportunities in the manufacture, construction, installation and servicing of ABETs. These new opportunities will be for masons involved in biogas plant construction as well as for metal fabricators for the manufacturing and repair of improved combustion stoves as well as gasifier stoves.

- Employment and entrepreneurship opportunities in the cultivation of biomass (e.g energy plantations) and processing of biomass, e.g. manufacturing of pellets and briquettes. At least one full time job can be created per hectare in establishment and management of energy plantations [Gokhale, et al. 2006]. Semi-mechanized biomass briquette plants producing 1800 to 3000 tons of briquettes annually provide employment to 4-10 persons [Hi-Tech, 2007]. Employment opportunities will also be created in the supply and distribution of the processed biomass fuels.

1. Way forward at the national level [requires use of inputs from B-1]

Currently, clean cooking energy for the rural population is entirely excluded from government policies and programmes in the energy, environment and health sectors, representing the biggest barrier in the promotion of ABETs. The National Programme on Improved Cookstoves (NPIC) has been withdrawn a few years back and support for biogas programme has seen a cutback. Recent market-based pilot initiatives by corporate organizations and NGOs on clean biomass cooking energy show promise, but suffer from limited geographical coverage and reach. The current thrust of Government policies and programmes for rural energy, during the ongoing 10th five year plan and proposed 11th five year plan, is overwhelmingly focused towards building electricity infrastructure.

As mentioned earlier, high subsidy, inadequate emphasis on awareness and local capacity building and a general lack of a commercial approach resulted in poor replicability and sustainability after the end of NPIC. In the recent years, new market based approaches have been tried by Shell Foundation, BP, Phillips and their partners. However, due to the high first cost of devices, it would be difficult to reach the poorer sections through a market based approach only. Thus, a balanced approach which combines a market based approach for deployment of ABETs for institutional cooking and for economically well-off households and has provision for subsidy to poor household is needed for the promotion of ABETs.

<u>Targeting subsidies for cooking energy:</u> The Government of India continues to administer LPG prices for domestic liquefied petroleum gas. As a result, domestic LPG prices are substantially lower than the real market price for LPG. The under-recoveries on account of administered LPG prices added up to over Rs 28,000 crore (US $ 7 billion) during 2006-7 [ET, 11 September 2007]. The present LPG subsidy system which delivers a subsidy of Rs 1200-1500 per household per year, largely benefits the urban non-poor. A strong case has been made for withdrawal of this subsidy [PC, 2006] and retargeting to economically weak sections. LPG is currently used by 5% of rural households, with its penetration limited by factors other than affordability. Therefore, retargeting the LPG subsidy must include clean cooking energy options, other than LPG, to reach a significant fraction of the rural population.

The money made available from better targeting of the LPG subsidy, should be used for a national initiative for clean biomass energy technologies for micro-scale cooking applications. The main features of this initiative could be:

9. *Targeted technology development:* Some of the priority areas of the technology development programme would be: development of direct combustion advanced stoves, fine-tuning of gasifier stoves, field testing and development of non-dung based biogas plants, testing and development of machinery for pelletizing and briquetting. A technology development programme with clear time bound goals is needed. The programme should aim at bringing together all the available expertise in academic, public, NGO and private sectors.
10. *Subsidy to end-users:* A capital subsidy of 50% on all ABETs for domestic applications, needed to overcome the capital cost barrier. At the current prices, this would result in a 50:50 cost-share between the user and subsidy provider, with cost to each of around Rs 500 for an advanced stove, Rs 1500 for a gasifier stove and Rs 6000 for a biogas plant. In addition, a fuel subsidy is required for very poor households, for purchase of processed biomass fuel.
11. *Enterprise development:* Providing interest subsidy, along with technical support, to facilitate development of enterprises for (a) manufacturing, installing and servicing ABETs, and (b) supplying processed fuel e.g. pellets for gasifiers. Monetising reductions in GHG emissions through carbon finance routes must be integrated into enterprise development. Quick gains and capacity building, through a targeted programme for ABETs in institutional and commercial cooking would be very useful for a larger effort focusing on households. Recent developments show that some of the initiatives in the institutional cooking where ABETs have replaced fossil fuels are in a better position to access carbon finance. There is a case for build on this experience.
12. *Testing, quality control and certification:* One of the main reasons for the success of the Chinese improved cookstoves programme is attributed to the effective monitoring and quality control components. Thus, testing, quality control and certification should be an important element of the new initiative.

2. Summary and critical discussion

Biomass fuel use for cooking energy is currently predominant in rural India and various factors will retard the substitution of biomass fuels by fossil fuels, for a large part of the Indian population in the near-term. Currently used biomass energy technologies (CBETs) have low thermal efficiency and lead to significant emissions of pollutants. Exposure to the smoke particles has been linked to various ailments, and is the third largest source of burden of disease (premature death and illness) in India from various risk factors, following unsafe drinking water and AIDS. The emissions from CBETs contain significant amounts of GHGs and black carbon (BC), which are global warming pollutants. Further, BC could significantly influence water budgets on a regional scale, an important element of climate vulnerability in south Asia.

Promising advanced biomass energy technologies (ABETs) for households and institutional cooking include *gasifier stoves*, *biogas or anaerobic digester technology* and *direct combustion ABETs*, or stoves that directly burn biomass fuels. Biogas technology based on vegetable matter and kitchen waste has been demonstrated for institutional cooking. Large scale promotion of ABETs, to supply 50% of end use energy derived from biomass fuels in 2025, has been estimated to give significant fuel savings (30% overall), with savings of 97 MT y^{-1} fuelwood, 15 MTy^{-1} crop residues and 12 MT y^{-1} dry animal dung. There is an accompanying reduction in GHG emissions, from increases in thermal efficiency and reductions in pollutant emissions per unit fuel burnt, leading to an overall 36 MTy^{-1} of CO_2-eq emissions reductions of CH_4 and N_2O, and an additional 3.1 MTy^{-1} of fossil-CO_2 emissions reductions per 1 MT y^{-1} of LPG substituted by biomass fuels combusted in ABETs. These carbon reductions are currently tradable under the Kyoto Protocol at the prevailing market price of carbon. A total 134 MTy^{-1} of CO_2-eq mitigated, in terms of reduction in emissions of all PIC-GHGs and BC, representing the actual mitigation of global warming pollutant load to the atmosphere. However, there is limited experience and data on these technologies. Except the dung-based biogas technology, all the other ABETs need substantial R&D, field testing and customizing for user need. There is also need for strict product specifications and a testing and certification programme based on well established methodologies.

Currently, clean cooking energy for the rural population is entirely excluded from government policies and programmes in the energy, environment and health sectors, representing the biggest barrier in the promotion of ABETs. Earlier programmes had limited success from high subsidy, inadequate emphasis on awareness and local capacity building and a general lack of a commercial approach, resulting in poor replicability and sustainability. Recent market-based approaches by corporate and NGO partners are encouraging, but may be limited in reach because of high first cost of devices. Recently, a strong case has been made for withdrawal of GoI administered LPG prices and retargeting revenue to economically weak sections. LPG is currently used by 5% of rural households, with its penetration limited by factors other than affordability. Therefore, retargeting the LPG subsidy must include clean cooking energy options, other than LPG, to reach a significant fraction of the rural population. It is recommended that the revenue made available from better targeting of the LPG subsidy, should be used for a national initiative for clean biomass energy technologies for micro-scale cooking applications. The initiative must include elements of targeted technology development, subsidy to end-users and enterprise development to ensure sufficient reach and sustainability.

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7. Glossary and definition of terms

ABET	Advance biomass energy technology
BC	Black carbon
CBET	Currently used biomass energy technology
GHG	Greenhouse-related gases
GWP	Global worming potential
LPG	Liquefied petroleum gas
MNES	Ministry for non-conventional energy source
NFHS	National family health survey
NMHC	Non- methane hydrocarbons
NPBD	National program on biomass development
NPIC	National program on improved cookstoves
NSSO	Indian national l Sample survey organization
OC	Organic carbon
PIC	Products of incomplete combustion
PJ	Peta joules = 10^{15} joules
TBU	Technical back-up units
Tg	Tera gram = 10^{12} g = One Million Tons
REDB	Rural energy data base
RGGVY	Rajiv Gandhi Vidyutikaran Yojana
RWEDP	Regional wood energy development programme
UNFCCC	United Nations Framework Convention on Climate Change

Appendix A

Table A1: Summary of technologies disseminated during the NPIC.

Fuel /Stove	Design	Power output(kW)	Efficiency (%)	Burn Rate (kgh^{-1})	CO/CO_2 Ratio	TSP (mgm^{-3})
Wood/mud	18	1.4 (±1.4)	26 (±4)	1.2 (±0.7)	0.04(±0.009)	1.4 (±0.3)
Wood/ceramic	7	1.4 (±0.4)	27 (±8)	1.14 (±0.2)	0.03 (±0.01)	1.17 (±0.08)
Wood/ improved metal	3	1.7 (±0.9)	34 (±14)	1.19 (±0.27)	0.03 (±0.02)	1.4(±0.3)
Dung/mud	17	0.8 (±0.2)	20 (±4.4)	1.09 (±0.2)	0.06 (±0.02)	NA
Dung/ceramic	5	0.7(±0.32)	18 (±5)	1.3 (±0.5)	0.07 (±0.02)	NA
Dung/ metal	2	0.83(±0.4)	22 (±4)	1.3 (±0.5)	0.07 (±0.02)	NA
Crop waste/ mud	2	0.7(±0.2)	15 (±1.4)	1.0 (±0)	0.08 (±0.01)	NA
Crop waste/ ceramic	1	0.3	8	1 (±0)	1.1	NA
Crop waste/ metal	NA	NA	NA	NA	NA	NA

Source: 1993, MNES- RWEDP report

Table A2: Biomass energy technologies in China for micro-scale cooking applications

Cooking technology	Power output (kW)	Thermal efficiency (%)	Specific fuel consumption
PT-I	4.98	40.87	60
PT-II	4.72	38.72	
FL/CCS	2.94	28	42
FL/ PCS	4.56	37.96	59.1
WS	4.96	40	61
YS-I	4.22	35	59.3
YS-II	3.5	40	35
Suizhou-400	3.61	40.1	36
WH	4.49	42.5	52
ICS	10.51	53.44	51.2
DHS	3.4	32	42.5
LXF-40	4.5	70	18.4
LXF-60	7	70	28.7
LXF-80	10	70	40.9
LXS-50	5	70	18.6

Source: Bhattacharya 1999; RWEDP-FD-40, Chinese fuel saving stoves: food and agriculture organization of the United Nations, Bangkok, July 1993

Table A3. Comparison of estimates of biomass fuel consumption for cooking in India (Tg yr^{-1}) from end-use energy and energy survey approaches.

	End-use energy approach [Habib et al., 2004]	**Streets and Waldhoff, [1998][a]**	**Reddy and Venkataraman, [2002][a]**	**Streets et al., [2003][a]**	**Yevich and Logan, [2003][a]**	**Bond et al., [2004][a]**	**Smith et al., [2000][a]**
Base year	2000-01	1990	1996-97	2000	1985	1996	1990
Total	379 (247-584)[b] (*54%*)[c]	521 [573]	538 [581]	421 (*100%*)	399 [518] (*95%*)	478 [516][d] (*100%*)	286 [342]
Biofuel Types							
Fuel wood	281 (192-409) (*46%*)	271 [298]	302 [326]	316[e] (*100%*)	220 [286]	265 [286]	169 [202]
Dung-cake	62 (35-108) (*74%*)	124 [136]	121 [131]	105 (*200%*)	93 [120]	128 [138]	54 [65]
Crop waste	36 (20-67) (*86%*)	126 [139]	115 [124]		86 [112]	85 [92]	63 [75]

[a]Including biofuel used for cooking and water heating
[b]Central value and uncertainty ranges in parenthesis were calculated at 95% CI.
[c]Values are the 95% CI as percentage of central value.
[d]Values in are upgraded biofuel consumption estimates for the base year 2000-2001, using the ratio of rural population for current base year and the reported base of the study. These ratios were 1.3, 1.2, and 1.1 for base years 1985, 1990, and 1996 respectively.
[e]Including both the fuel wood and crop waste.

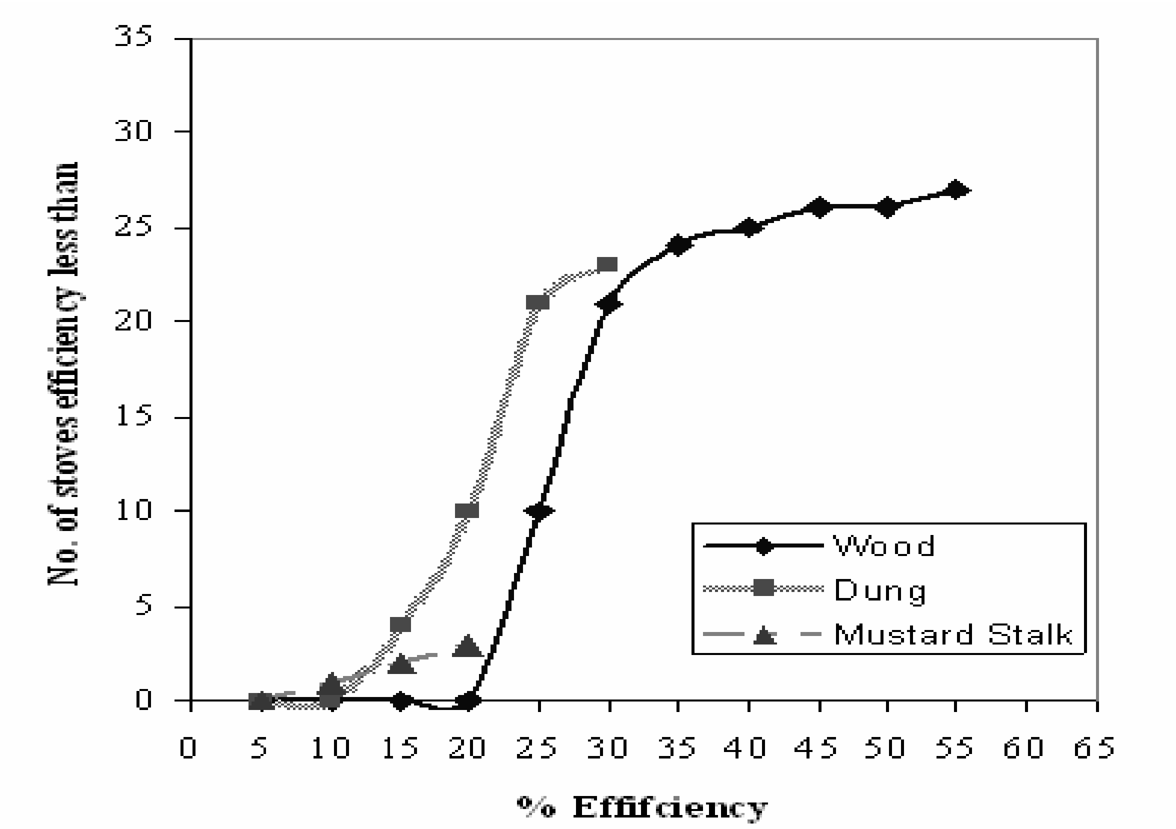

Figure A1: Cumulative frequency distribution of stoves based on thermal efficiency of stoves disseminated during NPIC measured in independent studies.

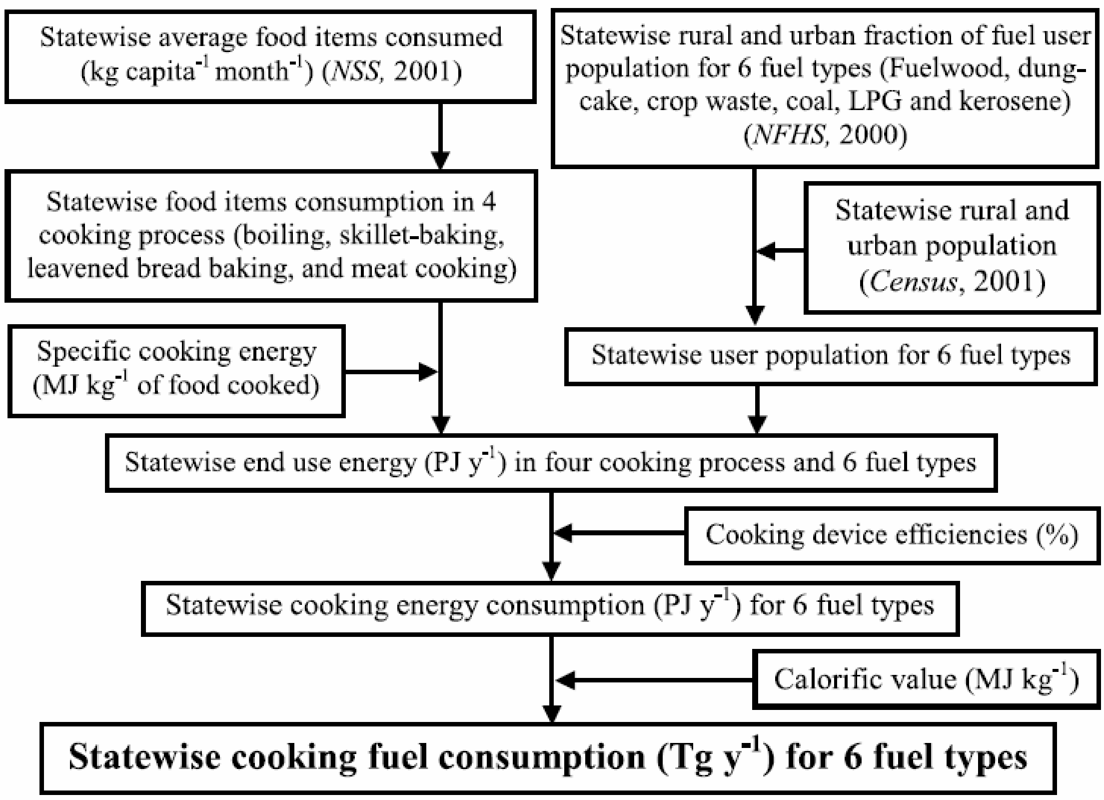

Figure A2. Methodology for estimation of state wise fuel use for cooking in India based on food consumption statistics, specific energy requirement for food preparation and fuel user population.

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A comparison of the annualized cost of cooking energy

	Traditional stove	Improved combustion stove	Gasifier stove	Biogas	LPG (Subsidized)	LPG (non-subsidized)
Stove price (Rs)	50	1000	3000	12000	1800	1800
Useful life (years)	3	5	7	15	15	15
Deposit or one time payment (Rs)	0	0	0	0	750	750
Interest (discount) rates (%)	12	12	12	12	12	12
Capital recovery factor	0.41	0.277	0.219	0.146	0.146	0.146
Annualized capital cost (Rs)	20.8	277.4	657.4	1761.9	264.3	264.3
Energy content of the fuel (MJ/kg or MJ/m^3)	15	15	15	19.6	45.5	45.5
Efficiency of the stove, burner (%)	18	35	35	55	60	60
Annual fuel usage (kg/year, m^3/year)	1162.8	598	598	290	115	115
Price of fuel (Rs/kg, Rs/litre)	1.00	1.00	3.00	0.0	19.7	32
Annual fuel cost (Rs)	1162.8	598	1794	0	2267	3680
Annualized maintenance expenses (Rs)	0	50	100	100	75	75
Total annualized cost of cooking energy (Rs)	1183.60	925.4	2551.40	1861.9	2606.3	4019.3

Notes:
1. Annualized cost =cost x capital recovery factor
2. The annual fuel use for a household is considered as 115 liters of LPG [D'Sa et al., 2004]
D'Sa Antonette, K.V.Narsimha Murthy (2004) Report on the use of LPG as a domestic cooking fuel option in India. Bangalore: International Energy Initiative, pp 75

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Development Benefits of Clean Energy in India

Indian National Coal Resources & Prospects

Sponsored by
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The Energy Resources Institute

Nov 14, 2007

Indian National Coal Resources and Prospects

Executive summary

Reserves and resources

1. The belief that India is blessed with abundant amount of coal is founded on a false notion of availability and extractability of coal resources and this perception is still deeply entrenched in the mindset of policy makers.
2. Indian coal resources are reported by GSI (Geological Survey of India) annually (***GSI 2007)*** on the basis of ISP (Indian Standard Procedure) which categorises coal resources as "proved", "indicated", and "inferred" based on the concentration of exploratory boreholes on the ground without considering the minability or extractability criteria (*CMPDI 2001)*.
3. The resource data is cumulative in nature and includes already mined and used coal, sterilised coal due to various reasons, deep-seated resources and the resources in absolutely "no go" areas such as reserve forest, tiger reserves etc.
4. In India the words "resources" and "reserves" are used interchangeably. While the "resources" are coal in-situ and all of it would not be extractable, "reserves" are a sub-set of "resources" which would be available for extraction at the present status of economics and technology.
5. All "proved" resource are not fully extractable and would get scaled down based on techno-economic feasibility of a particular deposit as also the recovery factor, which would depend on the technology of extraction. Coal extracted during actual mining may be even less than the mineable reserves.
6. To set the records right, India should recast its resources on UNFC (United Nations Framework Classification), which classifies resources based on feasibility, economic viability and geological estimates. The UNFC defines a 'Mineral Reserve' as the economically mineable (and technically feasible) part of a measured (proved) and/or indicated mineral resource (Mckay, Lambert et all).
7. Thus, only those reserves are 'proved' for which a detailed geological exploration and feasibility study has been carried out and a mining report has been prepared that proves the techno-economic feasibility of extraction.
8. The Indian coal resources are confined to two distinct geological periods known as Gondwana deposits found in the states of Andhra Pradesh, Jharkhand, Madhya Pradesh, Chhattisgarh, Maharashtra and Orissa and Tertiary deposits found in the states of Arunachal Pradesh Assam Meghalaya Nagaland respectively (*GSI 2006)*.
    - The **total coal resource**[12] of India has grown from 80 billion tonnes (Bt) in the year 1972 to over 255 Bt in 2007 with 254 Bt resources in Gondwana and less than a billion tonne in Tertiary coalfields.
    - About 61% of resources occur at 0-300m depth and almost 49% of this is 'proved' and 42% is 'indicated'. The proved resources in the depth range of 300-1200 m are only 3% of the total resources. This clearly indicates that exploration effort in the past have been restricted to 300m depth.
    - Indian coals in general are low in sulphur content and high in ash. The sulphur content is always less than 1% while the ash content can go as high as 45% in the delivered coal.
    - The only low ash high sulphur coal found in India is from the Tertiary coalfields in

[12] **Based on ISP as explained above.**

the North East of the country. The ash content varies between 8 to 10% (air dried basis) and the sulphur content generally varies between 2% to 7%.

- The national coal inventory shows that 87% of total resource comprise of non-coking coal while coking coal is only 13% of which prime coking coal is a meagre 2%.
- The total non-coking coal resources are divided in to superior and inferior types based on grades. Almost 30 of the total resources are superior grades while the rest 70% is inferior coal.
- No more new discoveries may be possible in the coking coal resources. Accretion has occurred only in the non-coking coal resources and that too mostly in the "proved category" signifying larger effort in 'detailed exploration' by CMPDIL
- As reported by GSI, there is hardly any prospect of finding shallow coal reserves in the future exploration efforts (*GSI 2006)*.
- Though various documents provide different figures of net extractable reserves, it is accepted that the figure is small and is around 40-50 Bt as in 2007.
- Integrated energy policy, Report of the Expert Committee (Planning Commission 2006) accepts that large estimates of coal resources have resulted in a false notion of security of energy supplies. It agrees that extractable coal reserves would run out in 45 years if the coal industry continues to grow at 5% per year.

Production

9. Coal production in India has risen from about 70 million tonnes (Mt) in 1973 to about 431 Mt in the year 2006/07 (*CCO 2006*) by enhanced investment in the coal industry through full budgetary support from the Government and deliberate shift in technology towards opencast mining.
   - In 2006/07, CIL and SCCL produced 93% of coal while 4% came from captive coal blocks.
   - The opencast mines, which contributed only about 28% of the total production at the time of nationalization in 1973, increased their share to about 87% in 2006/07. This trend was deliberate because due to shorter gestation period, high recovery and safety, and lower cost of production it provided larger profits for the national coal companies.
   - All the coal produced from opencast mines comes from shallow deposits, mostly within 150m from the surface and is of inferior grade and quality deteriorated further due to contamination inherent in the technology chosen. Deep mining is not envisaged by the MOC (Ministry of Coal) (*MOC* 2005).
   - The annual production from underground mines has been stagnating around 50-60 Mt with constantly declining share in the total national coal production.
   - If and when India decides to go for serious underground mining effort, it will need a lot of time, effort and money for exploring and proving coal resources at depths greater than 300m before it can do so.
   - Coking coal of the desired quality being in short supply, the import of low ash coking coal started early and was about 22 Mt in the year 2006/07 (*CCO 2006*).
   - The need for import of non-coking coal was felt when the national coal companies could not meet the demand of coal consumers like power, cement and sponge iron manufacturers. The import of non-coking coal has been increasing rapidly in the last few years and is likely to continue to grow at a faster pace.
   - Many cement manufacturers have switched over to imported coal and some coastal power plants are also importing thermal coal to meet the 34% ash requirement of

MOEF (Ministry of Environment and Forest).
- Coal Vision 2025 of MOC suggested that CIL could reach a production figure of 500 Mt by the year 2011/12 and could remain at this level till 2036/37 if CIL is allowed to retain 289 identified virgin coal blocks out of a total of 499 coal blocks in addition to all its existing mines and projects (*MOC* 2005)

Consumption

10. Coal is again emerging as the preferred fuel for power generation in many countries primarily because it is widely distributed, is relatively plentiful; costs are comparatively lower and less volatile with mature technology available for its conversion. In India up to mid 1960s, the thrust was more on developing multipurpose hydel projects, but, since 1970s, the coal based thermal capacity has shown sharp increase.
11. Power sector has emerged as the major coal consumer and drives the demand of coal in India. From about 9 Mt in 1960/61, the consumption by the power utilities has grown to 287 Mt in 2005/06 and is slated to continue to grow in future. Additionally, the coal based captive plants associated with industries like cement, alumina, steel etc consume over 20 Mt annually (*CCO 2006)*
12. The Integrated Energy Policy Expert Committee (Planning Commission 2006) has worked out the demand of coal for various users under various scenarios. Under one of the possible scenarios, the projections show that the demand by the power sector would increase from 463 Mt in 2011/12 to over a billion and a half tonnes in next twenty years i.e. in the year 2026/27 and over two billion tonnes by 2031/32.
13. India has now no alternative but to remain as a coal-centric energy producer, at least for the next three decades. The main reason for this was the oil shock of seventies when India decided to use more and more coal to meet the energy needs of the country. Added to this was the way coal resource of the country has been presented which gave a false sense of abundance.

Outlook

14. The monopoly status gave CIL the chance to pick and choose the coal blocks; shallow deposits were obvious choice because of lower gestation lag, greater safety, greater flexibility in sizing and much lower cost compared to the option of developing deeper deposits via the underground route.
15. In the year 2006/07 CIL has produced 361 Mt while others including SCCL have contributed about 70 Mt. With the well explored shallow coal blocks available with CIL and by over-exploiting the existing large opencast mines, it can easily reach a production level of 500 Mt by 2011/12 but would not be able to sustain this production level up to the year 2036/37 because some of the CIL coal blocks (from the 289 held by CIL) have been offered for immediate projectisation to private/ state government/ state utilities.
16. The new capacities to be built by CIL and others would contribute for a minimum period of 30 years. However, the contribution from the existing mines and projects of CIL and SCCL would take a dip from the current 271 Mt to 159 Mt in 2016/17 (205 Mt in 2011/12). While the ongoing projects are supposed to contribute about 70 Mt in the next five years, the new projects are being projected to contribute from the current 20 Mt to 178 Mt in 2011/12 and 363 Mt in 2011/12 (WGCL 2006), which seems to be impractical in view of the lack of preparedness and existing socio-political environment in the country.
17. The land requirement for achieving the above production has been projected to be

about 3000 sq km with a 730 sq km component of forest land displacing 8,50,000 persons which seems a difficult preposition in today's socio-political environment (MOC 2005)

18. The above scheme of things is likely to work for about next 20 years. Due to overexploitation and failing to build enough new capacities, production from CIL /SCCL would fall very sharply and the other sources would not be able to meet the shortfall resulting in the inevitable situation of large-scale imports.

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Indian National Coal Resources and Prospects

Background

Before discussing coal resources of India, it is important to understand the method by which it is generally computed and reported by GSI (Geological Survey of India).

In the year 1956, Coal Council of India had set up the Committee on Assessment of Resources, which formulated the procedure known as ISP (Indian Standard Procedure). Apart from setting up norms for classification on the basis of rank, depth of occurrence and thickness of seam to be considered, ISP fixed the basis for the categories. The categories were "proved", "indicated", and "inferred" which were based on the distance between the exploratory boreholes in a given area or in other words, were based on the concentration of exploratory boreholes on the ground and related it to the degree of reliability of finding the coal therein. The basis of categorisation underwent minor modification in 1986. As it stands today, "proved resources" are those generated solely through detailed exploration while the other two categories namely 'indicated' and 'inferred' result from the regional exploration conducted by GSI.

The Planning Commission constituted a task force in the year 1972 with GSI as the nodal agency to compile and report the coal inventory of India for each of the known coalfields based on the categories as defined in ISP.

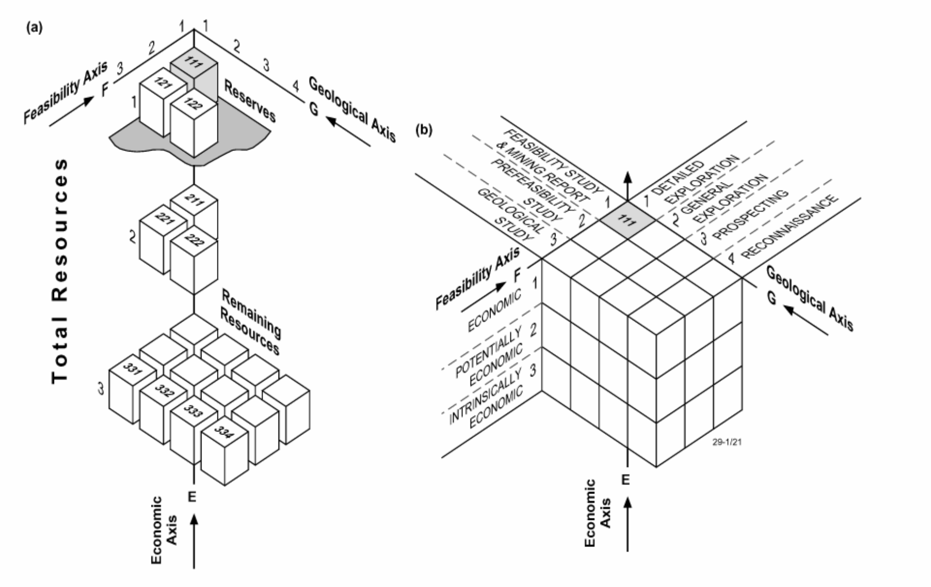
The ISP system is purely a geological resource accounting system and it does not consider the minability or extractability of resources. As a result, all types of coal whether they would ever be mined or not, are reported as resource. This report is cumulative in nature and it does not take in to consideration the coal that has already been mined and used. It also includes all those resources, which have been sterilised due to various reasons. One of the main reasons for such sterilisation is the partially developed thick seams, many of which are either on fire or are under water. Many such properties show large subsidence and leftover coal from these properties would never be recovered. It also includes the resources in absolutely "no go" areas such as reserve forest, tiger reserves etc.

As reported by CMPDIL (Central Mine Planning and Design Institute Limited), the R/P (Reserve to Production) ratio for Indian coal is about 4.7:1 meaning thereby that one needs to have 4.7 tonnes of coal in the ground to extract one tonne of coal. However, the rest 3.7 tonne would not be available for further extraction but the resource inventory includes this also (CMPDIL 2001). Due to all these incongruities, the reported Indian coal resources remain highly inflated.

The other reason for confusion about coal inventory in India is that the words "resources" and "reserves" are used interchangeably. While the "resources" are coal in-situ and all of it would not be extractable, "reserves" are a sub-set of "resources" which would be available for extraction at the present status of economics and technology.

UNFC (United Nations Framework Classification) has developed a uniform and internationally acceptable classification system of reporting of resources and reserves. This is a three dimensional system with feasibility, economic viability and geological estimates forming the three axes, EF and G. The UNFC defines a 'Mineral Reserve' as the economically mineable (and technically feasible) part of a measured (proved) and/or indicated mineral resource (Mckay, Lambert et all). Therefore, only those reserves can be reported as 'proved' for which a detailed geological exploration and feasibility study has been carried out and a mining report has been prepared that proves the techno-economic feasibility of extraction. (Block 111 in Figure 1)

Figure 1 UNFC mineral resource classification system



Source: Mckay, Lambert et all

In most cases "proved" resource is wrongly assumed to be fully extractable (BP 2006). Even these resources would get scaled down based on techno-economic feasibility of a particular deposit as also the recovery factor, which would depend on the technology of extraction. Actually coal extracted during actual mining may be even less than the mineable reserves. This basic difference has not been considered while reporting the figures of coal availability. The belief that India is blessed with abundant amount of coal is therefore founded on a false notion of availability and extractability of coal resources.

Review of conventional estimates of geological coal resources

With all these incongruities included, GSI continues to publish the "updated", gross, cumulative geological coal resource data every year since 1988. The total coal resources of India have grown from 80 billion tonnes in the year 1972 when it was first reported to over 255 billion tonnes in 2007. In the initial years, the resources were collated up to a depth of 600m only for all coal seams of thickness up to 1.2m. However, the geological coal inventory in 1978 jumped to 112 billion tonnes when coal seams up to a thickness of 0.5m were included and depth range was increased to 1200m. In the year 1990, the thickness was again increased to 0.9m, which continues even today (GSI 2006).

National Inventory by coal type

The national coal inventory as reported by MOC (Ministry of Coal) for the last four years is given in Table 1.

Table 1 Inventory of geological coal resources

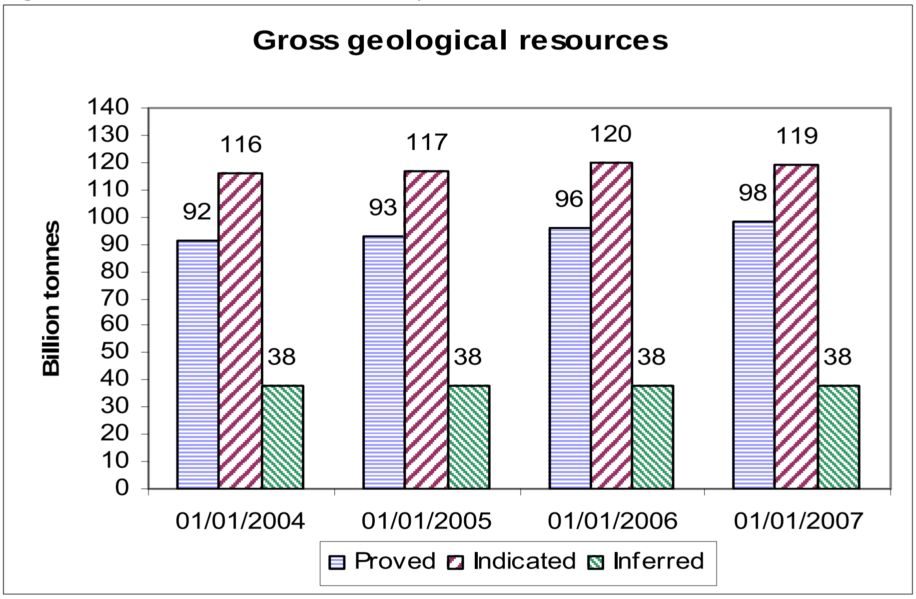
Type of coal	As on	Resources (million tonnes)			
		Proved	Indicated	Inferred	Total
Prime coking	01/01/2004	4614	699	0	5313
	01/01/2005	4614	699	0	5313
	01/01/2006	4614	699	0	5313
	01/01/2007	4614	699	0	5313
Medium coking	01/01/2004	11325	11839	1889	25053
	01/01/2005	11417	11765	1889	25071
	01/01/2006	11445	11751	1881	25077
	01/01/2007	11774	11601	1880	25255
Blendable / semi coking	01/01/2004	482	1003	222	1707
	01/01/2005	482	1003	222	1707
	01/01/2006	482	1003	222	1707
	01/01/2007	482	1003	222	1707
Non coking	01/01/2004	75096	102736	35787	213619
	01/01/2005	76447	103623	35686	215756
	01/01/2006	79325	106316	35564	221205
	01/01/2007	81050	105744	36176	222970
Total	01/01/2004	91517	116277	37898	245692
	01/01/2005	92960	117090	37797	247847
	01/01/2006	95866	119769	37667	253302
	01/01/2007	97920	119047	38278	255245

SOURCE: CCO 2006

Points to be noted are:

- Over last several years, the figures in prime coking and blendable / semi coking coal categories of resources have remained static though these types of coal are being continuously mined and used.
- Secondly, exploration efforts in these categories are absent meaning thereby that no more discoveries may be possible. Even in case of Medium coking coal, the figures have more or less remained stagnant. Thus there is no reason to believe that large accretion would result in future in these categories of resources
- The total gross resources have increased from 246Bt in 2004 to 255Bt in 2007. Also, in the last 4 years the proved resources have increased from 92BT to 98Bt. Thus, accretion of resources has occurred only in the non-coking coal and that too mostly in the “proved category” signifying larger effort in ‘detailed exploration’ by CMPDIL
- The percentage of each category of resources to the total resources has remained more or less constant over the years namely 38%, 47% and 15% for proved, indicated and inferred categories.

Figure 2 National coal inventory



SOURCE: CCO 2006

Distribution of resources in states

Indian coal resources are confined to two distinct geological periods known as Gondwana deposits and Tertiary deposits respectively. The resource data reported compiled for various states separately for the above two deposits are as given in Table 2 and 3.

Table 2 State-wise inventory of geological coal resources: **Gondwana coalfields**

State	As on	Resources (million tonnes)			
		Proved	Indicated	Inferred	Total
Assam	01/01/2006	0	3	0	3
	01/01/2007	0	3	0	3
Andhra Pradesh	01/01/2004	8091	6092	2514	16697
	01/01/2005	8263	6079	2584	16926
	01/01/2006	8403	6158	2584	17145
	01/01/2007	8475	6328	2658	17461
Jharkhand	01/01/2004	35305	30211	6348	71864
	01/01/2005	35417	30438	6348	72203
	01/01/2006	36148	31411	6338	73897
	01/01/2007	36881	31094	6339	74314
Bihar	01/01/2004	0	0	160	160
	01/01/2005	0	0	160	160
	01/01/2006	0	0	160	160
	01/01/2007	0	0	160	160
Madhya Pradesh	01/01/2004	7503	8233	2924	18660
	01/01/2005	7513	8815	2904	19232
	01/01/2006	7566	9258	2934	19758
	01/01/2007	7584	9259	2934	19777

Chhattisgarh	01/01/2004	8771	26419	4355	39545
	01/01/2005	9373	26191	4411	39975
	01/01/2006	9570	27433	4439	41442
	01/01/2007	9973	27035	4443	41451
Maharashtra	01/01/2004	4652	2156	1605	8413
	01/01/2005	4652	2309	1620	8581
	01/01/2006	4652	2432	1992	9076
	01/01/2007	4856	2822	1992	9670
Orissa	01/01/2004	14613	31239	15135	60987
	01/01/2005	15161	30976	14846	60983
	01/01/2006	16911	30793	14296	62000
	01/01/2007	17464	30239	14296	61999
Sikkim	01/01/2007	0	55	18	73
Uttar Pradesh	01/01/2004	766	296	0	1062
	01/01/2005	766	296	0	1062
	01/01/2006	766	296	0	1062
	01/01/2007	766	296	0	1062
West Bengal	01/01/2004	11383	11523	4488	27394
	01/01/2005	11383	11876	4553	27812
	01/01/2006	11383	11879	4553	27815
	01/01/2007	11454	11810	5071	28335
Gondwana	01/01/2004	91084	116172	37529	244785
	01/01/2005	92528	116984	37428	246940
	01/01/2006	95399	119663	37297	252359
	01/01/2007*	97452	118941	37909	254302

SOURCE: CCO 2006

Points to be noted are:

- Assam, Bihar and UP states have minor resource base. The resources in these states are not likely to increase in future.
- Resource base in Andhra Pradesh, Madhya Pradesh and Maharastra are likely to stagnate.
- Jharkhand, Chattisgarh and Orissa states are likely to supply most of the coal in future.

Table 3 State-wise inventory of geological coal resources: **Tertiary coalfields**

	As on	Resources (million tonnes)			
		Proved	Indicated	Inferred	Total
Arunachal Pradesh	01/01/2004	31	40	19	90
	01/01/2005	31	40	19	90
	01/01/2006	31	40	19	90
	01/01/2007	31	40	19	90
Assam	01/01/2004	279	24	34	337
	01/01/2005	279	24	34	337
	01/01/2006	315	24	34	373
	01/01/2007	315	24	34	373
Meghalaya	01/01/2004	118	41	301	460
	01/01/2005	118	41	301	460
	01/01/2006	118	41	301	460
	01/01/2007	118	41	301	460
Nagaland	01/01/2004	4	1	15	20
	01/01/2005	4	1	15	20
	01/01/2006	4	1	15	20
	01/01/2007	4	1	15	20
Tertiary coalfields	01/01/2004	432	106	369	907
	01/01/2005	432	106	369	907
	01/01/2006	468	106	369	943
	01/01/2007	468	106	369	943

SOURCE CCO 2006

Points to be noted are:

- Total gross coal resource in Tertiary coalfields is less than one billion tonnes.
- There are hardly any exploration efforts in these coalfields as the likelihood of discovering fresh resources is limited.

Inventory by depth range

Mining in India is generally restricted to 300m depths. CMPDIL/ MOC does not envisage the possibility of going beyond this depth for conventional mining of coal. The opencast mines are currently operating at a maximum depth of 120m but mines like Amlohri in NCL (Northern Coalfields Ltd) are planned to a depth of 300m. Sonepur Bazari in ECL (Eastern Coalfields Ltd) also has been planned to reach a depth of 270m(MOC 2005). Also, about 85% of national coal production comes from opencast mines. Probably this is the reason why most of the detailed exploration has been restricted to 300m depth and resources discovered/reported beyond this depth is meagre. Thus, roughly speaking, all coal resources in the depth range of 0-300m are minable by opencast or surface mining, subject to economic viability. Depth-wise gross geological resources are reported in Table 4 below.

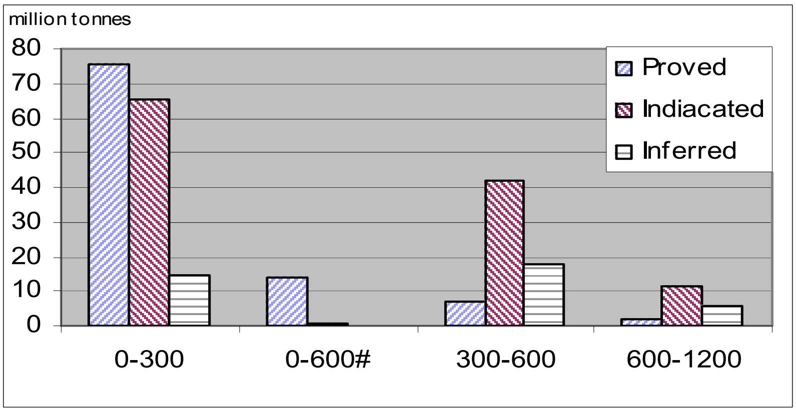
Table 4 Coal Resources (billion tonnes) 2007

Depth (m)	Proved	Indicated	Inferred	Total	%
0 – 300	75.76	65.56	14.42	155.74	61%
0 – 600 (Jharia)	13.71	0.5	0.0	14.21	6%
300 – 600	6.78	41.65	18.04	66.47	26%
600 – 1200	1.67	11.28	5.8	18.75	7%
Total	97.92	118.99	38.26	255.17	
% of total	38%	47%	15%		

SOURCE: GSI 2007

It may be noted here that about 61% of resources occur at 0-300m depth and almost 49% of this is under the proved category and 42% is under indicated category both of which are highest among all other depth range. The proved resources in the depth range of 300-600 and 600-1200 together are only 3% of the total resources. This clearly indicates that exploration effort in the past have been restricted to 300m depth.

Figure 3 Depth-wise resources 2007



SOURCE: GSI 2007

If and when India decides to go for serious underground mining effort, it will need a lot of time, effort and money for exploring and proving coal resources at depths greater than 300m before it can think of exploiting the resources.

Distribution of resources by ash and sulphur

Indian coals in general are low in sulphur content and high in ash. The sulphur content is always less than 1% while the ash content can go as high as 45% in the delivered coal.

The only low ash high sulphur coal found in India is from the Tertiary coalfields in the northeastern states of the country. The ash content varies between 8 to 10% (air dried basis) and the sulphur content generally varies between 2% to 7%. These resources are less than a billion tonnes in all.

Table 5 High sulphur coal resources 2007 billion tonnes

	Proved	Indicated	Inferred	Total
Coking	16.67	13.5	2.1	32.27
Non coking	80.58	105.58	35.79	221.95
High Sulphur	**0.47**	**0.11**	**0.37**	**0.95**
	97.72	119.19	38.26	255.17

SOURCE: GSI 2007

Distribution of resources by quality

The total non-coking coal resources are divided into superior and inferior types based on grades. The superior type are high in heat value and low in ash (grades A, B and C) and are used in industries like cement, sponge iron, chemicals, glass and ceramics etc. The inferior types consist of grades D, E, F and G and are high ash coal used largely by power sector. The range of heat value in these types is shown below:

Table 6 Heat values of various grades of coal (kCal/kg)

Type of coal	Grades	UHV	GCV
Superior NC	A to D	4200 to >6200	4800 to >6401
Inferior NC	E to G	1300 to 4200	3200 to 4800

The total non-coking coal resources in the *year 2006* were reported to be 220 billion tonnes. The distribution of these resources in terms of depth and grades is given in Table 7. It may be noted here that 55% of proved and indicated resources are of inferior grades while superior grades are only 30% of the gross resources.

Table 7 Grade-wise inventory of geological non-coking coal resources 2006 billion tonnes

	Proved resources			Indicated resources			Inferred resources	Grand Total
	Superior	Inferior	Total	Superior	Inferior	Total		
0-300	23.06	44.04	67.11	18.19	43.97	62.16	13.95	143.22
300-600	3.39	2.24	5.64	16.08	20.66	36.74	16.70	59.08
600-1200	0.06	0.45	0.51	3.71	3.10	6.81	4.54	11.86
0-600 (Jharia)	0.65	4.95	5.61	0.02	0.48	0.50	0.00	6.10
Total	27.17	51.68	78.86	38.00	68.21	106.21	35.20	220.26

SOURCE: CCO 2006

Critiques of conventional coal resource estimates

Millennium Coal Vision (CMPDIL 2001)

The first acceptance of the fact that the extractable coal resources are much lower compared to the published figure, which was being quoted nationally and internationally, came from GSI/ CMPDIL when they jointly presented a paper in a seminar in Delhi in December 2001 (CMPDIL 2001). It was suggested therein that current information on resources is an exaggeration because it does not include economic minability criterion.

At the time, the gross resources stood at 221 BT (up to a depth of 1200m) to which another 143 BT of prognosticated resources (to be brought under present categories in future) were added. Thus, the national inventory of coal resources stood at 364 BT (221+143) out of which only 40 BT was reported to be extractable. The report gave a timeframe of 45-50 years for the resources to last, including the 143 BT of 'prognosticated resources'. The report assumed that the ***national domestic production*** would reach a level of 500 million tonnes in 2006/07, 600 by 2011/12 and 770 million tonnes in 2016/17 and would remain at this level thenceforth.

Coal Vision 2025 (MOC 2005)

Coal Vision 2025 of MOC suggested that ***CIL*** could reach a production figure of 500 million tonnes by the year 2011/12 and could remain at this level till 2036/37 if CIL is allowed to retain 289 identified virgin coal blocks out of a total of 499 coal blocks in addition to all its existing mines and projects. The report does not spell out clearly but it is obvious that the production would start declining after the year 2037.

The total coal blocks numbering 499 are all that are available nationally as virgin coal blocks excluding a very few coal blocks with SCCL. In addition, there is supposed to be 94 billion tonnes of mostly indicated and inferred resources in "un-blocked" areas. For converting these in to coal blocks, large exploration effort would be needed.

Table 8 Coal blocks distribution

CIL blocks			289
Non-CIL blocks			210
	Captive blocks	136	
	Other than captive blocks	74	
Total			499

SOURCE: MOC 2005

The tentative extractable reserves from a total gross geological resource of 248 billion tonnes has been found to be 52 billion tonnes by applying an R/P ratio of 2.543:1 for CIL blocks and 4.7:1 for rest of the blocks. The differential R/P as applied to coal blocks signifies the fact that CIL blocks have been extensively and intensively explored and have largely 'proved' resources. The other 210 non-CIL blocks have very low proven reserves and very large indicated and inferred resources.

Table 9 Coal resources in coal blocks

	Proved	Indicated	Inferred	Total	Extractable
CIL	67.71	19.42	4.56	91.69	30.03
Rest*	25.25	97.66	33.24	156.15	22.21
Total	92.96	117.08	37.80	247.84	52.24

SOURCE: MOC 2005
*Includes SCCL, DVC, Tata, Jindal, and all others

Integrated energy policy, Report of the Expert Committee (Planning Commission 2006)

The Committee accepts that large estimates of coal resources have resulted in a false notion of security of energy supplies. Current and foreseeable technologies convert only a small fraction of resource into extractable coal. Limited exploration capacity of CMPDIL has resulted in low conversion of indicated and inferred resources into proved reserves (Planning Commission 2006).

Having said so, the Committee has gone back and used the earlier estimates of MOC for extractable coal which provides a very high R/P ratio of 147 to 186 meaning thereby that extractable coal would last for 147 to 186 years at the present level of production (MOC 2005). It further suggests that "proved reserves could last for 80 years at current rate of consumption"! It also wishes that if all the inferred resources also materialise (get converted to proved reserves?), then the coal and lignite would last for 140 years at current rate of extraction. Quoting such figures confirms that the finitude of coal resources has not fully registered with the policy makers. However, at the end, the report agrees that extractable coal reserves would run out in 45 years if the coal industry continues to grow at 5% per year.

The Committee has also suggested that all those CIL coal blocks, which CIL does not propose to projectise by 2016/17, should be offered to others who should be asked to start the production by the year 2011/12. In effect, this would increase coal availability in the short run but would result in much faster decline of CIL's production.

Domestic coal production, imports and transportation

Coal production in India has risen from about 70 million tonnes in 1973 to about 431 Million tonnes in the year 2006/07. In the year 2001/02, 95% of national coal production was contributed by CIL and SCCL, 4% was contributed by captive collieries and Meghalaya and only 1% came from the operators of captive blocks offered to private players and others. In the current year i.e. in 2006/07, CIL and SCCL produced 93% of coal while 4% came from captive coal blocks.

Table 10 Trend of production of coal and lignite (million tonnes)

Year	Raw coal	Lignite	Total solid fossil fuel
1997-98	300.4	23.2	323.6
1998-99	296.5	23.4	319.9
1999-00	304.1	22.5	326.6
2000-01	313.7	24.2	337.9
2001-02	327.8	24.8	352.6
2002-03	341.3	26.0	367.3
2003-04	361.2	28.0	389.1
2004-05	382.6	30.3	413.0
2005-06	407.0	30.1	437.1
2006-07(P)	430.9	31.1	462.0

SOURCE: CCO 2006

Such large increases in production could be achieved through enhanced investment in the coal industry through full budgetary support from the Government and deliberate shift in technology towards opencast mining. The opencast mines, which contributed only about 28% of the total production at the time of nationalization in 1973, increased their share to about 87% in 2006/07. This trend was deliberate because due to shorter gestation period, high recovery and safety, and lower cost of production it provided larger profits for the national coal companies. However all the coal produced from opencast mines comes from shallow deposits, mostly within 150m from the surface. Also, bulk of coal produced from opencast mines is of inferior grade and the coal supplies from such mines are still lower in grade due to contamination inherent in the technology chosen. As a result of this policy, the production of inferior grades of both coking and non-coking coal has been increasing in the last decades and this trend is likely to continue.

Table 11 Trend of production of raw coal from OC mines (million tonnes)

Year	Open cast			
	CIL	SCCL	Others	All India
1997-98	207.0	15.3	9.0	231.4
1998-99	203.2	14.4	11.2	228.7
1999-00	208.3	16.8	12.2	237.3
2000-01	217.6	16.5	13.6	247.6
2001-02	230.4	17.1	15.5	263.0
2002-03	242.3	20.4	15.4	278.1
2003-04	258.9	20.5	19.0	298.5
2004-05	276.5	22.3	21.4	320.3
2005-06	297.6	23.4	25.1	346.1
2006-07(P)	317.6	25.8	29.7	373.1

SOURCE CCO 2006

The annual production from underground mines has been stagnating around 50-60 million tonnes with constantly declining share in the total national coal production. In the last decade, the contribution of CIL has gone down from 54 million tonnes in the year 1997/98 to 43 million tonnes in 2006/07.

Table 12 Trend of production of raw coal from UG mines (million tonnes)

Year	Under ground			
	CIL	SCCL	Others	All India
1997-98	54.0	13.6	1.4	69.0
1998-99	53.3	13.0	1.5	67.8
1999-00	52.3	12.8	1.7	66.8
2000-01	50.6	13.8	1.7	66.1
2001-02	49.2	13.7	1.9	64.8
2002-03	48.4	12.8	1.9	63.2
2003-04	47.4	13.3	2.0	62.8
2004-05	47.0	13.0	2.3	62.3
2005-06	45.8	12.7	2.4	61.0
2006-07(P)	43.3	11.9	2.6	57.8

SOURCE: CCO 2006

India is deficient in coking coal resources which is confined to a very few coalfields while the availability of non-coking coal, especially of inferior grades is much larger and is found in all coalfields of India. The production of coking and non-coking coal is give below:

Table 13 Trend of production of different types of coal (million tonnes)

Year	Coking coal			Non-coking	Total raw coal
	Metallurgical	Non-Metallurgical	Total coking		
1997-98	23.6	20.2	43.8	256.6	300.4
1998-99	23.8	15.4	39.2	257.3	296.5
1999-00	21.2	11.8	33.0	271.1	304.1
2000-01	19.5	11.4	30.9	282.8	313.7
2001-02	18.0	10.7	28.7	299.1	327.8
2002-03	18.4	11.8	30.2	311.1	341.3
2003-04	18.3	11.1	29.4	331.8	361.2
2004-05	18.2	12.0	30.2	352.4	382.6
2005-06	17.1	14.4	31.5	375.5	407.0
2006-07(P)	17.2	15.0	32.2	398.7	430.9

SOURCE: CCO 2006

Due to this shortage of coking coal of right quality, the import of low ash coking coal started early and was about 22 Million tonnes in the year 2006/07. The need for import of non-coking coal was felt when the national coal companies failed to meet the increasing demand of coal consumers like power, cement and sponge iron manufacturers.

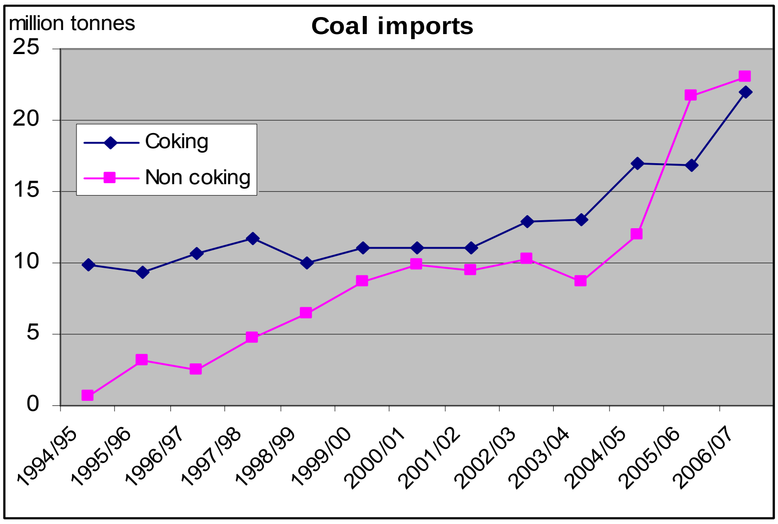
Table 14 Trend of import of coal and coke (million tonnes)

	Coking	Non coking	Total	Coke
1994/95	9.87	0.68	10.56	0.67
1995/96	9.38	3.13	12.51	1.18
1996/97	10.62	2.56	13.18	1.24
1997/98	11.75	4.70	16.44	2.28
1998/99	10.02	6.51	16.54	1.57
1999/00	10.99	8.71	19.70	2.41
2000/01	11.06	9.87	20.93	2.42
2001/02	11.11	9.44	20.55	2.28
2002/03	12.95	10.31	23.26	2.25
2003/04	12.99	8.69	21.68	1.89
2004/05	16.93	12.03	28.95	2.84
2005/06	16.89	21.70	38.59	2.62
2006/07	22.00	23.00	45.00	3.80

SOURCE: CCO 2006

The import of non-coking coal has been increasing rapidly in the last few years and is likely to continue to grow at a faster pace. Many cement manufacturers have switched over to imported coal and some coastal power plants are also importing thermal coal to meet the 34% ash requirement of MOEF (Ministry of Environment and Forest).

Figure 4 Import of coking and non-coking coal



SOURCE: CCO 2006

Coal in India moves by various modes, predominant among them is the rail. Coal supplies to pithead power stations are normally executed by MGR (Merry Go Round, a circular railway), which has emerged as the second largest mode. It is likely that more coal in future would move by MGR as more pithead power plants are planned.

Table 15 Movement of coal by various modes (million tonnes) 2006-2007

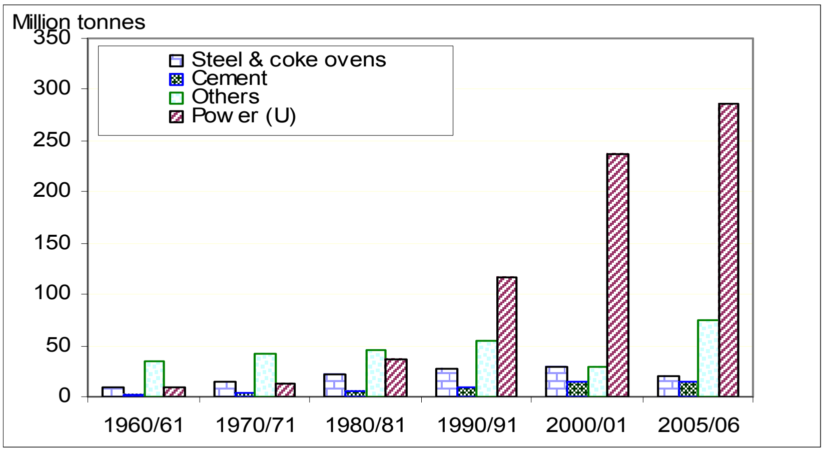
	Rail	Road	MGR	Belt	Rope	Total
CIL	179.61	58.56	78.78	7.13	5.83	329.91
SCCL	18.57	9.31	9.11	0.00	0.50	37.48
Other public	0.00	1.39	0.00	0.00	0.00	1.39
Private	8.74	8.29	0.00	0.00	0.00	17.03
Total	206.92	77.55	87.89	7.13	6.33	385.81
Internal	1.87	18.95	0.00	10.23	2.63	33.68
G Total	208.79	96.49	87.89	17.36	8.96	419.49

Note: In addition, 21.6 million tonnes of middlings by rail and 6 million tonnes of middlings moved by road.
SOURCE: CCO 2006

Review of coal use in power generation

After the Indian Railways decided to phase out the steam engines in nineties, power sector started emerging as the major coal consumer. From about 9 million tonnes in 1960/61, the consumption by the power utilities has grown to 287 million tonnes in 2005/06 and is slated to continue to grow in future. Additionally, the coal based captive plants associated with industries like cement, alumina, steel etc consume over 20 million tonnes annually. Being the major consumer of coal, power sector drives the demand of coal in India.

Figure 5 Sectoral coal consumption



SOURCE: CCO 2006

Projections for next 20 years

The Integrated Energy Policy (Planning Commission 2006) has worked out the demand of coal for various users under various scenarios. Under one of the possible scenarios, the projections show that the demand by the power sector would increase from 463 million tonnes in 2011/12 to over one and a half billion tonnes in next twenty years i.e. in the year 2026/27 and over two billion tonnes in the year 2031/32. The details are given in the Table 16.

However, this may not be treated as the best case scenario and figures of demand for coal would change with the change in the availability and price of other energy sources considered in the model.

Table 16 Projections of coal use (million tonnes)

		Power	Non power*	Total
XI Plan	2011/12	463	164	627
XII Plan	2016/17	603	221	824
XIII Plan	2021/22	832	299	1131
XIV Plan	2026/27	1109	408	1517
XV Plan	2031/32	1475	562	2037

SOURCE: Planning Commission 2006
*Including coking coal

The potential for coal fuel supply in the next 20 years

Coal is again emerging, as the preferred fuel for power generation in many countries primarily because it is widely distributed, is relatively plentiful; costs are comparatively lower and less volatile with mature technology available for its conversion. In India, up to mid 1960s, the thrust was more on developing multipurpose hydel projects, but, since 1970s, the coal based thermal capacity has shown sharp increase.

India has now no alternative but to remain as a coal-centric energy producer, at least for the next three decades. There are several reasons that can be attributed to this, the main being the oil shock of seventies when India officially decided to use more and more coal to meet the energy needs of the country. Added to this was the way coal resource of the country was being presented, which gave a false sense of abundance. Nationalisation of the coal sector at this juncture also boosted coal use as the total control of the sector went into the hands of CIL - SCCL combine. CIL emerging as the monopoly coal producer and CMPDIL (a subsidiary of CIL) being the sole custodian of coal blocks and detailed exploration data, it was very difficult to make any headway in unravelling the myth of abundance, perpetuated over decades. The monopoly status gave CIL the chance to pick and choose the coal blocks; shallow deposits were obvious choice because of lower gestation lag, greater safety, greater flexibility in sizing and much lower cost compared to developing deeper deposits via the underground route. This also reflects in the resource base data where extensive exploration has been done in the 0-300m depth range and the exploration of deeper deposits has been ignored.

Various CIL, MOC and Planning Commission documents have pointed out that there are large areas of the country, which is unexplored, and more coal resources would be available when these areas are taken up for exploration. However, it has been reported that only 17,300 sq. km area spread over forty four Gondwana and sixteen Tertiary coalfields is supposed to contain economically viable coal resources. It is reported that 141 billion tonnes of un-graded coal resources up to a depth of 1200m have been prognosticated within the above coalfields. Significant part of this would be deep seated (>600m) and some at intermediate levels (300-600m) in many coalfields being exploited currently. Coal resources in the shallow depth range of 0-300m would be available in only Hasdeo- Arand coalfields (GSI 2006). Large resources at depths greater than 1200m has also been prognosticated at some places in the country which has been confirmed by deep drilling undertaken for oil /gas exploration.

The CMPDIL accepted in 2001 that the present extractable reserves stand at only 40 billion tonnes even after taking in to consideration the 143 billion tonnes of prognosticated resources. Followed by this, the Coal Vision 2025 in the year 2005 reports that the extractable resources are just over 52 billion tonnes taking into consideration all the coal blocks on the selves of CMPDIL and also the coal contained in the unblocked acreage.

In the year 2006/07 CIL has produced 361 million tonnes while others have contributed about 70 million tonnes. With the well explored shallow coal blocks available with CIL and by over-exploiting the existing large opencast mines, it can easily reach a production level of 500 million tonnes by 2011/12 but would not be able to sustain this production level up to the year 2036/37 as suggested in Coal Vision 2025 because some of the CIL coal blocks (from the 289 held by CIL) are being offered for immediate projectisation by private/ state government/ State Utilities. These agencies have also been offered the other coal blocks known as non-CIL blocks, which are also likely to be projectised early with MOC exerting the pressure through the threat of taking away the blocks in case of failure to operationalise within a given time frame. These new capacities would contribute for a period of about 30 years; so also the new capacities to be built by CIL. However, the contribution from the existing mines and projects would slide as shown below:

Table 17 Production program of CIL and SCCL (million tonnes)

Coal India Limited	X Plan 2006/07	XI Plan 2011/12	XII Plan 2016/17
Existing mines / completed projects	241.8	186.0	151.5
Ongoing projects	102.4	165.3	181.6
New projects	19.6	169.2	330.9
Total	363.8	520.5	664.0
Singareni Coal Company Limited			
Existing mines / completed projects	29.6	18.9	7.0
Ongoing projects	7.9	13.6	6.3
New projects	0.0	8.3	31.7
Total	37.5	40.8	45.0

SOURCE: MOC 2006

Within the next ten years, the contribution from existing mines/ completed projects of CIL would be reduced by 90 million tonnes and that of SCCL by about 23 million tonnes or a total of 110 million tonnes of national coal production. However, with the new capacities CIL would be able to produce over 500 million tonnes in 2011/12, another 40 million tonnes coming from SCCL. Balance demand is expected to be met by production from private / state utilities/ captive mines etc and imports. Similarly, for meeting the demand in future years, imports and increasing contribution from others would supplement the national coal company's production

The above scheme of things is likely to work for about next 20 years. Due to overexploitation and not able to build new capacities, production from CIL would fall very sharply and the other sources would not be able to meet the shortfall resulting in the inevitable situation of large scale imports.

Summing up

The perception that India is bestowed with extremely large coal resources strengthened by the published resource data is still deeply entrenched in the mindset of policy makers.

Historically, the figures of geological resources have been reported in such a way that it is very difficult to estimate extractable reserves with any degree of certainty or accuracy.

The exaggerated resource reporting has put the country on to a path of coal-centric energy supply, at least for the next three decades

However, this is now almost certain that the total extractable reserves may be just enough for a couple of decades, that too without meeting the demand of all consumers in full.

The shortages between demand and supply by domestic sources would result in large-scale imports of coal giving rise to many serious concerns including hardening of coal price in the international, shortages of dry bulk carriers resulting in increased ocean freight and problems associated with handling of such large volumes at Indian ports with inadequate capacities.

The time is running out and the next thirty years or so seems to be the only period left within which India needs to aggressively develop all possible sources of energy supplies including renewables to provide some kind of energy security for itself.

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Development Benefits of Clean Energy in India Advanced Technology for Coal Power Generation

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Executive Summary

Advanced Technology for Coal Power Generation

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1. Background and issue/problem introduction

Coal based thermal generation accounts for about 70% of electricity generated by the Indian power sector in 2004-05 [MOP, 2007]. About 75% of India's coal consumption is in the power sector. Power development is the key to economic development. Power generation in India ranks third among the coal producing countries of the world. Indian coals are classified as high quality, low grade with a low sulphur content (<0.6%) and high ash content (>40%).

Though there is some uncertainty in the coal reserve estimates the static reserve / production ratio for coal ranges from 80 years (using proven reserves) to 140 years (using proven and indicated reserves). Out of the different grades of non-coking coal available in India the grades D, E and F are generally used for power generation.

It is expected that coal will continue to the main fuel source for the Indian power sector in the near future. The Integrated Energy Policy indicates that coal would account for 75% of the total installed capacity for power generation in 2025.

In order to select a technology for the Indian context the performance characteristics of the existing power plants must be evaluated. The technical, environmental and economic performance of the existing thermal power plants in the country, and the advanced technologies are analysed and compared in this project. The compatibility of advanced technologies with Indian context is also required for selection of appropriate technology for capacity addition in thermal power generation.

2. Indian Thermal Power Stations and Advanced Coal Technologies

Performance Characteristics

The technical performance of any thermal power plant can be characterised by Station Heat Rate (SHR), average auxiliary power consumption and operational availability. Station Heat Rate (SHR) is an important index for assessing the efficiency of a thermal power station. Heat rates for various coal based unit operating in the country is provided by the Central Electricity Authority (CEA). Data related to Station Heat Rate was available from 57 thermal power stations during 2005-2006, which was compiled and analysed. The average auxiliary power consumption for the thermal power stations in India for 2005-2006 is 9.5 %.

The environmental performance is characterised by green house emissions, human health damaging pollutants, Suspended Particulate Matter and NOX. The CO_2 emissions from thermal power plants is calculated using the methodology suggested by IPCC (1996). The N_2O emissions from thermal power plants is estimated in the same way as that of CO_2. The average N_2O emission coefficient for Indian coal is taken as 0.03 kg of N_2O/ton of coal. The SO_2 emissions were estimated using the guidelines provided by IPCC (1996). The data for Suspended Particulate Matter (SPM) is taken from CEA for 2005-2006. The NO_2 emissions from thermal power plants is estimated based on the IPCC guidelines (1996).

The economic performance is characterised by capital costs, fuel costs and O&M costs.

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Coal based Power Generation in India

The data for technical, environmental and economic performance of the existing thermal power plants in the country are collected, analysed and arrived at the current operating values, which will be used to select an appropriate advance coal technology for India. In India, power generation from coal, uses the conventional steam cycle with sub-critical steam parameters (ranging from 535-575^{o}C, 175-230 bar) with pulverized coal combustion. Unit size variation for small power plants ranges from 30-500 MW (mean of 175 MW, mode – 210 MW).

Advanced Coal Based Technologies

Supercritical Pulverised Plants: ***Supercritical PC technology operates on the same cycle as the conventional sub critical cycle. However Supercritical PC technology has higher steam conditions in the order of 226-248 bar and temperatures in the range of 530-580^{o}C. Supercritical PC plants operate at higher efficiency than the conventional plants and have lower g/kWh emissions. There are about 250 above SC plants operating worldwide, most of thwe units are of the size range 500-600 MW. The heat range ranges from 1870 to 2150 kcal/kWh (40-46 % efficiency). At present there are no supercritical plants installed in India though several plants are in the planning and implementation stage.***

Ultra Supercritical Pulverised Plants: ***Ultra Supercritical PC technology operates on the same cycle as the Supercritical PC technology has higher steam conditions in the order of 270-285 bar and temperatures in the range of 580-630 °C. Supercritical PC plants operate at higher efficiency than the conventional plants and have lower g/kWh emissions. There are also 24 ultra-supercritical units operating worldwide, which achieve even higher efficiencies than supercritical PC plants, with units in Denmark, Germany, Japan, the Netherlands, and USA.***

AFBC: ***AFBC is a Fluidised Bed combustion technology in which the bed operates at atmospheric pressure and the products of combustion are used to generate steam for power generation using the Rankine cycle. It is a commercially mature technology that has been used worldwide for over 50 years. There are two types of AFBCs:- 1) Bubbling Fluidised Bed Combustion. 2) Circulating Fluidised Bed Combustion.***

There are about twenty commercial Circulating Fluidised Bed Combustion (CFBC) plants around the world (ranging from 37 MW to 200MW). The heat rate ranges from 2150 kcal/kWh (efficiency 29% to 40%).

PFBC*: Pressurised Fluidised Bed Combustion employs a combination of the Rankine cycle and Brayton cycle in order to achieve higher efficiencies and reduced emissions.*

IGCC: Integrated Gasification Combined Cycle There are a few (about five) IGCC installations worldwide (100-350 MW range).

Table 1 shows the performance characteristics of Indian Coal Based Power Generation and Advanced Coal Based Technologies. Table 2 shows the Indian experience with advanced coal technologies.

Table 1: Performance Characteristics of Indian and Advanced Coal Based Power Generation Technologies

Sr. No.	Criteria	Indian Thermal Power Stations			Supercritical PC		CFBC		PFBC			IGCC		
		Av.	Min.	Max.	Min	Max	Min	Max	Av.	Min	Max	Av.	Min	Max
I	**Technical Performance Characteristics**													
	a. Heat Rate (kcal/kWh)	3218	2489.5	6341	1872	2153	2923	2153	2242	2012	2533	2020	1861	2190
	b. Efficiency (%)	27.7	13.58	34.6	40	46	29	40	38.6	34	42.8	40.6	38	43.7
	c. Operational Availability (%)	9.52	5.59	16.2	86	92	87	88	59.6	52.5	69.5	83.8	60	95
	d. Auxiliary Consumption (%)											17.1	12.7	25.2
II	**Environmental Performance Characteristics**	1.04	0.784	1.608										
	a. CO_2 (kg/kWh)	7.55	1.44	24.6										
	b. SO_2, (g/kWh)	3.502	2.47	5.62	100	200	170	400	1.19	0.205	2.55	0.173	0.06	0.39
	c. NO_2 (g/kWh)	198.5	11	923	200	650	80	300	0.55	0.25	0.84	0.325	0.09	0.5
	d. SPM (mg/nm3)				10	25	~ 25					0.02	0.016	0.022
III	**Economic Performance Characteristics**													
	a. Capital costs (million Rs/MW)	29	21.5	44.6*	42.8+	72	45	72	107.8	67.5	129.4	108	67.5	129.4
	US $/kW	650	480	990	950	1600	1000	1600	2396	1500	2875	2396	1500	2875

* this is the minimum, maximum and average of the actual cost of the power plants built in India during the last few years

+ the values for the advanced coal technologies are taken in US $ conversion used is Rs. 45/$ (2006 exchange rate)

Table 2: Indian Experience with Advanced Coal Technologies

Indian CFBC experience (GIPCL)

Characteristics	**CFBC**	**IGCC**
Capacity (MW)	2x125	6.2
Year of Commissioning		1989
Units generated (GWh)	1651	
Lignite consumption (ktons)	1611	
Efficiency	27.5	39
Heat Rate (kcal/kWh)	3128	2209
Auxiliary Consumption (%)		
Availibility (%)	88	
Capital Cost (Rs/kW)	48400	24200
Operating Cost		
Fuel cost		
CO_2 (kg/kWh)	0.95	
SO_2 (g/kWh)		
NO_2 (g/kWh)		
SPM (g/kWh)		

3. Analysis of technology mix

Power generation technologies are frequently coupled with technologies for various emission removal or reduction such as for SOx, NOx and Suspended Particulate Matter (SPM). An analysis of each power generation technology with a combination of emission removal technologies for SOx, NOx and Suspended Particulate Matter (SPM) is performed to arrive at the capital cost, operating cost and the emission levels for each of the combinations selected. Table 3 shows the matrix of advance power generation technologies, SOx removal technologies, NOx removal technologies and SPM control technologies.

Table 3: Matrix for analysis of technology mix

Power generation technologies	SOx emission removal technologies	NOx emission removal technologies	SPM emission removal technologies
Supercritical Pulverised Coal Combustion	Sorbent Injection	Low NOx burners	Electrostatic Precipitators
Circulating Fluidized Bed Combustion (CFBC)	Dry scrubbing	Selective Non-Catalytic Reduction	Fabric Filters
Pressurised Fluidized Bed Combustion (PFBC)	Wet Scrubbing	Selective Catalytic Reduction	
Integrated Gasification Combined Cycle (IGCC			

The efficiency of emission removal, capital cost and operating cost of each technology is presented in the Table 4

Table 4: Summary of emission removal technologies

Sr No.	Technology	Efficiency	Capital cost	Operating cost
I	**SOx Removal**			
1	Sorbent Injection	70	3950	0.135
2	Dry Scrubbing	82	6300	0.135
3	Wet Scrubbing	85	9000	0.09
II	**NOx Removal**			
1	Low NOx burners	55	1800	0
2	SNCR	70	800	0.09
3	SCR	80	3200	0.18
III	**SPM Removal**			
1	ESP	99.5	1350	0.18
2	Fabric filters	99.5	2250	0.06

Also the efficiency, costs and emission levels of different advance coal technologies are presented in Table 5.

Table 5: Summary of Advanced coal technologies

	Efficiency	Capital cost (Rs./kW)	*SOx mg/m3*	NOx mg/m3	SPM mg/m3	Operating Costs Rs./kWh
Supercritical	43.0%	57400	200	650	25	0.128
CFBC	34.5%	58500	170	300	25	0.14
PFBC	38.6%	107820	200	320	10	0.14
IGCC	40.6%	107820	100	150	10	0.25

The combination of technologies is assigned a code for ease of analysis. Detailed analysis is done and the results of all the combinations are presented in form of graphs in the report.

4. Analysis of Advanced coal technologies with relevance to Indian coals

The effect of Indian coals on advance coal technologies has to be analysed. The feasibility of these technologies with coal having 40 45% ash has to be checked. In order to study the effect of coal ash content on the efficiency of these technologies, a simulation run of these technologies with varying ash content is to be performed.

The characteristics of Indian coal in form of proximate and ultimate analysis are given in Table 6.

Table 6: Characteristics of Indian Coal

Proximate analysis (% by weight, dry basis)	
Fixed carbon	25.5
Volatile matter	31.4
Mineral Matter	43.1
Elemental analysis (% by weight)	
Carbon	38.9
Hydrogen	2.6
Oxygen	6.7
Nitrogen	0.7
Sulphur	0.6
Moisture	5.7
Lower Heating Value (MJ/kg)	14.5
Fuel Exergy (MJ/kg)	16.5

The model created for simulation is a lumped model considering the furnace and boiler as a black box and analysing the energy and mass flows in and out of this black box. The mass and energy balance across the control volume is computed in order to see the effect of coal ash on the efficiency of each of the power generating cycles. Here the evaporator, reheater, economizer and air pre-heater are considered enclosed in the control volume. An energy balance is computed across this control volume considering the energy interactions across the control volume.

Supercritical Pulverized Coal Combustion

Supercritical pulverized coal combustion technology is similar to subcritical technology in terms of combustion of coal. However a supercritical plant operates at higher temperatures and pressure that exceeding the critical point. The supercritical plant considered for study has (600^{o}C/300bar) a double reheat cycle. With increase in coal ash, the efficiency of power generation of supercritical technology decreases. At the ash content of 40-45%, the efficiency is about 37.5%.

Ultra Supercritical Pulverized Coal Combustion

Ultra supercritical pulverized coal combustion technology is similar to supercritical technology with higher temperatures and pressure. The ultra supercritical plant operates at about 720^{o}C/390bar.

Circulating Fluidised Bed Combustion

The Circulating Fluidised Bed Combustion technology for power generation has a similar layout as that of subcritical pulverized plant except for the boiler. The boiler in CFBC is a fluidised bed boiler. Simulation run for the CFBC plant was carried out using the same conditions of steam (170^{o}C/550 bar) single reheat cycle as that for subcritical pulverised. However the boiler is a circulating fluidised bed boiler. The efficiency for FBC here is only a function of the heat carried away by the ash which is in turn is a function of the ash content in coal. For FBC boilers the combustion efficiency is high and is unaffected by ash content in coal

Pressurised Fluidised Bed Combustion

Pressurised Fluidised Bed Combustion technology is similar in layout to the CFBC technology, but in that it has a pressurized boiler. In the PFBC combustor as similar to the CFBC boiler the bed material is combusted in an upward flow of air. Generally the bed material consists of finely powdered coal and a sorbent (limestone) for SO_2 capture. But in case of Indian coals where sulphur content is low, very little or no sorbent is added. The ash content of coal as seen from the trend has very little effect on the efficiency of the cycle.

Integrated Gasification Combined Cycle

In the case of IGCC the effect of ash cannot be checked with the lumped model. Hence the IGCC performance with respect to coal characteristics was analysed based on previous studies and experiments conducted on pilot plants. The high ash content lowers the efficiency of the gasification step which in turn has a direct impact on the efficiency of the whole IGCC plant. The use of high ash coal not only requires handling of a larger quantity of inert material in coal and a greater number of gasifiers but involves penalties in terms of higher raw material consumption and lower gasification efficiency.

The environmental and economic performance characteristics of advance coal technologies with Indian coal are calculated. The cost of generation is estimated with annualised capital cost; O&M cost and fuel cost. The performance characteristics of advanced coal based power generation technologies with Indian coal are given in Table 7.

Table 7: Performance Characteristics of Advanced Coal Based Power Generation Technologies with Indian Coal

Sr. No.	Criteria	SC*	USC	CFBC*	PFBC	IGCC*
I	**Technical Performance Characteristics**					
	a. Heat Rate (kcal/kWh)	2012		2538	2242	2020
	b. Efficiency (%)	36.4	44.1	27.5	38.6	39
	c. Operational Availability (%)	>86	88	88	59.6	83.8
	d. Auxiliary Consumption (%)					17.1
II	**Environmental Performance Characteristics**					
	a. CO_2 (kg/kWh)	1.07	0.98	0.95	0.68	0.67
	b. SO_2, (g/kWh)	7.08	6.52	6.33	4.54	4.47
	c. NO_2 (g/kWh)	2.64	2.43	2.36	1.69	1.66
	d. SPM (mg/nm3)			~ 25		0.02
III	**Economic Performance**					
	a. Capital costs (Rs/kW)	42000		48400	95840	108000
	b. Fuel costs (Rs/kWh)	0.49	0.45	0.44	0.315	0.31
	c. O & M costs (Rs/kWh)	0.14	0.14	0.14	0.14	0.14

**Efficiency, Capital cost and Availability as per Indian Experience*

5. Emissions

The existing coal based power plants in India account for 70% of the electricity generation (443 Billion kWh in 2003-4). The carbon dioxide emissions from these plants was about 460 million tonnes. The total coal used in the power sector (including non utility power plants greater than 1 MW) was about 317 million tonnes in 2003-4. Table 8 compares the international advanced technologies with the subcritical technology operating in India.

Table 8 Comparison of advanced technologies with Indian subcritical plants

Characteristics	**Subcritical**	**Supercritical**	**CFBC**	**PFBC**	**IGCC**
Max Capacity (MW)	500		300	360	335
Efficiency	27.7	43	35	38.6	40.6
Heat Rate (kcal/kWh)	3218	2012	2436	2242	2020
Auxiliary consumption	9.52				17.1
Availability (%)	88	89	87.5	59.6	83.8
Capital Cost (Rs/kW)*	29000	57000	58500	108000	108000

* Cost of Advanced Coal Technologies as per international data

Table 9 shows the annual coal consumption in 2025 based on existing heat rates (1450 million tonnes). The Business as Usual scenario has been computed assuming that the new plants would have an average operating net heat rate of 2500 kcal/kg. This results in a coal requirement of about 1200 million tonnes (this is likely to include some coal imports) and a carbon dioxide emission of 1740 Mt. A strategy for aggressive adoption of super-critical plants and advanced coal technologies would result in the new plants would have an average operating net heat rate of 2200 kcal/kg. The coal requirement reduces to less than 1100 million tonnes resulting in an annual saving of 100 million tonnes of coal and a saving of 150 Mt of carbon dioxide.

<u>Development Benefits of Clean Coal Technology:</u> The main development benefit would be the reduced coal consumption. In view of the constraint of coal availability, the reduction of annual coal consumption in 2025 by 10% or more (100 million tonnes) would result in extending the coal reserves and reducing coal imports. The disadvantage would be the higher capital investments required. Another advantage would be the reduced NOx and particulate emissions with consequent lower health impacts from outdoor air pollution exposures and lower damage from acid precipitation.

Table 9 Estimated Coal Consumption and Emissions from Coal Power Plants in 2025

Year	**Electricity Generation (Billion kWh)**	**Electricity at Bus Bar ((Billion kWh)**	**Peak Demand (GW)**	**Installed Capacity (GW)**	*Mt of coal*	**Coal Based generation (Billion kWh)**	**MT CO2**
2003-4	633	592	89	131	318	443	461
2025	2704	2528	412	542	1450	2028	2109
2025 BAU	2704	2528	412	542	1198	2028	1736
2025Adv	2704	2528	412	542	1093	2028	1584

Barriers

1. The Indian power sector has inadequate exposure to advanced clean coal technologies.
2. The indigenous efforts at technology development and research and development have been limited. BHEL's experiment with IGCC in the 1980's was not followed up with a technology development programme.
3. There are relatively few active research groups working on advanced coal and clean coal technologies in India.
4. The international technologies developed for IGCC have not been tried with Indian coals.
5. The investments in R & D have been low and there is an absence of a concerted technology development mission. In 2000 the Prime Ministers office and the Principal Scientific Advisor to the Government established a committee consisting of BHEL and NTPC to decide a strategy for establishing an IGCC
6. There is an absence of an incentive for utilities and generation companies to invest in more capital-intensive clean coal technologies.
7. There is no incentive provided by regulatory authorities for clean coal technologies.

Strategies

There is a need to support the establishment of prototype clean coal technologies (at least one plant each of CFBC, PFBC and IGCC). This can be done based on competitive bidding with the joint involvement of indigenous companies and foreign suppliers. This has to be supported by a multi-institutional research initiative to provide the necessary analytical and experimental support. For the super-critical plants India's strategy should be to build a number of plants and then assess their performance vis-à-vis the sub-critical plants.

For the advanced clean coal technologies a critical assessment of the prototypes and performance after a period of about 5 years should result in a commercial deployment strategy.

A clean coal fund can be established or an incentive provided for a higher efficiency or reduced emissions. Innovative financing mechanisms may be explored with government support to defray the higher initial capital cost of these plants.

The advanced coal scenario outlined here results in significant savings of coal and extends the use of India's national coal resource. This also results in a reduction of CO_2 emissions from the power sector by 150 million tonnes in 2025 (about 9% of the emissions from coal power plants). The strategy involves building prototype power plants using PFBC and IGCC. In case these are successful in terms of operational availability at reasonable capital cost, they may form a part of the new coal based generation. This would result in a larger quantity of carbondioxide savings from the power sector in 2025.

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Indian National Coal Resources & Prospects

Contents

I. Introduction

Power development is the key to economic development. Power generation in India is predominantly based on coal based generation technology. The technology used is for coal based power generation is based on subcritical pulverised coal technology which is less efficient than the advanced coal technologies. To be able to use coal efficiently and in an environmentally acceptable manner, advance coal based power generating technologies must be employed. In order to select a technology for the Indian context the performance characteristics of the existing power plants must be evaluated. This report presents the technical, environmental and economic performance of the existing thermal power plants in the country.

II. Indian Power Scenario

The per capita electricity consumption of India has risen from 338 kWh in 1998 to 474 kWh in 2006. Majority of the thermal power plants in the country consists of coal based steam power plants and gas turbine power plants with some diesel engine power plants. The figure 1 presents the break up of the total units generated in 2004-2005.

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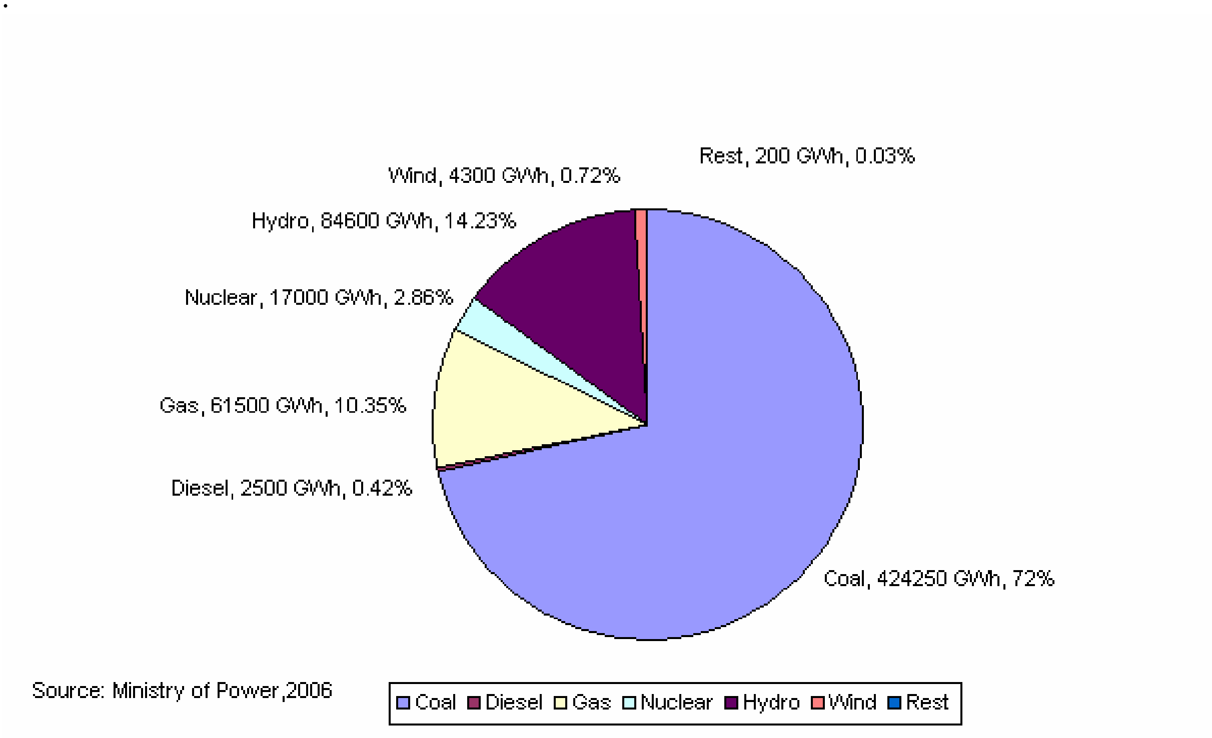


Figure 1 Breakup of the total units generated in 2004-05

Generating capacity has grown from 1,712 MW in 1950 to more than 112,000 MW in 2006 with compound annual growth rate of 7.75%. According to the target set by the Ministry of Power for 2012, additional capacity of 1,00,000 MW is envisaged. The key development objective of the power sector is supply of electricity to all areas including rural areas as mandated in section 6 of the Electricity Act. As per census 2006, about 44% of the households do not have access to electricity[1]. About 56% of rural households have not yet been electrified. About 84% of 587,000 villages have been electrified[1]. Almost 95000 village remain to be electrified [1]. Hence meeting the target of providing universal access requires significant addition to generation capacity.

III. Need for Capacity Addition

Inadequacy of generation has characterized power sector operation in India. Today, most of the regions in the country face power shortages leading to erratic and unreliable supply. The problem becomes acute during peak hours and thus necessitates planned load shedding by many utilities. To provide availability of over 1000 units of per capita electricity by year 2012 it had been estimated that need based capacity addition of more than 1,00,000 MW would be required during the period 2002-12. A total capacity addition of 46,185 MW had been fixed for X Five Year Plan (2002) and balance 60, 885 MW in XI Plan (2007) [1].

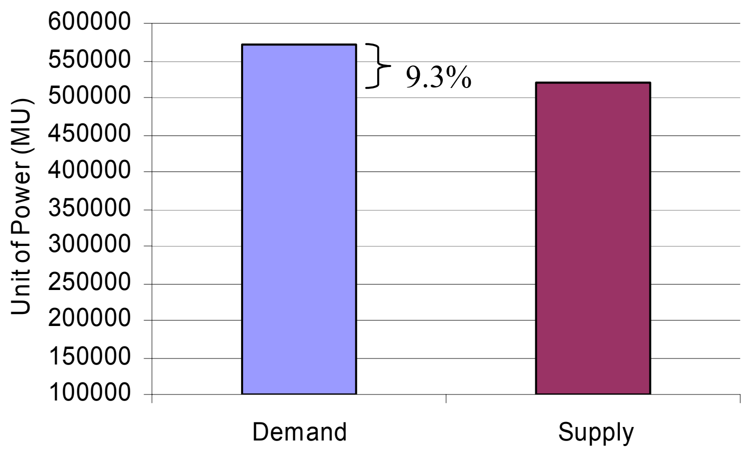


Figure 2 Demand and Supply for 2006

IV. Status of Coal based Power generation in India

Coal is expected to remain the primary fuel for meeting future electricity demand. The dominance of coal based power plants is due to the abundance of coal reserves in the country. India ranks third among the coal producing countries of the world. In 2003-2004, India consumed 355 MT of coal of which 75 % was consumed by the power sector alone. As per the current 2006 estimates, India has 253.3 billion tons of geological resources of coal. Indian coals are classified as high quality, low grade with a low sulphur content (<0.6%) and high ash content (>40%). Out of the different grades of non-coking coal available in India the grades D, E and F are generally used for power generation.

Table 1: Grades of Indian Coals

Grade	Ash % + Moisture %	GCV (kcal/kg)
A	<19.5	>6454
B	19.6-23.8	6049<GCV<6454
C	23.9-28.6	5597<GCV<6049
D	28.7-34.0	5089<GCV<5597
E	34.1-40.0	4324<GCV<5089
F	40.1-47.0	3865<GCV<4324
G	47.1-55.0	3113<GCV<3865

In India, power generation from coal, uses the conventional steam cycle with sub-critical steam parameters (ranging from 535-575 ^oC, 175-230 bar) with pulverized coal combustion. Unit size variation for SPP ranges from 30-500 MW.
Figure 3 presents the no. of each unit size operating in the country and figure 4 presents the frequency distribution of plants with age in India.

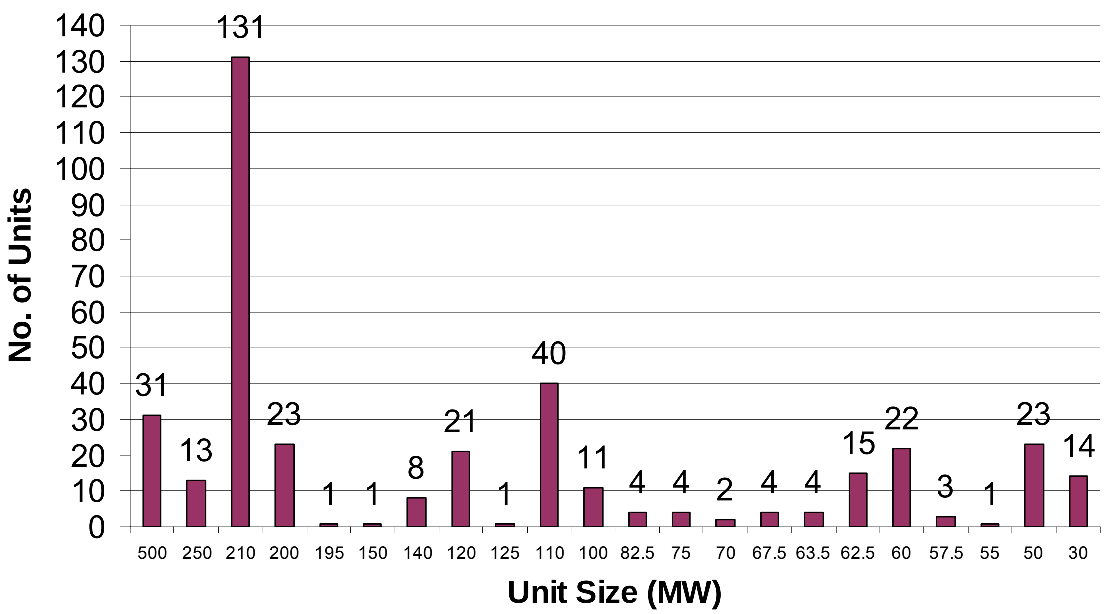


Figure 3 Unit Size variation to No. of Plants

Mean	Std. Deviation
175	**117**

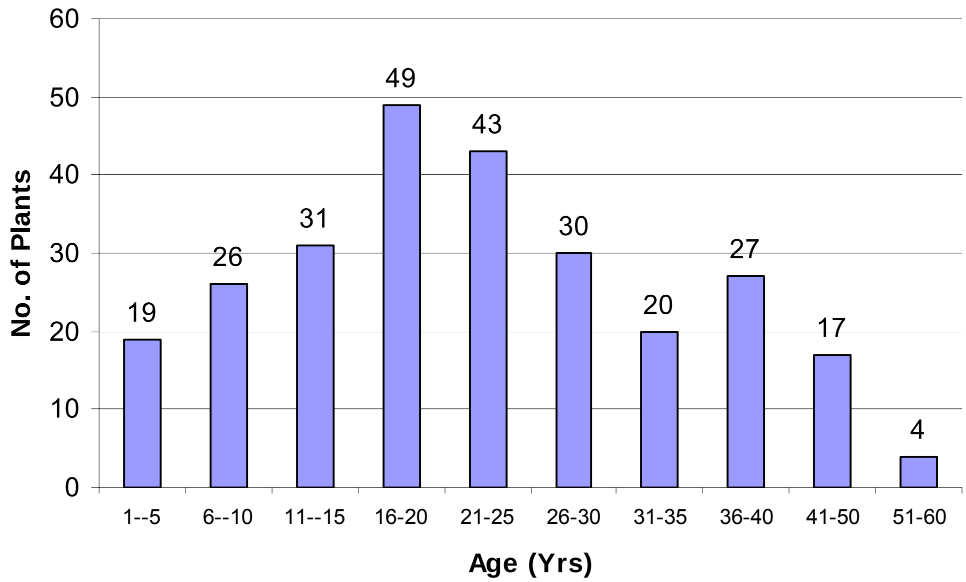


Figure 4 Distribution of Age of plants to No. of Plants

Mean	Std. Deviation
28	13.5

The performance of coal based power plants is characterized by thermal, environmental and economic performance characteristics.

1. Technical Performance Characteristics

a. Heat Rate

Operational Heat Rate is defined as

= Sp. Coal consumption (kg/kWh) x G.C.V (kcal/kg) + Sp. Oil consumption (L/kWh) x G.C.V (kcal/L)

Where, Sp. Coal consumption = $\frac{\text{Total Coal consumption in a month (kg)}}{\text{Net Generation for that month (kWh)}}$

Station Heat Rate (SHR) is an important index for assessing the efficiency of a thermal power station. Heat rates for various coal based unit operating in the country is provided by the Central Electricity Authority (CEA). Data related to Station Heat Rate was received from 57 thermal power stations during 2005-2006, which was compiled and analysed. Data provided by CEA is for Gross Heat Rate and not for Net Heat Rate. However other data such as auxiliary consumption, total generation, coal and oil consumption were also provided with the help of which Net Heat Rate was computed. Data provided was for the entire plant and not for individual units operating therein. Plants having single unit size (No variation in unit size) were segregated and the data for that plant was safely assumed as the data for the unit size operating therein. The data for plants having a unit size variation could not be segregated into data for individual unit sizes. The variation in heat rate with respect to unit size of power plants and frequency distribution of plants with heat rate are shown in figures 5 and 6 respectively.

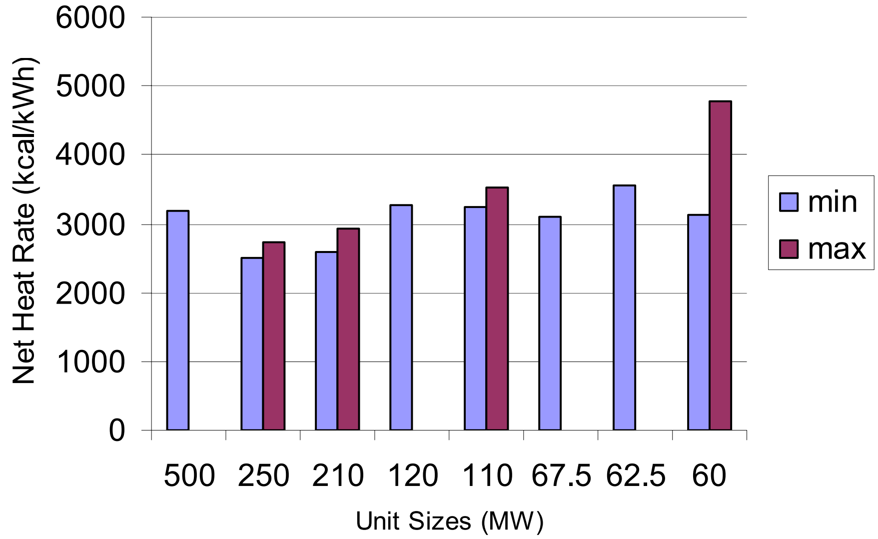


Figure 5 Range of Heat Rate Vs Unit Size

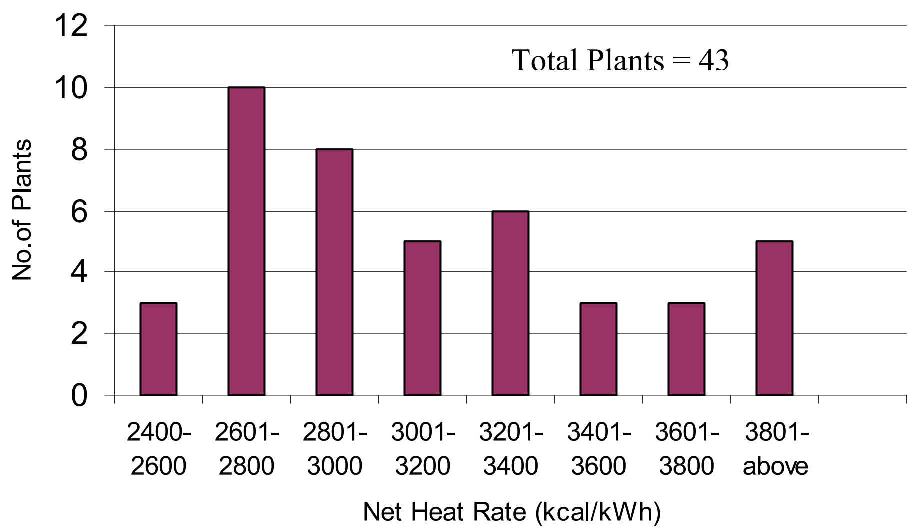


Figure 6 Distribution of Heat Rate to No. of Plants

Mean	Std. Deviation
3218	**715**

b. Auxiliary Consumption

The average auxiliary power consumption for the thermal power stations in India for 2005-2006 is 9.5 %. This auxiliary consumption is the power consumed by all the station utilities as well as the common application such as station lighting, air conditioning etc. Variation of average auxiliary consumption with size of power plant is represented graphically in figure 7.

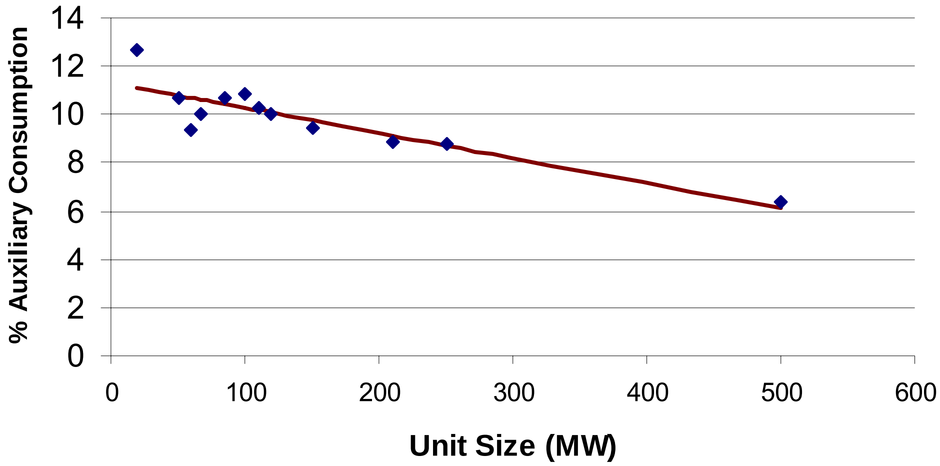


Figure 7 Auxiliary Consumption Vs Unit size (MW)

Mean	Std. Deviation
9.5	**2.3**

Table 2: Summary of Auxiliary Consumption

	Average	Minimum	Maximum
% Auxiliary Consumption	9.52	5.59	16.2

c. Operational Availability

Table 3: Unit Size wise Operational Availability

Capacity Group MW	Operating Availability (%)
500	87.21
250	89.23
210	86.44
150	75.43
120	63.47
110	62.65
100	66.82
85	84.07
67.5	77.79
60	54.31
50	42.36
20	62.02

2. Environmental performance characteristics

a. Green-House pollutants

CO_2

The CO_2 emissions from thermal power plants is calculated using the methodology suggested by IPCC (1996).

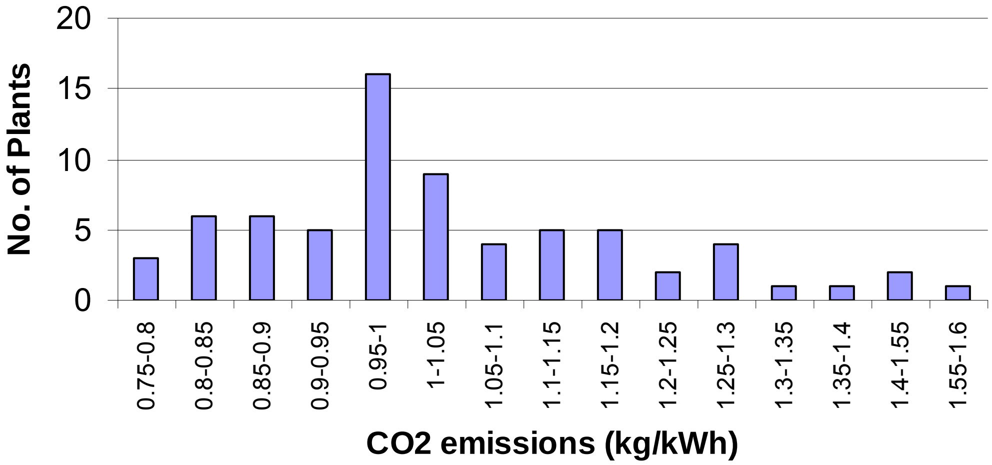


Figure 8 Distribution of CO_2 emissions to No. of Plants

Mean	Std. Deviation
1.04	0.17

N_2O

The N_2O emissions from thermal power plants is estimated in the same way as that of CO_2. The average N_2O emission coefficient for Indian coal is taken as 0.03 kg of N_2O/ton of coal. The total emission of N_2O from thermal power plants for 2005-2006 is 8000 tons.

b. Human health damaging pollutants

SO_2

The SO_2 emissions were estimated using the guidelines provided by IPCC (1996). The SO_2 emission factors for fuel combustion are a function of fuel sulphur content, combustion technology and pollution control equipment employed. For estimating the SO_2 emissions a plant wise sulphur content for the coal supplied was used.

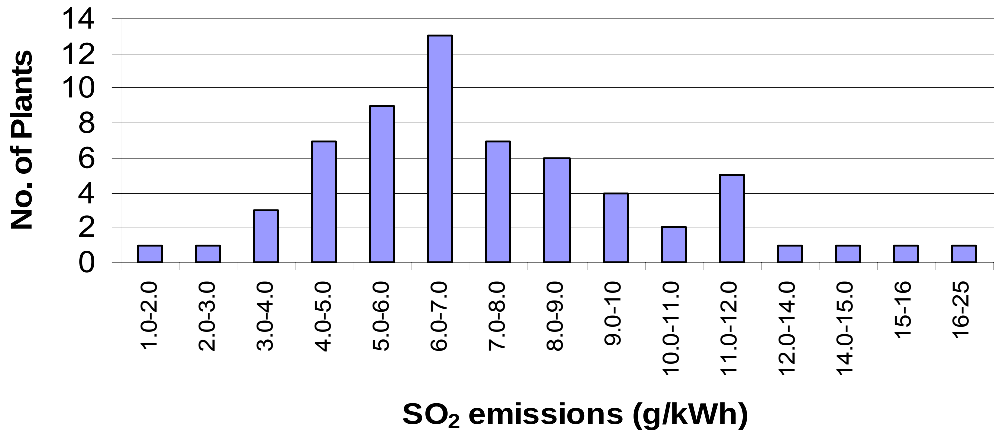


Figure 9 Distribution of SO_2 emissions to No. of Plants

Mean	Std. Deviation
7.5	**3.56**

Table 4: Ambient Air Quality SO_2 Standard

Pollutant	Industrial Area (µg/m3)	Res. Rural Other areas (µg/m3)	Sensitive Area (µg/m3)
Sulphur Dioxide (SO2)	80	60	15

SPM

The data for Suspended Particulate Matter (SPM) is taken from CEA for 2005-2006. The data is segregated for emission based on unit size.

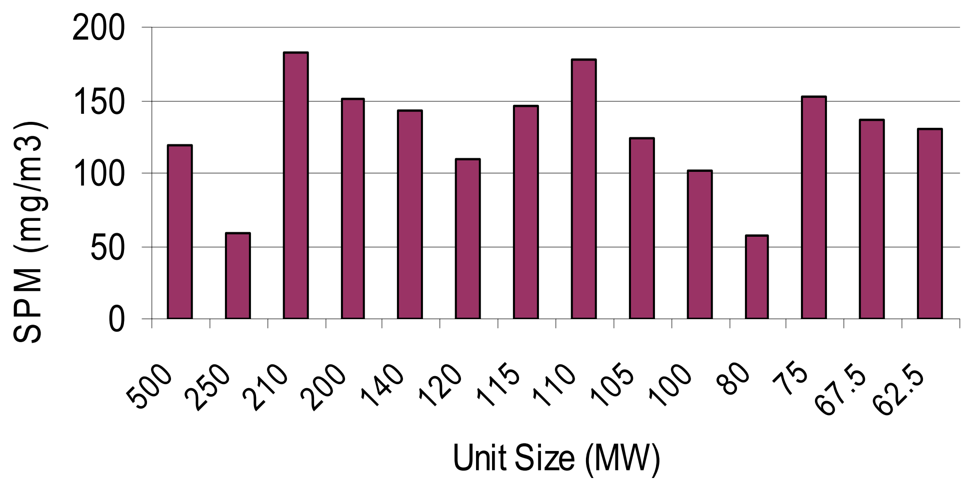


Figure 10 Distribution of SPM emissions

Mean	Std. Deviation
156	**145**

Table 5: Standards for SPM Emissions

1	Generation capacity 62.5 MW or more	150 mg/Nm3
2	Generation capacity less than 62.5 MW and plant commissioned prior to January 1982	350 mg/Nm3
3	Units located in protected area irrespective of generation capacity	150 mg/Nm3

NOx

The NO_2 emissions from thermal power plants is estimated based on the IPCC guidelines (1996). The average NO_2 emission coefficient for Indian coal is taken as 4.35 kg of NO_2/ton of coal. The total emission of NO_2 from thermal power plants for 2005-2006 is 0.6137 MT

Table 6: Summary of NO_2 emissions

Pollutant	Average (g/kWh)	Minimum (g/kWh)	Maximum (g/kWh)
NO_2	3.502	2.47	5.62

Table 7: Ambient Air Standard for NO_2 emissions

Pollutant	Industrial Area (µg/m3)	Res. Rural Other areas (µg/m3)	Sensitive Area (µg/m3)
Oxides of Nitrogen (NOx)	80	60	15

c. Other environmental damages

Soil pollution

The coal fired thermal power stations produce enormous quantities of ash. Indian coals are typically high ash coals and the ash content of coals supplied to majority of power stations is of the order of 36 to 44 %. Table 8 shows the generation and utilization of ash for 2006. The existing thermal power plants as on September 1999 according to the MOEF's notification are to achieve ash utilization level of 100% in a phased manner by 2013-14 in accordance with 15 years action plan. The new power plants subsequent to September 1999 are to achieve ash utilization level of 100% in a phased manner as per 9 years action plan and with effect from the date of publication of the notification dated 14th September, 1999. Various methods adopted for ash utilization are Land development, Cement/Concrete, Roads/Embankment, Mine filling, Bricks and Ash Dyke raising.

Table 8: Summary of Ash Utilisation for 2006

No. of Plants considered	Fly ash Production (MT/y)	Fly Ash Utilisation (MT/y)	% Utilisation
84	98.7	37.57	38

3. Economic performance characteristics

a. Capital costs

The data for capital cost is provided by CEA. The data has been corrected for price inflation and presented in figure 11 in 2005-2006 Rupees.

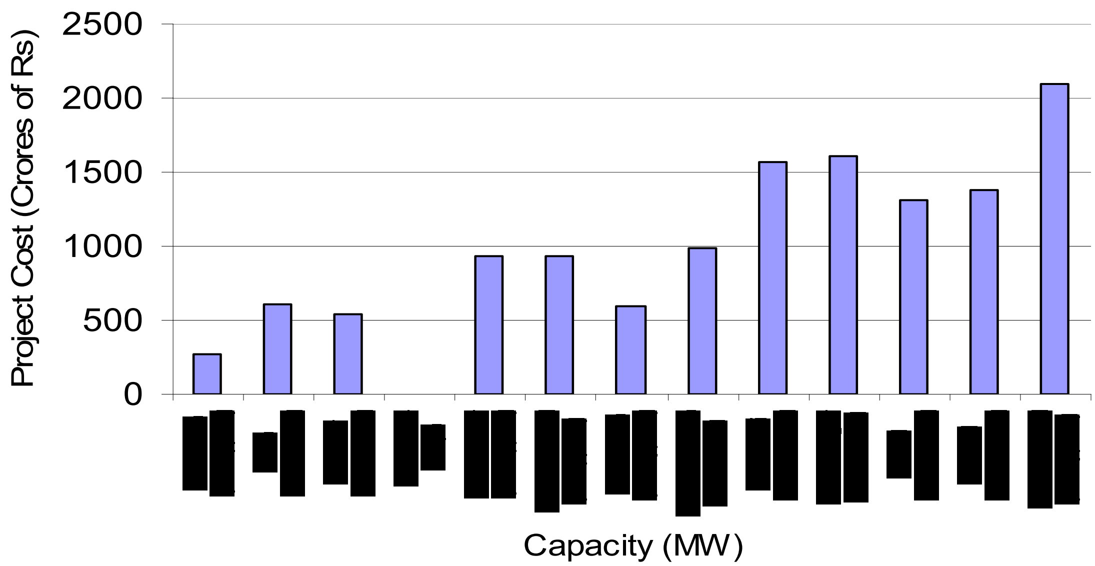


Figure 11 Capital Cost Vs Unit Size

b. Fuel costs

Fuel cost for a power plant is dependent upon many factors. The variable components of fuel price are:

1. Price of commodity
2. Transportation Cost

The table 9 presents the basic Run of Mine prices for various grades of non-coking coals by different mining companies. The transportation cost component varies significantly from plant to plant depending upon the proximity to the coal mines from which coal is procured.

Table 9: Basic Price List of Indian ROM Coals for 2006-07

	Non-Coking Coal Grades (Rs/Ton)						
Field/ Co.	**A**	**B**	**C**	**D**	**E**	**F**	**G**
ECL/ Raniganj	1740	1640	1440	1240	770	570	380
ECL	1350	1220	1020	820	620	480	340
ECL/ Mugma	1550	1380	1180	980	780	580	380
ECL/ SP Mines	1870	1670	1470	1270	850	650	450
ECL/ Rajmahal	-	-	-	-	810	690	550
BCCL	1310	1190	990	820	650	520	370
CCL	1340	1210	1010	830	650	520	370
NCL	1230	1110	910	760	610	480	350
WCL	1320	1250	1160	1100	900	710	540
SECL	1080	1010	860	730	600	470	350
MCL	1050	940	780	650	510	400	290
SCCL	1528	1419	1277	1130	817	681	503

c. O & M costs

The Operation and Maintenance consists of the following costs

i. Operation
ii. Maintenance (Man, Machines and Service)
iii. Engineering Support staff
iv. Administration
v. Taxes, Duties & Insurance

The Operating Cost for all SEBs for 1999 was obtained from Central Electricity Regulatory Commission (CERC). The Costs are summarized in table 10.

Table 10: Summary of Performance characteristics for Indian TPS

Sr. No.	Criteria	Average	Minimum	Maximum
I	**Technical Performance Characteristics**			
	a. Heat Rate (kcal/kWh)	3218	2489.5	6341
	b. Efficiency (%)	27.7	13.58	34.6
	c. Operational Availability (%)			
	d. Auxiliary Consumption (%)	9.52	5.59	16.2
II	**Environmental Performance Characteristics**			
	a. CO_2 (kg/kWh)	1.04	0.784	1.608
	b. SO_2, (g/kWh)	7.55	1.44	24.6
	c. NO_2 (g/kWh)	3.502	2.47	5.62
	d. SPM (mg/nm3)	198.5	11	923
III	**Economic Performance**			
	a. Capital costs (Rs/kW)	29,000	21,500	44,600
	b. Fuel costs (Rs/kWh)	0.53	0.07	1.1
	c. O & M costs (Rs/kWh)	0.14	0.03	0.6

Table 11: Beneficiation of Indian coals

Type of Coals	Company	Washery Capacity (Mt/y)
Coking Coals	Coal India Limited	20.1
	Private	12.27
Non Coking Coals	Coal India Limited	20.2
	Private	50.15
Total Capacity		**102.72**
Capacity Employed for Power Plants	55.5 Mt/y	
Total Production from CIL washeries for 05-06	3.69 MT	

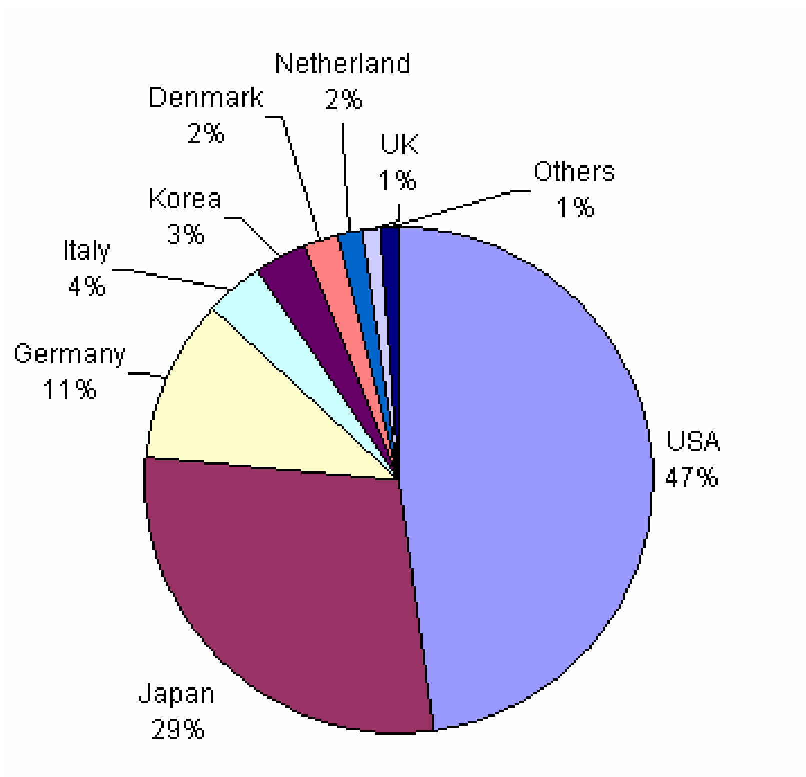
V. Need For Advance Coal Technologies

Going by the target set by the Ministry of Power of 'Power to All', an augmentation in generating capacity of about 1,00,000 MW is forecasted by 2012. Achieving such an enormous target by using the existing Subcritical PC technology with maximum efficiency of only 34% would result in a tremendous loss of energy. Lower efficiency inevitably results in higher CO2 and SO_2 emissions (kg/kWh). Advance Coal Technologies which are already operating and proven in different parts of the world is the solution to increased efficiency and lower emissions from thermal power plants in the country.

VI. Status of Advanced Clean Coal Technologies

1. Supercritical Pulverised Plants

Supercritical PC technology operates on the same cycle as the conventional sub critical cycle. However Supercritical PC technology has higher steam conditions in the order of 226-248 bar and temperatures in the range of 530-580^{o}C. Supercritical PC plants operate at higher efficiency than the conventional plants and have lower g/kWh emissions. There are about 250 above SC plants operating worldwide with a distribution as shown in the chart below. The figure 12 shows the percentage of the worldwide SC plants operating in each country.



Source: CERC 2006 Hirma project report

Figure 12 Country wise distribution of existing supercritical technologies for 2006

The figure 13 shows the unit size variation with the no. of plants. Here we see that, the maximum no. of plants are in the range of 500-600 MW capacity. Figure 14 shows the frequency distribution of supercritical plants with age and table 12 includes the performance characteristics of supercritical coal plants.

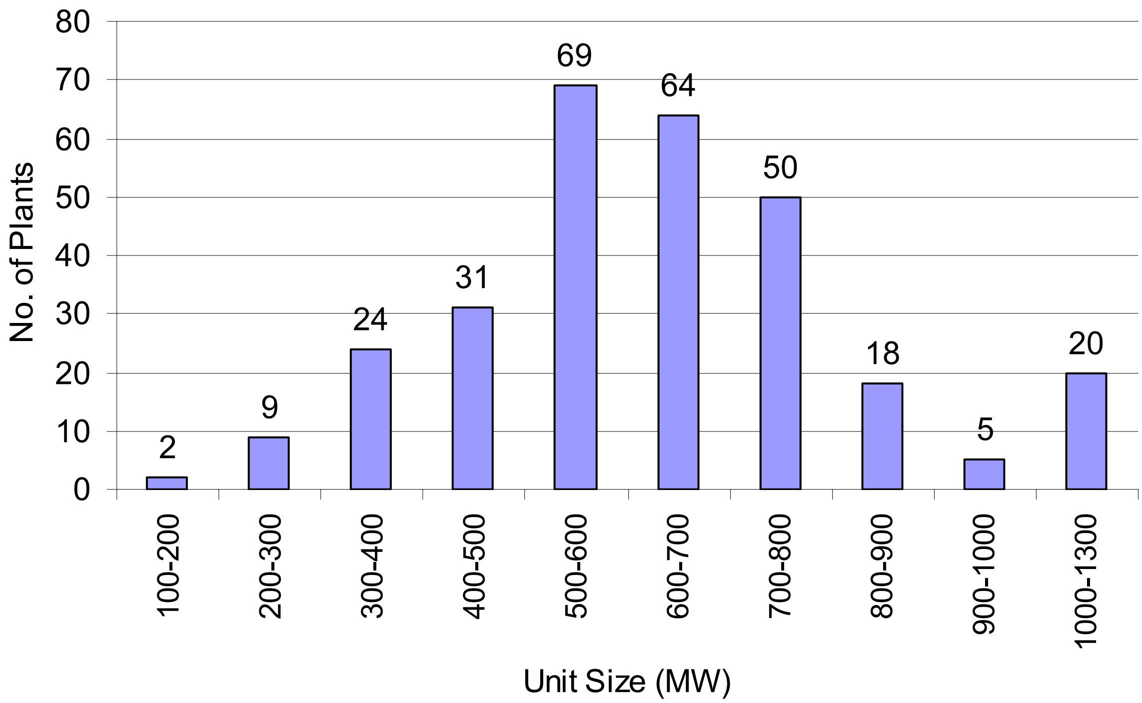


Figure 13 Distribution of No. of Supercritical plants with unit size

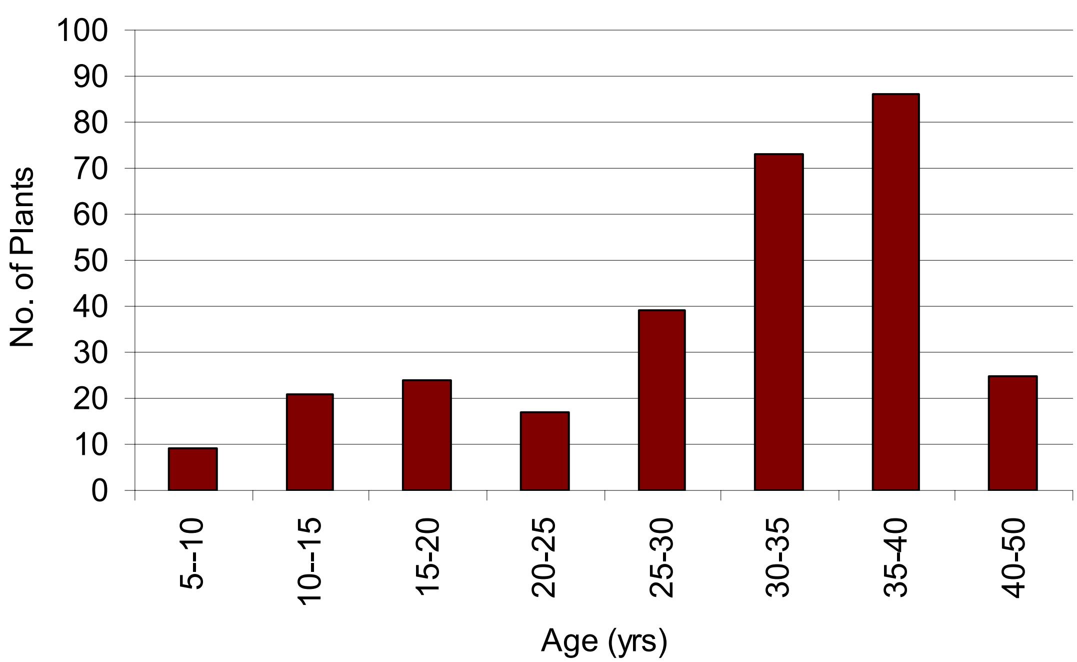


Figure 14 Distribution of Supercritical plants with age

Table 12: Summary of Supercritical Pulverised Plants

Sr. No.	Supercritical Characteristic	Min	Max
I	**Technical performance characteristics**		
	a. Efficiency (%)	40	46
	b. Heat Rate (kcal/kWh)	1872	2153
	c. Availability (%)	86	92
	d. Auxiliary consumption (%)		
II	**Emission characteristics**		
	a. CO_2 (kg/kWh)		
	b. SO_2 (mg/Nm^3)	100	200
	c. NO_2 (mg/Nm^3)	200	650
	d. SPM (mg/Nm^3)	10	25
III	**Cost characteristics**		
	a. Capital cost ($/kW)	950	1600
	b. Operating cost ($/kW)		
	c. Fuel cost		

2. Ultra Supercritical Pulverised Coal Plants

Ultra supercritical pulverized coal combustion technology is similar to supercritical technology with higher temperatures and pressure. The ultra supercritical plant operates at about 720 ^{o}C/390bar.

There are 24 ultra-supercritical units operating worldwide, which achieve even higher efficiencies, with units in Denmark, Germany, Japan, the Netherlands, and USA. Temperatures and pressures above those of ultra-supercritical plant could potentially yield further efficiency improvements, however new materials must be found that are able to handle such extreme operating conditions.

3. Atmospheric fluidized bed technology (AFBC)

AFBC is a Fluidised Bed combustion technology in which the bed operates at atmospheric pressure and the products of combustion are used to generate steam for power generation using the Rankine cycle. It is a commercially mature technology that has been used worldwide for over 50 years. There are two types of AFBCs:- 1) Bubbling Fluidised Bed Combustion. 2) Circulating Fluidised Bed Combustion

CFBC

As in the case of BFBC, CFBC is also a technology that relies upon fluidized bed combustion. But in the case of CFBC the fluidization air velocities are much higher than the former**.** Higher air velocities result in higher turbulence and in turn better combustion efficiency. Due to higher velocity the fuel ash and unburnt fuel are carried out of the combustor along with the flue gases. These fly off are then collected in the cyclone and returned back to the combustor. Table 13 shows a list of CFBC installations worldwide.

Table 13 List of CFBC installations

Company	Country	Unit Size MW
TriState Generation & Trans Co.	USA	110
Kainuun Voima Oy	Finland	95
Vasikiluodon Voima Oy	Finland	125
Rheinisch Westfalisches Elect works	Germany	100
Nova Scotia Power Inc.	Canada	180
IVO internation Oy	Finland	110
CMIEC/Neijiang	China	100
Turow Power Station	Poland	3x235
Nation Power supply	Thailand	2x150
EC Katovice S.A.	Poland	180
Jacksonville	USA	300
Emile Hutchet Kirraube	France	125
Provence Gardanne Power Plant	France	250
Changguang Coal Mine Co Zhejiang	China	155
Rostovenergo Nesvetay	Russia	163
Elektrocieplownia Tychy SA	Poland	37
KEPCO Seoul	Korea	2x200

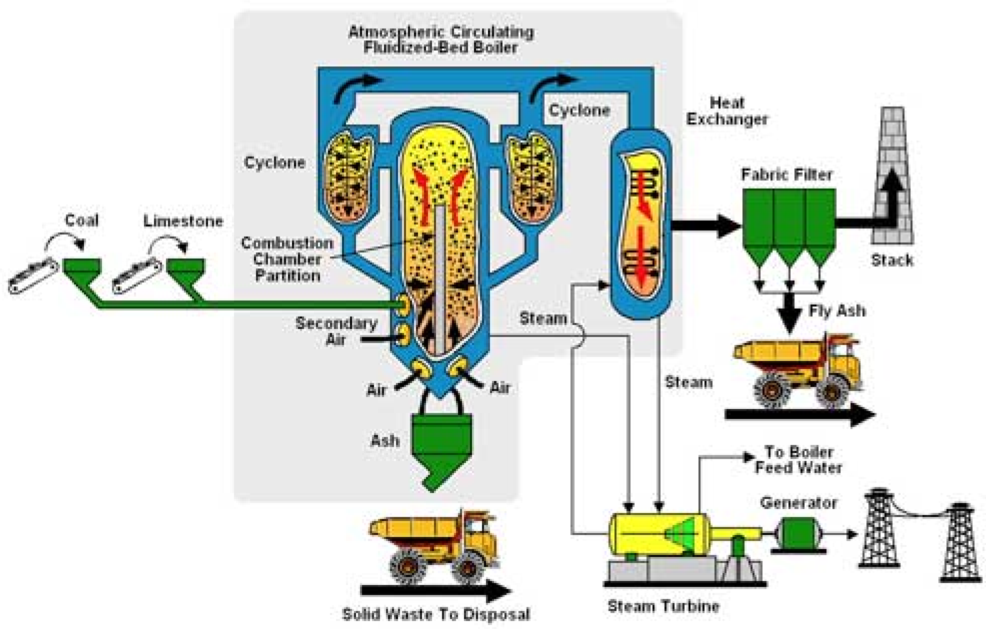


Figure 15 Schematic of CFBC Plant [13]

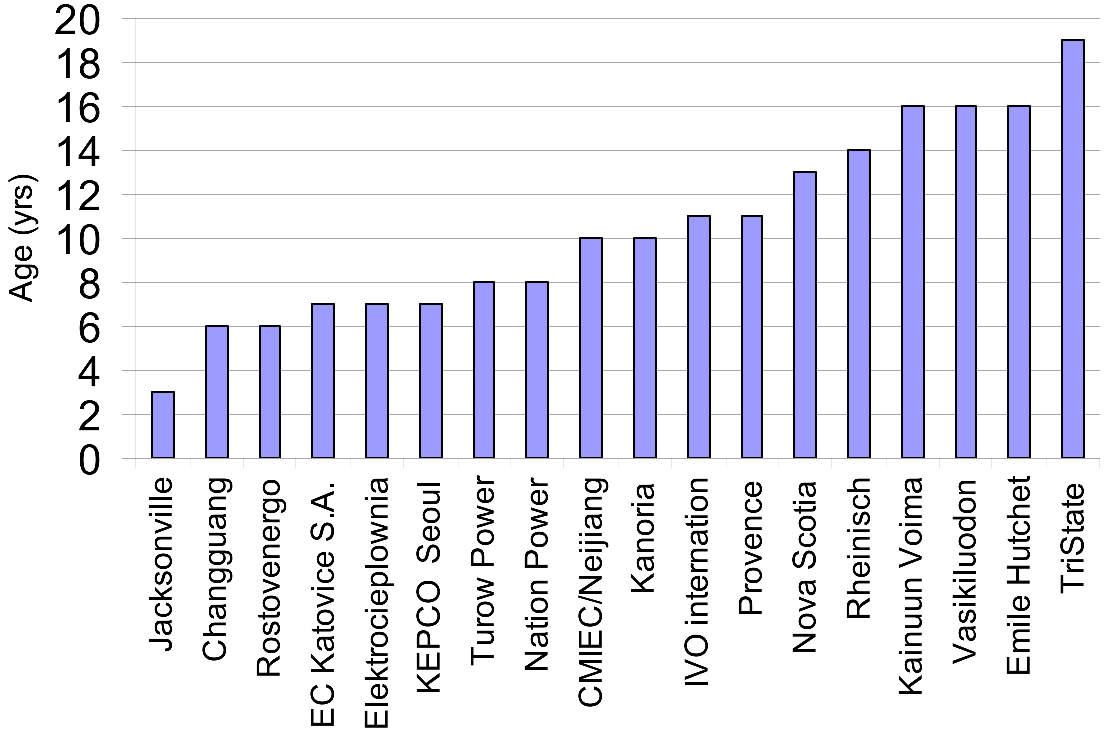


Figure 16 Distribution of CFBC plants with age

Table 14: Summary of CFBC plants

Sr. No.	CFBC Characteristic	Min	Max
I	**Technical performance characteristics**		
	a. Efficiency (%)	29	40
	b. Heat Rate (kcal/kWh)	2923	2153
	c. Availability (%)	87	88
	d. Auxiliary consumption (%)		
II	**Emission characteristics**		
	a. CO_2 (kg/kWh)		
	b. SO_2 (mg/Nm^3)	170	400
	c. NO_2 (mg/Nm^3)	80	300
	d. SPM (mg/Nm^3)	~ 25	
III	**Cost characteristics**		
	a. Capital cost ($/kW)	1000	1600
	b. Operating cost ($/kW)		
	c. Fuel cost		

4. Pressurised fluidised bed technology (PFBC)

Pressurised Fluidised Bed Combustion employs a combination of the Rankine cycle and Brayton cycle in order to achieve higher efficiencies and reduced emissions. The fuel and sorbent is fed into the pressurized combustion chamber the flue gases generated are cleaned and then expanded in the gas turbine to generate power. After passing through the gas turbine the heat of the flue gas is utilized in steam generation for the Rankine cycle. Thus the combination of two cycles results in higher cycle efficiencies which are about 3-4 % higher than the conventional steam plants.

Table 15: List of PFBC installation

Country	Unit Size (MW)	Steam Temperature (^oC)	Pressure (MPa)
Sweden (Vartan)	135	530	13.1
Spain (Escatron)	79.5	510	9.3
America (Tidd)	74	496	8.8
Germany (Cottobus)	75.6	537	13.8
Japan (Wakamatsu)	71	593	10
Japan (Karita)	360	566	24.1
Japan (Tomatouazuma)	85	566	16.6
Japan (Osaki)	250	566	16.6

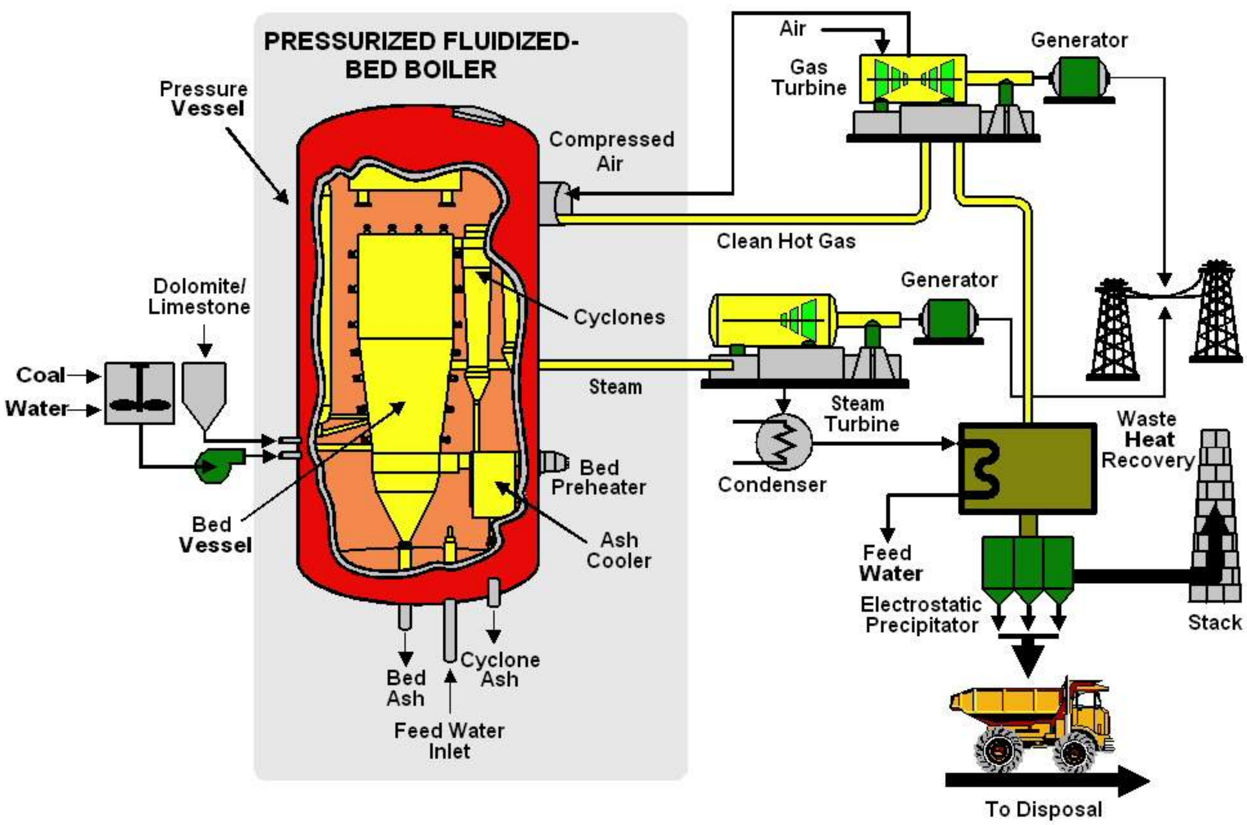


Figure 17 Schematic of a PFBC plant [9]

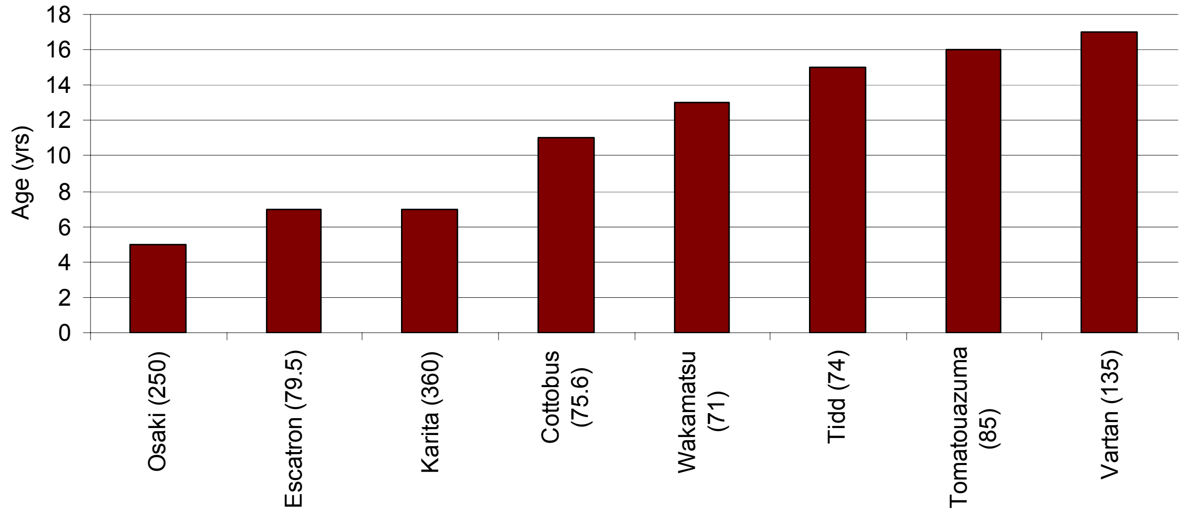


Figure 18 Distribution of PFBC plants with age

I. Technical Performance Characteristic

a. Heat Rate

The figure 19 shows the heat rates of the PFBC plants operating worldwide. The data for heat rates collected from literature does not specify gross or net heat rate. Since the data for heat rates are collected from various sources, it would not be save to assume.

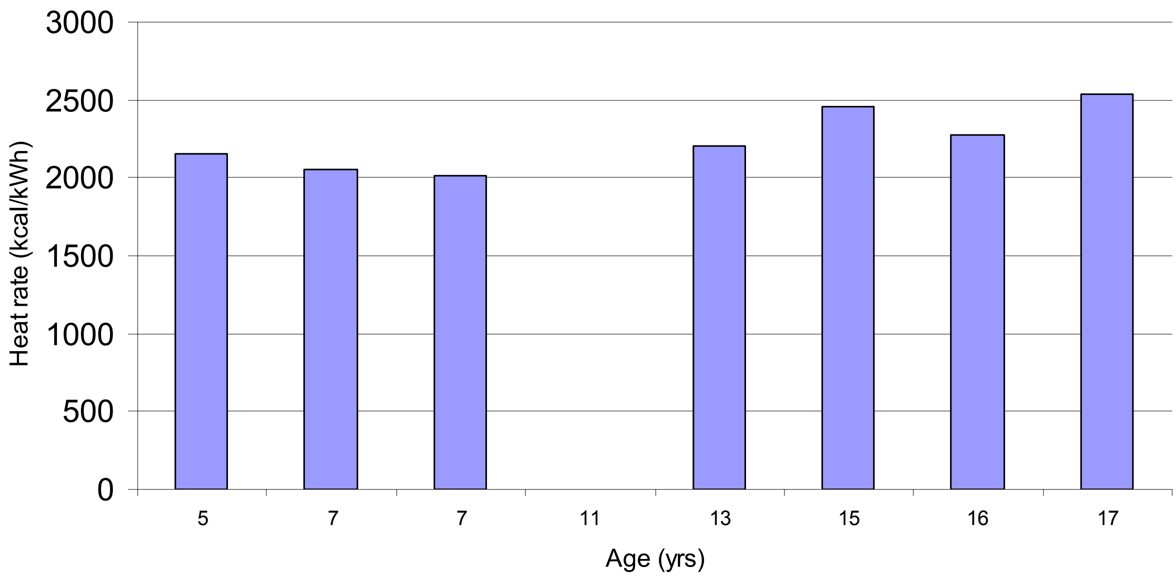


Figure 19 Distribution of PFBC plants with Heat rate Vs Age

Mean	Standard deviation
2242.3	197

b. Efficiency

The figure 20 shows the efficiencies of the PFBC plants.

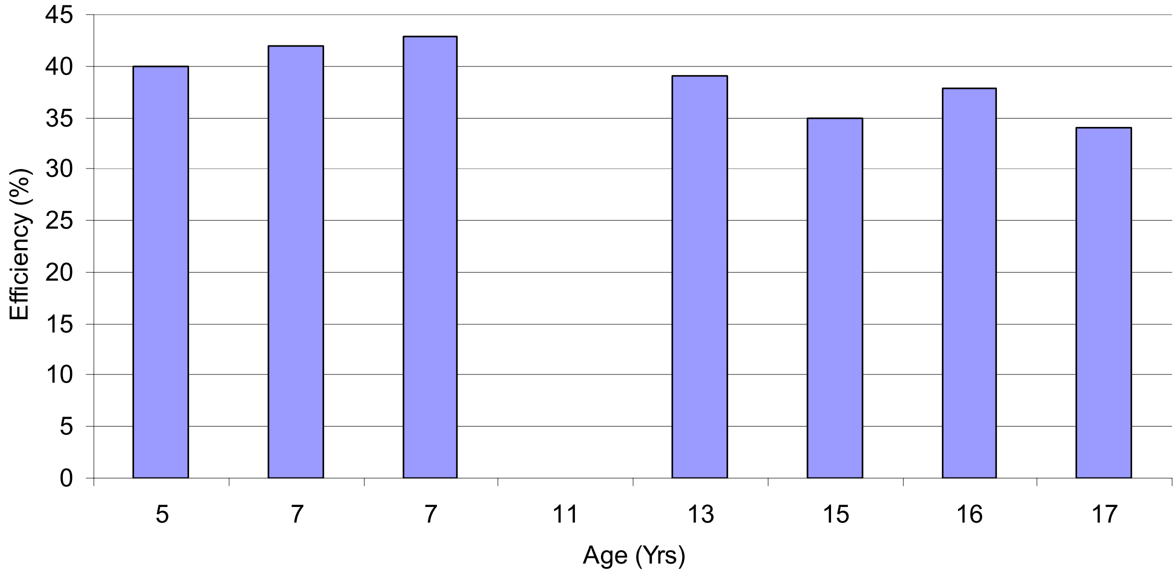


Figure 20 Distribution of PFBC plants with Efficiency

Mean	Standard deviation
38.6	3.31

c. Availability

The figure 21 shows the operating availability of the PFBC plants operating worldwide. The Availability for some of the plants has not been reported in literature.

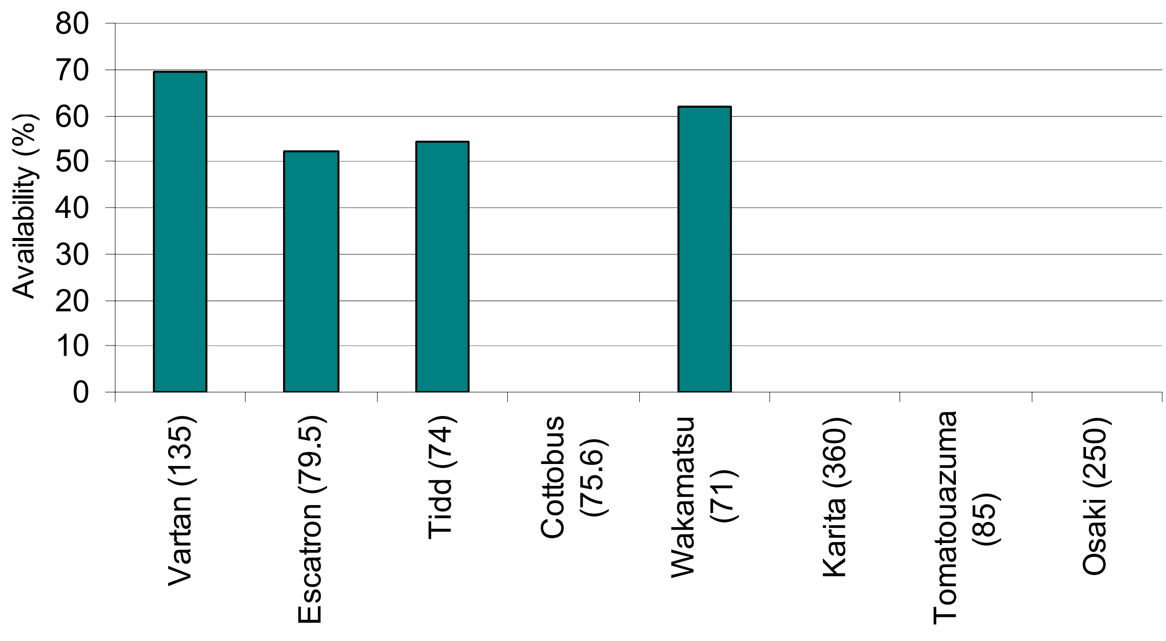


Figure 21 Distribution of PFBC plants with Availability

II. Economic Performance

a. Capital cost

The figure 22 shows the capital cost (\$/kW) of the PFBC plants. The capital costs for some of the plants have not been reported in literature.

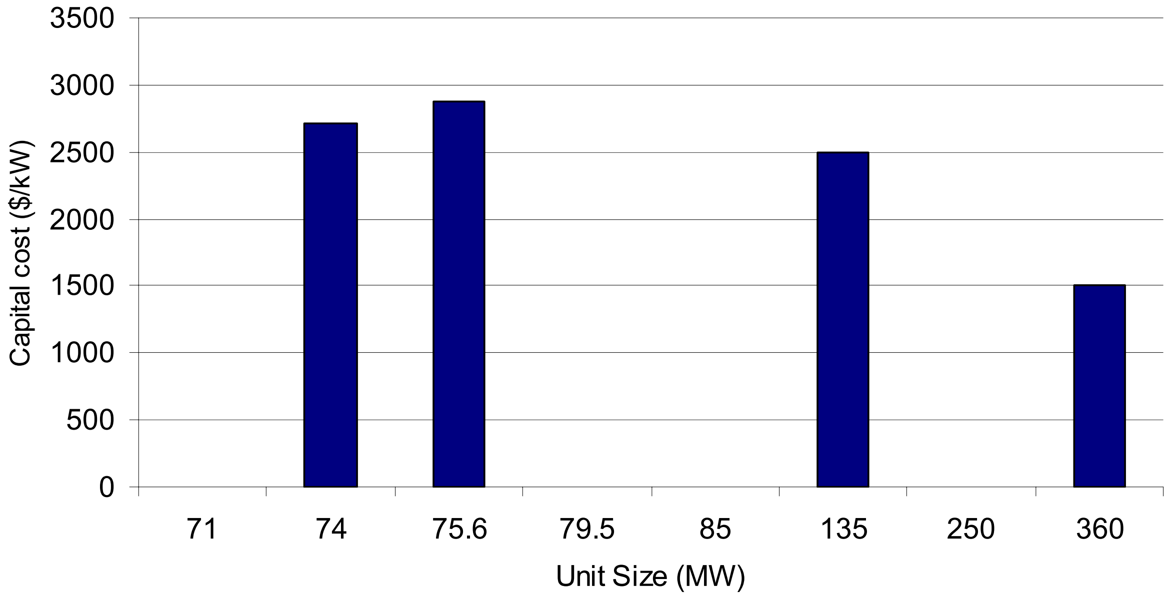


Figure 22 Distribution of PFBC plants with Capital costs

III. Environmental Performance

a. SO_2 emissions

The figure 23 shows the SO_2 emissions from the PFBC installations. However, it is uncertain whether any additional SO_2 removal technologies have been employed in each of the plants after the inherent sorbent injection method.

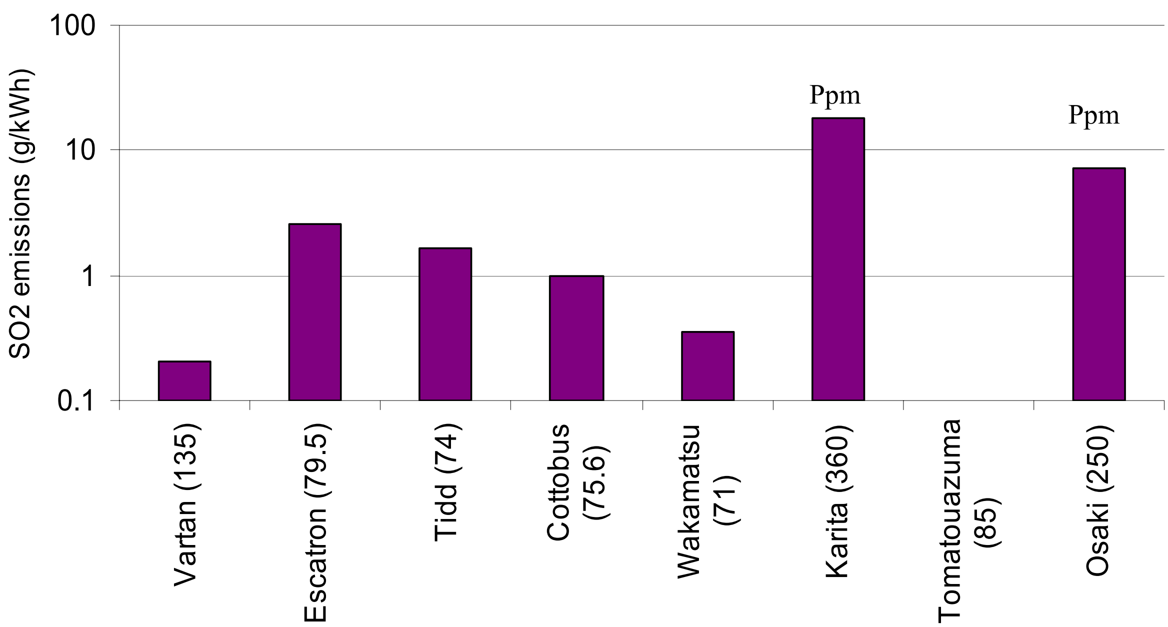


Figure 23 Distribution of PFBC plants with SO_2 emissions

b. NO_2 emissions

The figure 24 shows the NO_2 emission from the PFBC installations. The method of NO_2 removal in each of the plants has not been reported in literature.

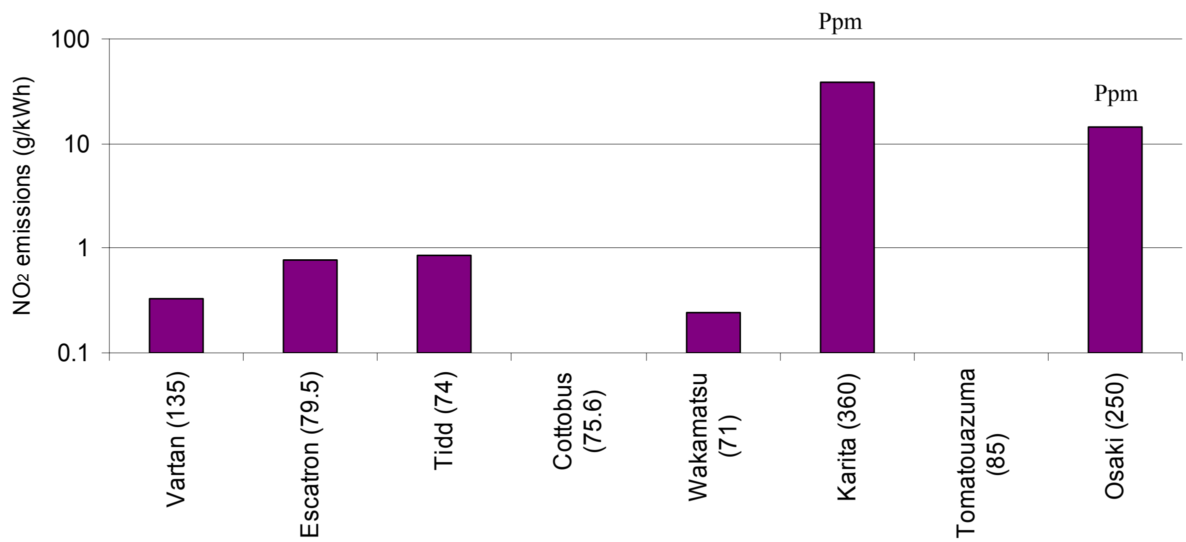


Figure 24 Distribution of PFBC plants with NOx emissions

Table 16: Summary of PFBC plants

Sr. No.	PFBC Characteristic	Average	Min	Max
I	**Technical performance characteristics**			
	a. Efficiency (%)	38.6	34	42.8
	b. Heat Rate (kcal/kWh)	2242	2012	2533
	c. Availability (%)	59.6	52.5	69.5
	d. Auxiliary consumption (%)			
II	**Emission characteristics**			
	a. CO2 (kg/kWh)			
	b. SO2 (g/kWh)	1.19	0.205	2.55
	c. NO2 (g/kWh)	0.55	0.25	0.84
	d. SPM			
III	**Cost characteristics**			
	a. Capital cost ($/kW)	2396	1500	2875
	b. Operating cost ($/kW)			
	c. Fuel cost			

5. Integrated Gasification Combined Cycle (IGCC)

Table 17 List of IGCC installations worldwide

Country	Unit Size (MW)
USA (Wabash)	262
USA (Tampa Polk)	250
USA (Pinion Pine)	100
Netherlands (Buggenum)	253
Spain (Puertollano)	335

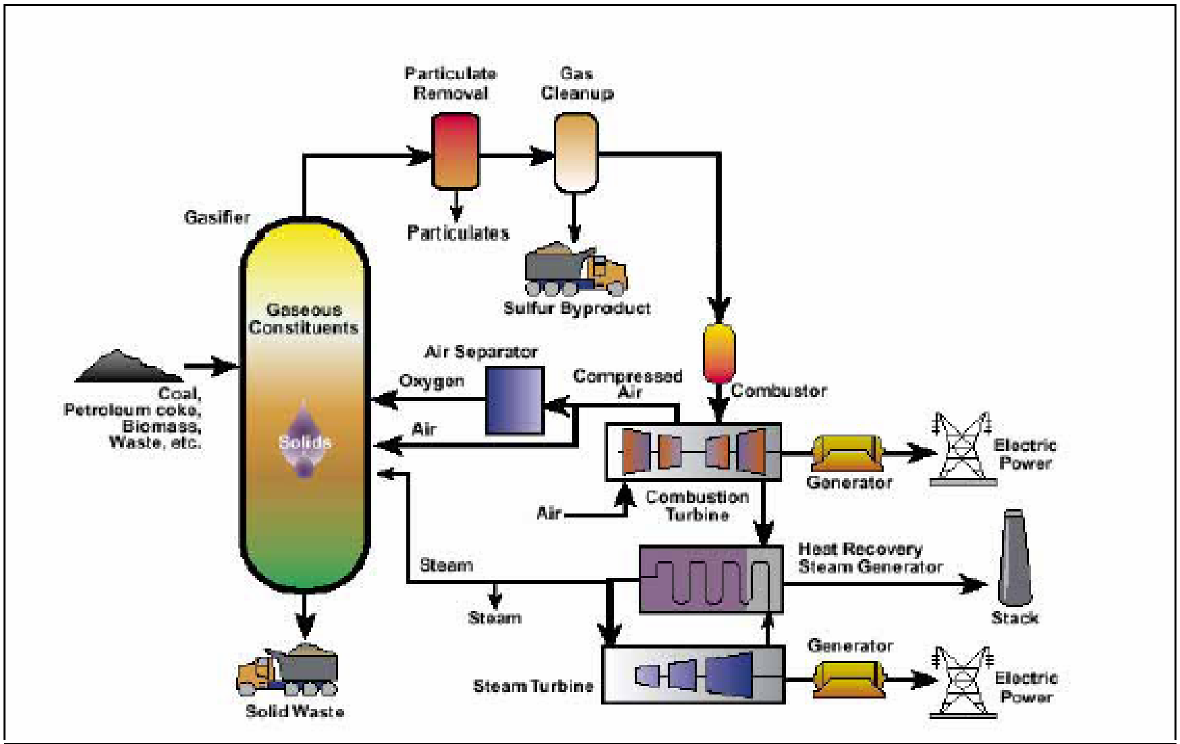


Figure 25 Schematic of an IGCC plant [14]

Table 18 Capacity and age of IGCC plants worldwide

Country	Plant	Capacity (MW)	Age (yrs)
USA	Sierra Pacific Pinion Pine (100)	100	9
Spain	ElcoGas, Puertollano (335)	335	10
USA	TECO Polk (250)	250	11
USA	PSI Wabash (262)	262	12
Netherlands	Demkolee Buggenum (253)	253	14

I. Technical Performance Characteristic

a. Heat Rate

The figure 26 shows the heat rates of the PFBC plants operating worldwide. The data for heat rates collected from literature does not specify gross or net heat rate. Since the data for heat rates are collected from various sources, it would not be safe to assume.

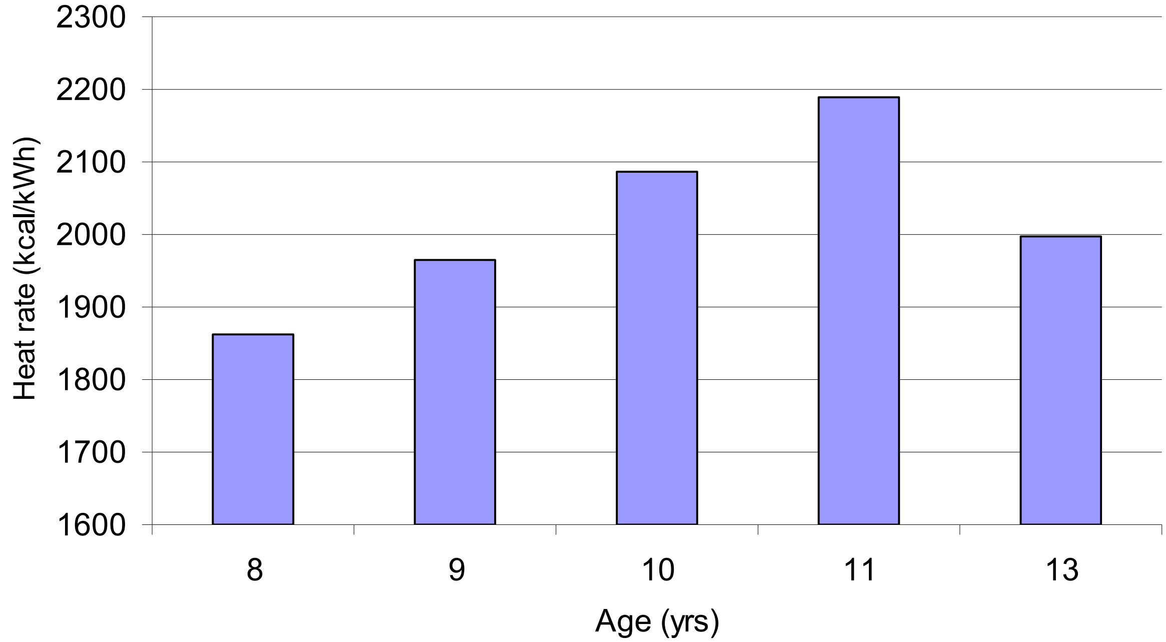


Figure 26 Distribution of IGCC plants with Heat rate

b. Efficiency

The figure 27 shows the efficiencies of the PFBC plants.

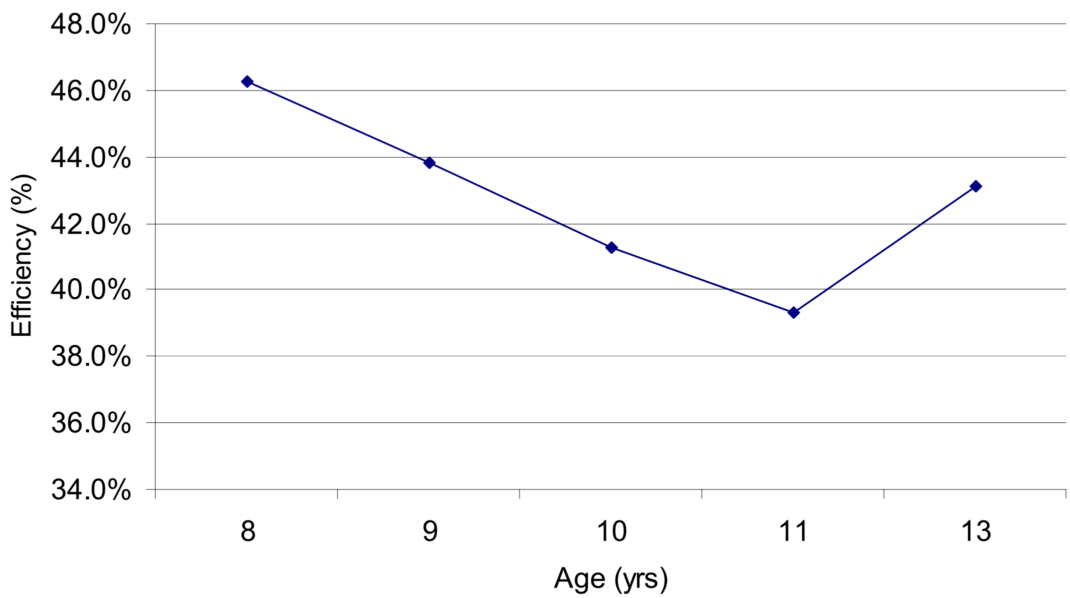


Figure 27 Distribution of IGCC plants with Efficiency

c. Auxiliary Consumption

The figure 28 shows the auxiliary consumption of the IGCC plants as a percentage of the power generated.

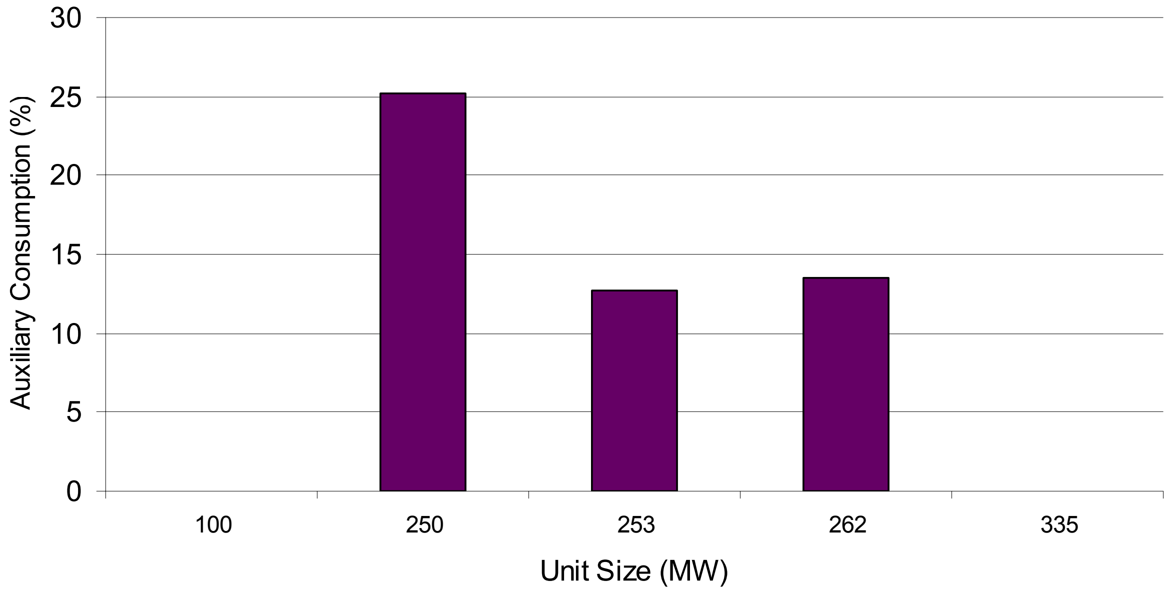


Figure 28 Distribution of IGCC plants with Auxiliary consumption

d. Availability

The figure 29 shows the operational availability of the IGCC plants operating worldwide.

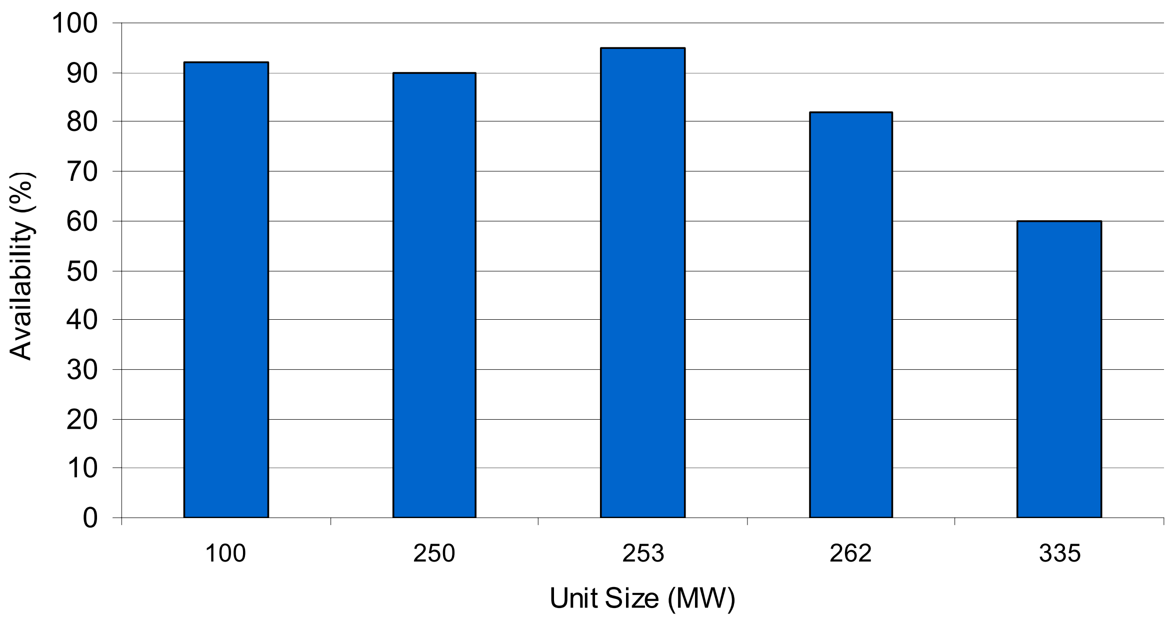


Figure 29 Distribution of IGCC plants with Availability

II. Economic Performance

a. Capital cost

The figure 30 shows the capital cost of the IGCC installations in terms of $/kW

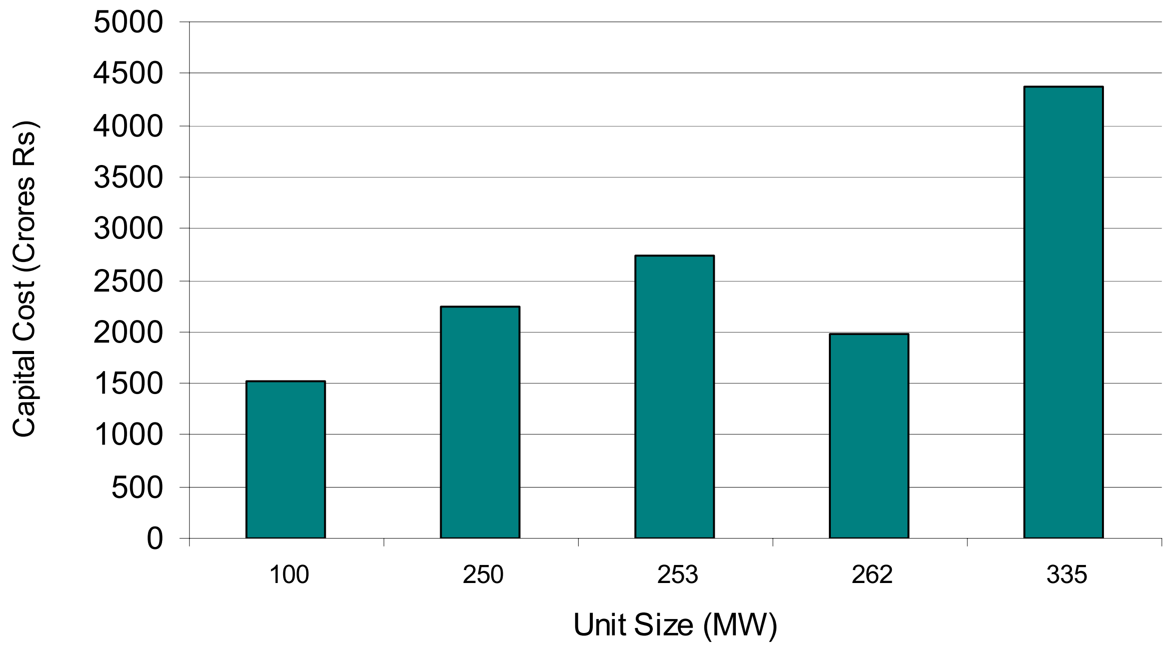


Figure 30 Distribution of IGCC plants with Capital costs

III. Environmental Performance

a. SO_2 emission

The figure 31 shows the SO_2 emissions from the IGCC installations. However, it is uncertain whether what method SO_2 removal technologies have been employed in each of the plants.

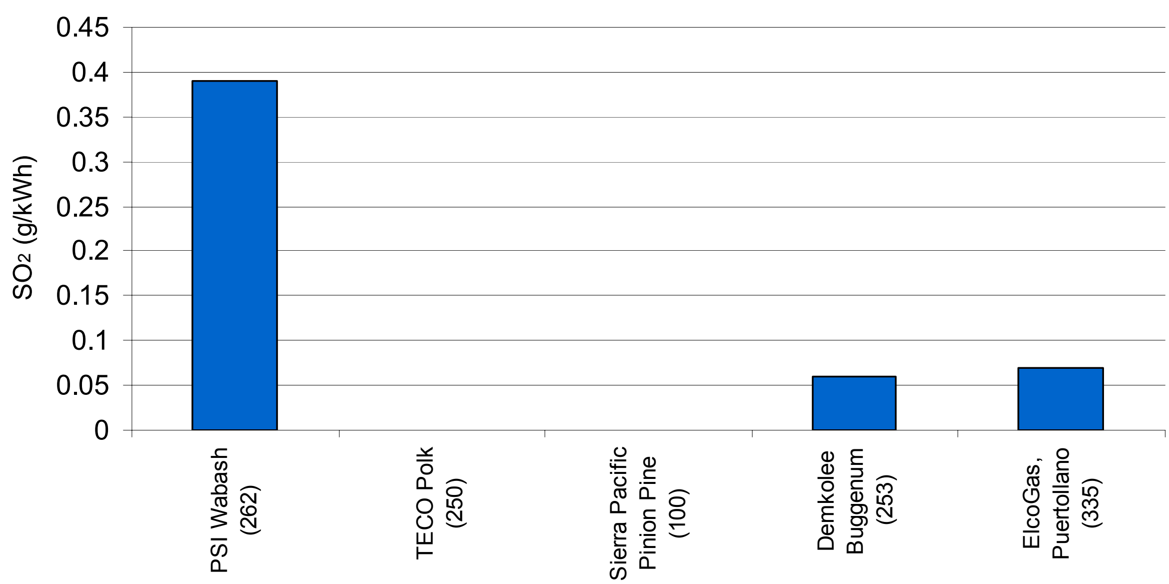


Figure 31 Distribution of IGCC plants with SO_2 emission

b. NO_2 emission

The figure 32 shows the NO_2 emission from the PFBC installations. The method of NO_2 removal in each of the plants has not been reported in literature

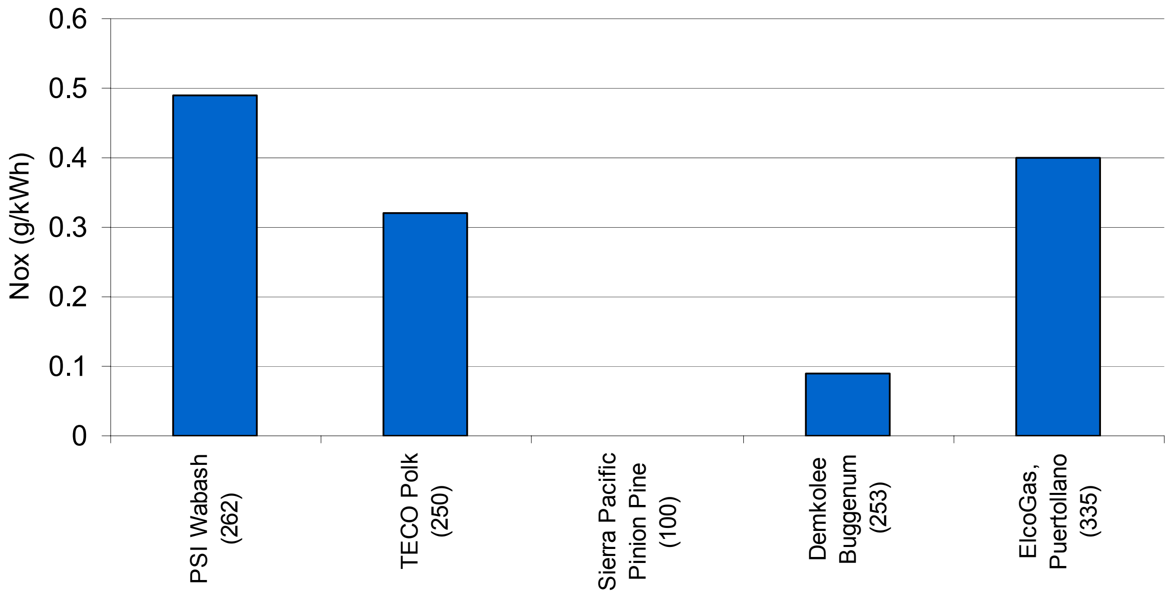


Figure 32 Distribution of IGCC plants with NOx emissions

c. SPM emission

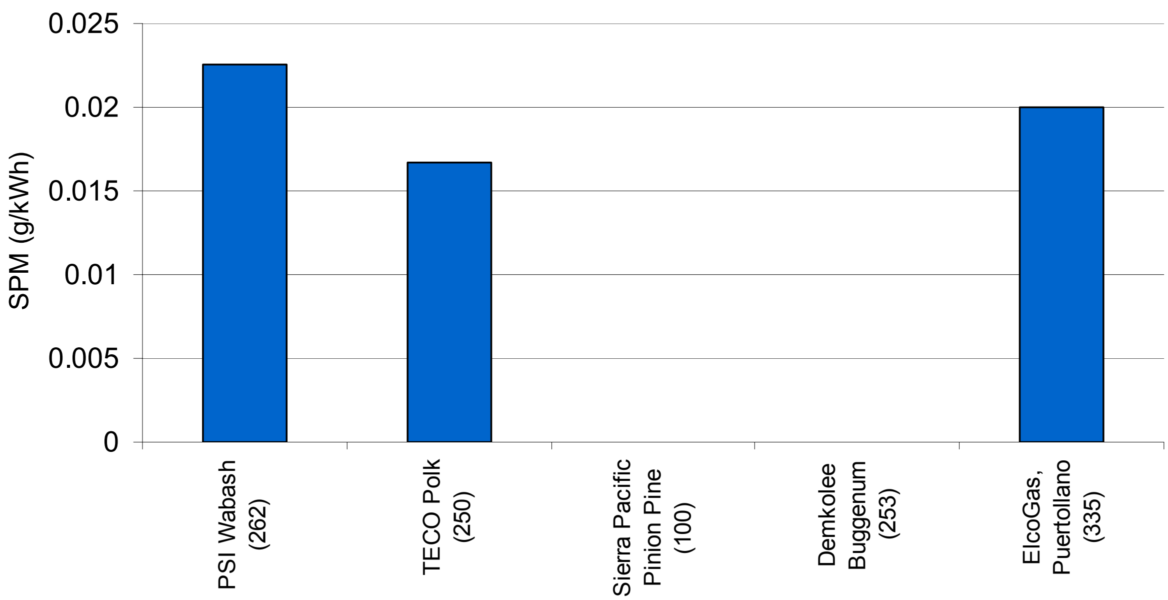


Figure 33 Distribution of IGCC plants with SPM

Table 19: Summary of IGCC plants

Sr. No.	IGCC Characteristic	Average	Min	Max
I	**Technical performance characteristics**			
	a. Efficiency (%)	40.6	38	43.7
	b. Heat Rate (kcal/kWh)	2020	1861	2190
	c. Availability (%)	83.8	60	95
	d. Auxiliary consumption (%)	17.1	12.7	25.2
II	**Emission characteristics**			
	a. CO2 (kg/kWh)			
	b. SO2 (g/kWh)	0.173	0.06	0.39
	c. NO2 (g/kWh)	0.325	0.09	0.5
	d. SPM (g/kWh)	0.02	0.016	0.022
III	**Cost characteristics**			
	a. Capital cost ($/kW)	2396	1500	2875
	b. Operating cost ($/kW)			
	c. Fuel cost			

ii. Indian Experience with Advanced coal technologies

Table 20: Indian CFBC experience (GIPCL)

Characteristics	CFBC	IGCC
Capacity (MW)	2x125	6.2
Year of Commissioning		1989
Units generated (GWh)	1651	
Lignite consumption (ktons)	1611	
Efficiency	27.5	39
Heat Rate (kcal/kWh)	3128	2209
Availibility (%)	88	
Capital Cost (Rs/kW)	48400	24200
CO_2 (kg/kWh)	0.95	

There are few projects based on advanced coal technologies which are planned to be installed in near future in India.

Table 21: Future Projects using advanced technologies

Sr. No.	Company	Plant	Technology	Size	Expected Year of commissioning
1	NTPC	Sipat (Chattisgarh)	Supercritical	3x660	2007-2008
2	NTPC	Barh (Bihar)	Supercritical	3x660	2007-2008
3	Reliance & Southern Elec. (USA)	Hirma	Supercritical	3960	2008
4	APGENCO	Krishnapattam (Tamil Nadu)	Supercritical	2x800	2010-2011
5		Surat (Gujarat)	CFBC (Lignite)	2x125	
6		Neyveli (Tamil Nadu)	CFBC (Lignite)	2x250	

iii. Analysis of technology mix for emission removal

Power generation technologies are frequently coupled with technologies for various emission removal or reduction such as for SOx, NOx and Suspended Particulate Matter (SPM). There are several technologies available for the control of the above mentioned emissions. These technologies brings along with them a capital cost and an operating cost which are taken into consideration when arriving at a capital cost or operating cost for the power plant as a whole. Apart from the cost, the efficiency of these emission removal technologies also varies.

An analysis of each power generation technology with a combination of emission removal technologies for SOx, NOx and Suspended Particulate Matter (SPM) is performed to arrive at the capital cost, operating cost and the emission levels for each of the combinations selected. Following is a list of advance power generation technologies, SOx removal technologies, NOx removal technologies and SPM control technologies.

I. Power generation technologies
   1. Supercritical Pulverised Coal Combustion
   2. Circulating Fluidized Bed Combustion (CFBC)
   3. Pressurised Fluidized Bed Combustion (PFBC)
   4. Integrated Gasification Combined Cycle (IGCC)

II. Sox emission removal technologies
   1. Sorbent Injection
   2. Dry scrubbing
   3. Wet Scrubbing

III. NOx emission removal technologies
   1. Low NOx burners
   2. Selective Non-Catalytic Reduction
   3. Selective Catalytic Reduction

IV. SPM emission removal technologies
   1. Electrostatic Precipitators
   2. Fabric Filters

The combinations of technologies is assigned a code for ease of analysis. The combinations under each code is presented in the following table in the order of power generation technologies as supercritical, CFBC, PFBC and IGCC.

Table 22: Supercritical Pulverised

	A1	A2	A3	A4	A5	A6
SOx removal	Sorbent Injection	Sorbent Injection	Sorbent Injection	Sorbent Injection	Sorbent Injection	Sorbent Injection
NOx removal	Low Nox Burners	Low Nox Burners	SCNR	SCNR	SCR	SCR
SPM removal	ESP	Fabric Filter	ESP	Fabric Filter	ESP	Fabric Filter

	B1	B2	B3	B4	B5	B6	B7
NOx removal	none	Low Nox Burners	Low Nox Burners	SCNR	SCNR	SCR	SCR
SPM removal	none	ESP	Fabric Filter	ESP	Fabric Filter	ESP	Fabric Filter

A7	A8	A9	A10	A11	A12
Dry Spray Scrubber	Dry Spray Scrubber	Dry Spray Scrubber	Dry Spray Scrubber	Dry Spray Scrubber	Dry Spray Scrubber
Low Nox Burners	Low Nox Burners	SCNR	SCNR	SCR	SCR
ESP	Fabric Filter	ESP	Fabric Filter	ESP	Fabric Filter

A13	A14	A15	A16	A17	A18
Wet spray scrubber	Wet spray scrubber	Wet spray scrubber	Wet spray scrubber	Wet spray scrubber	Wet spray scrubber
Low Nox Burners	Low Nox Burners	SCNR	SCNR	SCR	SCR
ESP	Fabric Filter	ESP	Fabric Filter	ESP	Fabric Filter

CFBC, PFBC and IGCC inherently have limestone injection in the bed and gasifier respectively and hence have very low level of SOx emissions. Thus these technologies require no additional SOx emission control technologies.

CFBC

PFBC

	C1	C2	C3	C4	C5	C6	C7
Nox removal	none	Low Nox Burners	Low Nox Burners	SCNR	SCNR	SCR	SCR
SPM removal	none	ESP	Fabric Filter	ESP	Fabric Filter	ESP	Fabric Filter

IGCC

	D1	D2	D3	D4	D5	D6	D7
Nox removal	none	Low Nox Burners	Low Nox Burners	SCNR	SCNR	SCR	SCR
SPM removal	none	ESP	Fabric Filter	ESP	Fabric Filter	ESP	Fabric Filter

The efficiency of emission removal, capital cost and operating cost of each technology is presented in the Table 23

Table 23: Summary of emission removal technologies

Sr No.	Technology	Efficiency	Capital cost	Operating cost
I	**SOx Removal**			
1	Sorbent Injection	70	3950	0.135
2	Dry Scrubbing	82	6300	0.135
3	Wet Scrubbing	85	9000	0.09
II	**NOx Removal**			
1	Low NOx burners	55	1800	0
2	SNCR	70	800	0.09
3	SCR	80	3200	0.18
III	**SPM Removal**			
1	ESP	99.5	1350	0.18
2	Fabric filters	99.5	2250	0.06

Also the efficiency, costs and emission levels of different advance coal technologies are presented in Table 24

Table 24: Summary of Advanced coal technologies

	Efficiency	Capital cost (Rs/kW)	Sox mg/m3	Nox mg/m3	SPM mg/m3	Operating Costs
Supercritical	43.0%	57400	200	650	25	0.128
CFBC	34.5%	58500	170	300	25	0.14
PFBC	38.6%	107820	200	320	10	0.14
IGCC	40.6%	107820	100	150	10	0.25

After adding up all the cost of technologies for each of the codes, we arrive at a total capital cost for each of the combinations as presented in figure 34.

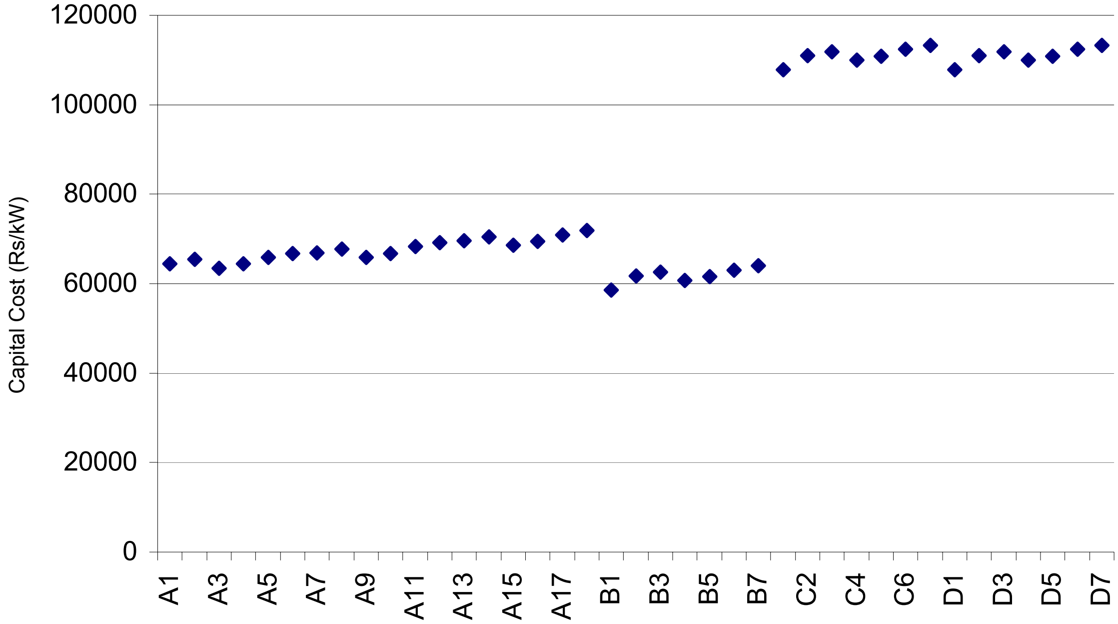


Figure 34 Capital cost (Rs/kW) for each of the technology combinations

The figure 35 shows the operating cost of each of the technology combination.

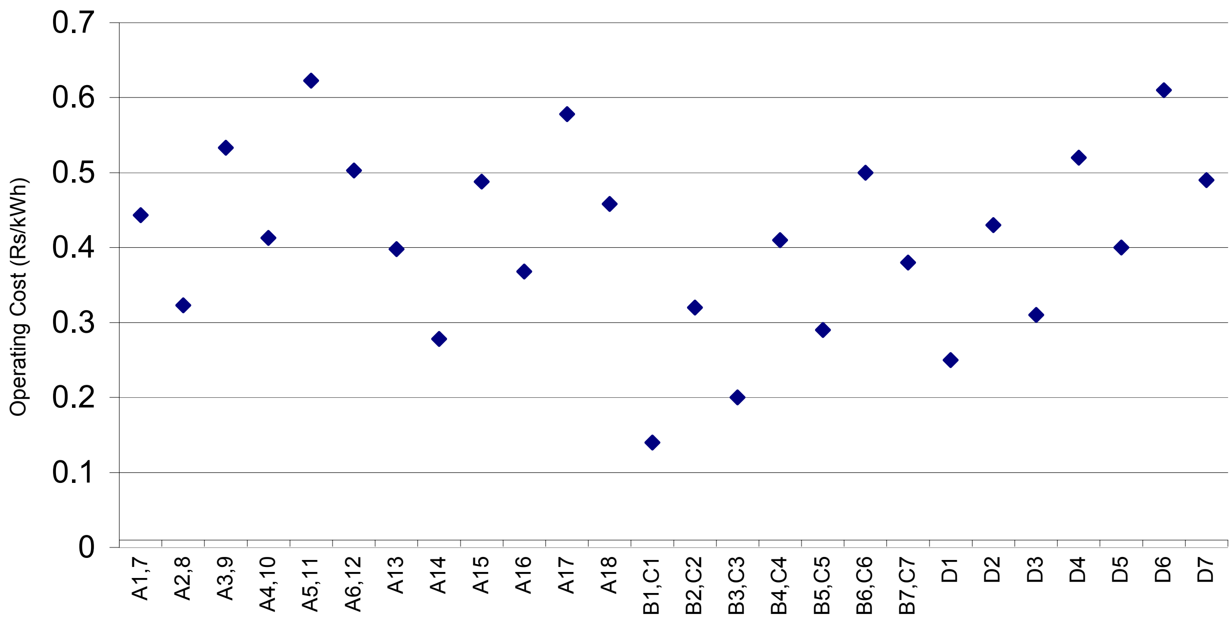


Figure 35 Operating costs (Rs/kWh) for each of the technology combinations

The figure 36 shows the SOx emissions level for each of the technology combinations after passing through the respective SOx control technologies.

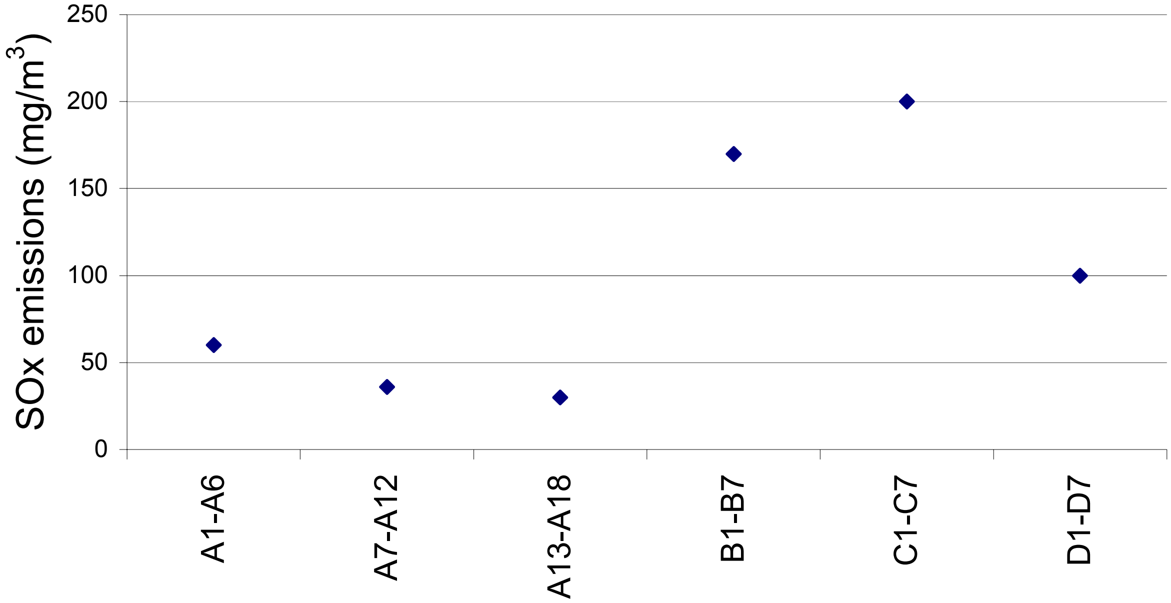


Figure 36 SOx emission levels (mg/m^3) for each of the technology combinations

Figure 37 shows the NOx emissions level for each of the technology combinations after passing through the respective NOx control technologies.

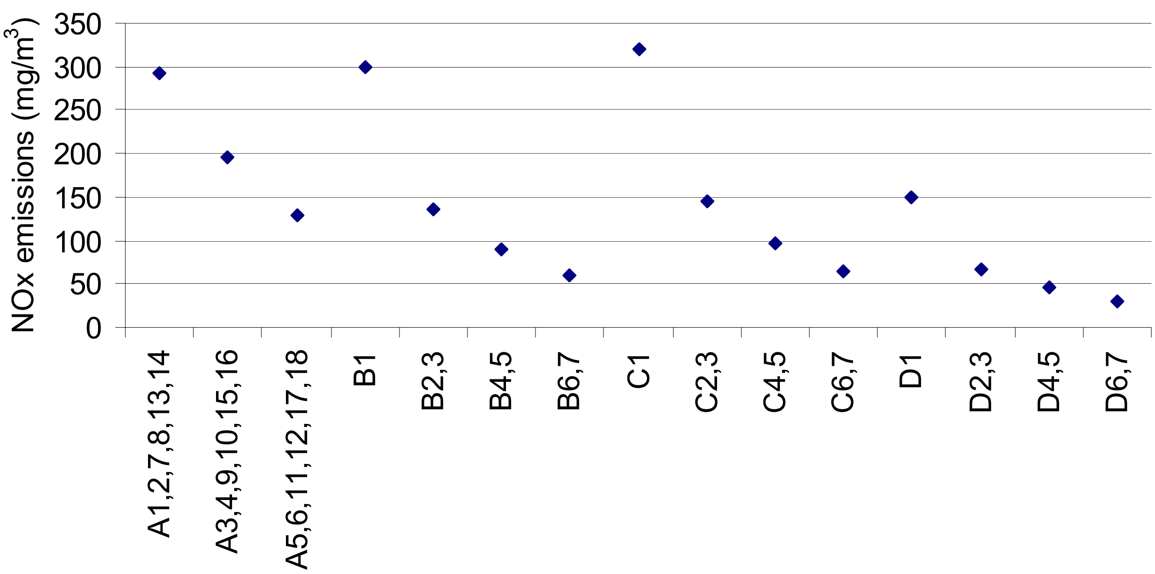


Figure 37 NOx emission levels (mg/m^3) for each of the technology combinations

Figure 38 shows the SPM emissions level for each of the technology combinations after passing through the respective SPM control technologies.

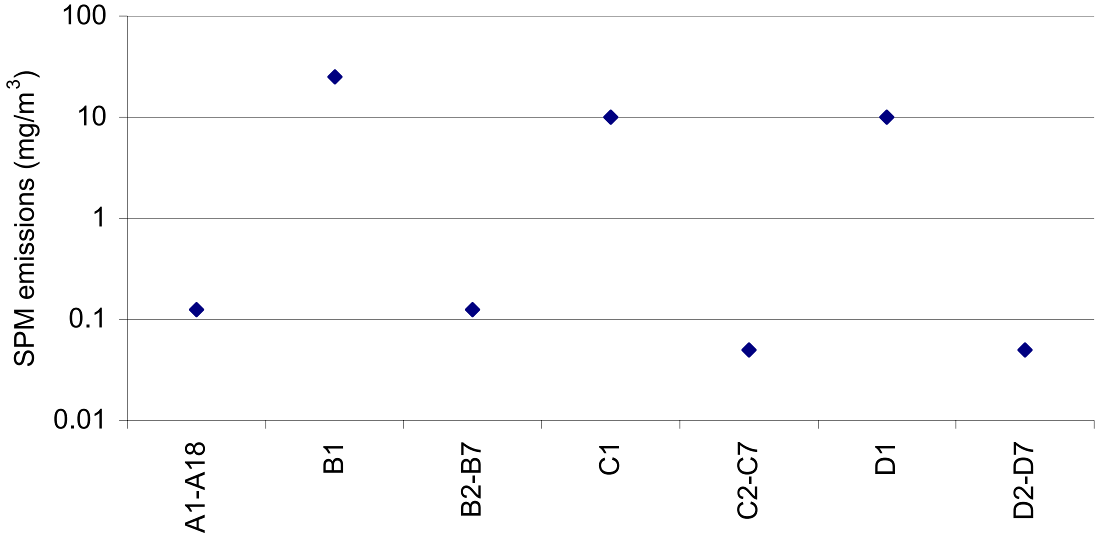


Figure 38 SPM emission levels (mg/m^3) for each of the technology combinations

iv. Analysis of Advanced coal technologies with relevance to Indian coals

The effect of Indian coals on advance coal technologies have to be analysed. The feasibility of these technologies with coal having 40 45% ash has to be checked. In order to study the effect of coal ash content on the efficiency of these technologies, a simulation run of these technologies with varying ash content is to be performed.

The model created for simulation is a lumped model considering the furnace and boiler as a black box and analyzing the energy and mass flows in and out of this black box. The mass and energy balance across the control volume is computed in order to see the effect of coal ash on the efficiency of each of the power generating cycles.

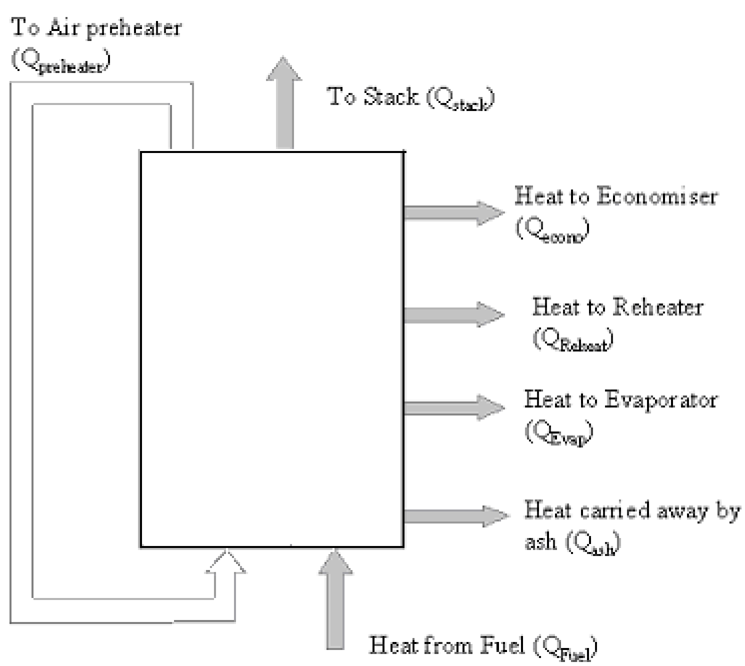


Figure 39 Schematic of energy balance

Here the evaporator, reheater, economizer and air pre-heater are considered enclosed in the control volume. An energy balance is computed across this control volume considering the energy interactions across the control volume. The incoming stream consists of energy supplied by the combustion of coal and pre-heated combustion air. The energy from pre-heated combustion air is considered as completely recycled energy and hence is eliminated from the energy balance. The outgoing streams of energy are of the energy supplied to the evaporator to convert water to the desired steam condition, energy supplied at the reheater, energy supplied to pre-heat the incoming water to the evaporator at the economizer. The outgoing loss streams consists of energy taken away by flue gases at the stack and heat carried away by fuel ash. The following equation represents the energy balance mathematically.

$$Q_{fuel} = Q_{evap} + Q_{reheat} + Q_{econo} + Q_{stack} + Q_{ash} \tag{1}$$

Elaborating the last two variables of the equation, we get

$$m_{fuel} \times CV = \left(Q_{evap} + Q_{reheat} + Q_{econo}\right) + m_{fg} \cdot c_{p_{fg}} \cdot (T_{stackout} - T_{amb}) + m_{ash} \cdot c_{p_{ash}} \cdot (T_{ashout} - T_{amb}) \tag{2}$$

Further,

$$m_{fuel} \times CV = \left(Q_{evap} + Q_{reheat} + Q_{econo}\right) + m_{fuel} \cdot \psi \cdot c_{p_{fg}} \cdot (T_{stackout} - T_{amb}) + m_{fuel} \cdot \beta \cdot c_{p_{ash}} \cdot (T_{ashout} - T_{amb}) \tag{3}$$

Where,

$m_{fg} = \psi \cdot m_{fuel}$ $\quad\psi =$ kg of flue gas/kg of fuel fired

$m_{ash} = \beta \cdot m_{fuel}$ $\quad\beta =$ kg of ash generated/kg of fuel

Then we simplify the equation to arrive at the mass of fuel (kg/s)

$$m_{fuel} = \frac{\left(Q_{evap} + Q_{reheat} + Q_{econo}\right)}{\left(\begin{array}{l} CV - \psi \cdot c_{p_{fg}} \cdot (T_{stackout} - T_{amb}) \\ - \beta \cdot c_{p_{ash}} \cdot (T_{ashout} - T_{amb}) \end{array}\right)} \tag{4}$$

Initially a simulation run for a subcritical pulverized coal plant (170^{o}C/550 bar) single reheat cycle was carried out with varying ash content from 7-45 %. Assumptions made are: 1) The boiler and furnace are completely insulated and there are no heat losses from the boiler surface. 2) Flue gas exit temperature at stack is 200^{o}C. 3) Bottom ash exit temperature from the furnace is 1300^{o}C. The coal composition with varying ash % is from various coalfields of India. Table 25 presents the various coal compositions used for simulation.

Table 25: Indian Coal compositions

Composition	**Singrauli Coalfields**						**Korba Coalfields**	**Talcher Coalfields**	**Bisrampur Coalfields**
Carbon (**C**)	36.4	38.1	44.5	47.8	50.9	54.8	65.6	66.2	73.1
Hydrogen (**H_2**)	2.1	2.2	2.6	2.9	3	3.2	3.7	4.5	4.1
Nitrogen (**N_2**)	1.1	0.7	0.9	1	1	1.2	1.3	1.2	1.4
Sulphur (**S**)	0.3	0.4	0.3	0.3	1	1.7	0.3	0.6	0.5
Mineral Matter	45.6	39.1	34.7	30	25.6	20	15.2	10.2	7.1
C.V. (kcal/kg)	3425	3590	4215	4530	4805	5220	6240	6505	7025

Figure 40 shows the schematic of the subcritical plant used for simulation. The figure 41 shows the effect of coal ash on the efficiency of the subcritical pulverised coal plant considered for study

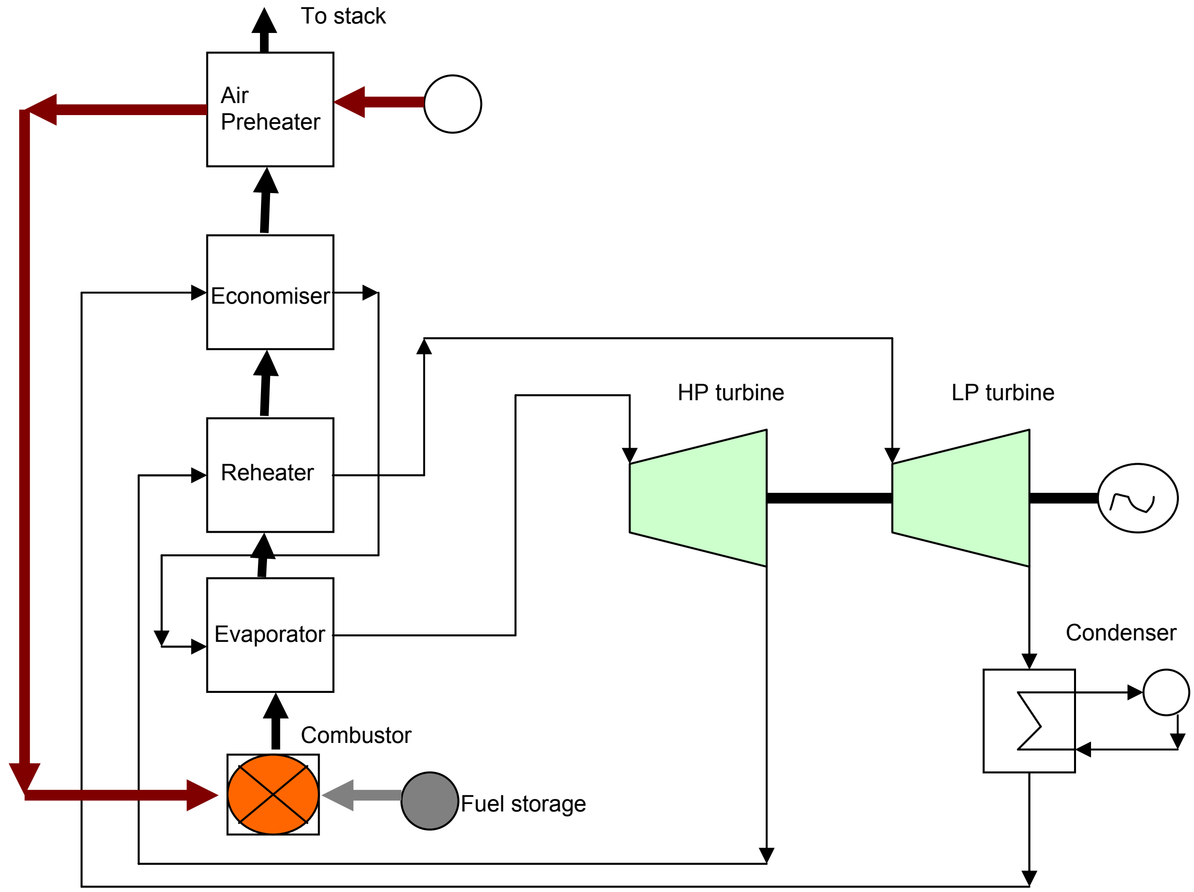


Figure 40 Schematic of subcritical pulverized plant

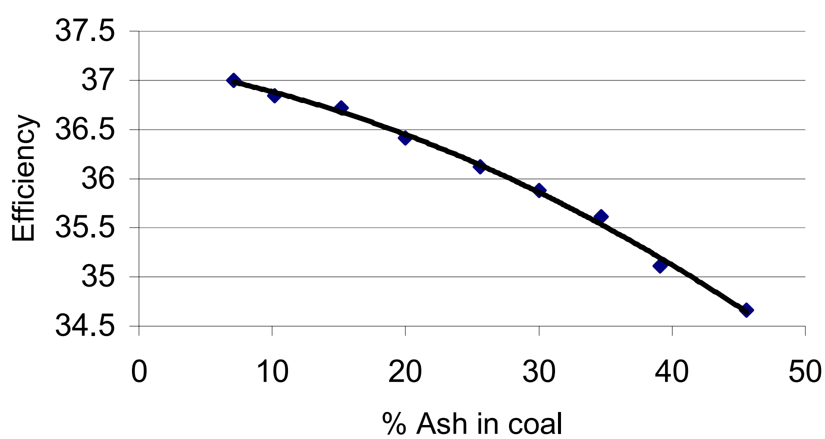


Figure 41 Coal ash % Vs Subcritical plant efficiency

In the lumped model the efficiency is a function of the quantity of heat carried away by the bottom ash and the combustion efficiency of the boiler. In the above figure we see that as the coal ash content increases the heat carried away by the ash increase leading to higher heat losses from the furnace. Higher ash content in fuel also reduces the combustion efficiency of the pulverized boiler which leads to inefficient fuel combustion resulting in unburnt heat losses.

Nov 14, 2007

Similar simulation runs with varying ash % is carried out with advanced coal technologies. We first begin with Supercritical pulverized combustion technology.

1. Supercritical Pulverised Technology

Supercritical pulverized coal combustion technology is similar to subcritical technology in terms of combustion of coal. However a supercritical plant operates at higher temperatures and pressure that exceeding the critical point. The supercritical plant considered for study has (600°C/300bar) a double reheat cycle.

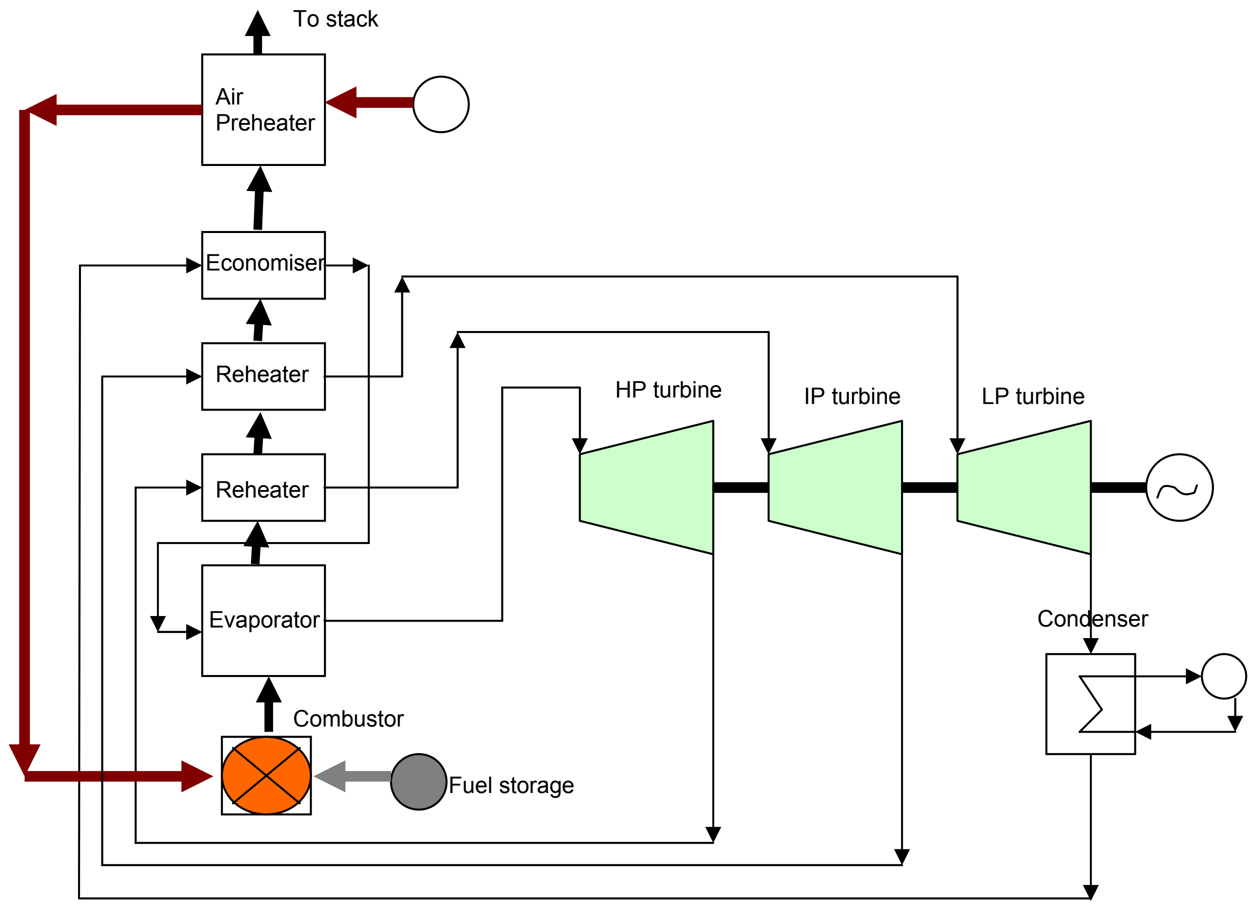


Figure 42 Schematic of a Supercritical pulverized coal power plant

Assumptions made for supercritical simulation are the same as that for subcritical. The coal compositions also are the same. The figure 43 shows the variation of cycle efficiency with the ash content in coal.

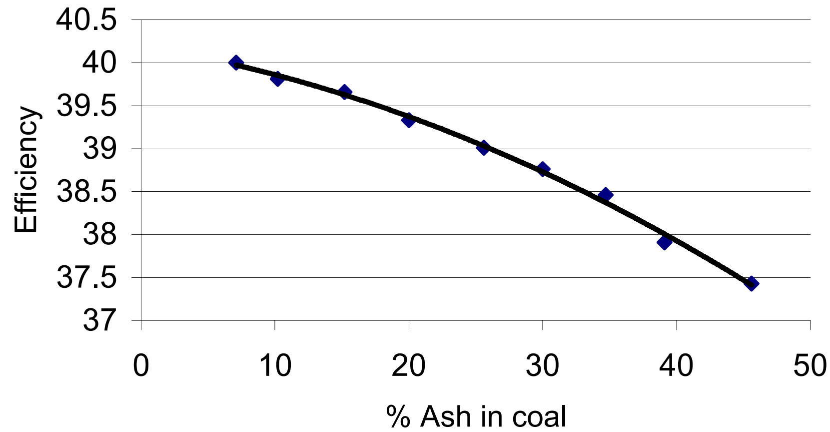


Figure 43 Coal ash % Vs Supercritical plant efficiency

Here again we see the effect of coal ash on the efficiency of power generation of supercritical technology. The efficiency is a function of heat loss from ash and heat loss from unburnt coal which is a function of combustion efficiency in the boiler.

2. Circulating Fluidised Bed Combustion (CFBC)

The Circulating Fluidised Bed Combustion technology for power generation has a similar layout as that of subcritical pulverized plant except for the boiler. The boiler in CFBC is a fluidized bed boiler. The finely powdered coal is combusted in the suspended state ie it is fluidized with the help of the incoming primary fluidization air. The secondary combustion air is supplied higher up the bed. The turbulence in the CFBC boilers is high due to higher fluidization velocities as a result the combustion efficiency of the CFBC boilers is high and almost unaffected by the composition of the coal fired. Due to higher fluidization velocities, some of the fuel particles get carried away by the flue gas which is collected by the cyclone and returned back to the boiler from the bottom.

Simulation run for the CFBC plant was carried out using the same conditions of steam (170 ^{o}C/550 bar) single reheat cycle as that for subcritical pulverized. However the boiler is a circulating fludised bed boiler. Figure 45 shows the schematic of the CFBC plant.
The efficiency for FBC here is only a function of the heat carried away by the ash which is in turn a function of the ash content in coal. For FBC boilers the combustion efficiency is high and is unaffected by ash content in coal. For CFBC boilers where turbulence is high, combustion efficiency very close to 100% is achieved. For simulation purpose however, the combustion efficiency is assumed to be 99%.

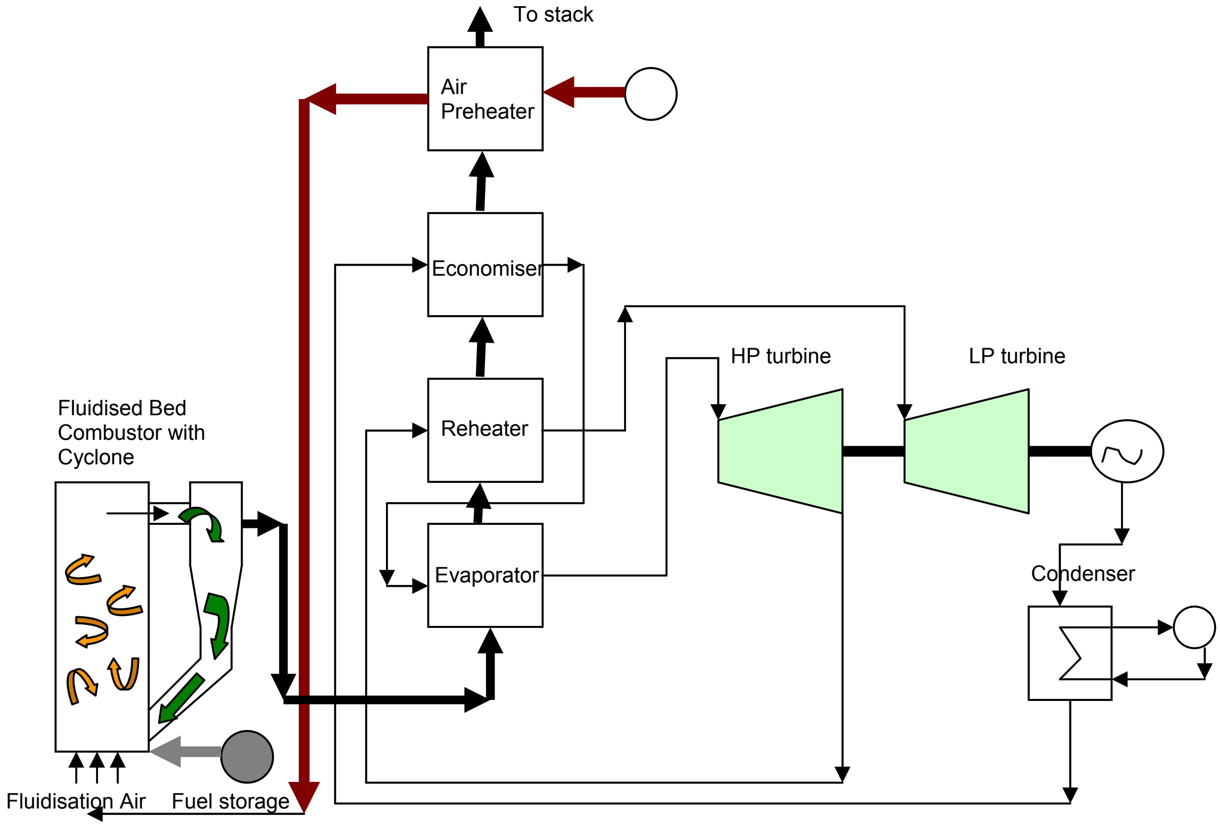


Figure 44 Schematic of a CFBC power plant

The figure 45 shows the effect of coal ash content on the efficiency of the CFBC plant for power generation.

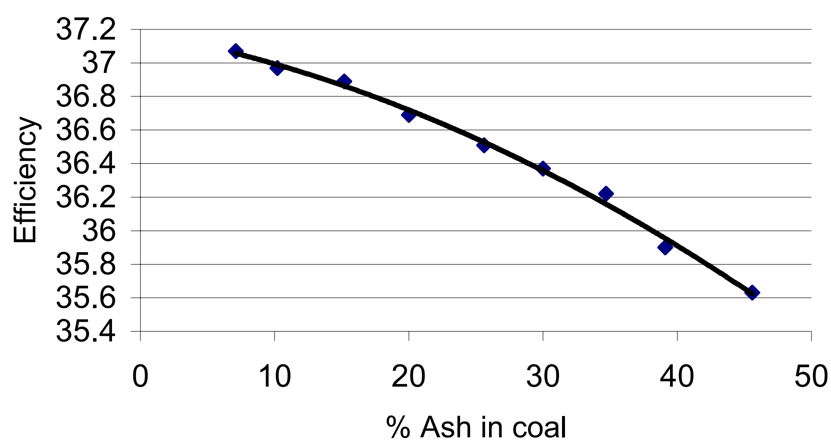


Figure 45 Coal ash % Vs CFBC plant efficiency

3. Pressurised Fluidised Bed Combustion (PFBC)

Pressurised Fluidised Bed Combustion technology is similar in layout to the CFBC technology, but in that it has a pressurized boiler. The flue gases at a pressure of about 10 bar after generating steam in the boiler tubes embedded in the combustor is directed to a gas turbine to generate electricity. The PFBC has a steam turbine and gas turbine working together to produce electricity in a 80:20 ratio respectively. In the PFBC combustor as similar to the CFBC boiler the bed material is combusted in an upward flow of air. Generally the bed material consists of finely powdered coal and a sorbent (limestone) for SO2 capture. But in case of Indian coals where sulphur content is low, very little or no sorbent is added. Fig 46 shows the schematic of the PFBC layout used for simulation.

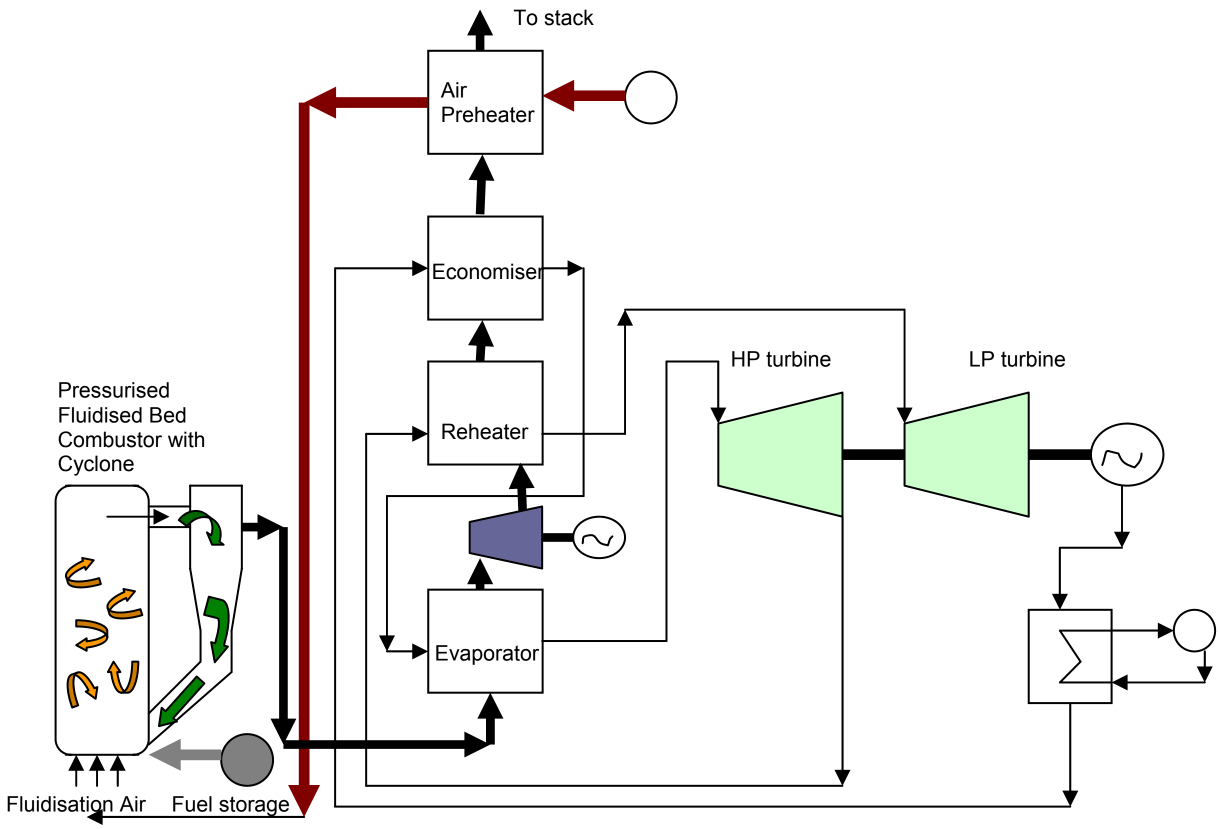


Figure 46 Schematic of a PFBC power plant

Figure 47 shows the effect of coal ash on the efficiency of the PFBC cycle.

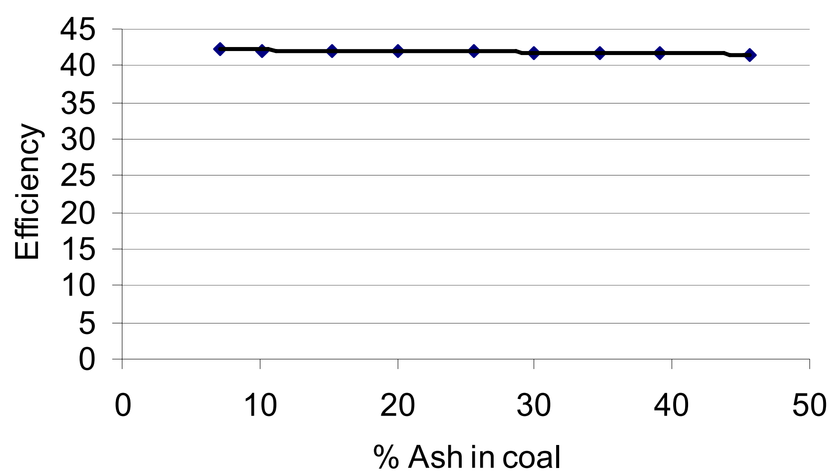


Figure 47 Coal ash % Vs PFBC plant efficiency

The ash content of coal as seen from the trend has very little effect on the efficiency of the cycle. This is because the heat carried away by the ash is very low. The ash is cooled in ash coolers before been taken out. The ash is cooled by the combustion air and thus the heat from the ash is recovered by the combustion air and is taken back to the combustor. After the ash cooler the ash is taken out at about 320^{o}C

4. Integrated Gasification Combined Cycle (IGCC)

In the case of IGCC the effect of ash cannot be checked with the lumped model. Hence the IGCC performance with respect to coal characteristics was analysed based on previous studies and experiments conducted on pilot plants. During these tests, the effects of operating variables were studied in order to assess the quality of gas produced, gas yield and raw material consumption. Four samples of Indian coals with ash content varying from 15 to 32 % were used for the studies. The high ash content lowers the efficiency of the gasification step which in turn has a direct impact on the efficiency of the whole IGCC plant. Figure 48 represents the effect of ash on the efficiency of the IGCC cycle of power generation.

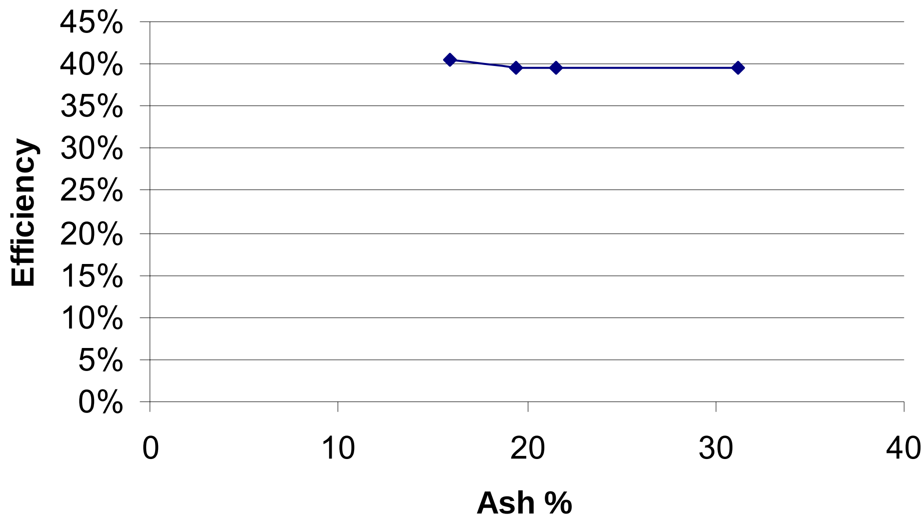


Figure 48 Coal ash % Vs IGCC plant efficiency

The use of high ash coal not only requires handling of a larger quantity of inert material in coal and a greater number of gasifiers but involves penalties in terms of higher raw material consumption and lower gasification efficiency. Studies on washing characteristics of Indian coals with different techniques of beneficiation are therefore worth considering as to evaluate the overall economics of the process with beneficiated coal.

The performance characteristics and emissions in advanced coal technologies with Indian coal are estimated with average characteristics of Indian coal. The characteristics of Indian coal are seen in table 26.

Table 26: Characteristics of Indian Coal

Proximate analysis (% by weight, dry basis)	
Fixed carbon	25.5
Volatile matter	31.4
Mineral Matter	43.1
Elemental analysis (% by weight)	
Carbon	38.9
Hydrogen	2.6
Oxygen	6.7
Nitrogen	0.7
Sulphur	0.6
Moisture	5.7
Lower Heating Value (MJ/kg)	14.5
Fuel Exergy (MJ/kg)	16.5

The performance characteristics estimated are given in table 27.

Table 27: Performance Characteristics of Advanced Coal Based Power Generation Technologies with Indian Coal

Sr. No.	Criteria	SC*	USC	CFBC*	PFBC	IGCC*
I	**Technical Performance Characteristics**					
	a. Heat Rate (kcal/kWh)	2012		2538	2242	2020
	b. Efficiency (%)	36.4	44.1	27.5	38.6	39
	c. Operational Availability (%)	>86	88	88	59.6	83.8
	d. Auxiliary Consumption (%)					17.1
II	**Environmental Performance Characteristics**					
	a. CO_2 (kg/kWh)	1.07	0.98	0.95	0.68	0.67
	b. SO_2, (g/kWh)	7.08	6.52	6.33	4.54	4.47
	c. NO_2 (g/kWh)	2.64	2.43	2.36	1.69	1.66
	d. SPM (mg/nm3)			~ 25		0.02
III	**Economic Performance**					
	a. Capital costs (Rs/kW)	42000		48400	95840	108000
	b. Fuel costs (Rs/kWh)	0.49	0.45	0.44	0.315	0.31
	c. O & M costs (Rs/kWh)	0.14	0.14	0.14	0.14	0.14

**Efficiency, Capital cost and Availability as per Indian Experience*

Table 28 shows the annual coal consumption in 2025 based on existing heat rates (1450 million tonnes). The Business as Usual scenario has been computed assuming that the new plants would have an average operating net heat rate of 2500 kcal/kg. This results in a coal requirement of about 1200 million tonnes (this is likely to include some coal imports) and a carbon dioxide emission of 1740 Mt. A strategy for aggressive adoption of super-critical plants and advanced coal technologies would result in the new plants would have an average operating net heat rate of 2200 kcal/kg. The coal requirement reduces to less than 1100 million tonnes resulting in an annual saving of 100 million tonnes of coal and a saving of 150 Mt of carbon dioxide.

Table 28 Estimated Coal Consumption and Emissions from Coal Power Plants in 2025

Year	**Electricity Generation (Billion kWh)**	**Electricity at Bus Bar ((Billion kWh)**	**Peak Demand (GW)**	**Installed Capacity (GW)**	*Mt of coal*	**Coal Based generation (Billion kWh)**	**MT CO2**
2003-4	633	592	89	131	318	443	461
2025	2704	2528	412	542	1450	2028	2109
2025 BAU	2704	2528	412	542	1198	2028	1736
2025Adv	2704	2528	412	542	1093	2028	1584

X Required uncertainties requiring additional R & D

Use of high-ash coals aggravates the erosion problem in gasifier equipment, FBC boilers, gas lines and pulverizing (milling) sections; this becomes more serious when using Indian coals containing ash of abrasive nature. Erosion is a serious problem in FBC boilers and gasifiers. The turbulent nature of the process aggravates the erosion much more than in pulverized boilers. There has been very little research carried out in terms of the erosion due to coal ash. This problem should be studied in detail for the nature of erosion and to suggest ways to minimize this problem and to use erosion resistant lining in boilers and gasifiers.

Use of high ash coals in power plants not only involves handling the extra burden of inert material which passes through different sections but also requires elimination of a higher volume of ash from the gasifier resulting in heat losses and lower efficiency. The beneficiation of coal should be carried out for the new technologies. The cost and technological analysis for the washing of coal should be carried out for these new technologies to check whether rise in efficiency from washing would atleast breakeven the washing costs involved.

The FBC boilers and Gasifier equipment even though they are not affected by the type of coal, practically there is a range of ash percentage for which these technologies are design and any deviation from the prescribed range of coal results in serious loss of efficiency. Before designing a FBC or an IGCC plant the availability of coal for which the plants are designed has to be checked

XI Most promising power generation technology and national benefits

Out of the four advanced technologies it is very difficult to point out one technology that is conducive in all respects. There has to be a trade-off reached between the various parameters of these technologies in order to select the most appropriate technology. The following data compares the advanced technologies with the subcritical technology operating in India.

Table 29: Performance Characteristics of Indian and Advanced Coal Based Power Generation Technologies

Sr. No.	Criteria	Indian Thermal Power Stations			Supercritical PC		CFBC		PFBC			IGCC		
		Av.	Min.	Max.	Min	Max	Min	Max	Av.	Min	Max	Av.	Min	Max
I	**Technical Performance Characteristics**													
	a. Heat Rate (kcal/kWh)	3218	2489.5	6341	1872	2153	2923	2153	2242	2012	2533	2020	1861	2190
	b. Efficiency (%)	27.7	13.58	34.6	40	46	29	40	38.6	34	42.8	40.6	38	43.7
	c. Operational Availability (%)	9.52	5.59	16.2	86	92	87	88	59.6	52.5	69.5	83.8	60	95
	d. Auxiliary Consumption (%)											17.1	12.7	25.2
II	**Environmental Performance Characteristics**	1.04	0.784	1.608										
	a. CO_2 (kg/kWh)	7.55	1.44	24.6										
	b. SO_2, (g/kWh)	3.502	2.47	5.62	100	200	170	400	1.19	0.205	2.55	0.173	0.06	0.39
	c. NO_2 (g/kWh)	198.5	11	923	200	650	80	300	0.55	0.25	0.84	0.325	0.09	0.5
	d. SPM (mg/nm3)				10	25	~ 25					0.02	0.016	0.022
III	**Economic Performance Characteristics**													
	a. Capital costs (million Rs/MW)	29	21.5	44.6*	42.8+	72	45	72	107.8	67.5	129.4	108	67.5	129.4
	US $/kW	650	480	990	950	1600	1000	1600	2396	1500	2875	2396	1500	2875

* this is the minimum, maximum and average of the actual cost of the power plants built in India during the last few years

\+ the values for the advanced coal technologies are taken in US $ conversion used is Rs. 45/$ (2006 exchange rate)

The annual reduction in coal consumption is also calculated for advanced technologies. The comparison is on the basis of the electricity generated by subcritical power station using coal for 2004-05.

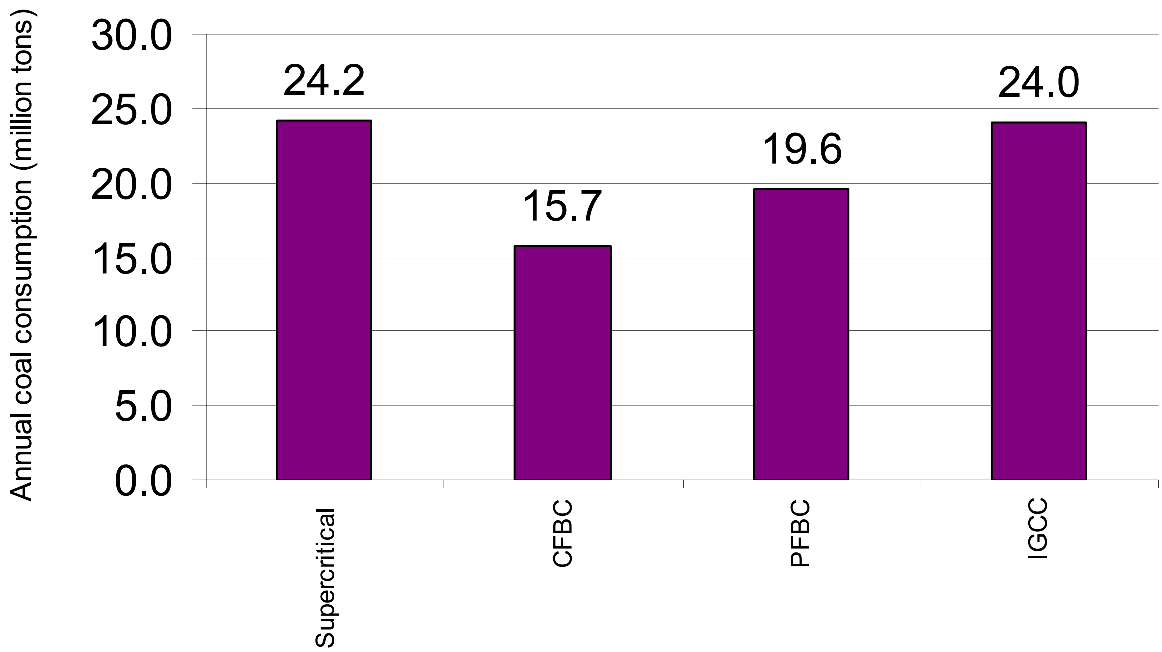


Figure 49 Reduction in coal consumption as compared to subcritical Indian thermal power plants for 2004-05

XII Barriers

- The Indian power sector has inadequate exposure to advanced clean coal technologies.
- The indigenous efforts at technology development and research and development have been limited. BHEL's experiment with IGCC in the 1980's was not followed up with a technology development programme.
- There are relatively few active research groups working on advanced coal and clean coal technologies in India.
- The international technologies developed for IGCC have not been tried with Indian coals.
- The investments in R & D have been low and there is an absence of a concerted technology development mission. In 2000 the Prime Ministers office and the Principal Scientific Advisor to the Government established a committee consisting of BHEL and NTPC to decide a strategy for establishing an IGCC
- There is an absence of an incentive for utilities and generation companies to invest in more capital-intensive clean coal technologies.

- There is no incentive provided by regulatory authorities for clean coal technologies.

XIII Strategies

There is a need to support the establishment of prototype clean coal technologies (at least one plant each of CFBC, PFBC and IGCC). This can be done based on competitive bidding with the joint involvement of indigenous companies and foreign suppliers. This has to be supported by a multi-institutional research initiative to provide the necessary analytical and experimental support. For the super-critical plants India's strategy should be to build a number of plants and then assess their performance vis-à-vis the sub-critical plants.

For the advanced clean coal technologies a critical assessment of the prototypes and performance after a period of about 5 years should result in a commercial deployment strategy.

A clean coal fund can be established or an incentive provided for a higher efficiency or reduced emissions. Innovative financing mechanisms may be explored with government support to defray the higher initial capital cost of these plants.

XIV Summary and conclusions

The choice of advanced technology for power generation in India has to reach a trade-off between different technical, economic and environmental parameters. It is however, not easy to reach this trade-off by analysis and simulation of these technologies, which gives us an fair indication of the merits and demerits of these technologies on a macro level.

The proposal is therefore to build a pilot plant for each advanced technology and study the parameters on a micro level to see the effect of Indian conditions and fuel on these technologies. For setting up of the pilot plants various factors such as size of the plant, technology availability, governmental support etc have to be taken into consideration.

Only after a thorough analysis of each technology with respect to the pilot plants can a technology selection be made and deployment on a commercial scale can be taken up.

The advanced coal scenario outlined here results in significant savings of coal and extends the use of India's national coal resource. This also results in a reduction of CO_2 emissions from the power sector by 150 million tonnes in 2025 (about 9% of the emissions from coal power plants). The strategy involves building prototype power plants using PFBC and IGCC. In case these are successful in terms of operational availability at reasonable capital cost, they may form a part of the new coal based generation. This would result in a larger quantity of carbon dioxide savings from the power sector in 2025.

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Development Benefits of Clean Energy in India

Energy Efficiency in the Power Sector Power Transmission and Distribution

Sponsored by
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Energy Systems Engineering
Indian Institute of Technology Bombay

Sarag J Saikia
Prof. Rangan Banerjee

November 10, 2007
Final Report COP-13

Executive Summary

Efficiency in the Power Sector Transmission and Distribution

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Indian Institute of Technology Bombay

Introduction

The power sector is a key infrastructure sector for India's development. The present installed capacity of around 135,400 MW (July, 2007 *[1]*) is predominantly based on coal (accounts for 53 % of total installed capacity). The installed capacity has been growing at 5.2 % per year. Despite the growth, there is a peak shortage (GW) of 12.3 % and an average energy (GWh) shortage of 8.1 % during the period 2002-7 *[2]*. More than 50% of the households do not have access to electricity; consequently, the per capita electricity consumption for India is 590 kWh (2003-4), which is only around 20% of the world average. The development challenge is to provide access to these households. The growth rate of installed capacity has not kept pace with the growth in energy demand. The capacity addition during the 10th plan (2002-7) was around 27000 MW against the target of 41110 MW *[2]*. With the projected growth rate (8%), it is estimated that installed capacity by the year 2025 would be around 540 GW *[3]*, and net energy[13] demand of 2528 billion kWh.

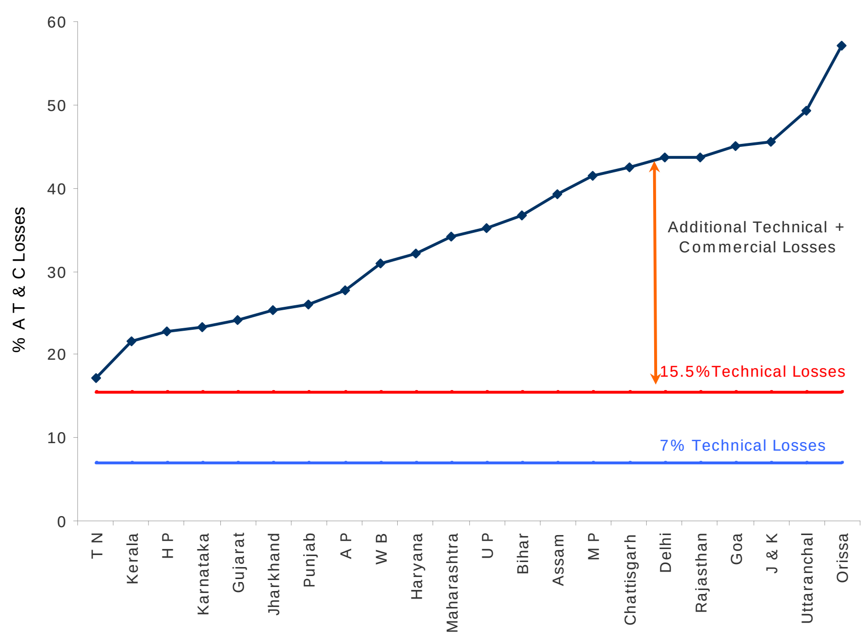

Figure 1: A T & C Losses of various states with optimum bounds of pure technical losses [CEA, 2003-04]

It is estimated that the power sector accounted for about 519 Mt of carbon dioxide emissions in 2003-4 (~60% of India's total CO_2 emissions). The annual growth rate of CO_2 emissions is about 5.1 % (2002-7). With the anticipated growth in energy demand

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[13] *Net energy generation = Gross Generation – Auxiliary consumption*

and assuming the existing power sector performance, the total annual emissions in 2025 from power sector alone would be around 2217 Mt.

Although there are many technological options, we propose the following key options, which have the potential to improve the financial performance of the utilities, and the access of energy, as well as in the annual reduction of CO_2 emissions.

A. Improved accounting methodology for T & D loss reduction

The average aggregate technical and commercial (AT & C) losses in the power sector accounts for about 33% *[4]* of the electricity available at bus-bar[14]. T & D losses include technical losses plus a high proportion as commercial losses (theft, unbilled energy, uncollected bills) as seen in *figure 1*. In addition, there are uncertainties in the quantification of unmetered consumption (low usage residential, subsidized agricultural). The quantification of consumption of these segments is based on empirical methods. The average AT & C losses as a percentage of the total energy available at the bus-bar *[4]* in different states vary from 17% in Tamil Nadu to as high as 65 % in Manipur.

It is therefore proposed to have systematic accounting (energy audits) at the sub-station level. This needs to be carried out with metering of all distribution transformers (less than 20% for most of the states in 2005-6). Quantification of sub-station wise electricity usage and comparison with billed amounts can be used to determine the T & D losses for each substation. An analysis of the data for different sub-stations would help in estimating norms and reducing AT & C losses. A study *[5]* carried out by IISc and Karnataka Power Trading Company Limited (KPTCL) indicated that the average uncertainty in the estimation of losses by a current method is around 10% with a maximum of 22%. Low collection efficiency is a major cause of commercial losses and needs to be improved by adoption of new technologies and increased accountability. Better accounting is critical to quantify and implement efficiency programmes.

With the projected generation of electricity *[3]* in the year 2025 (2528 billion kWh) and at present loss rates, AT & C losses would amount to 834 billion kWh. We expect that bringing down the AT & C losses to a level of 25% is possible by 2025 and would contain the losses to around 630 billion kWh. This would improve the financial operation of the utilities.

Distribution Transformer Efficiency and Replacement Programme

The number of distribution transformers (DTs) is more than 2.5 million *[4]* in India, with an aggregate capacity of 207000 MVA. DTs normally contribute around one-third of the technical losses under optimal network configuration and loading. It is estimated that the capacities of more than 90% of the total DTs in India range between 10 to 315 kVA. The average DT capacities of various states vary from approximately 50 kVA (Jharkhand) to high value of 500 kVA in Delhi *[4]*. After transmission and distribution lines, DTs are the largest contributor to system-wide losses. The figures of losses of DTs vary depending on many factors like average and peak loading, maintenance. Several studies *[6]* show the loss levels of distribution transformer as in *table 1*.

Table 1: Breakdown of losses of major power systems components

[14] *Energy at bus-bar = Gross Generation – Auxiliary Consumption (GWh)*

Components losses as % of total losses					
	Transformers		Lines		Others
Studies	Power	Distribution	HT	DT	
USA – 1	0.3	1.2	2.3	3.2	0.2
USA – 2	0.2	2.6	0.7	3.1	0.6
UK – 1	0.6	1.8	1.5	3.3	
UK -2	0.7	2.3	1.1	3.1	0.2
Australia	0.2	3.8	1.9	3.6	

Source: Targosz et. al. [6]

In India, BEE[15] has developed a classification scheme as a part of the standards and labeling program. This classifies DT in the range of 16 – 200 kVA into 5-star based on total losses at 50% and full load. The 5-star unit is highly efficient while BEE of minimum standard recommends the 3-star. Star 1 DTs are high loss units that correspond to IS 1180 standard for DT. *Figure 2a* compares the efficiencies at various loading of a 16 kVA DT of various BEE standards. *Figure 2b* compares the NEMA TP1 standards with 5-Star DT of BEE, India standard of DTs of various sizes.

Table 2: DT failure rates and feeder outage rates[16] of in select circles of a few states (2005-6)

	DT Failure Rates			**State Avg. feeder outages per month**			
	Minimum	**Maximum**	**Avg.**		**Min**	**Max**	**Avg**
Chhattisgarh			16.4	Chhattisgarh	2	41	
Goa			5.3	[17]Jharkhand	54	167	80
Rajasthan	7	30		A P	4	300	
Punjab[18]	2.7	27		Punjab	2	33	
Karnataka			8	West Bengal	9	200	
West Bengal	5	22					
Himachal Pradesh			4				

Source: MoP

Actual losses in DTs in India are high owing to unplanned network expansion leading to DT overloading and due to improper protection and poor preventive maintenance. DT failure rates give a good indication of operating performance of distribution transformers and that of the utilities. While DT failure rate of 1.5% per annum is assumed as baseline my MoP considering reliability aspects, the actual rates are very high *(see table 2)*. A study *[7]* of a sample of 4500 DTs by Bangalore Electricity Supply Company Limited (BESCOM) indicated that losses in more than 30 percent of the transformers was more than 5% and losses in another 30 percent was more than 10% of the total AT & C losses.

[15] Bureau of Energy Efficiency India

[16] The prescribed level of DT failure rate is 1.5 % per annum and that of Feeder outage level is one outage per month

[17] Feeder outages values only for four test checked circles – Dumka, Dhanbad, Daltonganj and Hazaribagh

[18] Average DT failure rate for 2002-6.

Owing to the growing energy demand and the need of rural electrification, DT market in India is expected to grow with an annual rate of around 10% [BEE]. Therefore energy savings is possible from:

c. Replacement and refurbishments of lowest efficiency DTs with energy efficient DTs, and
d. Standardization of efficiencies and to initiate mandatory minimum efficiency standards to promote use/ installations of efficient DTs with demonstrated benefits.

It has been estimated that replacing a 1 star DT with a 3 star DT will result into 40% reduction in annual energy losses of a DT and replacing a 3 star DT with a 5 star DT will result into more 30 % of annual energy losses of the DT.

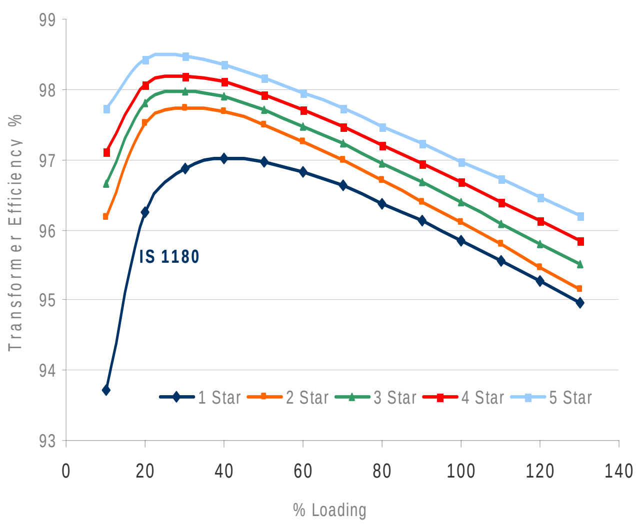

Figure 2a: Efficiencies of 16 kVA DT of five different standards
Source: BEE[19] & NEMA TP1 Standard

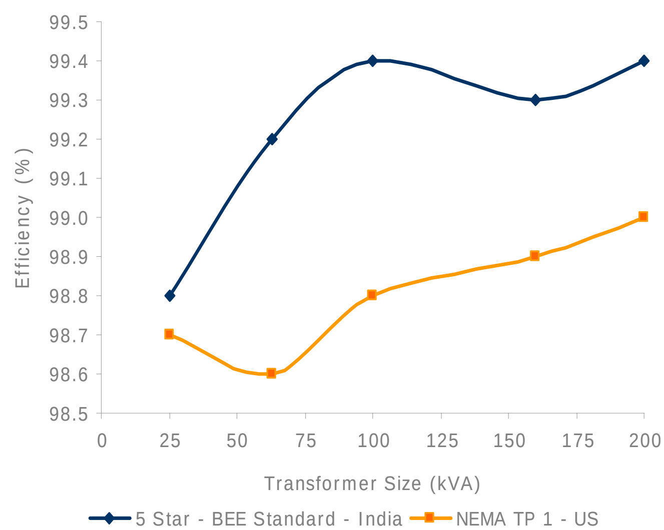

Figure 2b: Comparison of efficiencies of five different transformer sizes, at 50 % loading, unity pf – Indian, BEE and US NEMA TP 1 standard

Table 3: Annual energy savings by replacing high loss DTs with energy efficient DTs

Transformer Size	Star Rating	No Load Losses (W)	Full Load Losses (W)	Effective Load Factor	Annual Energy Losses (kWh)	Ex-Works Price (Rs.)	Annual Losses per kVA (kWh)	Reduction in Losses by replacing 1 Star DTs
63	1 Star	182	1233	0.5	2098	32900	33	-
63	2 Star	90	1160	0.5	1262	41400	20	40%
63	3 Star	50	1000	0.5	847		14	60%

Source for calculations: BEE

[19] Bureau of Energy Efficiency

Similar energy savings calculations have been made by BEE, but the standard set by BEE, though ambitious, is voluntary due to which the benefits are not fully verifiable. We, therefore propose to formulate strategies for timely replacement of overloaded and high loss DTs. The incentive and motivation for the use of energy efficient DTs needs to be made more prominent and transparent which will ensure the participation of the stakeholders (manufacturers, utilities etc.). More accurate DT loading data should be made available to make more realistic potential energy savings calculations. Such data could be used to evaluate the Total Owning Cost for future DT installations.

There is a need to classify DTs based on their size as well as the demand side considerations i.e. DTs serving loads of different consumer groups (operates at different efficiency level) - loading also affects DT life considerably. Further efficiency improvements efforts can be undertaken by estimating the efficiency standards of DTs of different sizes based on the loading pattern of different consumer groups.

Energy auditing at DT level would assist in identifying high loss DTs where systematic replacement programme could be implemented based on cost benefit analysis. Average DT capacity needs to be brought down in states with high rural and agricultural consumption (based on load factors) with a consequent reduction in distribution line lengths and implementation of High Voltage Distribution System (HVDS). A framework for optimum transformer selection based on data on loading and load concentration/ spread region-wise needs to be prepared.

B. Optimal Distribution Network Planning

Under optimal distribution network configuration the low voltage distribution lines contribute to around 3-5% *[8]* of the total losses. The length of low voltage distribution lines in India is more than 3.9 million kilometers, which is more than 60% of the total line length. This has led to suboptimal network configuration leading to a high length of distribution lines served by a single DT that varies from 0.7 km (average DT capacity 55 kVA) in Uttar Pradesh to more than 9 km (average DT capacity 415 kVA) in Uttaranchal. The mean value of low tension (LT) distribution lines length for the country is around 3 km per DT (average DT capacity 130 kVA) – (see figure 3). A state with more rural area and population would have a high LT DT lines per DT. There are no minimum standards set for LT DT lines served by a DT and without a timely DT replacement programme which leads to overloading of both lines and DT and causing high rate of feeder tripping and outages as seen in *table 2*.

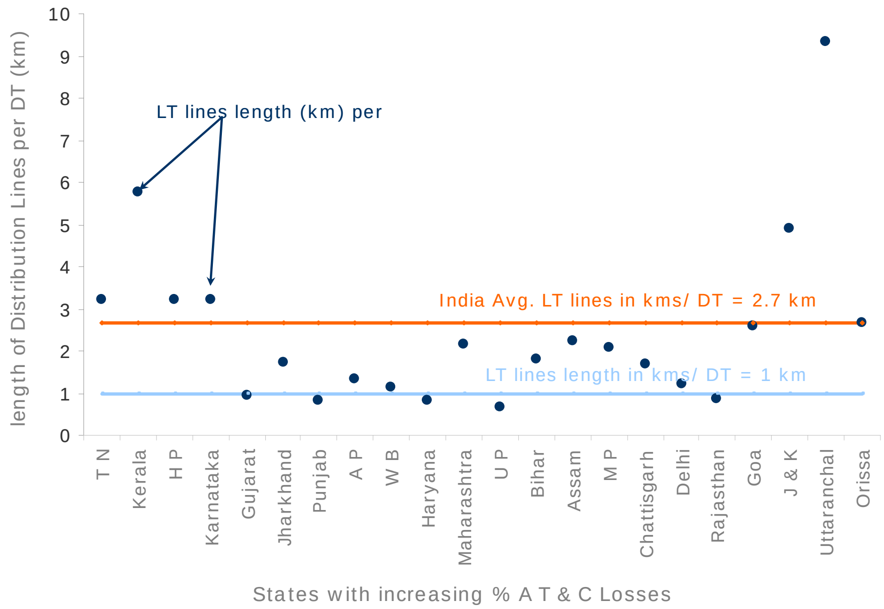

Figure 3: Spread of length of LT distribution lines (<500) in km per DT for various states with India average and of unity value [4]

We propose a plan for optimal distribution network planning and maintaining standard values of LT lines length as per DT capacity in rural and urban areas. This would involve systematic reduction of the LV/ HV line length ratio by the implementation of HVDS in future network installation and upgradation wherever practicable. This would result in a reduction of the average DT capacity and therefore LV lines length per DT. It is estimated that the distribution transformer efficiency and optimal network planning options would result in a reduction of AT&C losses by 5% in 2025.

C. Efficient Agricultural Pumping System

There are more than 14.1 million agricultural pumpsets *[4]*, which consumed around 25 % (87,000 GWh) of the total electricity generation, in India (2003-4). The tariff for agricultural consumption is subsidised and is usually based on the horsepower (HP) pumpset rating (i.e.) connected load instead of the actual consumption.

The efficiency of a pumping system is a function of the efficiency of the pumpset and the piping, valves. The difference between the efficiency of a standard motor and an efficient motor is of the order or (5 – 10) % *[9]*, however, less efficient motors are mainly in use due to initial cost considerations. There are no standard procedures for proper pump selection and pump head selection in India. The minimum efficiency standards laid down by [20]BIS can be upgraded considering the fact that high efficiency pumps are readily available from reputed Indian manufacturers.

Improper sizing of pipes for pumping operation, quality of foot valves and other accessories are important aspects to be considered for efficiency improvement. Standards should be laid out for optimum pipe sizing for minimum overall cost of pumping

[20] *Bureau of Indian Standards*

(including capital and running cost). Existing standards are sub-optimal and voluntary which are most of the times not followed by manufacturers and farmers.

It has been estimated that by improving the pump efficiency standards as well as by improved pump designs (improved head-efficiency curve) would result in around 15% of energy savings. Appropriate pump pipe sizing and standard upgradation have the potential of around 20 % of energy savings *[9]*.

Policy formulation to introduce incentives to farmers for efficient pumping use can help in reduction of theft and overuse of pumps. This can be realized by metering of pump sets and subsidized tariffs be based on actual energy consumption rather than on connected load.

Agricultural feeder separations, metering of pump sets, efficiency standards for new installations are elements of an efficient agricultural pumping programme. The existing average efficiency of motor-pump sets is about 20%. A DSM programme focusing on efficient agricultural pumping can enhance this average to 30% in 2025.

D. Innovative Rural Electrification Programmes

More than 56% of households *[2]* in India are not electrified. The development goal of providing access would result in a thrust on rural electrification. Rural power distribution is characterized by low electricity usage densities, dispersed load (consequently high line losses) and high transaction costs against the actual revenue generated.

Load factor needs to be improved by connecting rural industries to the grid. High line losses, pilferages should be avoided by optimum planning of rural network and by implementation of HVDS wherever viable. A plan providing a unique solution for country wide rural electrification does not seem practicable, as the actual situation and constraints are different for different regions. Innovative rural power distribution schemes can be planned based on replication of best practices (like Gram Vidyut Pratinidhi of Karnataka). Although a number of rural electrification models have been devised and implemented, many have failed or have had limited success. This was primarily due to the top-down approaches adopted for their implementation. Innovative load management schemes (like Akshay Prakash Yojana of Maharashtra) with bottom-up approach could be initiated by utilities.

To take care of low load densities electricity usages, optimal distribution network planning, implementation of HVDS, energy efficient transformers and electric devices would drive the future electrification and expansion of rural network.

E. Efficient Lighting Programmes

Lighting load accounts for 17% [BEE] of the installed capacity of India. Efficiency programmes and innovative schemes for the replacement of incandescent bulbs by Compact Fluorescent Lights (CFL) and Fluorescent Tube Lights (TFL) by efficient TFLs are considered. Replacing a 60 W incandescent bulb by a 15 W CFL would result in 75% power saving. Similarly, replacing an ordinary TFL (56W) with energy efficient TFL 5 tube light (28W) would result in 50% of power saving *[8]*.

The higher initial capital cost and the high consumer discount rates for these options result in relatively few adoptions. Thus there is a need for efficient lighting programmes that provide reduced capital cost options through large scale procurement and provide the possibility of payments through installments in utility bills [e.g. [21]BELP]. Utilities need to be able to quantify the system wide potential for such programmes. A study for Maharashtra *[9]* revealed that there is a potential of 2335 GWh in energy saving and peak demand reduction of 703 MW in rural area, and a potential of 2121 GWh in energy savings and peak demand reduction of 663 MW [2004-5]. The electricity savings achievable through an efficient lighting programme is estimated to be 150 Billion kWh in 2025.

F. Adoption of Solar Water Heating Systems (SWHS)

Solar Water Heating is an option that can reduce the morning peak demand significantly. In many urban areas (Pune, Bangalore), there is a large number of residential Solar Water Heating installations. Despite the fact that SWHS are reliable and economically viable (payback periods 3-4 years), the actual installed capacity is only a small fraction of the potential (2% of the estimated potential). The CO_2 savings by use of SWHS instead of electric heating is 0.87 kg of CO_2 per kWh of electricity saved. The annual electricity savings potential has been estimated to be around 12.2 BU *[9]* for 60 million sq. m. of collector area, which amounts to around 10.5 million tonnes of CO_2 savings annually (2005-6). The annual electricity savings in 2025 through this option is estimated to be 20 Billion kWh (assuming a diffusion curve with a fraction of the potential being achieved).

Barriers

1. Subsidized electricity to low usage residential and agricultural from equity considerations. Hence significant part of electricity usage is not accounted for. This makes it difficult to monitor consumption.
2. Low electricity usage densities that entail high transaction costs making it economically not viable.
3. Replicability of schemes of power distribution in rural areas. Lack of documentation and consolidation of best practices.
4. The operating areas of utilities are large and there are not mechanisms to ascertain sub-station demand, shortages. Lack of accountability at substation is an issue.
5. Tariff based on HP rating for agricultural pumpsets due to which there is no motivation for energy-water use inefficiencies. In addition, *lack of metering* encourages power pilferages.
6. Efficiency standard programmes for DTs and agricultural pumps can be ambitious, but due to its voluntary nature, the level of participation may take considerable time.
7. There are no utility data on transformer loading, losses from which valuable parameters can be extracted on its performance and hence for planning.
8. State Electricity Boards, Distribution companies are supply focused and have little or no experience on DSM and energy efficiency techniques.
9. Utilities do not have idea and framework of the transaction costs for efficiency programmes.

[21] *BESCOM Efficient Lighting Program*

10. The significant extent of 'commercial' losses (theft) is a barrier to the commercial operation of electricity supply companies and makes returns on investments in power distribution uncertain.
11. High initial capital cost and high consumer discount rates for solar water heaters and efficient lighting is a hurdle to their adoption.

Strategies

In order for the electricity sector to be viable, it is essential that the AT & C losses are reduced significantly. This can be achieved by improved accounting methodologies and metering of distribution transformers coupled with an energy audit framework and public availability of sub-station wise loss data. There is a need for country-wide programme for replacements/ refurbishments of high loss DTs, standardization of efficiencies and initiation of mandatory minimum efficiency standards to promote use/ installations of efficient DTs with demonstrated benefits. Standardization of minimum efficiency for agricultural pumps, procedures for optimum motor pump pipe sizing and proper pump selection and pump head selection should be formulated to increase pumping efficiency. Minimum Efficiency Programmes may be mandatory or voluntary with its incentives well demonstrated for a reasonable level of involvement of the stakeholders.

This would have development benefits and would facilitate the adoption of optimal network planning and agricultural motor pump efficiency programmes. Innovative Demand Side Management (DSM) programmes for efficient lighting and Solar Water Heaters can help in widespread adoption and result in significant energy and carbon di-oxide savings. These would need utilities to set up separate DSM cells with realistic budgets and energy saving (MW generation) targets. Monitoring and verification of DSM programmes and public reporting of actual performance would help in building cost-effective DSM programmes. An analysis of different rural electrification models can help identify a few options that may be replicable and address the issue of cost recovery.

Development benefits

Improving the accounting methodology for T & D loss reduction will improve the financial position of the utilities. This is critical for attracting investments in this sector. An estimated 200 Billion units can be reduced from AT&C losses in 2025. This is not likely to actually reduce the total demand, as it is only a reduction of theft. This would result in additional revenue of about Rs. 500 Billion (in present prices) and would help in eliminating the annual deficit of the power utilities. This will enable more accurate estimation of savings and costs of energy efficiency and demand side management programmes. Options for distribution transformer efficiency and HVDS would reduce losses, improve voltages and reduce the cost of supply. These measures are also likely to improve the supply availability and reduce outages. The agricultural pump set efficiency; efficient lighting and solar water heating programmes reduce the energy requirement in 2025 by about 520 Billion units. The system peak requirements would be reduced and this would result in a reduction of about 110,000 MW of future capacity (capacity saving of Rs 4400 Billion at present prices). This would facilitate the provision of access to un-electrified households and remote villages.

Potential Savings

In 2003-4, the electrical energy available at the bus-bar was 592 billion kWh and the estimated AT & C losses were 195 billion kWh as shown in *table 3*. With the projected generation of electricity *[3]* in the year 2025 (2528 billion kWh at bus bar) and at present loss rates, AT & C losses would amount to 834 billion kWh.

The impact options considered have been quantified as shown in *table 3*. In the case of energy accounting a reduction of AT & C losses to a level of 25% is reasonable. However it is expected that the major part of this improvement would result in reduction of pilferages, which in turn would assist in increase in revenue generated by improving billing efficiency. Significant saving of nearly 33 % of the agricultural consumption (~9% of the total electricity consumption) is possible by increase in efficiencies of agricultural pumping systems.

Table 3: Impact options for CO_2 saving for the year 2025 from T&D and Efficiency

Year	[1] Energy at Bus-bar (BU)		[2] AT & C losses (33%) (BU)	[3] CO_2 Emission (Million Tonnes)	
2003	592		195	519	
2025	2528		834	2217	
	Energy at Bus-bar (BUs)	Key Options	Saving Potential (BUs)	CO_2 emission savings (Million Tonnes)	% CO_2 emission savings
2025	2528 BU	[a] Energy Accounting/ improved collection/ billing efficiency	200	Nil	
		[b] Efficient Distribution Transformer	125	103	~5
		[b] Line Losses/ Pilferages			
		[c] Efficient Agricultural Pumping System	225	185	8
		[d] Efficient Lighting	150	123	~6
		[e] Solar Water Heating	20	16	~1
		Total of all options	**720**	**427**	**20**

Assumption for calculations

[1] Energy at bus-bar = gross generation – auxiliary consumption; auxiliary consumption = 6.5% of gross generation

[2] Energy losses calculated as a percentage of energy available at bus bar

[3] Share of thermal generation projected to be 75% of gross generation in 2025

[a] Improvement of collection and billing efficiency> 90%, % AT & C loss reduction to 25%

[b] Improvement in DT efficiency and line loss reduction, % AT & C loss reduction by 5%

[c] Improvement of efficiency agricultural pumping systems by 30%, and assuming share of agricultural consumption to be constant at 25% of the total for the year 2025

[d] 6% savings from efficient lighting is being assumed for India [10]

e Potential estimated by model developed in [12] 2005-6

Conclusion

The option for improved accounting in T & D systems can result in an improvement in the financial viability of the utilities. Though this may not reduce emissions per se, this is a prerequisite for quantifying and implementing many of the DSM and energy efficiency options in the power sector. A total saving of 520 billion units in 2025 is achievable through these options. This would result in a reduction of about 20% in the electricity requirement. These options are classic win-win options as they meet the development goals by providing additional electricity availability as well as reduce GHG emissions.

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Energy Efficiency in the Power Sector
Power Transmission and Distribution

Contents

I. Introduction – Power Sector Status

The power sector is a key infrastructure sector for India's development. The present installed capacity of around 135,400 MW (July, 2007 *[1]*) is predominantly based on coal based thermal power (accounts for 53 % of total).

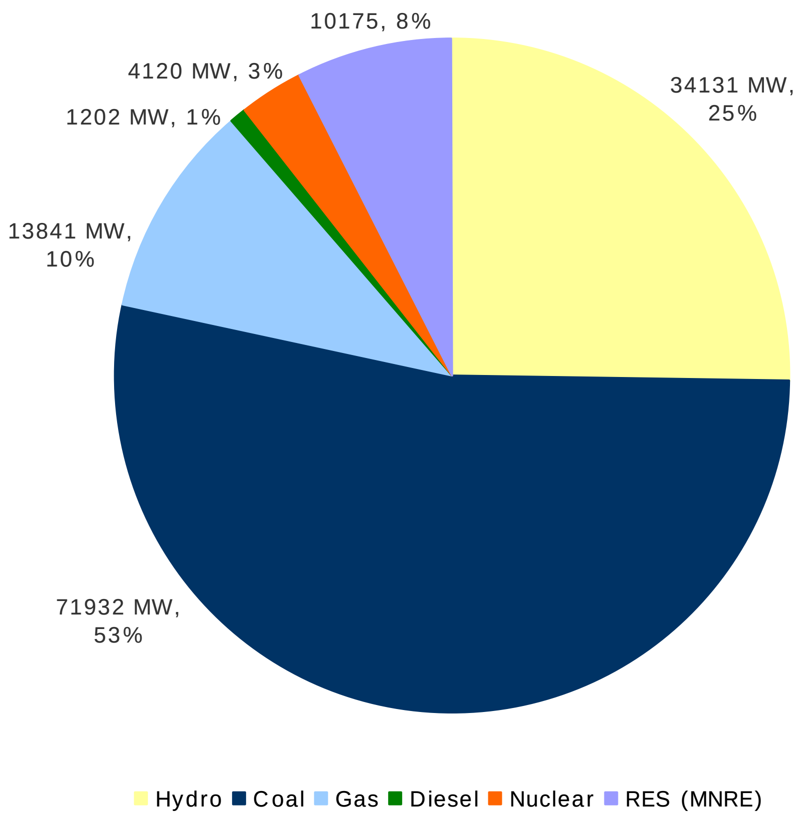


Figure 1: Installed capacity if power generating plants, July 2007 [CEA]

The installed capacity has been growing at a mean annual rate of 5.2 % and despite the growth there is a peak shortage (GW) of 12.3 % and an average energy (GWh) shortage of 8.1 % *[2]* (*see table 1*).

Table 1: Power supply position of India

Year	Peak		Energy	
	Availability (MW)	Shortage (%)	Availability (GWh)	Shortage (%)
2002-3	71547	12.2	48	8.8
2003-4	75066	11.2	40	7.1
2004-5	77652	11.7	43	7.3
2005-6	81792	12.3	53	8.4

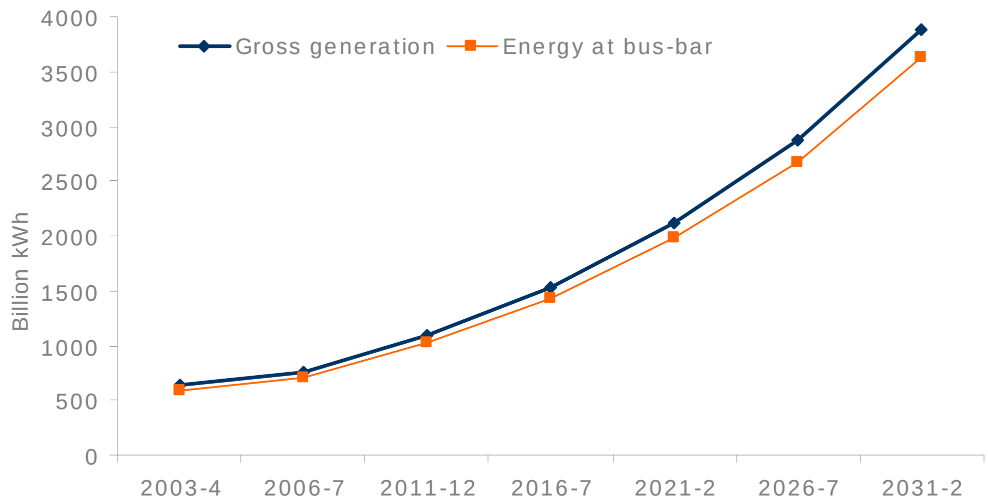


Figure 2: Projection of electricity requirement at 8% annual GDP growth [IEP]

With the projected growth rate (8%), it is estimated that installed capacity by the year 2025 (*see figure 2*) would be around 540 GW *[3]*, and *net energy demand* of 2528 billion kWh (BUs) to catch up with the growth rate (presently 5.1%) and deficit in peak demand and energy shortages.

It is estimated that the power sector accounted for about 519 Mt of carbon dioxide emissions in 2003-4 (~60% of India's total CO_2 emissions). The annual growth rate of CO_2 emissions is about 5.1 % (2002-7). With the anticipated growth in energy demand (for 8% GDP growth rate) and assuming the existing power sector performance, the total annual emissions in 2025 from power sector alone would be around 2217 Mt (*see table 2*).

Table 2: CO_2 emissions from thermal power generation

Year	[1] Energy at Bus-bar (BU)	[2] AT & C losses (33%) (BU)	[3] CO_2 Emission at present rates (Million Tones)
2003	592	195	519
2025	2528	834	2217

II. Transmission and Distribution of Electricity

Generation, Transmission and Distribution are the three main aspects related to the production, distribution and usages of electricity. Electricity is produced with the help of different types prime movers viz. thermal, hydro, nuclear, wind etc. Electricity thus produced is then transmitted at high voltages (~ 400-220 kV) through a transmission network to load center and is then distributed to the end consumers after being stepped down to the proper voltage levels as per the needs of the different consumers segments.

The power transfer system from the generating system can be divided into the following sub-systems:

1. Extra High Voltage (EHV) Transmission Network
2. Sub-Transmission Network
3. Distribution Network

Figure 3 shows how generation, transmission and distribution of electrical power take place in a power distribution system. The diagram also depicts a typical current Indian power system with the designated voltage levels. The entire power system can be broadly divided into the following three sub-systems:

A. **EHV and Sub-transmission System**: It is characterized by transmission of power at high voltage (~ 400 kV, 132 kV, 66 kV). Hence the losses occurs at this point are only technical losses which are marginal. The reasons of losses are being depicted in figure 2. The losses in the HT transmission can be identified as long feeder length, network configuration and partly due to relatively lower transmission voltages (compared to 800 kV in some countries). Marginal increase of these losses can be minimized by increasing the transmission voltage and by incorporating HVDS System. Theft is absent in this section of the system due to high operating voltage.

B. **HT Distribution System**: It's characterized by relatively lower operating voltages (~ 33 kV/ 11 kV) which mainly cater to the HT Industrial customers. Losses occurring at this level are a large volume of theft by a small number of consumers. Some of the gradations of the losses in this section of distribution system are:

    1. Low transmission voltage
    2. Over loaded feeder
    3. Low power factor
    4. High demand
    5. Distance between DT and load

C. LT Distribution System:

The operating voltages for this part of the distribution system are 440/ 220 V in India which makes it much easier for theft and pilferages. The distribution sector supply to both rural and urban areas and both have its own distinct problems and issues. This part caters to LT customers and power theft by a large number of customers is prevalent. In addition to this, it also caters to agricultural customers and other subsidized customers, which are mostly unmetered. LT feeders could be quite long and many of the DTs only cater to IP loads in rural areas but some in addition also supply to rural domestic loads.

The gradations of losses in the LT distribution system are similar to the ones for HT distribution system but more compounded by the losses for the unaccounted losses or unrealized energy.

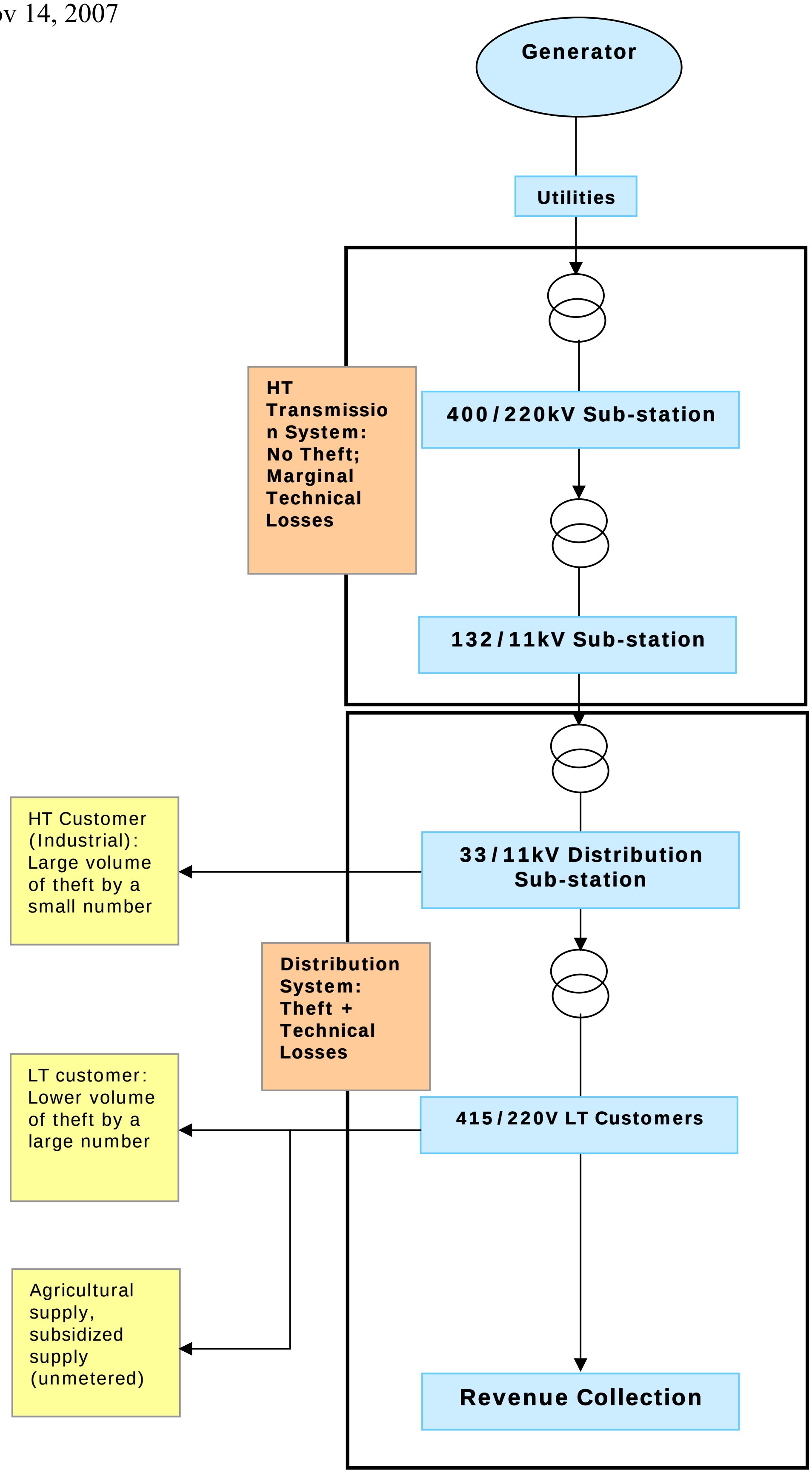


Figure 3: Scenario of energy flows in a typical India electricity distribution system [MoP]

III. Losses in Power Transmission and Distribution

However the whole of energy generated are never received by the consumers as losses occurs at different point of the power system described by figure 1. Losses occur in between the point of electricity generation to the point of consumption. The losses in any electricity network can be broadly classified into two categories:

1. **Technical Losses**
   Technical losses are due to energy dissipated in the conductors and equipment used for transmission, transformation, sub-transmission and distribution of power. These losses are due to system components and can only be reduced to an optimum level adopting advanced technologies and efficient system equipments.
2. **Non-technical losses or commercial losses.**
   The commercial losses are caused by theft/ pilferage, defective meters, and errors in meter reading and in estimating unmetered supply of energy, collection inefficiency. This is the type of loss that can be minimized to the maximum with appropriate technologies and policies.

a. Trend of Transmission and Distribution Losses in India

The officially declared transmission and distribution (T & D) loss in India has gradually risen from about 15 percent till 1966-7 to around 33 percent in 2003-4 *[4]*. *Figure 4* below shows the variation of T & D losses in India over the year since the nineties.

Transmission and distribution losses can be different for different utilities based on power distribution network configuration, type of loads, load densities, efficiency of equipments among other factors. However, there's a lower and an upper bound *[EPRI]* of power losses in different segments/ components of a power transmission and distribution system operating optimally.

Table 3 gives an idea of the expected limits of the level of losses in various segments of a power system. Performance of utilities can be ascertained based on their existing losses compared with these standard values.

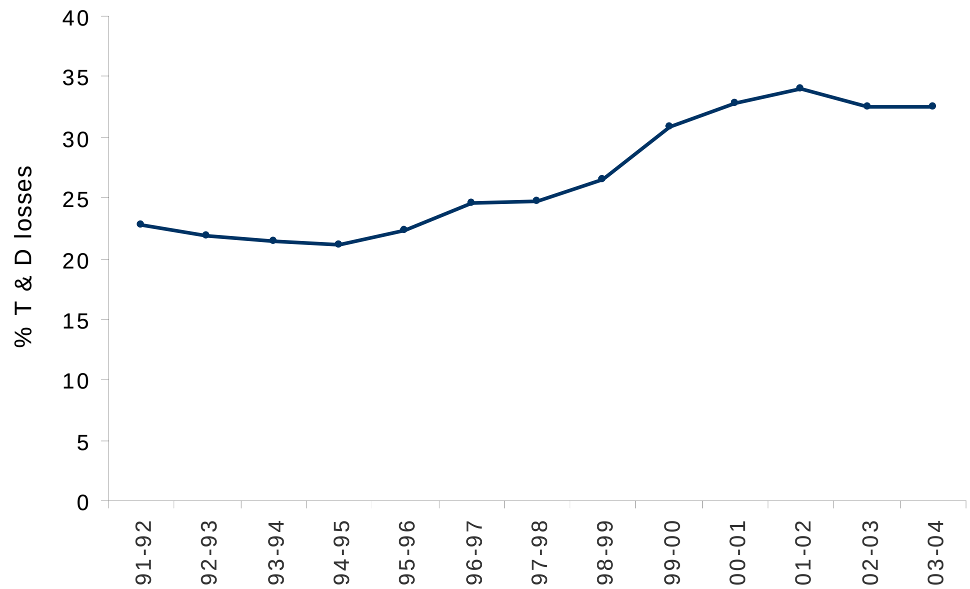


Figure 4: Variation of transmission and distribution losses in India over the years [MoP]

Table 3: Level of losses in various segments of a T & D system [2]

System Element	Power Losses (%)	
	Min	**Max**
Step-up Transformers & EHV transmission system	**0.5**	**1**
Transformation to intermediate voltage level, transmission system and step down to sub-transmission voltage level	**1.5**	**3**
Sub-transmission system and step-down to distribution voltage level	**2**	**4.5**
Distribution lines and service connections	**3**	**7**
Total Losses	**7**	**15.5**

On similar lines, erstwhile MSEB had adopted certain bounds in the levels of losses of various segments of a power system *(see table 4)*.

Table 4: Typical losses in the MSEB system

System Element	Loss	Suggested Upper Limit
EHV transmission	3 %	3 – 4% depending on Voltage level considered
Sub-transmission	4 %	4 – 4.5 %
Distribution	8.5 – 9 %	8 %
Total	**15.5 %**	**14 – 15.5 %**

Source: MSEB

The above figures are ideal considering Indian system point of view. They hold true particularly for many of the developed countries. The losses in any system would, however, depend on the pattern of energy use, intensity of load demand, load density, and capability and configuration of the transmission and distribution system that vary for various system elements.

Apart from the losses as in *tables 3 & 4*, a major portion of the losses is contributed by non-technical (commercial) losses, due to which losses of India are high compared to the developed and many other developing countries (*see figure 5*).

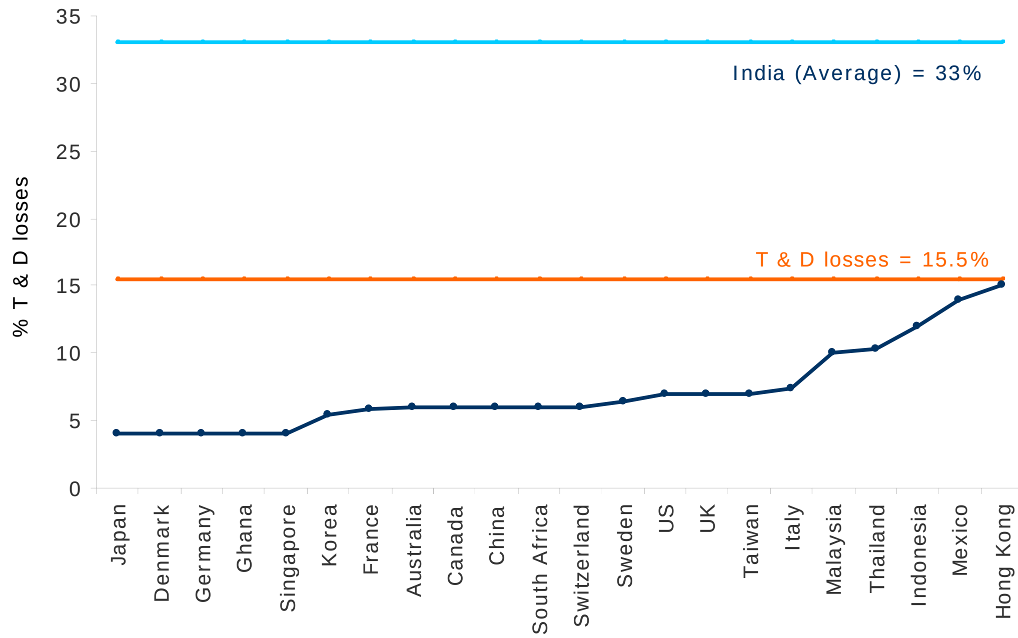


Figure 5: Comparison of T & D losses of India and some select countries [MoP]

b. Level of Losses in India

The average aggregate technical and commercial (AT & C) loss in the Indian power sector accounts for around 33% of the energy available at bus-bar[22]. The average AT & C losses in different states vary from a low of 17% in Tamil Nadu to a high of 65% in Manipur. There is a global variation of losses among the states in India and variation among the different distribution companies within a state. The reported AT & C losses of various states for the period 2003-4 are shown in *figure 6*.

[22] Energy available at bus-bar = gross generation – auxiliary consumption (kWh)

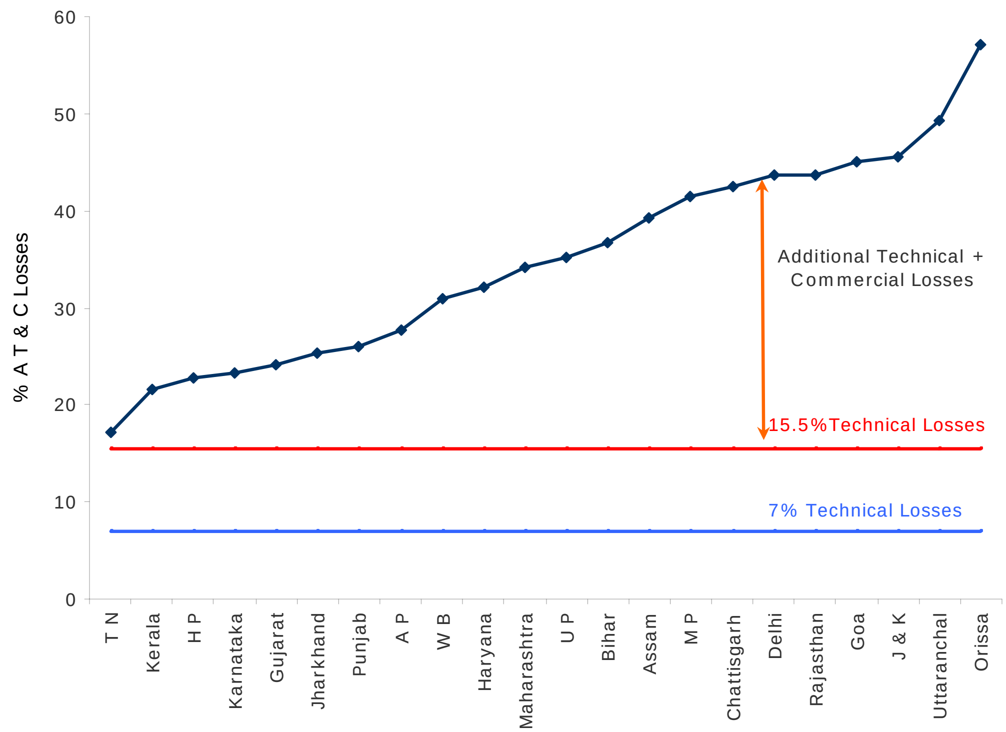


Figure 6: A T & C Losses of various states with optimum bounds of pure technical losses [CEA, 2003-04]

Based on the above figure different states of India are being grouped according to the level of present AT&C losses in the *table 5*:

Table 5: Various states grouped under different level of AT & C losses [3]

Less than 20%	Between 20—30%	Between 30-40%	Above 40%
Tamil Nadu	Kerala	West Bengal	Madhya Pradesh
	Himachal Pradesh	Haryana	Chhattisgarh
	Karnataka	Maharashtra	Delhi
	Gujarat	Uttar Pradesh	Rajasthan
	Jharkhand	Bihar	Jammu & Kashmir
	Punjab	Assam	Uttaranchal
	Andhra Pradesh		Orissa

c. Computation of Losses

Previously transmission and distribution (T & D) losses were used to measure the performance of a power system. Previously T & D losses were computed taking into account the electricity bill issued to the consumers as accrued income and not on actual collection. Clearly T & D losses computation did not capture the gap between the amount of billing and collection which arises mainly due to –

1. Losses due to unbilled energy – unmetered consumption and pilferages.
2. Losses due to unpaid energy – low collection efficiency.

Because of all the anomalies in determining the actual losses, the concept of Aggregate Technical & Commercial (AT & C) loss was introduced in 2001-02 to capture total performance of a utility. AT & C loss is the difference between units input into the system and the units for which the payment is collected. AT & C Loss is a comprehensive measure of overall efficiency as it measures both the technical and the commercial losses. AT & C loss is calculated as:

$$A.T\ \&\ C\ losses(\%) = \frac{(Energy\ Input - Energy\ \mathrm{Re}alized)}{Energy\ Input}\ X\ 100 \qquad (1)$$

Where,

$$Energy\ realized = Energy\ Billed\ X\ Collection\ Efficiency \qquad (2)$$

$$Collection\ Efficiency(\%) = \frac{Amount\ \mathrm{Re}alized}{Amount\ Billed}\ X\ 100 \qquad (3)$$

Even from the above relations, the magnitude of technical and commercial losses cannot be determined accurately. The primary criterion in the direction of reducing the losses is to have a clear understanding of the magnitude of technical and commercial losses. We shall see that due to absence of detailed metering and energy accounting at various levels, poor accountability and data unavailability, there are uncertainties in the values of losses declared by utilities.

Some of the primary factors which have been identified for increased losses and reduced performance of the Indian power distribution utilities. They are discussed below.

IV. Investment in the Transmission and Distribution Sector

One reason for the reduced performance of Indian utilities is the inadequate investment in the transmission and distribution sector. This has resulted in inadequate and unplanned network expansion of the distribution lines without commensurate strengthening and augmentation of other critical system components. This caused overloading of power transformers, distribution transformers, and 33 kV and 11kV feeders leading to higher losses than designed values. Reinforcement of existing network in the form of new transformers, new lines and augmentation of existing transformers and lines is meager.

Too many stages of power transformations, improper load management and poor quality of equipment used in agricultural pumping in rural areas are some key contributors to the system performance. Additionally most of the distribution networks in India are quite old which results into reduced reliability and suffers from low HT/ LT ratio consequently leading to increased losses and poor quality of supply. *Figure 7* shows the differential investment in both T&D (low) and generation sector considered to be one of the main reasons for increases in losses.

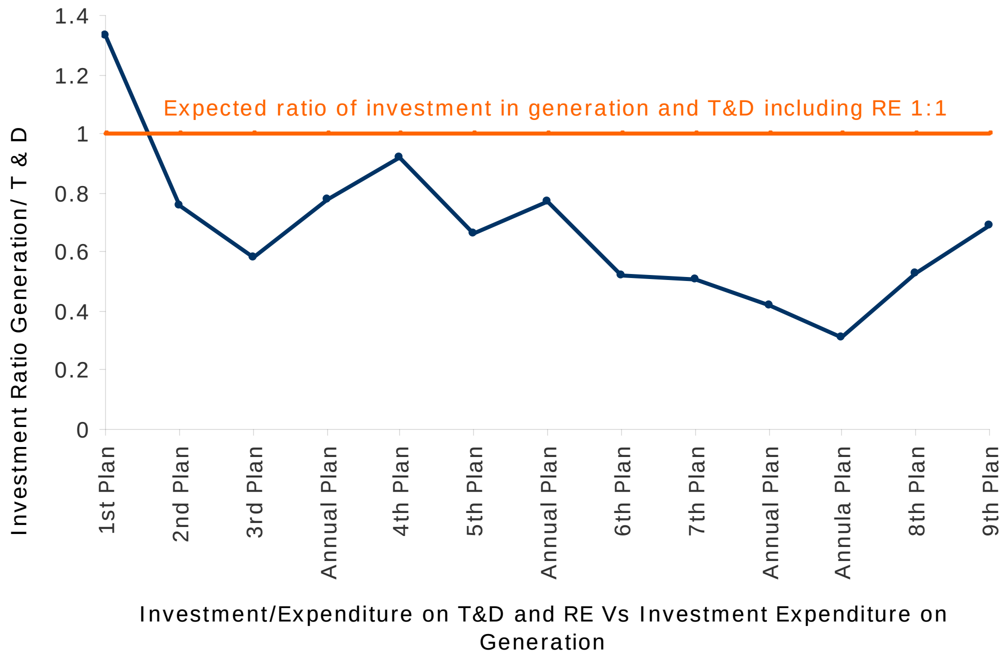


Figure 7: Investment in the Generation, Transmission & Distribution sector in India [MoP]

V. Methods of Loss Estimation

Energy consumption and hence losses in Indian power distribution systems are estimated rather than measured because of two main reasons.

a. Inadequate metering at various points in the distribution system
b. High cost of data collection

Due to absence of metering at various critical points in the power distribution system, the exact quantification of losses in different segments of the system has not been possible. Some of methods engaged by the SEBs for the assessment of unmetered energy consumption are enumerated below:

1. Estimation based on feeder wise theoretical calculation of losses

2. Load factor based estimation

3. Estimation based on reading of meters installed at all the DTs located on a feeder.

One of such method employed for the estimation of losses is the km-kVA method *[5]*. The annual losses in a particular distribution network is given by –

$$Annual\ Losses\ =\ 0.105 \times \frac{P^2 R_T}{2 \times LDF} \frac{LLF}{DF^2} \quad kWh \qquad (4)$$

Where,

P	$\sum$ (kVA of all distribution transformers)
N	Number of segments of feeders
R_i	Resistance/ unit length of the i^{th} feeder segment
L_i	Length of the i^{th} feeder segment
P_i	$\sum$ (kVA of DTs supplied through segment i)
L	$\sum_{i=1}^{N} L_i$
R_T	$\sum_{i=1}^{N} R_i L_i$
DF	Diversity factor P / Peak Load in kVA
LF	Load factor, energy sent out/ peak load X 8760
LLF	Loss load factor, $0.2LF + 0.8LF^2$
Km-kVA	$\sum_{i=1}^{N} L_i P_i$
LDF	Load distribution factor, (P X L)/ (km-kVA)

a. Assessment of Uncertainty

Certain assumptions such as uniform load distribution; constant feeder voltage (at all nodes at all times) has been made for the HV line loss computation formula given by equation A. In the above equation, accurate estimation of the total losses depends on the meaningful estimates of the parameters such as DF[23], LF, LLF etc. which is indeed complicated.

Several empirical methods of loss estimation have been developed based on the quadratic correlation between load and amount of losses. Most of these methods have seen to use loss and load factors or the loss and load for the formulation of the relationship. A quick survey of some select methods of estimation is given in *table 6* along with necessary condition of the accuracy of measurements.

[23] Diversity Factor: The ratio of the sum of the individual maximum demands of the various parts of a power distribution system to the maximum demand of the whole system. The diversity factor is always greater than unity.

Table 6: Comparison of loss estimation methods

Study/ Method	**Requirements**	**Accuracy**
Km-kVA	Intensive data to arrive at accurate values of parameters as DF, LF, LLF, V etc. (to many to be assumed)	Deviates as feeder characteristics changes
Rao & Deekshit	Detailed and accurate metering and data collection, mean loss curve	Accurate than the standard load flow models, Temperature correction factor for R modeled
A L Shenkman [6]/ Using statistical techniques	Daily load curves (DLC) of different kinds of loads, metering	Accuracy depends on the system load data
M W Gustafson [7]/ Empirical Equation	Load factors (LFs), Empirical hour loss factor (EQF), VAR req. is proportional to load, Statistical techniques	Accuracy depends on the system load data and metering system. Results varies for different feeders

A majority of the empirical loss estimation methods idealized load and feeder models are assumed for computations. Techniques where comprehensive load and feeder models are used, the accuracy of results are a function of accurate load data. The idea of a precise universal feeder model (either for rural or urban areas) is impractical considering wide variations in different power distribution network configurations. In addition, in the absence of comprehensive metering, load data are not readily available. Data provided by utilities are often misrepresented and possesses an undetermined degree of uncertainty.

b. Level of Uncertainty - study

A combined study was carried out by *Rao and Deekshit [5]* and the Karnataka Power Trading Company Limited (KPTCL) on the candidate 11 kV rural feeder.
Some details of the feeder under study are:

Table 7: Feeder details

Feeder	11 kV rural, Bukkasagara
No. of transformers	70
Installed capacity	5183 kVA
Conductor types	Squirrel (20 mm^2), Weasel (30 mm^2), Rabbit (50 mm^2)

3-phase electronic energy meter in the feeder input and digital meter in the DT secondary with data logging facilities were used for installed for measurements. The 11 kV feeder losses were calculated as –

$$\text{HV Feeder Losses} = \text{Feeder Input} - \sum \text{(power output of all the DTs)}$$

The losses were measured and *figure K* shows the comparison of the input, measured and estimated energy of the candidate feeder.

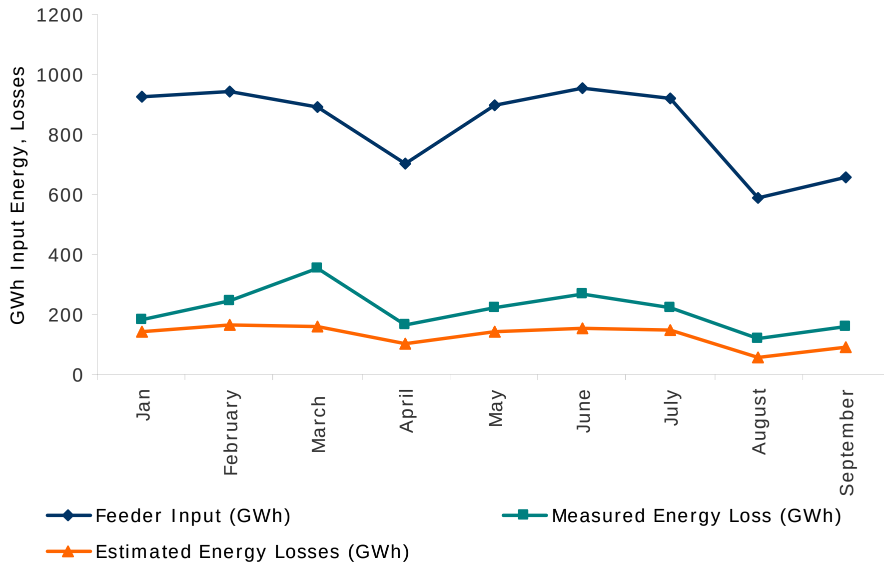


Figure 8: Comparison of input, measured and estimated energy of the Bukkasagara (Karnataka) feeder [5]

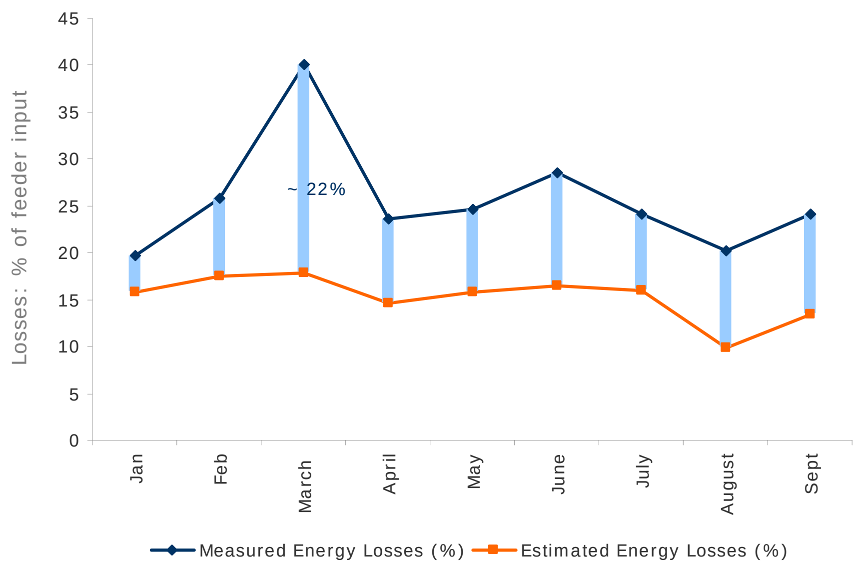


Figure 9: Uncertainties in loss estimation methods in practice

For the reasons discussed, uncertainties in estimation of losses were expected and are shown in *figure 9*. The average uncertainties in the estimation of losses compared to the measured quantity is around 10% with a maximum of 22%.

c. Consumer Metering

As discussed previously comprehensive metering at consumer, distribution transformer and 11 kV feeder levels in the power distribution network is a critical step in the correct estimation and therefore reduction of losses. The level of metering has not been satisfactory in Indian utilities and due to poor accountability it is often misreported. This introduces a degree of uncertainty in the energy accounting in various states. Comparison of levels of metering of some select states for three years has been presented in the *figure 10.*

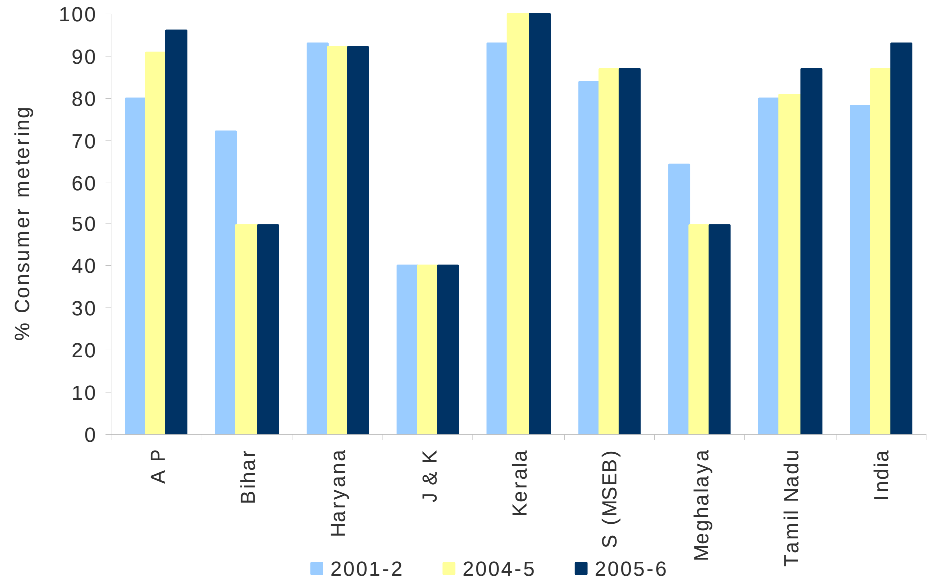


Figure 10: Consumer metering status of some selected states [3]

In India, an extremely low percentage of the total energy consumed is metered (less than 40% in a majority of cases) and metering is usually limited to urban areas. The consumption of unmetered categories of consumer (low usage residential, subsidized agricultural) are guess-estimated leading to uncertainties. The difference between the energy available to bus-bar and the estimated consumption is considered to be loss. Furthermore, there are unauthorized consumers and without proper metering it is difficult to spot and segregate such customers.

d. Distribution Transformer metering

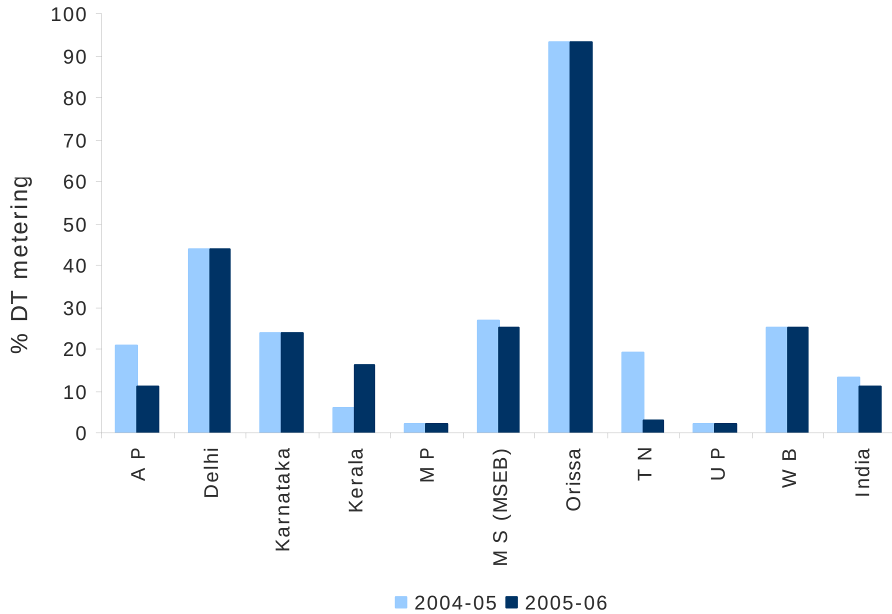


Figure 11: DT metering status for various years in some selected states [3]

Distribution transformer metering level is fairly low and has not improved. With proper DT metering it is not possible to have a proper energy accounting or energy measurement. Consequently in most of the cases losses are estimated as discussed earlier with inaccurate methods leading to both under/ over estimation of the energy and losses. *Figure 11* shows the percentage metering of some select states in India. We see that average metering level for India is just around 13. With more than 5 million DTs in India *[4]*, corresponding figures of unmetered DTs can be realized.

e. Level of Collection Efficiency

Collection efficiency is a measure of the amount of revenue generated from consumers against sale of energy compared to the amount billed. Therefore,

$$Collection\ \ Efficiency\ \ (\%)\ =\ \frac{Amount\ \ \mathrm{Re}\,alized}{Amount\ \ Billed}\ \ X\ \ 100$$

There are not any mandatory obligations for utilities to provide and publish these data.

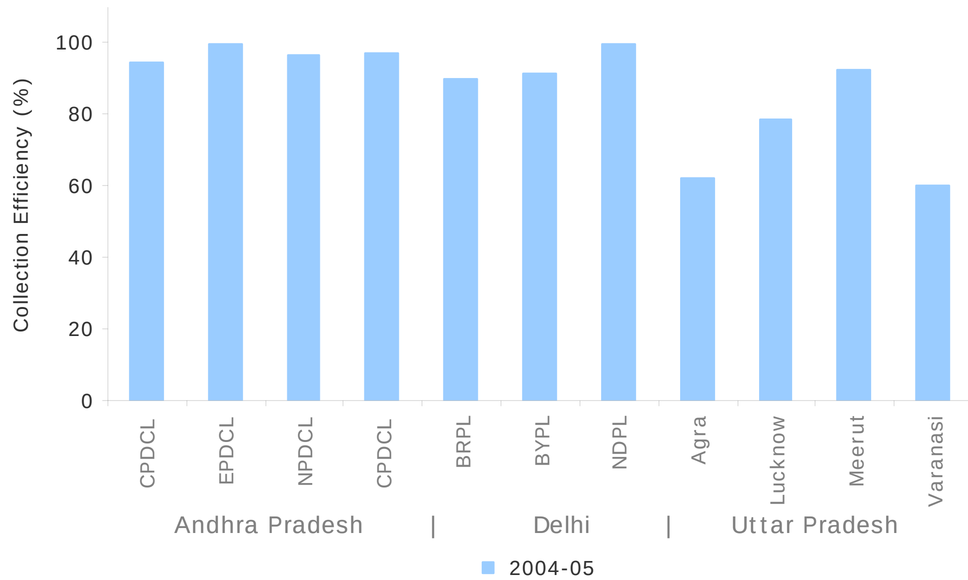


Figure 12: Collection efficiencies of distribution utilizes[24] of three selected states [2]

The values of billing and collection efficiencies provide an idea of commercial losses, but district/ utility wise data are not readily available. In many cases value of collection efficiencies are often misrepresented. Collection efficiencies the distribution companies/ district of three states are shown in *figure 12*.

VI. Distribution Transformer Efficiency

The number of DTs is more than 5 million *[4]* which make up a considerable portion of the losses in the Indian power distribution system. DTs normally contribute around a maximum of 3.5% of the total energy generated (~ one-third of the total technical losses) under optimal network configuration and loading. Poor maintenance and suboptimal network configurations often lead to overloading of DTs. The average AT & C losses per DT have seen to have a positive correlation with the average energy input to a DT. The average DT capacities of some select states are given in *table 8.*

[24] CPDCL: Central Power Distribution Company of AP Ltd., EPDCL: Eastern Power Distribution Company of AP Ltd., NPDCL: Northern Power Distribution Company of AP Ltd., BRPL: BSES Rajdhani Power Ltd., BYPL: BSES Yamuna Power Ltd., NDPL: North Delhi Power Ltd.

Table 8: State-wise average DT capacities and percent AT & C losses [4]

State	% AT & C Losses	Mean DT Capacity (kVA)
Rajasthan	43.7	47.4
W B	31.0	50.9
U P	35.2	54.9
A P	27.7	62.7
Punjab	26.0	65.0
Haryana	32.1	71.5
Chattisgarh	42.5	72.6
Bihar	36.7	81.0
Gujarat	24.2	83.0
Orissa	57.1	83.3
Karnataka	23.3	88.6
M P	41.4	88.6
Assam	39.3	94.3
Jharkhand	25.3	97.0
T N	17.2	121.6
Maharashtra	34.1	122.4
Kerala	21.6	132.3
J & K	45.5	156.1
Uttaranchal	49.2	416.2
Delhi	43.7	504.9

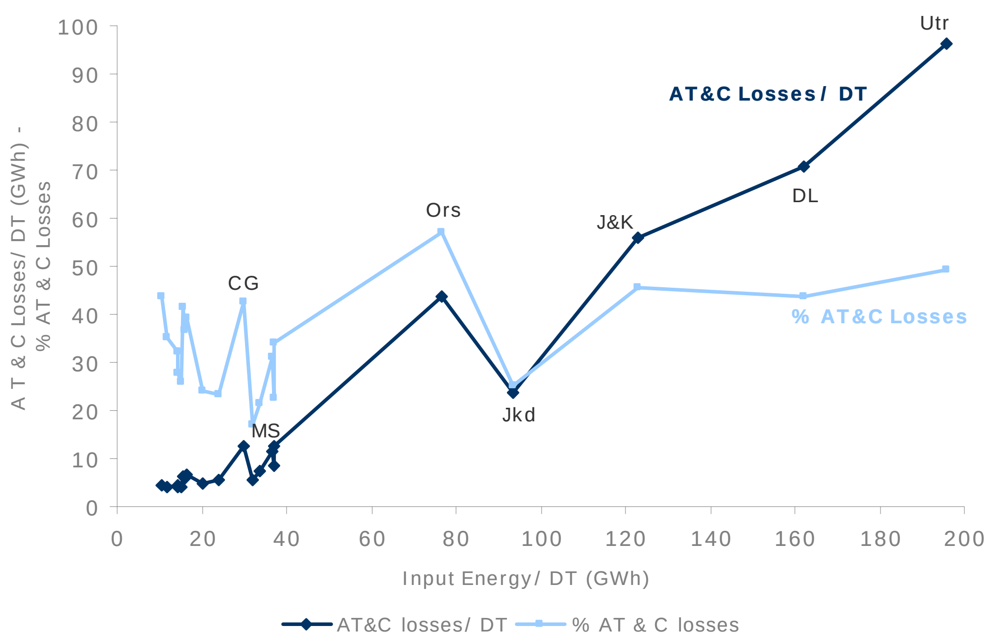


Figure 13: Sensitivity of AT & C losses per DT to input energy of the DT [4]

Due to different load characteristics of areas in different states, the energy handled by a DT varies. This have an impact on the losses in a particular DT as losses tends to increase in a quadratic manner with overloading and also with load factor. We see from *figure 13* that there is a positive correlation between the average input energy to a DT and the average AT & C losses of a DT. The average DT capacities of various states have been observed to vary widely from approximately 50 kVA (Rajasthan) to high value of 500 kVA in Delhi *(see figure 14)*.

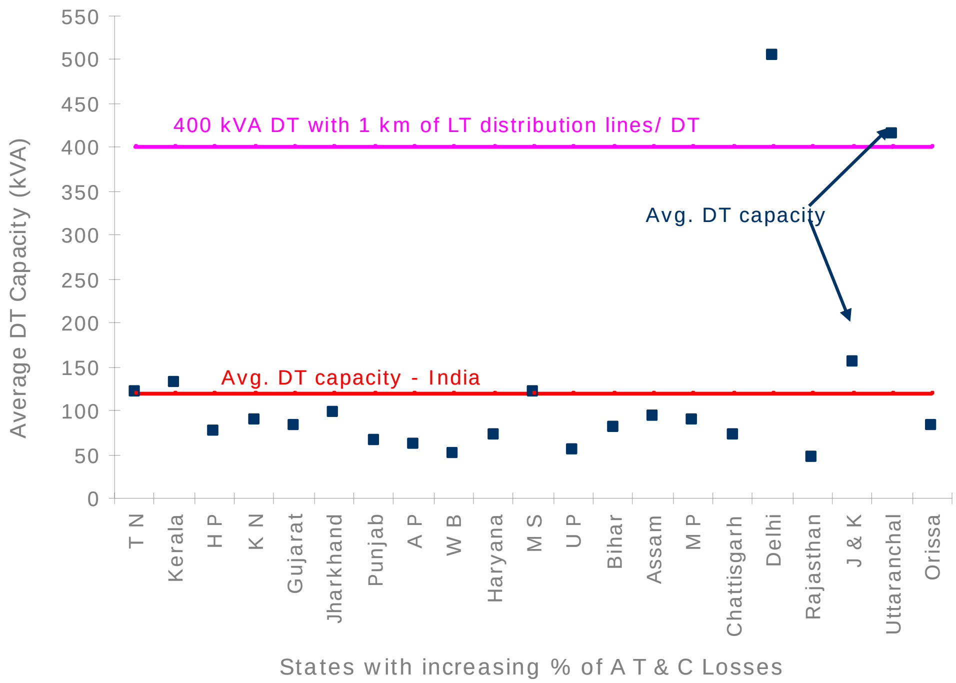


Figure 14: Comparison of average DT capacities of various states [CEA]

Measure of loading and individual efficiencies of installed DT would yield significant indicators of the present operating conditions of the DTs as well as the individual loss levels. However, as previously discussed, it would require comprehensive energy audits at the DT/ sub-station level and therefore metering is required. Some separate comprehensive energy audits, though rare, have been carried out by some utilities. The results of these studies unambiguously points to the fact that a majority of the DTs have loss levels more than designed.

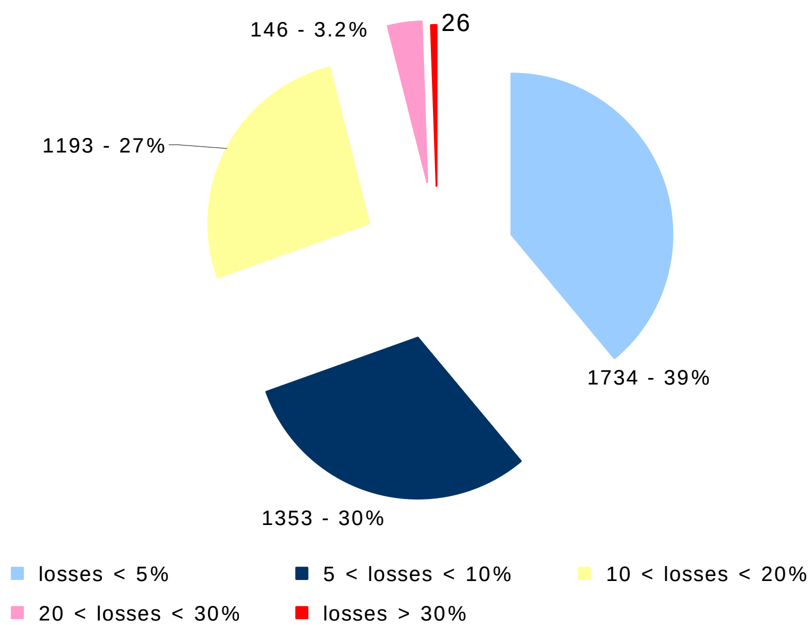


Figure 15: Gradation of DTs based on their loss levels [8]

Bangalore Electricity Supply Company (BESCOM) did a comprehensive energy audit on a sample of 4452 DTs. Accordingly numbers of consumer fed from each DT were identified and meters were fixed. The losses were measured and the transformers graded according to the level of losses. It is not very surprising to observe from the figure above that more than 60 % of the sample DTs, the losses were more than 5 %. A considerable improvement can be done with the improvement in the efficiency of DTs alone.

VII. Distribution Network Performance

Under optimal distribution network configuration low voltage distribution lines contributes to around 4-5% *[9]* of the total losses. The length of low voltage distribution lines in India is more than 3.9 million kilometers which is more than 60% of the total line length. This has led to suboptimal network configuration leading to high length of distribution lines served by a single DT which varies from 0.7 km (average DT capacity 55 kVA) in Uttar Pradesh to more than 9 km (average DT capacity 415 kVA) in Uttaranchal. The mean value of LT distribution lines length for the country is around 3 km per DT (average DT capacity 130 kVA). The typical capacities of distribution transformers (DTs) in a city like Mumbai (where load concentration is one of the highest across the country) are 400, 630, 990, 1250, 1500, 2000 kVA. DT of an appropriate capacity is installed considering the load density such that length of the LT distribution lines per DT does not exceed more than 1000-1200 meters.

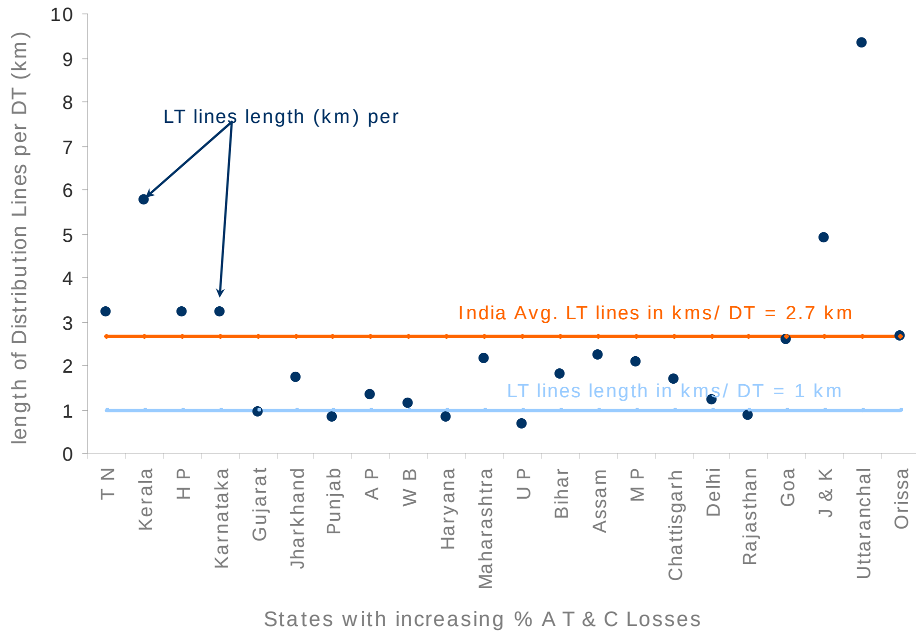


Figure 16: Distribution of length of LT distribution lines (<500) in km per DT for various states with India average and of unity value [4]

Although the lengths of LT distribution lines per DT are comparatively lower (< 2.5 kms) for majority of states, but, their corresponding average DT capacities are much low than values that would keep the values of the pure technical losses within the bounds of the maximum and minimum values as in *figure 16. LT distribution lines length of around 1.2 km per DT would make sense if the corresponding DT capacity is at least 400 kVA for the technical losses to be within the bounds.* Even if the same may not be true for all the DTs – separate analysis, block/ circle/ district wise would assist in narrowing into the loss prone areas. For optimum performance we must have:

1. **High Load Density Area**: High DT capacity and relatively low lengths of LT distribution lines per DT. *E.g. for city like Mumbai the minimum and maximum DT capacity cater to loads through not more than 1 – 1.2 kms.*
2. **Low Load Density Areas**: Low DT capacity and low lengths of LT distribution lines per DT. E.g. Rural Areas.

There is a separate aspect to this problem too which can be analyzed by an example. The state of UP has a low length of LT distribution lines per DT. Since it has a very high numbers of DTs and with low aggregate MVA capacity, its average DT capacity (~54 kVA) is also low. *Such a high number of transformers may not be suitable and could account for a high portion of the total losses. The same is discussed in the succeeding part. This describes the need of incorporating High Voltage Distribution System (HVDS) to reduce the losses due to the above mentioned reasons.*

VIII. Agricultural and Rural Energy Sector

The Indian rural energy scenario is characterized by a multitude of issues spanning technological, social, economic and political dimensions. India is a country with a dominant rural population *[10]*, comprising of 72 % of the total and dependent of agriculture. *Figure 17* shows the % rural population distribution across some selected states.

The experience of the drought that India saw in the '60s necessitated to formulate sustainable solution for food security. Although ground water based irrigation system using electrical pumps were recognized as a short-term solution compared to canal based, it still forms a dominant form of irrigation.

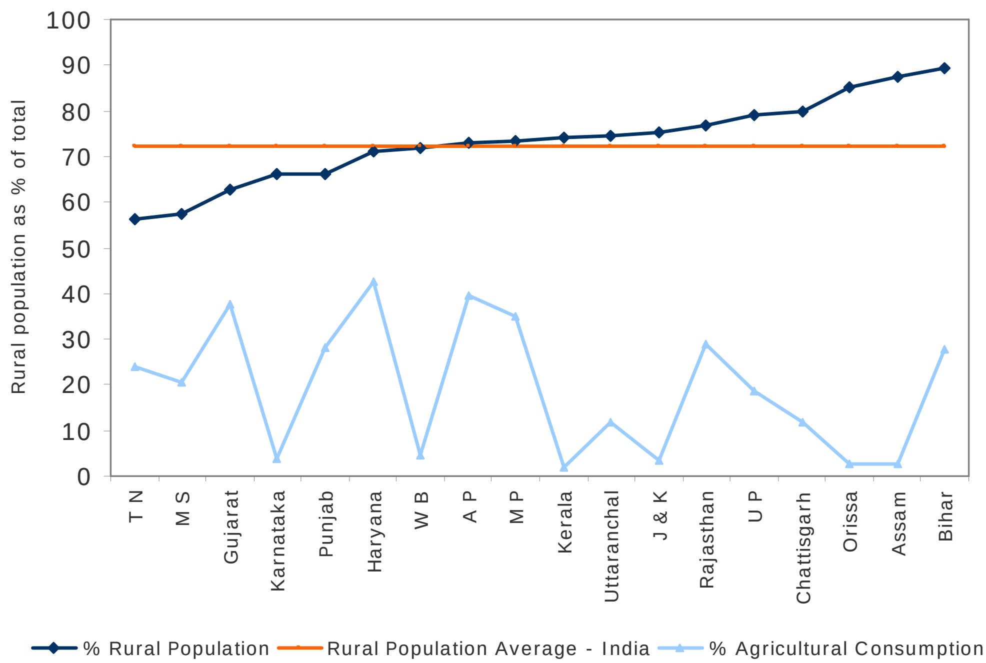


Figure 17: Rural population distribution of select states as percentage of total [10]

Self-sufficiency in agricultural produce was only possible due to increased production commensurate with the demands of the increasing population. Irrigation and reliable electricity services plays a vital role in the Indian agricultural sector with diverse geographic conditions. A comparison of the yield of food grains for select states and their respective level of irrigation has been made for two consecutive periods as in *figure 18*. These substantiate the necessity of irrigation to meet the present and future food grain demands.

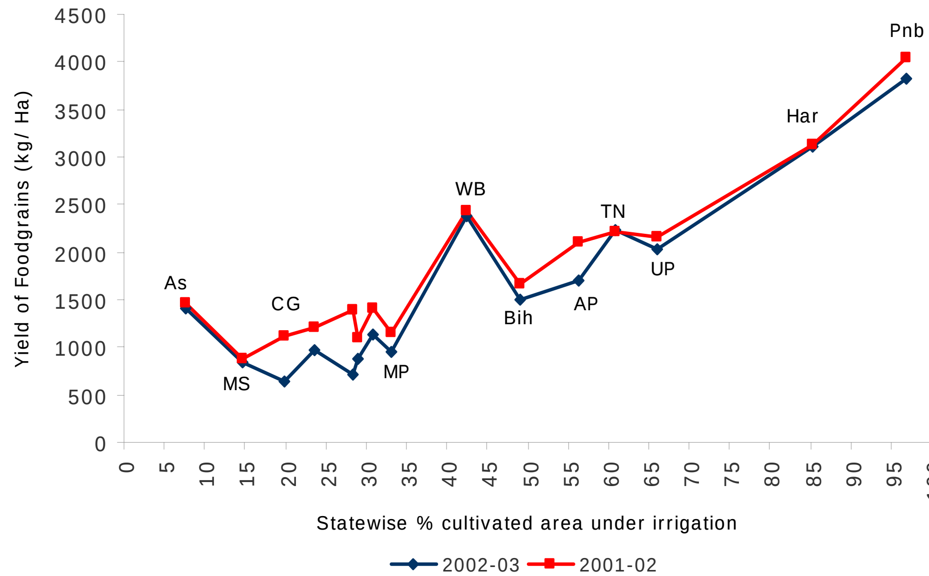


Figure 18: Yield of food grains against the level of irrigation of select states [11]

The corresponding percentage consumption by agricultural pumps of various states is shown in *figure 17*, and exhibits considerable disparity. Average annual rainfall and water basin data also affects the level of energy consumption in the agriculture [support data] sector. However, figure 2 illustrates the agriculture intensive states (Gujarat, Haryana, and Andhra Pradesh) in India in order of their agricultural consumption. Unfortunately, India has the largest number of households without access to proper electricity, and agriculture sector accounts for just around 22 % *[4]* of the total electrical energy consumption in India.

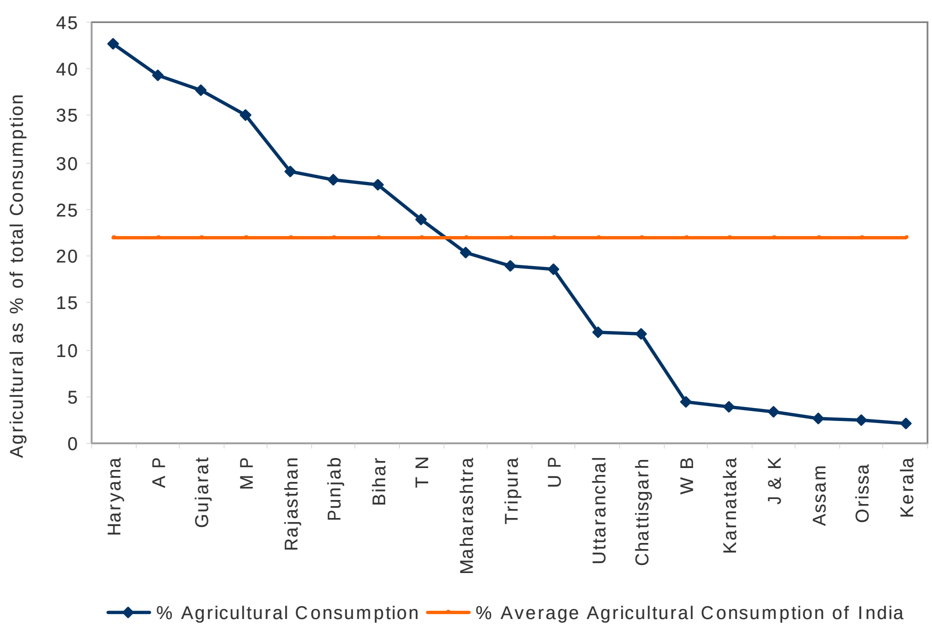


Figure 19: Consumption in agricultural sector as a percentage of the total [4]

It is therefore reasonable to conclude that rural electrification at village, farmland and household levels is the foundation of India's economic development. Access to electricity has enabled improved life style, health, education, access to better communication, lighting, and public security in the rural areas. Other than stated above, increased productivity in agriculture, labor, and employment generation are among the most dominant outcome of access to electricity. However, it is known that such benefits can be reaped only in the presence reliable electricity services. On the contrary, access to reliable, quality and uninterrupted electricity services in the rural areas is still a dream to be cherished in India. Electricity distribution in rural areas has long suffered which in turn has affected the progress in rural development. A multitude of factors have plagued this sector and have harmed the power sector since long. The factors are both technical and non-technical which needs careful examination and finally eradication to rejuvenate energy services in rural India.

As discussed above the problems in this sector are quite intricate, and will be practical to deal with it from two perspectives:

1. Agricultural Sector – Pumps Sets Energization
2. Electrification of villages/ households - definition

IX. Agricultural Sector – Pump Sets Energization

Irrigation, power supply and rural development are strongly interrelated; however, the three systems more or less work independently in Indian scenario. Irrigation sector has been primary to India's economic development and poverty mitigation and 65 % of employment is based on agriculture. India is a monsoon dependent country for its water resources.

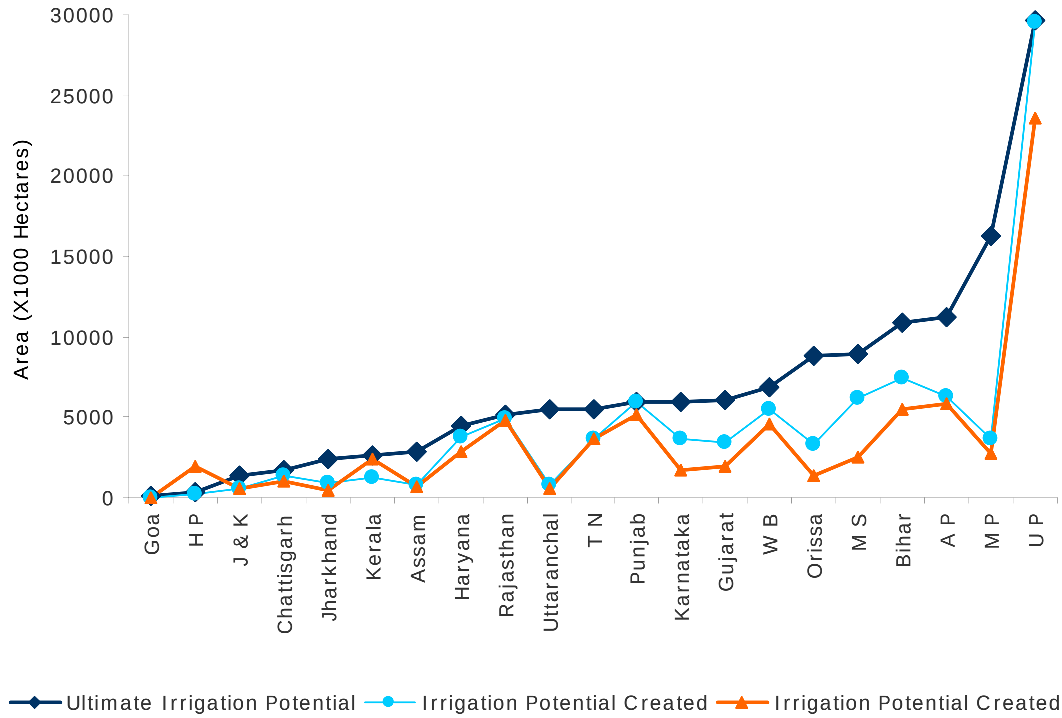
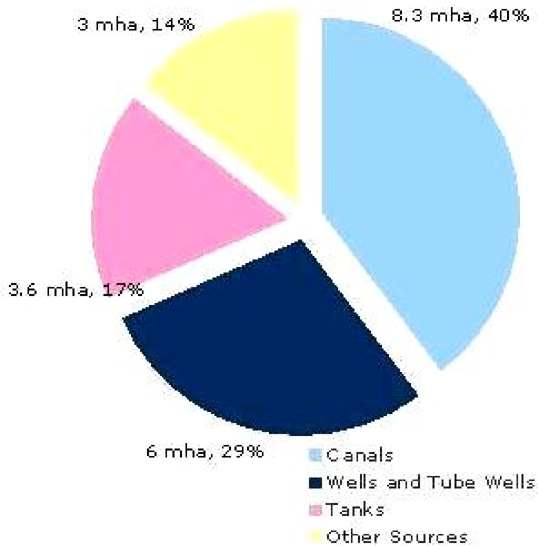


Figure 20: Ultimate Irrigation Potential (UIP), Potential Created and Irrigation Potential Utilized of various states across India [13]

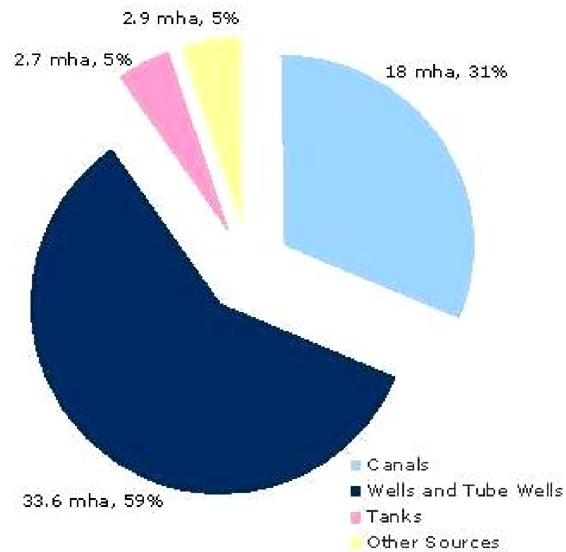
Arable land in India is of around 192 million hectares and early 60% of the arable land in India is still completely dependent on rainfall, as no other source of water is available and the rest (around 40%) on irrigation. Owing to different water resources, level of irrigation achieved is differential in different states – with Tamil Nadu (100%), Punjab and Rajasthan achieving more than 75 % *(see figure 20)* of the Ultimate Irrigation Potential (UIP). Distribution of water resources is quite uneven in India – *figure 20* indicates that the ultimate potential under major and medium irrigation in eastern states (except West Bengal), Bihar, UP, MP Orissa put together works out about 50 % of the total ultimate potential of the country. Irrigation potential which stood at 22.6 mha in 1950-51, has now reached about 100 mha, and as a result food production increased from 50 m tonnes in 1951 to about 208 m tonnes in 2005. Area wise, the need for irrigation would only increase in the coming years to meet the demand for food production considering the future population projection and the subsequent food requirements.

X. Issues in the Agriculture – Irrigation Sector

a. Water – Energy use



a. 1950 - 51



b. 1999 - 2000

Figure 20A: Comparison of Area and Percentage share of different irrigation sources [14]

Although canal irrigated has increases from 8.3 million hectares to 18 hectares during 1950-51 and 1999-00, its percentage share has decreased with the tube well irrigation accounted for nearly 59 % (*see figure 20A*) of the total irrigated area. Hence irrigation pumping for agriculture is the central form of irrigation; it has been continuously termed as the prime cause of poor cost recovery and the ailing financial health of the State Electricity Boards (SEBs).

Electrical energy used to operate pumps to derive water (another critical resource), has led to the rise of the water-energy nexus in India, where the agriculture uses around 85 % of the available fresh water. It can reiterated that –

"Overuse of electricity leads to overdrawl of water and vice versa – critically threatening the depletion of both the resources at the same time"

India is one of the largest extractor of ground water in the world every year, and the use of electricity in pumping groundwater makes water-energy usages quite interweaved. In addition, the efficiency of irrigation schemes which is reasonably low considering standards, also affects energy use. % Agricultural consumption and % A T & C losses of various states are shown in *figure 21*.

Water loss reduction amounts to considerable saving in energy. Water-use efficiency depends on a number of factors – technological, economic and psychological. The causes/ factors are of water-energy use can be enumerated as below:

1. Crop Pattern
2. Modes of Irrigation

3. Irrigation Efficiency
4. Reliability of electric supply – secondary factor

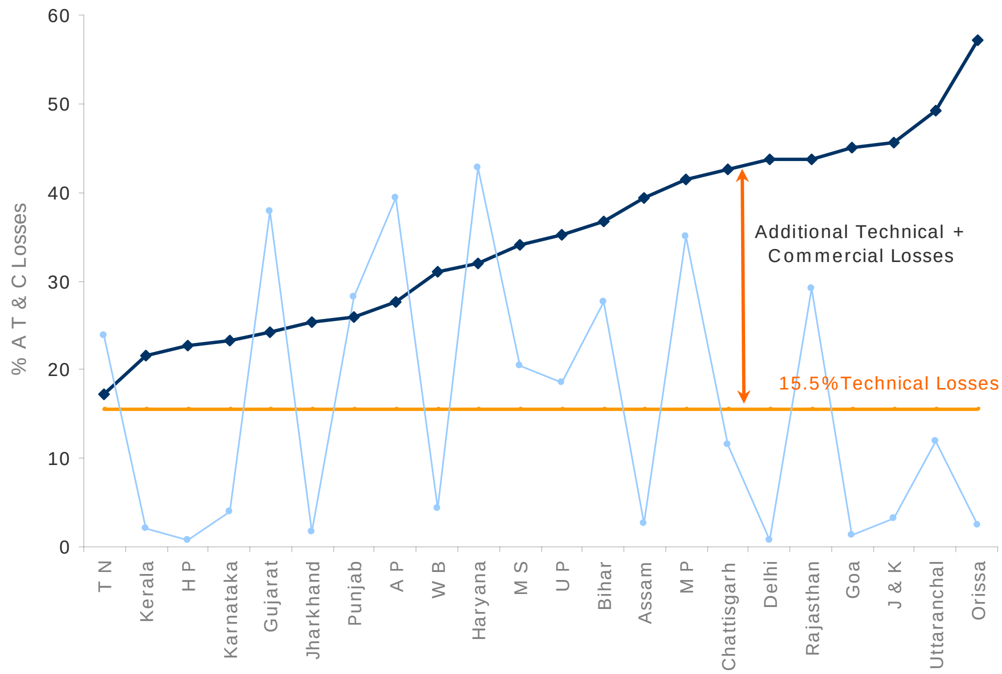


Figure 21: % Agricultural consumption against % AT & C losses in various states [4]

Case study of water overuse

Several studies points out over exploitation of groundwater resources and hence electrical energy. Kumar et. al. *[15]* did a comprehensive study of seasonal behavior of spatial variability of groundwater level of the Maheshwaram watershed in Monsoon climate. The Maheshwaram watershed situated in the Ranga Reddy district of Andhra Pradesh, India about 30 km south of Hyderabad, covering an area of 60 km^2, is a representative watershed in hard rocks with geological outcrops, structures and fracture system present.

With over-exploitation of groundwater resources, water tables in Maheshwaram have declined sharply resulting in more energy being needed to draw water from greater depths. Low water availability has led to smaller areas under irrigation, resulting in decreased crop production hence lower incomes for farmers. This has also been the focus of research conducted by the International Water Management Institute (IWMI).

Table 9

No of Connections		Percentage	No of Pumps per DT	
Authorized	Illegal	Increase in Connections	Official	Actual
873	1219	39%	10-15	15-20

Consumption monitoring in the Maheshwaram watershed showed that, due to shortage of water, the 346 more pumps were illegally connected against the official figure of 873 – which signified a net 39% in connections. Moreover, a single DT catered to an average of 18 pump sets connections instead of 13, which means increased loss due to over loading of DTs and distribution lines during peak hours. Farmers who use non-standard pumps and motors also contributed further to voltage drop and burnouts incurring heavy losses and repair costs.

XI. Subsidies in Agricultural Sector

It has been already stated that agricultural consumption accounts for around 22 % *[4]* of India's total energy consumption. Consumption is higher for states such as Haryana, Gujarat, Andhra Pradesh, and Madhya Pradesh where the agricultural consumption accounts for more than 35 % of the total consumption. However, due to large geospatial load distribution and subsidies, sale of electricity to rural areas often amounts to no more than 5-10% of the state electricity revenues.

Performance in the agricultural sector is crucial to economic and social development; hence access to reliable electricity services against subsidized prices is essential for proper agricultural activities. However, for the mutual benefit of the rural people and the power sector such subsidy mechanism is required to be correct and justified. In India, agricultural tariff have had political implication too and is a contentious issue – state governments determines the tariffs instead of the SEBs. Hence in most of the states tariffs for electricity in rural areas are highly subsidized or provided free of cost.

Figure 22 shows the level of subsidy provided for various states of India as compared with the average cost of supply for the base year 2003-04; the average cost of supply for India being around 42 paise/ kWh. It can be observed that the subsidy in the cost of electricity in most of the agriculture intensive states is high, hence in such a case the performance of the utilities is driven by government policies related to agricultural tariff.

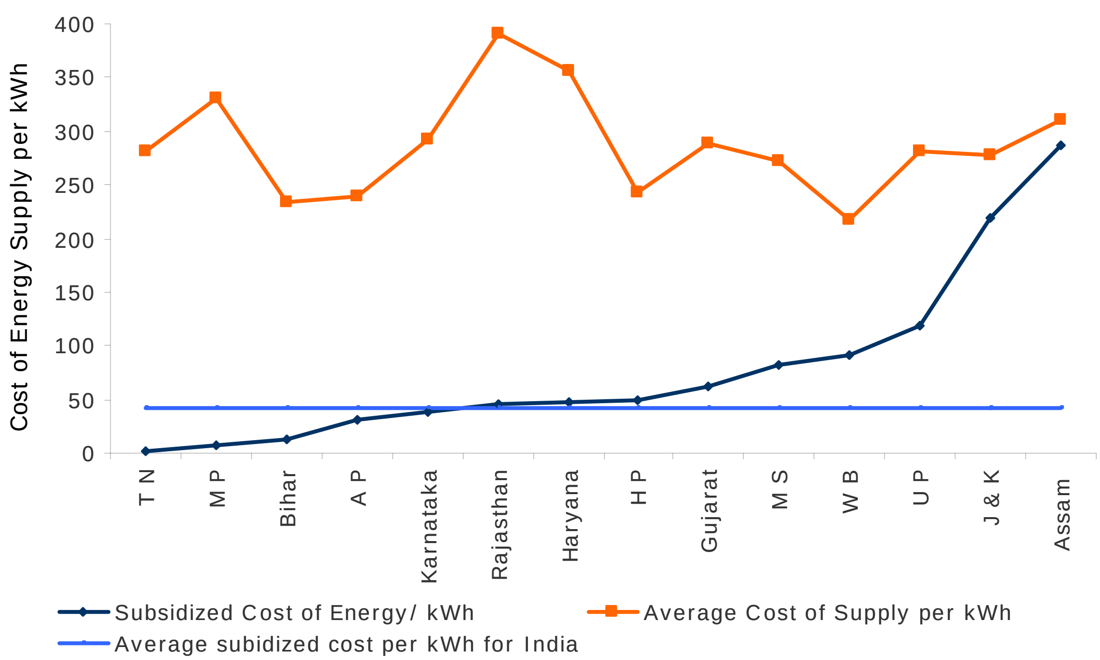


Figure 22: Comparison of average and subsidized cost of supply (domestic consumer, 100kWh/month) of electricity per kWh of some selected states [CEA]

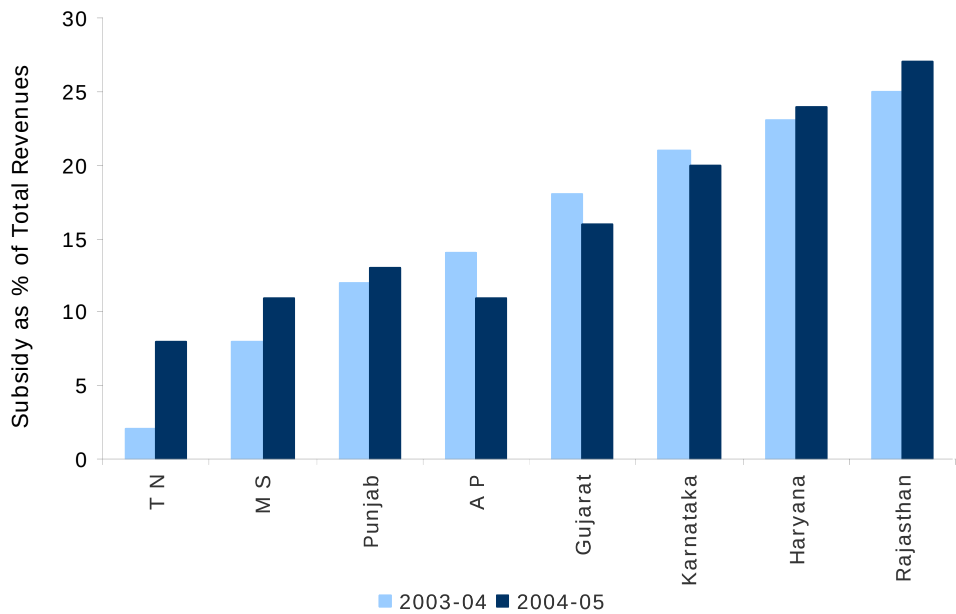


Figure 23: Subsidy in energy supply as percentage of total revenues [2]

Since, there were no regulation to the subsidized consumption of electricity, access to power without charges accelerated the rate of consumption which in turn power subsidies in revenues. *Figure 23* gives an indication of the level of subsidy in a few energy intensive states. Total revenues represented in figure only accounts for the total energy realized – more losses incur due to low billing and collection efficiency.

The subsidized sales of energy to agricultural and domestic consumers are some times partially compensated by the respective state governments. The efficiency of the reimbursement mechanism is questionable – the reason for financial losses of the SEBs.

XII. Metering - Tariff in Agricultural Sector

Subsidized rate of electricity for agricultural and domestic consumers has accelerated a rapid growth in the electrically operated pumps and hence energy consumption. Agricultural pump loads are the dominant loads in rural areas with minor lighting loads. Since the revenue prospect is less, there's no incentive for metering due to high cost of data collection systems and equipment. Hence without proper accounting system, the losses are estimated rather than measured. The tariff structure for power supply in agriculture sector is on a flat-rate basis – a consumer pays a low fixed price per horse power per month. Therefore the charges are based on hp ratings of the motors and not on their energy consumption. Since the marginal cost of pumping is minimal, consumers tend to forge HP ratings to ensure estimation of low consumption.

1. Energy Wastages
2. Unsustainable exploitation of ground water
3. Inefficient selection of crops
4. Associated Losses due to increase energy use and overloaded DTs and distribution lines

XIII. Method of Estimation - Quantification

The methods to estimate energy consumption by agricultural consumers are inappropriate and needs revision. Two methods employed normally to estimate agricultural consumption are discussed below:

1. In the first method *[2]*, first, a farmer pays a fixed amount per HP per month for energy usage. The method of calculation of agricultural consumption is:

$$E_{LV} = N \times P_{AV} \times H \tag{5}$$

Where,

E_{LV} = Energy consumption of agricultural pumps (kWh)
N = Number of agricultural pumps
P_{AV} = Average capacity per pump set (kW)
H = Hours of operation of the pumps (hours/ day)
$P_{AV} \times H$ = Average consumption per pump set

However, estimating energy consumption in the agricultural sector introduces errors in the value of E_{LV}. The value of N (the number of agricultural pumps) is tentative and does not always represent the illegal pump connections. The hours of operation (H) does not also stand for the actual value as many pumpsets are found to operate with a load factor of more than 1.0 where they are not expected to run for more than 12 hours a day at some places i.e. a load factor of 0.5. All these make the process of estimation of actual consumption and the losses inaccurate.

2. Secondly, there's another method *[5]* being used in Karnataka Power Transmission Corporation Limited (KPTCL) and a few other states. The formula used for the calculation of losses is:

$$E_{LV} = \frac{\left\{\sum_{i=1}^{N} hp_i^2 \times km_i\right\} \times 0.746^2 \times LLF \times T \times R}{V^2 \times \eta^2 \times pf^2 \times DF^2} kWh \tag{6}$$

Where,

E_{LV} = Energy losses (unmetered)
hp_i = Total horse power ratings of IP sets in the i^{th} conductor segment
km_i = length in km of the i^{th} conductor segment
N = number of conductor segments in the LV feeder
LLF = Load Loss Factor
T = Time period of interest (hours)
R = feeder resistance (Ω/km)
V = Secondary voltage of DT (kV)
η = Average efficiency of the pump sets
pf = Average power factor

DF = Diversity factor
LLF = $0.3LF + 0.7LF^2$ assumed for LV system

As same as in *equation (5)*, it can be seen that most of the parameters in the *equation (6)* requires assumed rather than measured values. It's very difficult to accurately assume values of parameters like Voltage (V), DF, η and LLF etc. Further more the exact value of hp_i is difficult to ascertain and are misreported many a times. The uncertainties in the calculation of unmetered energy consumption can be understood from the analysis of one study done by Tata Consulting Engineers on the energy consumption patterns of agricultural and other unmetered consumers for the period 2000-2001 for Karnataka.

XIV. Case studies

Case: KPTCL

A combined study *[16]* of the Tata Consulting Engineers (TCE) and the Karnataka Power Transmission Corporation Limited (KPTCL) also revealed over use of electricity by pump owners. *As per the available figures, for the period 2000-01 around 24 % of the agricultural area in Karnataka was irrigated.* And the number of consumers estimated for that period was around 12, 46,810 – around 850 % increase than the corresponding figures of 1970-71. Correspondingly the energy consumption (which was assessed) increased from 179 MUs to 7045 MUs.

A sample size of pump sets was metered to monitor the consumption which logged the following data:

Table 10:Month-wise agricultural consumption in kWh [12]

Month	Consumption (kWh)	Month	Consumption (kWh)
April 2000	696.50	October	372.89
May	589.67	November	547.47
June	428.67	December 2000	637.73
July	505.59	January 2001	698.84
August	525.32	February	777.34
September	521.6	March 2001	730.51

A few of the findings from the analysis from the logged data are:

1. The load factor of the pump sets in the sample size was greater than 1.0 i.e. the pumps were running for more than 24 hours a day.
2. It implies that supply was used for the purposes other than pumping, and/ or
3. More than one pump was into service.

In addition to this, the values in the table were not used to calculate the average consumption per pump set ($P_{AV} \times H$) in *equation (1)* which will affect the values of energy consumption and hence the losses. The remaining consumption above the declared ratings was considered as commercial losses.

Case: Diesel and Electric operated pumps

Although a major portion of the agricultural pumps are electrically operated, diesel operated pumps are also use in certain areas. While subsidy is available for electrical energy, the price of diesel to operate pumps is not relaxed, hence cost of generating unit electrical energy is more by diesel compared to electrical pumps. Hence it becomes advantageous to use/ overuse electrical pumps to pump water as there are not any regulations to control the extent of operation leading to waste of water-energy. A study done by T Shah et. al. *[17]* revealed overuse of energy to run pumps.

The period of operation of a sample of around 2, 234 tube well irrigators were monitored across India in 2002 which consisted tube wells of both flat tariff and diesel operated. The study showed that electric tube well owners paying a flat tariff operated their pumps for 40 %– 250 % greater hours per year than the diesel tube wells.

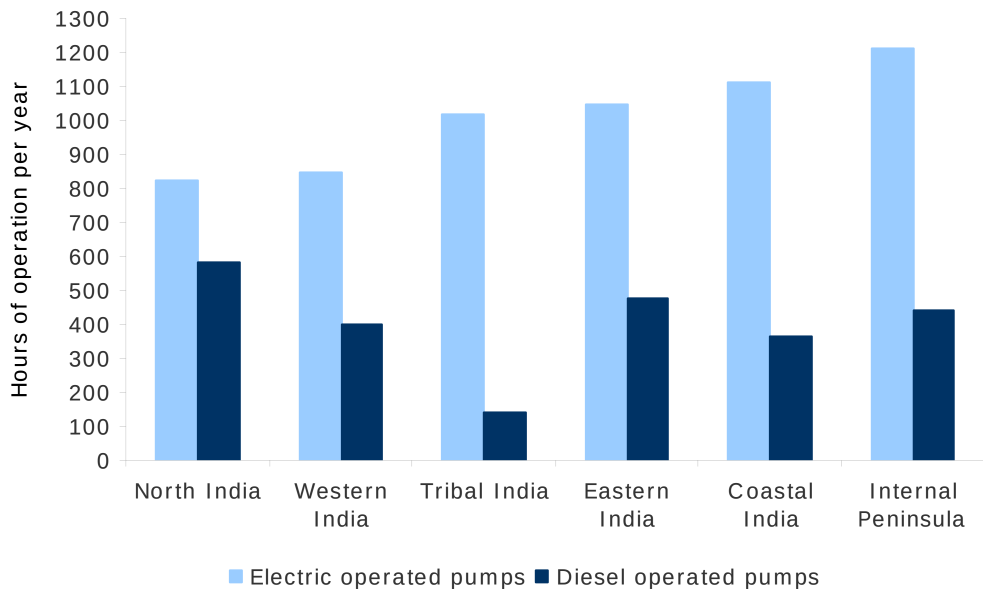


Figure 24: Comparison of hours of operation of electric and diesel operated agricultural pumps in different regions of India [17]

Figure 24 compares the hour of operations of the electric and diesel operated tube wells for different regions of India. However the numbers are not indicative but long operation of flat rate based electric pumps provides a qualitative indication of the over-use of electricity at no or very low additional cost. The study is also important considering the fact that the sample space for the study encompasses data from diverse geographical areas in India and the results also points the expected trend. It can be clearly understood that in tribal areas the difference in the hours of operation is quite striking followed by coastal areas and then the internal peninsula.

XV. Scope of Improvements

Separation of Agricultural Feeders

Separation of feeders mainly for agricultural loads has long been identified for the improvement of performance in the power sector. In this separate feeder are to supply to the agricultural load. This will help in:

- Separating agricultural from non-agricultural loads, which will further help in -
- Having a proper accounting system,
- Removing irregularities in loss measurements due to the unmetered energy
- Improvement in load management and hence to ensure that the villages continue to get power during the load shedding period while shedding the power for agricultural pumps

This methodology of separation of feeders will be particularly feasible for those states where the percentage agricultural consumption is more than 20 %. In addition to this, better load management and monitoring can be achieved if agricultural pumping load is separated from the non-pumping load in all rural feeders. This will help in regulating, limiting and proper measurement of hours of operation of agricultural pumps. Because of this, valuable energy-water can be saved which has already been discussed. Andhra Pradesh, Gujarat and Punjab are the states which have initiated to separate agricultural feeders.

Recommendations have been made in the 11th plan for the single phasing rural feeders which contains varied loads. This can be envisioned to have changeover switches at sub-stations, where, during nominal operation can cater to three phase loads on the 11 kV network from three phase transformers. Single rural lighting and other loads through three number of single phase transformers when the change over switch position is changed.

A summary of the scope of improvements in the agricultural sector are as follows:

1. Use of agricultural pumpsets based on least energy requirements and of international standard should be made obligatory
2. Development of efficient irrigation mechanisms
3. Diesel pumpsets should be replaced by non-conventional sources of energy that include bio-fuels wherever possible
4. Separation of agricultural feeders
5. Metering of agricultural consumers
6. Benchmarks in India for the utilization of ground water and power to energize agricultural pumps
7. Specific studies should be carried out about the groundwater level, cropping pattern, energy requirements etc.
8. Subsidies extended on agricultural tariff should be fully compensated. Moreover, such subsidies should be preferably given to small and marginal deserving farmers only.

XVI. Rural Electrification – Introduction

Rural electrification is mandatory for rural economic development. At the same time it's universally acknowledged that the rural electricity services have suffered since many decades. Although a number of schemes and models have been devised and implemented, most of them failed or has seen limited success. Providing electricity services in the rural areas both for household/ village electrification and pump energization present dual challenges to the utility which are complementary to a higher degree in the Indian scenario.

- Increase the level of rural electrification
- Minimizing the system losses to a minimum acceptable level

The problems associated with the rural power sector can be qualitatively stated as:

1. *Low load density due to geographical spread leading to high costs*
2. *Low load factor due to low individual consumption leading to high costs*
3. *High Aggregated Technical and Commercial (A T & C) losses*
4. *Low paying capacity*
5. *Unmetered supply to irrigation pumps and theft of power*
6. *Unplanned expansion of distribution network*

a. Rural electrification – Present Status

Pre- October 1997 definition deemed a village to be 'electrified' if electricity was being used within its revenue area for any purpose. The definition of *'rural electrification'* has changed from time to time and suffered from ambiguities in the past. The levels of electrification with the kind of aforementioned characterization essentially show higher statistical figures. The actual level of penetration into a particular village is disputed. The most recent definition *[2]* was adopted during 2004-05 by the SEBs which says that a village would be declared electrified if:

1. Basic infrastructure such as DT and distribution lines is provided in the inhabited locality as well as the dalit hamlet where it exists.
2. Electricity is provided to public places like schools, Panchayat offices, health centers, dispensaries, community centers etc, and
3. The number of households electrified should be at least 10% of the total number of households in the village.

Clearly even the newest definition is not all-inclusive as it fails to answer certain critical issues. Power quality and regularity of supply – two elementary issues in the power sector are not attended to under the aegis of the new definition. Moreover there are no provisions as to how and when 100% electrification would be achieved.

Electrification, as anticipated have had positive effect on the productivity of a state ensuring better standard of living, access to health care and technology. However there is more potential of achievement as the level of household electrification is still low, of the order of 50%. Moreover, the definition as described is also not all-encompassing. The per capita Domestic Product of a state has a definitive correlation with the level of household electrification *(see figure 24)*.

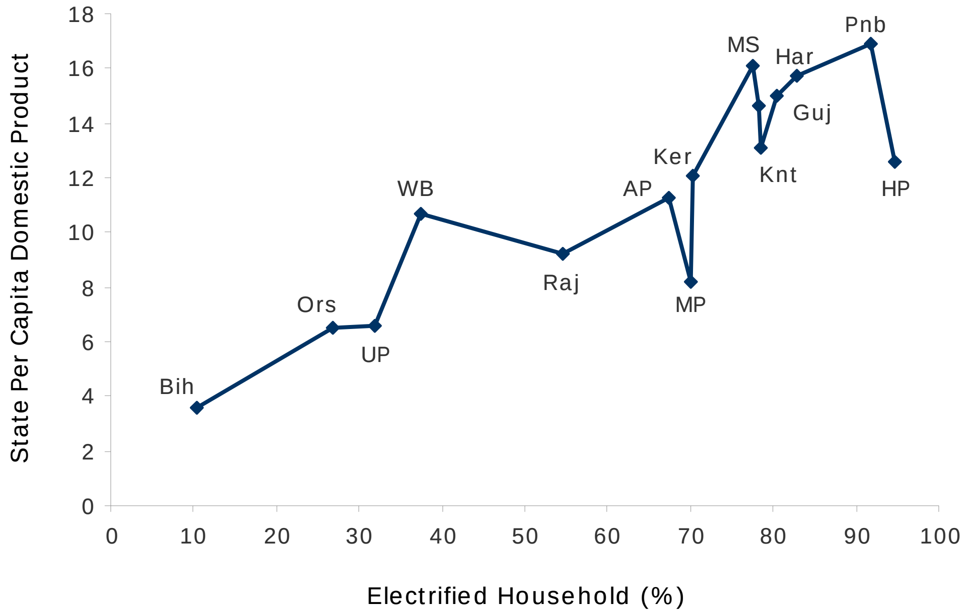


Figure 24: Growth of State Per Capita Domestic Product with village electrification for some major states of India [10]

The expected effect of irrigation on agricultural productivity has already been discussed in *figure 18*. The level of household electrification at the national level is poor with around 46 % electrified. Only around 6.02 crores households out of 13.8 crores use electricity as a source of lighting, which is quite low compared to standards.

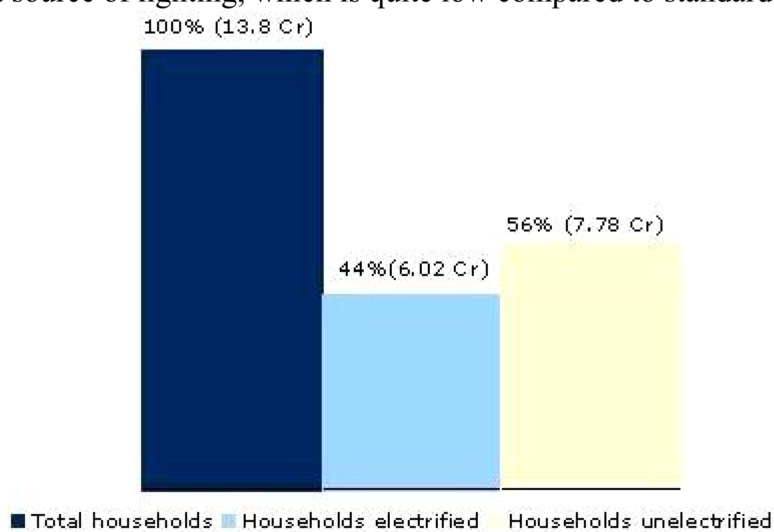


Figure 25: Level of household electrification in India [2]

Village electrification, on the other hand has seen improvements in leaps and bounds over the years – *figure 26* shows the progress of village electrification since independence.

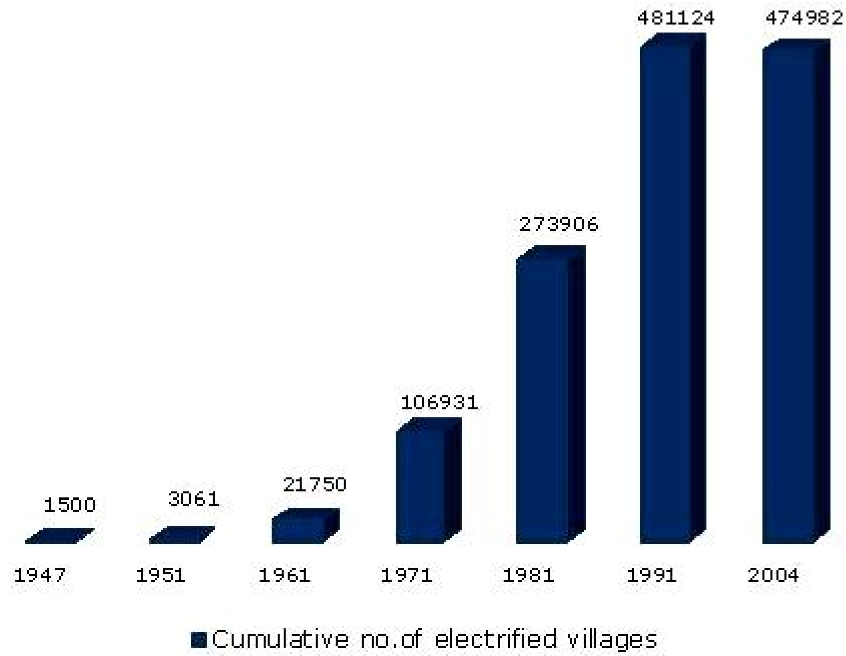


Figure 26: Progress of village electrification in India

Values in *figure 26* do not represent the actual consequences of village electrification because of the varying and non-comprehensive definition adopted for *'village electrification'* from time to time. Level of village electrification, when weighed against the no. of households electrified (which is low) reveals that village electrification is not conclusive factor. The number of villages electrified has changed owing to the changes in the definition itself – figure 4 illustrates this fact.

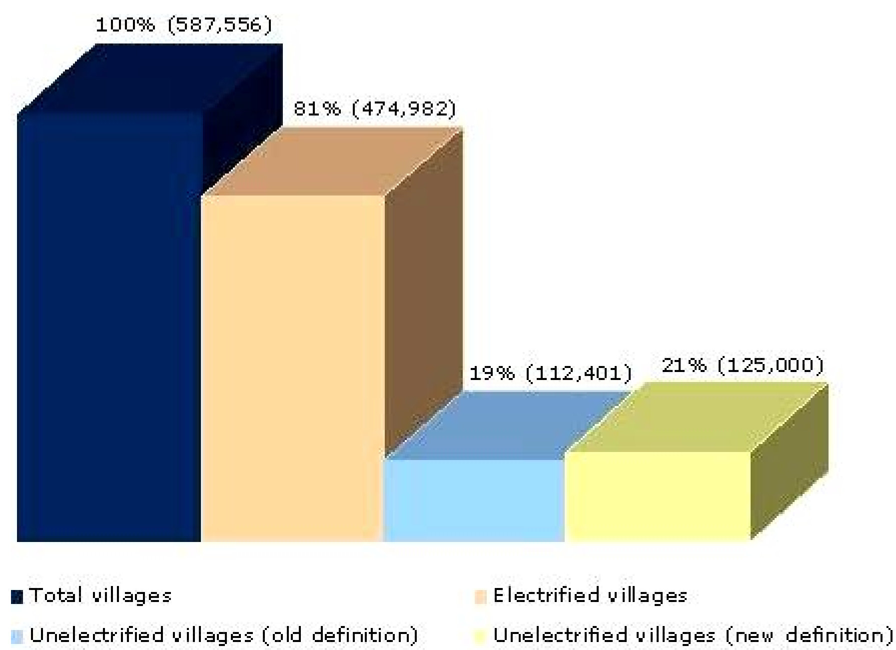


Figure 27: Status of village electrification in India

The rate of village electrification has declined over the years with only 11000 villages electrified during the 9th Plan compared with 120,000 during the 6th Plan *(see figure 28)*. Given the facts, it is rational to conclude that the problem is far *more complex because agriculture, irrigation, power supply and rural economics are intricately interlinked in the Indian energy scenario and have technical, socio-economic and political implications*. But such interlinkage has been recognized very late and little level of integration has taken place. *Not much targeted work has been done so far*, and even if done, a multitude of factors has obscured reasonable conclusions and insights. An attempt has been made to formulate the problem in a *cause-effect* diagram by restructuring the problem into more *understandable* and *tractable* form as shown in *figure 29*.

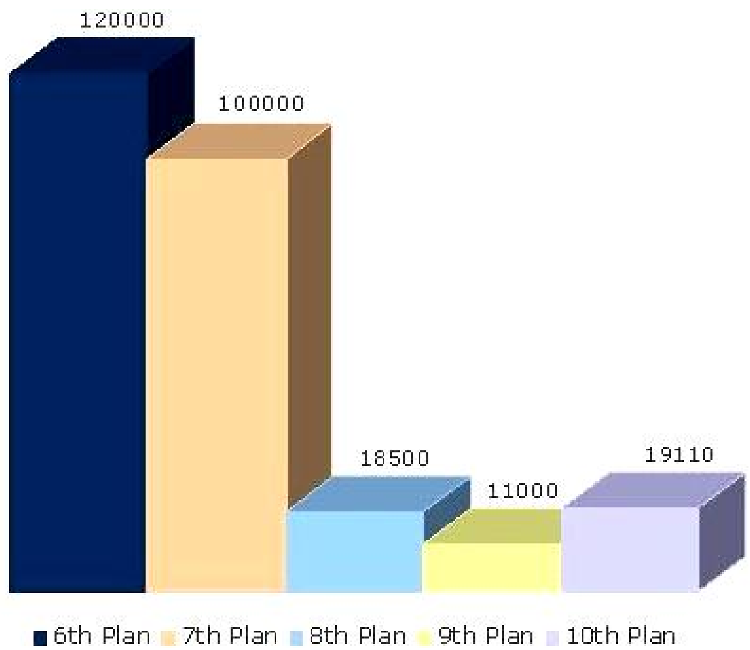


Figure 28: Rate of village electrification in India

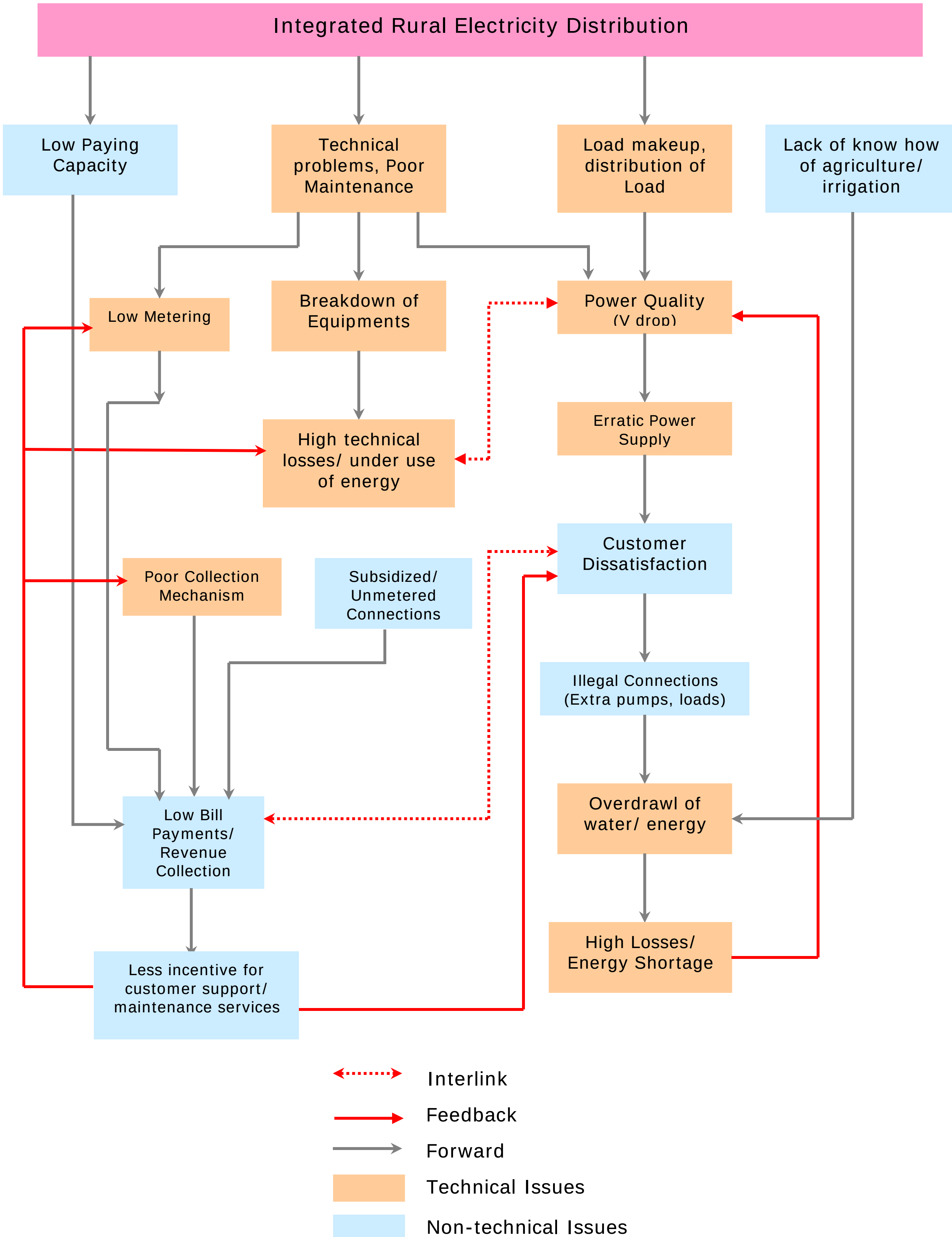


Figure 29: Interlinkage of issues in the rural power distribution sector - cause-effect diagram

b. Innovative Solution

As household electrification is slated to increase, therefore for sustained growth and to increase the per capita energy consumption rural electrification would see significant expansions in the coming years. On the contrary rural power distribution is characterized by low electricity usage densities and dispersed load and consequently high line losses and high transaction costs against the actual revenue generated.

Although a number of rural electrification & energy conservation schemes and models have been devised and implemented, most of them failed or has seen limited success. A few of them like Gram Vidyut Pratinidhi institutionalized by BESCOM, Karnataka, has succeeded, but have not been replicated elsewhere in the country. There are no proper bench marking of the best practices build up from case studies within the country and from around the world. Without any mechanism there are no feedback loop among the utilities and more or less they have had worked independently. Evidently, failure of many of these schemes was primarily due to the top-down approaches adopted for their implementation. Innovative load management schemes (*e.g. Akshay Prakash Yojana*) with bottom-up approach should be initiated by all utilities.

C. Solution Requirements

It must be understood that issues in rural electrification arise due to a complex interplay of multiple factors which may be both technical and non-technical in nature (as depicted in *figure 29*). Moreover, the intensities of problems may vary widely region wise with some factors playing a dominant role over others in a particular region. As an illustration, geographical distribution of load may prove to be a major factor in sparsely populated areas while low paying capacity may be a dominant factor in low income areas. In addition, there are certain socio-economic and political issues specific to a particular region. The extent to which the existing system takes care of these factors determines what improvements need to be made and the time frame in which they can be made.

Thus, in essence, a plan that seeks to improve the rural electrification scenario in India needs to consider the following:

- Factors specific to a particular region and their relative intensity
- Existing condition of the system in different regions

A plan providing a unique solution for country wide rural electrification may discount the above practical issues and hence may not yield desired results, thus making a strong case for situation/region specific plans. In this light, we intend to present a plan flexible enough to address situation/region specific variations.

A comprehensive survey of key rural electrification programmes implemented in India and some developing countries was done. A summary of the key strengths/ weaknesses and features of various rural electrification schemes is given below.

Table 11: Rural Electrification Schemes in Americas *[18, 19]*

Model	Features of Model	Extent/Scale	Result	Reasons for Success/Failure
US Model	- Farmers required to form co-operatives. - Representatives to co-operatives elected locally. - Co-operatives had to maintain reserve funds. - 40 Year period Loans given for Infra on an area coverage basis. - Electricity authority fulfilled a supervisory role.	N.A.	Success	- Model was a perfect wi win situation for all stakeholders. - Fu government support
Argentina Model	- Private operators are paid lowest subsidy required to connect off-grid customers using renewable energy. - In absence of local operator tenders floated on a cheapest subsidy basis - Connection costs subsidized by WB loan, EDA loan and Govt. run electricity reserve. - Users must contribute at least 10% of costs	70,000 households and close to 1,100 schools and clinics	Success	- Competitive bidding - Profit making incentive for private operators - Users also pay for costs no complete dependence on subsidy
Chile Model	- Private bidders offered subsidies on competitive basis. - Creation of rural electrification fund with a life of 10 years. - Local operators work with community groups. - Subsidy given upfront against an undertaking to pump in a fixed contribution	Targets 100% rural electrification.	Electrification increased by 50% from 1994-99. On way to success.	- Competitive bidding - Profit making incentive for Private operators - Local community involvement - Ration funding measures
Panama Model	- Variant of Chile Model: "open season" competition whereby blocks of money offered to bidders for largest no. of connections. - Social funds used for blocks of money. - Post construction, distri. system transferred to local distri. company for O&M for 20 yrs on an upfront subsidy payment.	In 1999, about 100 projects with average size of 34 connections	Success	- Limited geographical spread and hence less overall hassles - Proper database maintained for connectio to facilitate bidding.

Table 12: Rural Electrification Schemes in South Asia [18]

Model	Features of Model	Extent/Scale	Result	Reasons for Success/Failure
Philippines Model	- Boards of Co-operatives locally. - Planning and operation handled by professional managers guided by state owned utility-NEA. - Loans not paid to co-ops but used by NEA. - Operating budget of NEA depended on revenues generated by co-ops.	119 co-ops serving 5 mn connections to 30 mn people as of 2002	Success initially, suffered midway, recovered again.	- Reason for failing midway was corruption, lack of oversight, political exploitation - Eventually successful because of USAID, World Bank's loans and professional management.
Palli Bidyut Samitis (PBS) / Rural Electrification Boards (REB) , Bangladesh	- Similar to Philippines but the REB directly controls the financial operations of the co-ops. - Co-ops not independent private entities. - Co-ops do not retain or control operating margins	REB has established 67 PSBs to date. 3.8 mn connections to 15 mn people. Approx. 20% of rural population.	Success. Collection efficiency up to 97%. Ave. sys. Loss down to 16%.	- Engg. and construction standards followed accurately. - System for monitoring PBS - Priority basis system - REB offered proper training - System losses and collection efficiency closely monitored
Mini Hydro Application, Nepal	- 1 KV distribution. lines using lightweight transformers suited for transport in hilly terrain with poor roads. - Two 17 MW mini-hydro generators. - Demand based tariffs: tariff structure based on power instead of energy. - Involvement of local community for equipment maintenance, bills collection, etc. - Innovative ways to create awareness.	20,776 consumers in extreme hilly terrains	Success	- Local involvement in constr. and maint. reduced costs - Proper training provided to locals - Effective awareness spread mechanism - Reduction in metering costs due to demand based tariff system - No thefts possible in 1 KV line
Grameen Shakti (GS), Bangladesh	- Renewable energy company co-affiliated to Grameen Bank - Various renewable energy programs like Solar program, Bio-Gas program, Bio-mass program, Wind program.	43 branch units of the company	Success	- Excellent networking and after-sales service - Attractive financing in affiliation with Grameen Bank

Table 13: Rural Electrification Schemes in India [2, 18]

Model	Features of Model	Extent/Scale	Result	Reasons for Success/Failure
Rural Electric Co-operatives	- Established by Rural Electrification Corporation. - Set up to cater to local distribution needs. - Initially, start-up capital invested by government - Run as a typical co-operative society under Co-operative Societies Act.	41 RECS initially sanctioned across 12 states. 33 survive, 8 taken over by respective SEBs	All RECS except 3 are failures	- Lack of freedom to fix tariffs - Unfavorable load mix - Political interference - Misuse of Regulatory powers - Inefficiency and Corruption at operational level
Anakapalle Rural Electric Co-operative Society (ARECS), Andhra Pradesh	- Started in 1974 with a capital of Rs. 45 lakh provided by AP State Govt. - Took over distribution operations and maintenance from SEB in 1976. - Equity contributions from members.	- 350 villages, hamlets and colonies - 96,140 members - 97,107 service connections across 1115 sq. km	Success. Monthly revenues of Rs.1.4 Cr. Zero Debt. Cumulative Profits of Rs.95.03 lakhs.	- Active community involvement - Robust financial model , supportive govt. framework and debt financing - Collection Efficiency improvement and losses reduction - Dedicated service personnel
Gram Vidyut Pratinidhi, Karnataka	- Local unemployed and qualified rural citizens employed by BESCOM as collection agents called Gram Vidyut Pratinidhis (GVPs). - Activities include: meter reading, billing, bill distribution, revenue collection, registering complaints, grievances handling - GVP is NOT an employee of BESCOM. - Compensation based on attainment of collection target. Termination in case of non-performance.	3425 GVPs working in 5605 Panchayats across 17,125 villages	Success. Average collection 125-130% of baseline target. Thefts down. Collection Efficiency Up.	- Local youth involvement improves trust. - Target-Incentive system drives performance - Thefts reduction - GVPs act as effective communication channel between villages and utility leading to superior service levels
Village Electricity Management Board (VEMB), Nagaland	- Electricity Management Boards set up as sub-committees under Village Councils - Electricity billed on a Single Point Metering (SPM) Basis. - VEMB given 20% margin on every unit sold. - To get full benefit VEMB needs to ensure 100% billing of energy from customers.	452 villages	Success	- Profit making opportunity for both utility and VEMB - Local community involvement improves trust - Theft reduction due to 100% billing recovery condition

Single Point Supply System (SPSS), Assam	- Input based franchisees and collection based franchisees at distribution transformers - Franchisee can be NGO, users' body, village body, an individual - 15% commission subject to 10% distribution losses	816 villages. Extension due for another 816.	Success	- Incentive to reduce losses leads to overall improvement - Franchisee takes care of distribution system as his own to maximize earnings
Akshay Prakash Yojana (APY), Maharashtra	- Based on Collective Responsibility of villagers. - Voluntary control on use of power by villagers. - Voluntary measures to improve supply quality. - Surveillance committees for removal of unauthorized connections.	N.A.	Failure	- Entirely voluntary, no incentive - Implemented in haste as a reaction to customer angst over load shedding - Inadequate awareness generation

XVII. Need for Mapping – Critical Mapping Elements

Due to host of issues affecting rural electrification which vary region wise, there is a need to come up with a set of factors specific to regions, quantification of which can throw significant light on intensities of issues local to that region which in turn can suggest alterations in the business plan.

Kalra et al [18] have identified similar criteria for choice of rural electrification models. However, the criteria identified (distance of load from grid) is not exhaustive enough to encompass all issues shown in *Figure 29*. Therefore we suggest criteria for particular regions (village wise/ block wise), which may address most of the issues associated with rural distribution. Hereafter, we will refer to these criteria as *'Critical Mapping Elements' (CME)*.

- Distance of loads from grid
- Consumer segment makeup – agriculture, households etc.
- Past consumption statistics
- Household Income
- Population Density
- Geographical Terrain
- Suitability for alternate sources, for e.g. coastal location for wind power etc.
- Extent of Irrigation
- Willingness of local populace

However, the above list may not be exhaustive and some more relevant mapping parameters may be introduced based on the experiences of utilities across different schemes. Most of the 'Critical Mapping Elements' can be easily quantified using existing databases available with the district administration, Central Electricity Authority (CEA), National Informatics Centre (NIC) and utilities. Thus the business plan can be mapped onto specific situations/regions using the aforementioned 'Critical Mapping Elements'.

XVIII. High Voltage Distribution System (HVDS)

Owing to rapid developments over the years, proportionate expansion of both the urban and rural power distribution system has taken place. Increasing load demand has resulted into considerable but unplanned expansion of the LT distribution network. The LT line lengths of some states are around 70 – 80 % of the total circuit line lengths and the average is around 60 %. Lengthy LT distribution line lengths may results in:

1. High load losses
2. Excessive voltage drops
3. Frequent occurrence of faults on the LT network
4. High rate of DT failures
5. High prospect of theft

HVDS already in place is to run 11 kV lines up to the loads and setting up small sized DTs to supply to consumers with least LT lines. It is estimated that with the present power distribution system, the current LT system is 28 times than in the 11 kV systems. Thus, load losses are scaled down around 800 times with the reduction of voltage drops. HVDS helps in addressing all the shortcomings of LT lines mentioned above. The major impediment in the large scale implementation of HVDS is the initial investment; however, the benefits are enormous, immediate and sustainable. Moreover the benefits in the 11 kV systems outweigh the huge losses associated with the LT system. States of

Andhra Pradesh, Gujarat, Maharashtra, Uttar Pradesh, West Bengal and Karnataka are in various stages of implementing HVDS and have started gaining benefits. Although the present HT: LT ratio estimated is around 1: 2.5 and HVDS can help in achieving the same.

Key Options

Discussions and analysis made so far has helped to identify some of the critical factors which are affecting the state of India's power transmission and distribution system significantly. The list of 'Best Practices' in India can be readily found in literatures and have been adopted and discussed by respective utilities (in reports). The best practices adopted for improving both the technical and commercial losses, no doubt, have helped in their reduction. However, previous discussion shows that metering at different levels (11 kV, DT and consumer) are inadequate and hence an appropriate energy accounting and auditing is also not possible. As such the factual achievements of the adoption of best practices of different utilities are not verifiable. In addition there are no proper charted methodologies or practices to document the implementation of these best practices, and meager replication of such elsewhere other than where initiated.

Although there are many technological options, we propose the following key options which when systematically implemented; have the potential to improve the financial performance of the utilities, improving the access of energy, as well as in the annual reduction of CO_2 emissions.

G. Improved accounting methodology for T & D loss reduction

The average aggregate technical and commercial (AT & C) losses in the power sector accounts for about 33% *[4]* of the electricity available at bus-bar[25]. T & D losses include technical losses plus a high proportion as commercial losses (theft, unbilled energy, uncollected bills). In addition, there are uncertainties in the quantification of unmetered consumption (low usage residential, subsidized agricultural). The quantification of consumption of these segments is based on empirical methods and does not capture the actual losses. Most of the methods as shown in *table 6* necessitate accurate power system data which is possible only through comprehensive metering in the distribution system.

It is therefore proposed to have systematic accounting (energy audits) at the sub-station level. This needs to be carried out with metering of all distribution transformers (less than 20% for most of the states in 2005-6 – *figure 11*). Quantification of sub-station wise electricity usage and comparison with billed amounts can be used to determine the T & D losses for each substation. An analysis of the data for different sub-stations would help in estimating norms and reducing AT & C losses. The study *[5]* done by IISc and Karnataka Power Trading Company Limited (KPTCL) has already indicated that the average uncertainty in the estimation of losses by current methodologies is around 10% with a maximum of 22%. Low collection efficiency is a major cause of commercial losses and needs to be improved by adoption of new technologies and increased accountability. Better accounting is critical to quantify and implement efficiency programmes.

[25] *Energy at bus-bar = Gross Generation – Auxiliary Consumption (GWh)*

Collection and billing efficiency should be increased by adoption of innovative schemes/ technology with the help of information technology infrastructure in a systematic way.

With the projected generation of electricity *[3]* in the year 2025 (2528 billion kWh) and at present loss rates, AT & C losses would amount to 834 billion kWh. We expect that bringing down the AT & C losses to a level of 25% is possible by 2025 and would contain the losses to around 630 billion kWh. This would improve the financial operation of the utilities.

H. Distribution Transformer Efficiency and Replacement Programme

The number of distribution transformers (DTs) is more than 2.5 million *[4]* in India, with an aggregate capacity of 207000 MVA. DTs normally contribute around one-third of the technical losses under optimal network configuration and loading. It is estimated that the capacities of more than 90% of the total DTs in India range between 10 to 315 kVA. We also see from *figure 13* that there is a positive correlation between the average input energy to a DT and the average AT & C losses of a DT. The average DT capacities of various states have been observed to vary widely from approximately 50 kVA (Rajasthan) to high value of 500 kVA in Delhi *(see figure 14).*

After transmission and distribution lines, DTs are the largest contributor to system-wide losses. The figures of losses of DTs vary depending on many factors like average and peak loading, maintenance. Several studies *[20]* show the loss levels of distribution transformer as in *table 14*.

Table 14: Breakdown of losses of major power systems components

Components losses as % of total losses					
	Transformers		Lines		Others
Studies	Power	Distribution	HT	DT	
USA – 1	0.3	1.2	2.3	3.2	0.2
USA – 2	0.2	2.6	0.7	3.1	0.6
UK – 1	0.6	1.8	1.5	3.3	
UK -2	0.7	2.3	1.1	3.1	0.2
Australia	0.2	3.8	1.9	3.6	

Source: Targosz et. al. [20]

In India, BEE[26] has developed a classification scheme as a part of the standards and labeling program. This classifies DT in the range of 16 – 200 kVA into 5-star based on total losses at 50% and full load. The 5-star unit is highly efficient while the 3-star is of minimum standard recommended by BEE. Star 1 DTs are high loss units which corresponds to IS 1180 standard for DT. *Figure 30a* compares the efficiencies at various loading of a 16 kVA DT of various BEE standards. *Figure 30b* compares the NEMA TP1 standards with 5-Star DT of BEE, India standard of DTs of various sizes.

[26] Bureau of Energy Efficiency India

Table 15: DT failure rates and Feeder Outage rates[27] of in select circles of a few states (2005-6)

	DT Failure Rates			State Avg. feeder outages per month			
	Minimum	Maximum	Avg.		Min	Max	Avg
Chhattisgarh			16.4	Chhattisgarh	2	41	
Goa			5.3	Jharkhand[28]	54	167	80
Rajasthan	7	30		A P	4	300	
Punjab[29]	2.7	27		Punjab	2	33	
Karnataka			8	West Bengal	9	200	
West Bengal	5	22					
Himachal Pradesh			4				

Source: MoP

Actual losses in DTs in India are high owing to unplanned network expansion leading to DT overloading and due to improper protection and poor preventive maintenance. DT failure rates give a good indication of operating performance of distribution transformers and that of the utilities. While DT failure rate of 1.5 % per annum is assumed as baseline my MoP considering reliability aspects, the actual rates are very high *(see table 15)*. A study *[8]* of a sample of 4500 DTs by Bangalore Electricity Supply Company Limited (BESCOM) indicated that losses in more than 30 percent of the transformers was more than 5 % and losses in another 30 percent was more than 10% of the total AT & C losses.

Owing to the growing energy demand and the need of rural electrification, DT market in India is expected to grow with an annual rate of around 10%. Therefore energy savings is possible from:

e. Replacement and refurbishments of lowest efficiency DTs with energy efficient DTs, and
f. Standardization of efficiencies and to initiate mandatory minimum efficiency standards to promote use/ installations of efficient DTs with demonstrated benefits.

It has been estimated that replacing a 1 star DT with a 3 star DT will result into 40% reduction in annual energy losses of a DT and replacing a 3 star DT with a 5 star DT will result into more 30 % of annual energy losses of the DT (*see table 16*).

[27] The prescribed level of DT failure rate is 1.5 % per annum and that of feeder outage level is one outage per month

[28] Feeder outages values only for four test checked circles – Dumka, Dhanbad, Daltonganj and Hazaribagh

[29] Average DT failure rate for 2002-6.

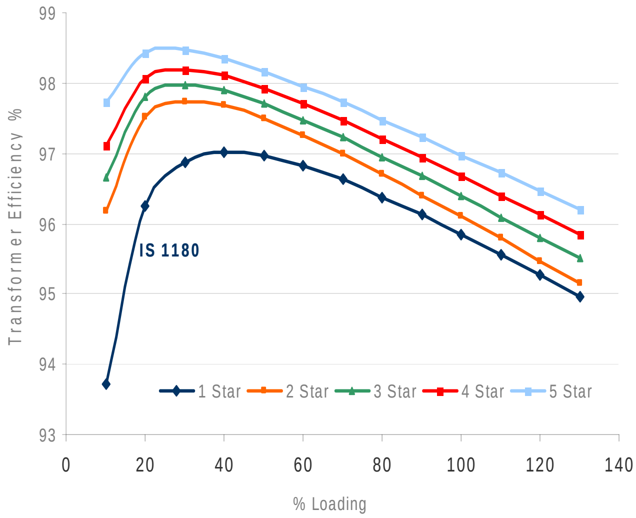


Figure 30a: Efficiencies of 16 kVA DT of five different standards
Source: BEE[30] & NEMA TP1 Standard

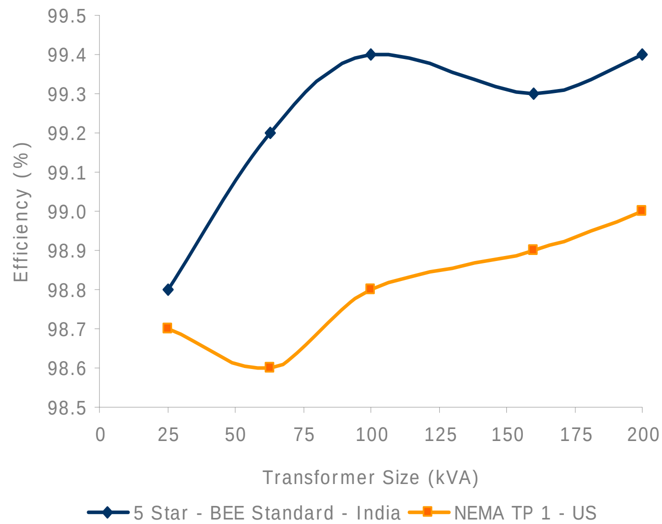


Figure 30b: Comparison of efficiencies of five different transformer sizes, at 50 % loading, unity pf – Indian, BEE and US NEMA TP 1 standard

Table 16: Annual energy savings by replacing high loss DTs with energy efficient DTs

Transformer Size	Star Rating	No Load Losses (W)	Full Load Losses (W)	Effective Load Factor	Annual Energy Losses (kWh)	Ex-Works Price (Rs.)	Annual Losses per kVA (kWh)	Reduction in Losses by replacing 1 Star DTs
63	1 Star	182	1233	0.5	2098	32900	33	-
63	2 Star	90	1160	0.5	1262	41400	20	40%
63	3 Star	50	1000	0.5	847		14	60%

Source for calculations: BEE

Similar energy savings calculations have been made by BEE, but the standard set by BEE though ambitious is voluntary due to which the benefits of the program is not fully verifiable. We therefore propose to formulate strategies for timely replacement of overloaded and high loss DTs. The incentive and motivation for the use of energy efficient DTs needs to be made more prominent and transparent which will ensure the participation of the stakeholders (manufacturers, utilities etc.). More accurate DT loading data should be made available to make more realistic potential energy savings calculations. Such data could be used to evaluate the Total Owning Cost for future DT installations.

There is a need to classify DTs based on their size as well as the demand side considerations i.e. DTs serving loads of different consumer groups (operates at different efficiency level) - loading also affects DT life considerably. Further efficiency

[30] Bureau of Energy Efficiency

improvements efforts can be undertaken by estimating the efficiency standards of the DTs of different sizes based on the loading pattern of different consumer groups.

Energy auditing at DT level would assist in identifying high loss DTs where systematic replacement programme could be implemented based on cost benefit analysis. Average DT capacity needs to be brought down in states with high rural and agricultural consumption (based on load factors) with a consequent reduction in distribution line lengths and implementation of High Voltage Distribution System (HVDS). A framework for optimum transformer selection based on data on loading and load concentration/ spread region-wise needs to be prepared.

I. Optimal Distribution Network Planning

Under optimal distribution network configuration the low voltage distribution lines contribute to around 3-5% *[3]* of the total losses. The length of low voltage distribution lines in India is more than 3.9 million kilometers, which is more than 60% of the total line length. This has led to suboptimal network configuration leading to a high length of distribution lines served by a single DT that varies from 0.7 km (average DT capacity 55 kVA) in Uttar Pradesh to more than 9 km (average DT capacity 415 kVA) in Uttaranchal. The mean value of low tension (LT) distribution lines length for the country is around 3 km per DT (average DT capacity 130 kVA) – (*see figure 16*). A state with more rural area and population would have a high LT DT lines per DT. There are no minimum standards set for LT DT lines served by a DT and without a timely DT replacement programme which leads to overloading of both lines and DT and causing high rate of feeder tripping and outages as seen in *table 15*.

We propose a plan for optimal distribution network planning and maintaining standard values of LT lines length as per DT capacity in rural and urban areas. This would involve systematic reduction of the LV/ HV line length ratio by the implementation of HVDS in future network installation and upgradation wherever practicable. This would result in a reduction of the average DT capacity and therefore LV lines length per DT. It is estimated that the distribution transformer efficiency and optimal network planning options would result in a reduction of AT & C losses by 5% in 2025.

J. Efficient Agricultural Pumping System

There are more than 14.1 million agricultural pumpsets *[4]*, which consumed around 25 % (87,000 GWh) of the total electricity generation, in India (2003-4). The tariff for agricultural consumption is subsidised and is usually based on the HP (horsepower) pumpset rating (i.e.) connected load instead of the actual consumption as already discussed in the previous sections.

The efficiency of a pumping system is a function of the efficiency of the pumpset and the piping, valves. There is a difference in the efficiency of standard motor and efficient motor of the order or (5 – 10) % *[21]*, however, less efficient motors are mainly in use due to initial cost considerations. There are no standard procedures for proper pump selection and pump head selection. The minimum efficiency standards laid down by BIS can be upgraded considering the fact that high efficiency pumps are readily available from reputed Indian manufacturers.

Improper sizing of pipes for pumping operation, quality of foot valves and other accessories are important aspects to be considered for efficiency improvement. Standards should be laid out for optimum pipe sizing for minimum overall cost of pumping (including capital and running cost). Existing standards are sub-optimal and voluntary which are most of the times not followed by manufacturers and farmers

It has been estimated that by improving the pump efficiency standards as well as by improved pump designs (improved head-efficiency curve) would result in around 15 % of energy savings. Appropriate pump pipe sizing and standard upgradation have the potential of around 20 % of energy savings *[21]*.

Policy formulation to introduce incentives to farmers for efficient pumping use can help in reduction of theft and overuse of pumps. This can be realized by metering of pumpsets and subsidized tariffs be based on actual energy consumption rather than on connected load.

Agricultural feeder separations, metering of pumpsets, efficiency standards on new installations are elements of an efficient agricultural pumping programme. The existing average efficiency of motor-pump sets is about 20%. A DSM programme focusing on efficient agricultural pumping can enhance this average to 30% in 2025.

K. Innovative Rural Electrification Programmes

More than 56% of households *[2]* in India are not electrified. The development goal of providing access would result in a thrust on rural electrification. Rural power distribution is characterized by low electricity usage densities and dispersed load and consequently high line losses and high transaction costs against the actual revenue generated.

Load factor needs to be improved by connecting rural industries to the grid. High line losses, pilferages should be avoided by optimum planning of rural network and by implementation of HVDS wherever viable. A plan providing a unique solution for country wide rural electrification does not seem practicable, as the actual situation and constraints are different for different regions. Innovative rural power distribution schemes can be planned based on replication of best practices (e.g. Gram Vidyut Pratinidhi of Karnataka). A summary of potential best practice that can be replicated in various parts of the country has already been provided. Although a number of rural electrification models have been devised and implemented, many have failed or have had limited success. This was primarily due to the *top-down approaches* adopted for their implementation. Innovative load management schemes (like Akshay Prakash Yojana of Maharashtra) with *bottom-up approach* could be initiated by utilities.

To take care of low load densities electricity usages, optimal distribution network planning, implementation of High Voltage Distribution System (HVDS), energy efficient transformers and electric devices would drive the future electrification and expansion of rural network.

L. Efficient Lighting Programmes

Lighting load accounts for 17% [BEE] of the installed capacity of India. Efficiency programmes and innovative schemes for the replacement of incandescent bulbs by Compact Fluorescent Lights (CFL) and Fluorescent Tube Lights (TFL) by efficient TFL are considered. Replacing a 60 W incandescent bulb by a 15 W CFL would result in 75%

power saving. Similarly, replacing an ordinary TFL (56W) with energy efficient TFL 5 tube light (28W) would result in 50% of power saving *[22]*.

The higher initial capital cost and the high consumer discount rates for these options results in relatively few adoptions. Thus there is a need for efficient lighting programmes that provide reduced capital cost options through large scale procurement and provide the possibility and payments through installments in utility bills [e.g. [31]BELP]. Utilities need to be able to quantify the system wide potential for such programmes. A study for Maharashtra *[23]* revealed that there is a potential of 2335 GWh in energy saving and peak demand reduction of 703 MW in rural area, and a potential of 2121 GWh in energy savings and peak demand reduction of 663 MW [2004-5]. The electricity savings achievable through an efficient lighting programme is estimated to be 150 Billion kWh in 2025.

M. Adoption of Solar Water Heating Systems (SWHS)

Solar Water Heating is an option that can reduce the morning peak demand significantly. In many urban areas (Pune, Bangalore), there are a large number of residential Solar Water Heating installations. Despite the fact that SHWS are reliable and economically viable (payback periods 3-4 years), the actual installed capacity is only a small fraction of the potential (2% of the estimated potential). The CO_2 savings by use of SWHS instead of electric heating is 0.87 kg of CO_2 per kWh of electricity saved. The annual electricity savings potential has been estimated to be around 12.2 BUs *[24]* for 60 million sq. m. of collector area, which amounts to around 10.5 million tonnes of CO_2 savings annually (2005-6). The annual electricity savings in 2025 through this option is estimated to be 20 Billion kWh (assuming a diffusion curve with a fraction of the potential being achieved).

Development benefits

Improving the accounting methodology for T & D loss reduction will improve the financial position of the utilities. This is critical for attracting investments in this sector. An estimated 200 billion kWh can be reduced from AT&C losses in 2025. This is not likely to actually reduce the total demand as it is only a reduction of theft. This would result in additional revenue of about Rs 500 Billion (in present prices) and would help in eliminating the annual deficit of the power utilities. This will enable more accurate estimation of savings and costs of energy efficiency and demand side management programmes. Options for distribution transformer efficiency and HVDS would reduce losses, improve voltages and reduce the cost of supply. These measures are also likely to improve the supply availability and reduce outages. The agricultural pumpset efficiency, efficient lighting and solar water heating programmes reduce the energy requirement in 2025 by about 520 Billion units. The system peak requirements would be reduced and this would result in a reduction of about 110,000 MW of future capacity (capacity saving of Rs 4400 Billion at present prices). This would facilitate the provision of access to un-electrified households and remote villages.

[31] *BESCOM Efficient Lighting Program*

Potential Savings

In 2003-4, the electrical energy available at the bus-bar was 592 billion kWh and the estimated AT & C losses were 195 billion kWh as shown in *table 3*. With the projected generation of electricity *[3]* in the year 2025 (2528 billion kWh at bus bar) and at present loss rates, AT & C losses would amount to 834 billion kWh.

The impact options considered have been quantified as shown in *table 3*. In the case of energy accounting a reduction of AT & C losses to a level of 20% is reasonable. However it is expected that the major part of this improvement would result in reduction of pilferages, which in turn would assist in increase in revenue generated by improving billing efficiency. Significant saving of nearly 33 % of the agricultural consumption (~9% of the total electricity consumption) is possible by increase in efficiencies of agricultural pumping systems.

Table 3: Impact options for CO_2 saving for the year 2025 from T&D and Efficiency

Year	[1] Energy at Bus-bar (BU)		[2] AT & C losses (33%) (BU)	[3] CO_2 Emission (Million Tonnes)	
2003	592		195	519	
2025	2528		834	2217	
	Energy at Bus-bar (BUs)	Key Options	Saving Potential (BUs)	CO_2 emission savings (Million Tonnes)	% CO_2 emission savings
2025	2528 BU	[a] Energy Accounting/ improved collection/ billing efficiency	200	Nil	
		[b] Efficient Distribution Transformer	125	103	~5
		[b] Line Losses/ Pilferages			
		[c] Efficient Agricultural Pumping System	225	185	8
		[d] Efficient Lighting	150	123	~6
		[e] Solar Water Heating	20	16	~1
		Total of all options	**720**	**427**	**20**

Assumption for calculations

[1] Energy at bus-bar = gross generation – auxiliary consumption; auxiliary consumption = 6.5% of gross generation

[2] Energy losses calculated as a percentage of energy available at bus bar

[3] Share of thermal generation projected to be 75% of gross generation in 2025

[a] Improvement of collection and billing efficiency> 90%, % AT & C loss reduction to 25%

[b] Improvement in DT efficiency and line loss reduction, % AT & C loss reduction by 5%

[c] Improvement of agricultural pumping efficiency to 40%, assuming share of agricultural consumption to be constant at 25% of the total for the year 2025

[d] 6% savings from efficient lighting is being assumed for India [8]

e Potential estimated by model developed in [9] 2005-6

Conclusion

The option for improved accounting in T & D systems can result in an improvement in the financial viability of the utilities. Though this may not reduce emissions per se, this is a prerequisite for quantifying and implementing many of the DSM and energy efficiency options in the power sector. A total saving of 520 billion units in 2025 is achievable through these options. This would result in a reduction of about 20% in the electricity requirement. These options are classic win-win options as they meet the development goals by providing additional electricity availability as well as reduce GHG emissions.

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Co-benefits of Climate Mitigation and Health Protection in Energy Systems: Scoping Methods

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Key Words: Greenhouse gases, global warming commitment, cost-effectiveness analysis, indoor air pollution, urban air pollution

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Abstract: Interventions in the energy sector offer significant opportunities for reducing both greenhouse and health-damaging pollution, resulting in what is called "co-benefits." The health community has a critical role in evaluating such interventions to optimize progress of both sorts, as both affect health. In detail, analyses require sophisticated modeling and specific local information. As a starting point, however, we offer here a set of scoping methods for obtaining a quick assessment of these co-benefits for interventions in the energy sector, the arena with the highest potential for significant co-benefits. For this purpose, we combine relevant methods developed separately in recent years for cost-effectiveness assessments in the climate change, health, and development communities. We offer example calculations, which illustrate the apparent high degree of co-benefit effectiveness for targeted interventions in the household energy sector in developing countries.

Glossary (including acronyms)

CRA: Comparative Risk Assessments derive health impacts from alternative activities using consistent frameworks, common databases, and systematic rules of evidence to provide coherent and systematic comparisons for policy decisions.
DALYs: Disability-Adjusted Life Years is a population ill-metric metric combining the burden of disease from years of life lost (YLLs) plus years lived with disability (YLDs)
Discount rate: Initially a financial instrument to calculate the present value of future benefits or costs that can also be applied to health, climate change, and other sectors. Discount rates are formulated as $1/(1+r)^t$ where r is the discount rate (0.01, 0.02, etc) and t is the year. Thus, at 2%, the value today of a cost or benefit in 10 years would be $1/(1.02)^{10} = 0.82$ as large.
GDP: Gross Domestic Product, a measure of national income.
GHG: Greenhouse Gases are those known to contribute to global warming.
GWC: Global Warming Commitment is the combined warming effect of a basket of GHGs emitted in a specific activity.
GWP: Global Warming Potential indicates the atmospheric warming effect of a given

mass of an individual GHG relative to carbon dioxide, the major GHG, over a specified time period.
IPCC: Intergovernmental Panel on Climate Change is a scientific body established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to evaluate the causes, impacts, and mitigation measures for anthropogenic climate change. It has produced four major sets of publications, the Fourth Assessment being published in 2007.
Kyoto Protocol: The Kyoto Protocol of the UNFCCC was ratified by sufficient countries in 2004 to come into force. It sets mandatory GHG emissions reduction targets for developed countries that have ratified the Protocol (almost all besides the United States and Australia) with an overall goal of reducing 5% below 1990 levels by 2012.
PPP (Purchasing Power Parity), adjusts costs for international comparisons to reflect differences in local (national) prices as determined by a standard market basket of goods and services.
tCO_2e: metric tons of carbon dioxide equivalent denotes the warming effect of a given quantity of GHGs expressed as the equivalent effect of a given mass of carbon dioxide.
UNFCCC: The United Nations Framework Convention on Climate Change is the international treaty signed at the 1992 Rio Earth Summit with the goal of mitigating climate change by reducing GHG emissions. Its most well-known protocol was signed in Kyoto in 1997. The UNFCCC Secretariat based in Bonn, Germany, implements the treaty and its protocols including setting rules for projects to qualify for claiming GHG reductions.
WHO: The World Health Organization was established in 1948 and today has 193 member nations. Its global headquarters are in Geneva, Switzerland.
YLD: Years Lived with Disability, which is determined as the time lived with an illness or injury multiplied by a severity factor ranging from 0-1.0.
YLL: Lost Life Years, which is based on the number of years the death occurs before normal life expectancy.

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Summary Points

- Projects to improve the efficiency and/or reduce the emissions of energy systems have the strongest co-benefits potential, i.e., ability to mitigate climate change and protect health
- The IPCC/UNFCCC and the WHO, in conjunction with other international organizations, have recently developed standard methods for scoping the benefits for greenhouse mitigation and health for development projects including risk factors relating emissions and impacts.
- We propose slight modifications of the methods developed in these separate realms to make them consistent with one another and thus suitable for simple scoping of co-benefits of energy projects
- Such simple scoping methods provide common starting points for co-benefits analyses that may then extend to more sophisticated assessment using local data.

Introduction: The Co-benefits Framework

Through international intergovernmental agreement in the Kyoto Protocol as well as a growing number of national, provincial, and local government and private sector actions, a range of activities are ongoing and planned to reduce greenhouse gas (GHG)[32] emissions to blunt the extent of coming climate change. Collectively termed mitigation, these activities can operate in a number of economic sectors, including agriculture, forestry, industry, and mining, and involve ways to capture GHGs from the atmosphere, for example by tree planting, as well as reducing net GHG emissions, for example by shifting to less damaging forms of halocarbons. The most important worldwide sources of anthropogenic GHGs, however, are those associated with combustion of fuels to meet human energy demands (33) and thus although actions in other sectors can help, serious global mitigation will require major changes in energy production and use.

In addition to its close association with GHG emissions, the energy sector also has close associations with public health primarily through air pollution, occupational hazards, and the risk of large-scale accidents (28). In the global Comparative Risk Assessment Project managed by WHO, for example, combustion of fuels leading to indoor and outdoor particle pollution together were found to be responsible for about 2.4 million premature deaths annually in 2000 with some additional accountable to the energy sector from among the 775,000 premature deaths attributed to occupational risks (12, 14, 64). Thus, energy production and use is responsible for substantially more environmentally mediated global mortality and morbidity than any other sector, including poor water supply and sanitation (58).

[32] Here we use the term GHGs as is common in the literature, but include airborne particles, which are now also thought to be important greenhouse-related pollutants (GHPs)

With the prospect for large changes in the energy sector in order to mitigate[33] GHG emissions and the close connection with health in some parts of the sector, a set of concerns are raised for public health (24, 44, 76). Among them are worries that

- Actions do not just shift the hazards from one population to another, e.g. shift the health burden from coal burning to a potentially even higher burden from nuclear accidents.
- The rush to find and implement ways to mitigate GHGs does not result in significant relaxation of the environmental and safety controls on new energy systems developed over the years to protect health.

Here, however, we invert this concern to look at these prospects as potential opportunities to ask the co-benefits question, and its corollary

- To what extent can mitigation measures for GHGs in the energy sector also achieve reductions in health burden?
- How would we combine our objectives in each of these realms to optimize progress toward both?

To answer these requires establishing a credible nexus for potential interventions among the three main elements: GHG reductions, health improvements, and economic valuations. In detail, each of these three arenas is complex and thus the subject of significant scholarly and scientific investigations well beyond what can be addressed here. In addition, there are important atmospheric interactions between the two classes of pollutants (25, 26).

What we can do, however, is review recent and important conceptual aspects of new techniques and metrics in each arena that together allow for a relatively quick scoping and comparison of the potential co-benefits of different classes of energy interventions and their trade-offs. Detailed studies of much greater sophistication using local data, however, are needed to pin down the details in any one location, particularly if fine distinctions are required (2, 9, 37, 56) (8, 11, 34, 41, 42, 53, 59, 66, 69, 73) (16, 68).[34]

The greenhouse pollutants

Official mitigation actions under the United Nations Framework Convention for Climate Change (UNFCCC), which implements the Kyoto Protocol, include only those directed toward reducing the six "Kyoto" gases (CO_2, CH_4, N_2O, and three halocarbons), as these were the best understood GHGs at the time for which the IPCC had published Global Warming Potentials (GWPs). GWPs are an estimate of the total radiative forcing for an equivalent amount of each gas released relative to CO_2. For example, 1kg of methane is

[33] In official IPCC terminology, "mitigation" refers solely to actions that reduce the emissions of GHGs or removes them from the atmosphere (IPCC 2007).
[34] A good example is the set of studies done in cities around the world as part of the Integrated Environmental Strategies Project of the US EPA http://www.epa.gov/ies/index.htm See also the online bibliographic database by the Wood Hole Research Center (75)

estimated to have 21 times more 'warming potential' over 100 years than 1kg CO_2, thus, the GWP is 21 (IPCC 2001). GWPs are not known precisely, however, because they depend on future estimates of the physical interaction of the gases with radiation as well as their lifetimes in the atmosphere, both of which are dependent to some extent on future atmospheric trends, for example the presence of other gases that react with them and the concentration of water vapor. Although alternative formulations have been proposed to take more account of these issues (40), the IPCC GWPs have come to be considered useful "rules of thumb" for combining the impacts across gases to judge the total global warming implications of an activity. Table 1 shows the IPCC GWPs for the three official GHGs that are most closely connected with combustion.

TABLE 1. Global Warming Potentials (GWPs) of combustion-related greenhouse gases: the relative warming of an emission of a non- CO_2 energy-related GHGs compared to the emission of an equivalent mass of CO_2.

Gas		**Lifetime (years)**	**Global Warming Potential (Time Horizon)**		
			20 yrs	**100 yrs**	**500 yrs**
Kyoto[a]					
Carbon dioxide	CO_2		1	1	1
Methane[b]	CH_4	12	56	21	6.5
Nitrous oxide	N_2O	114	280	310	170
Non-Kyoto (unoffical values)[c]					
Carbon monoxide	CO	~0.1	7	3	2
Total nonmethane hydrocarbons[d]	TNMHC	~0.05	29	10	6

[a] From (IPCC 1996), which is used by UNFCCC for GHG accounting   ‡ From (Smith 2000)
[b] The methane GWPs include an indirect contribution from stratospheric H_2O and O_3 production.
[c] The values for methane and nitrous oxide are adjustment times, which incorporate the indirect effects of emission of each gas on its own lifetime.
[d] Nonmethane hydrocarbon molecular weight is assumed to be 18, as is common for such calculations (IPCC 1990).

For an activity that releases more than one GHG, therefore, the Global Warming Commitment (GWC) can be determined as (65, 78)

1) $$GWC_t = \Sigma\, (Q_{CO2} + Q_{CH4}\, GWP_{CH4\text{-}t} + Q_{N2O} GWP_{N2O\text{-}t})$$

where Q refers to the amount emitted of each GHG and t refers to the time horizon of interest.

In addition to these "Kyoto" gases, here are other important combustion-related GHGs. In the newest IPCC assessment, for example, the two most important of all health-damaging air pollutants are now understood to play significant radiative forcing roles themselves: particles (aerosols) and ozone (33). Neither is likely to ever have simple GlobalWPs developed, however, because of the uncertainties and complexities of their creation and atmospheric transformation, and that their effects depend on local conditions

(6, 72). Similar constraints exist for the health-damaging combustion-related pollutants, carbon monoxide and non-methane hydrocarbons, which have clear indirect impacts on radiative forcing, but for which global values for use with every emission source everywhere are unlikely to be developed. Thus the Kyoto gases in Table 1 represent a conservative estimate of total climate impacts from combustion.

Discount rates and time horizons with GHGs

Official GHGs are listed in terms of "time horizons" with substantially different values for different periods, particularly for methane. This formulation was proposed as a means to deal with the need to take more account of near future than far future impacts. Without some way of doing so, the impact of relatively short-lived GHGs, such as methane, would not be counted at all as CO_2 has such a long lifetime. It would have been more realistic to use smooth annual discount rates in this process rather than step-function time horizons (why, for example, should we care equally about an annual impact for the next 100 years, but nothing in year 101?). This is the method used in most other fields, including for example financial analysis and health assessment. Nevertheless, it can be shown that the 20-year and 100-year time horizons in the GWPs are roughly equivalent to 4.3% and 0.7% discount rates, respectively.[35]

The Kyoto Protocol specifies that 100-year GWPs be used to compare and combine the contributions of the gases. For most analyses of potential mitigation options, however, a major purpose is to compare their cost-effectiveness. Do we reduce warming more by investments in hydropower or clean coal per dollar spent, for example? GWPs are used to combine the GHGs into an estimate of the reduction in total Global Warming Commitment (GWC) per unit investment. Financial analyses for public expenditures are typically done at discount rates of at least a few percent, however, and sometime over 5% (57). The WHO Guide to Cost-Effectiveness Analysis, which is part of the WHO CHOICE (***CHO***osing ***I***nterventions that are ***C***ost-***E***ffective) Project,[36] recommends 3% as the base case in cost-effectiveness analyses for health interventions, with 6% for sensitivity analysis (18).

Leaving aside the odd structure of time horizons, should the benefits of GHG reduction be discounted at the same rate as the financial resources required to achieve them? There is a literature addressing this question with regard to the other main benefit being considered here, health. Since society tries to reduce GHGs for the same sort of reasons it takes actions to improve health, i.e., to protect humanity from harm, and we are trying to develop as consistent a framework as possible for co-benefits analysis, similar arguments can be applied for GHG reductions as well.[37]

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[35] This is based on use of the "Bern Model" for CO_2 decay in the atmosphere (29) and a 12-year e-folding lifetime for methane (IPCC, 2001)

[36] http://www.who.int/choice/description/en/

[37] See (52) for a discussion of the effect of the uncertainty in discount rates on decisions related to GHG control .

The literature contains several views of the appropriate discount rates to use for the benefits in cost-effectiveness analyses, ranging from lower than the rate used for costs (23), to the same (20), to variable, i.e., decreasing over time (15) Variable rates complicate calculations and may lead to odd results favoring particular future generations merely because of the mathematical form chosen (20). Most attractive is choosing a rate equal to the rate chosen for cost calculations, typically around 3% (18).

As our purpose here is to focus first on standard well-accepted procedures for both health and climate change evaluations, we report values for Kyoto gases only. As with the approach taken with health, this has the advantage in justifying broad-scale analyses of being clearly conservative (underestimating GHG benefits) because it does not include the non-Kyoto GHGs.

Carbon Markets

A co-benefits calculation results in estimates of tons-CO_2-equivalent (tCO_2e) and DALYs averted by potential interventions. These can be compared directly, as shown below, or further elaborated into common monetary units, i.e., $US. Extensive and usually quite different kinds of approaches, sometimes involving sophisticated modeling, have been applied to estimate the economic impacts of greenhouse-gas warming and health impacts.[38] In the spirit of this presentation, however, we offer simple first cuts, which have the advantage, however, of being in a real sense "market-based," i.e., values that come from the operation of complex, unknown, and probably unpredictable, societal mechanisms, just as with prices in nearly all markets.

As avoided GHG emissions are now a market commodity with a floating international price, there are official carbon exchanges to serve the Kyoto-based Clean Development (CDM) and Joint Implementation mechanisms as well as the voluntary carbon markets. The value of one tCO_2e can easily be approximated simply by checking the European Union Allowance (EUA) futures price per tCO_2e on the web under 'Benchmark EUA Carbon Prices'. For example, as of April, 2007, the 2008 value was about 18 €/ tCO_2e.[39]

Health assessments

There are basically two types of risk evidence that are used routinely for environmental health assessments, epidemiologic and toxicologic, the latter based mainly on controlled animal exposures. Although supportive, other types of information, such as controlled human exposures and in vitro toxicology, are difficult to translate directly into quantitative estimates of actual disease. Here we only focus on exposures with demonstrated effects from disease-focused epidemiologic studies within populations similar to those of concern (43). This involves applying the population attributable fraction (PAF) calculus. (19).

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[38] See for example the work done by the Integrated Energy Strategies project (68), the Norwegian-Chinese collaborations (1, 3, 46, 70), and the useful methods papers (16, 37, 48)
[39] www.carbonpositive.net n.b. Short-term values in this website are not appropriate for this application.

2) $$PAF = \frac{P(RR-1)}{P(RR-1)+1} \quad (1a)$$

where RR refers to the relative risk from epidemiologic studies and P as the proportion of the population exposed.

The exposed population may itself be divided into multiple categories based on level or length of exposure each with its own relative risk. With multiple (*n*) exposure categories, the PAF is given by the following generalized form:

3) $$PAF = \frac{\sum_{i=1}^{n} P_i(RR_i - 1)}{\sum_{i=1}^{n} P_i(RR_i - 1) + 1} \quad (1b)$$

In this way, if enough information is available, one can partly adjust for non-linear exposure-response relationships. Once the PAF is determined, the attributable mortality, incidence, or burden of disease (AB) is then given as

4) $AB = PAF \times B$

where B is the total burden of disease from the disease

Thus, the burden is a function of not only the reduction in relative risk that occurs through reduction of the exposure, but also the background disease rate. The reduction of a certain degree of air pollution exposure in a population with higher background disease rates, for example, will have a bigger benefit than the same reduction in a population with lower background rates.

As ill-health is a function of both premature mortality and morbidity, there is need to apply a combined metric to capture both consistently. Here we use the Disability-Adjusted Life Year (DALY), as developed in (50). Although other lost-time metrics have been proposed (21), the DALY has the major advantage of being elaborated regularly by WHO in detailed, coherent, global, databases, differentiated by age, sex, disease category, and region (74). Lacking such databases, consistent comparisons across groups are not yet possible with burdens calculated in any other metric.

The DALY's characteristics need to be understood to use it effectively, however. In deference to its major guiding principle, "Like is like", the burden from all deaths and diseases are treated equally for everyone of the same age and sex. Social class, income, ethnicity, nation of origin, and all other distinctions are disregarded. This means that in terms of lost life years, a death of a 60-year-old male beggar on the streets of Kolkata is treated the same as that of a 60-year-old male billionaire dying in the Mayo Clinic. In other words, the same survival curve is applied globally. In reality, of course, if saved from the particular condition threatening death at age 60, US billionaires as a group have a longer life expectancy than Indian beggars. Use of such local survival curves is not part of the metric, however, for it would have the pernicious effect of diverting resources to the rich and healthy.

Similarly, the disability weights used for converting the duration of an illness or injury into a lost time metric (YLD: years lost to disability) are in general used globally in the DALY formulation, with the focus being on "disability" and not "handicap", the former being objectively determined while the latter is a function of local circumstances. In recent years, however, there are attempts to differentiate disability weights more regionally, but it is difficult to do so without violating the "Like is like" principle and leading to decisions that may not be widely seen as equitable.

In the spirit of using official IPCC GHGs now incorporated into the Kyoto Protocol, we propose use of the air pollution health burdens from the only existing global risk assessment using systematic methods across major risk factors, the WHO Comparative Risk Assessment (19). Through a process of "consensual discipline," the groups conducting analysis for each risk factor presented their preliminary methods and results to the entire group, with the result that each risk factor group was required to whittle down their list of disease endpoints to only those with the best available information so that there was some compatibility across the whole assessment. The resulting list of diseases and risks for the largest health risks associated with air pollution emissions from fuel combustion, indoor and outdoor, are summarized in Table 2 (12, 17, 55, 64). In the case of both types of pollution, however, a number of other disease endpoints have been associated with the pollution in multiple epidemiological studies. Thus, as with the Kyoto GHG list, the WHO CRA list of diseases is arguably conservative.

Table 2. Risks from outdoor and indoor air pollution with example from China. DALYs/exposure will be different in other countries due to different background disease risks. Sources: (12, 64) [0% DALY column to be added]

	Population	Exposure Metric	Relative risk per unit	DALYs/ exposure[a]
Outdoor		1000 people		3% DALY
Cardiovascular	Adults>30	10 µg/m3 PM2.5	1.059	1.56E-01
Lung Cancer	Adults>30	10 µg/m3 PM2.5	1.082	2.26E-02
ALRI	Children<5	10 µg/m3 PM10	1.01	1.64E-02
Indoor		Household (HH)		
COPD	Adults>30	Solid fuel use	3.2	1.17E-02
Lung Cancer	Adults>30	Solid fuel use	1.9	5.03E-03
ALRI	Children<5	Solid fuel use	2.3	7.58 E-03

a These values would be different in other parts of the world. See (17, 55)

Discount rates and time horizons in health assessments

Recognizing the need to strike a reasonable balance between near-term and far-term allocations of resources, the baseline DALY is formulated with an internal discount rate of 3%, which, as noted above, is about the lowest rate considered suitable in financial calculations.[40] This means that the death of a 5-year old girl, who has an actual lost life expectancy of 78 years, would count as just 36.6 years of life lost (YLL) at a 3% discount rate (50). The often unrecognized corollary to this, however, is that interventions to improve health that have long delays or only deal with chronic diseases that take many years to change need to be discounted back to the decision point as well (present value). For example, a change in air pollution that might start reducing heart disease in five years, but cancer in 15, would be given credit in a proposed project for a greater portion of the heart disease reduction than the cancer reduction because of discounting.

The WHO Guide to Cost-effectiveness Analysis recommends 3% as the base case, as with costs, but that a zero discount rate be applied as a sensitivity analysis for health benefits (18).[41] Any analysis using a zero discount rate will produce clearly unacceptable results, however, if applied to long-term programs. Would one, for example, count lives saved in a thousand years from actions taken today equal to those saved this year?[42] Because the WHO Guide, like the IPCC, adopts a time horizon (10 years) for evaluating programs, however, it side steps this dilemma.

Unfortunately, a 10-year time horizon is even more unrealistic than those used by IPCC, since there are many co-benefits activities with implications well beyond a decade, even taking longer to implement let alone reach their full health-protection and GHG-reduction potentials. To circumvent this problem and to be consistent with the effective discount rates used for the GWPs, therefore, we adopt a 1% minimum discount rate for health assessments.

Health "Markets"

There is a long and extensive literature on determining the costs of health impacts using various methods with focus in recent years on willingness to pay (WTP) approaches (54, 60). Depending on the needs of local policy makers, for the most convincing evidence in a particular setting it will likely be necessary to undertake such work with local data, which may even involve developing WTP factors from local surveys. For the kind of scoping exercise being discussed here, however, there is a much simpler alternative. In recent years, a kind of "market-based" value of the DALY has emerged in the international health academic and policy literature (32). One way to compare possible

[40] The GBD databases also provides tabulations of DALYs calculated with zero discount (39)

[41] See the summary (51) in (36), which also provides many examples of applications across health sectors. The approaches, which are elaborated in (35), were first framed in (77).

[42] This has been referred to as the "Rare disease paradox," i.e., that with a zero discount rate, all health resources would go into eradicating those few infectious diseases that can be completely eradicated, no matter how rare, because we would be thus saving millions of future generations from them (39).

interventions with large ranges in cost-effectiveness and total impacts is shown in Figure 1.

The international development agencies concerned with health, including WHO, the World Bank, UNICEF, have been promoting a kind of cost-effectiveness triage for countries in health-related investments, based on recommendations of the Commission on Macroeconomics and Health (13)

- "Very Cost-Effective": Less than the local GDP/capita per DALY ($GDP/capita-DALY) should be considered part of primary health promotion and be undertaken as quickly and widely as possible.
- "Cost-Effective": Between one and three times the local $GDP/capita-DALY, interventions should be seriously considered with appropriate attention to the needs of special populations, regions, etc and the cheaper ones should generally be undertaken first.
- "Not Cost-Effective" More than three times the local $GDP/capita-DALY, interventions should be left to private markets and not be part of government or donor activities.

For illustration, in China the value of a 2004 DALY saved would range $1500-$4500 (67). As there is a widely used and extensively documented methodology for determining the DALY impacts from air pollution and other interventions (19), this approach allows relatively easy conversion first to health impact and then to monetary value not only at present, but in future based on estimated changes in per capita GDP. Its disadvantage, however, is that DALYs may not directly reflect non-disease outcomes such as emergency hospital visits, lost work days, use of medication, etc., which often feature in studies of air pollution effects, although usually finding much lower total costs than due to lost lives (3). It is noteworthy, however, that the WTP approach seems to come to a similar overall result, for example $175,000 per lost life in China in 2002, which would seem to be roughly equivalent to the 3x$GDP/capita-DALY value in the same year, i.e. about 38 lost DALYs per death (10).

Summary of Metrics for Co-benefits Scoping

Table 3 summarizes the metrics recommended for use in co-benefits scoping exercises along with three variations in the set of discount rates for sensitivity analyses. The first variation, labeled the Kyoto Case, uses 100-year GWPs as specified by UNFCCC and the lowest discount rates for DALYs and dollars deemed feasible. The second is labeled Base Case because it would seem to be most realistic in terms of normal temporal discounting, uses 20-year GWPs and 3% discount rates for DALYs and dollars. The last labeled, Financial Case, applies a 6% rate to the dollars alone, more closely reflecting the actual rates in capital markets. Details of cost calculations, including ways to handle inflation and the reasoning for use of PPP, are found in (18)

Table 3: Summary metrics for use in co-benefits scoping.

	Health	Climate Change	Finances[a]	
Metric	DALYs	GWC	International Dollars	
	Disability-Adjusted Life Years	Global Warming Commitment	In general, for comparisons within a country, direct currrency exchange conversion	
Unit	Years	Tons CO_2 equivalent	US Dollars	
Formulation	Years lost from premature death plus weighted years lost to disability	Tons CO_2 plus tons other GHGs multiplied by their global warming potentials (GWPs)	In general, for international comparisons, use purchasing power parity (PPP) corrections	
Source of information	WHO Comparative Risk Assessment, if no local information	IPCC GWPs and default emission factors if needed	WHO Cost-Effectiveness Guidelines	
Valuation	1-3x local Gross National Income/capita per DALY. GNI from: http://hdr.undp.org/hdr2006/statistics/	International market value from: www.carbonpositive.net	PPP conversions from: http://hdr.undp.org/hdr2006/statistics/	
Discount Rates	DALYs[b]	GWPs	Benefits	Costs
Kyoto Case	0%	100-year ~ 0.7%	1%	3%
Base Case	3%	20-year ~ 4.3%	3%	3%
Financial Case	3%	20-year ~ 4.3%	3%	6%

a. Many other considerations also go into the calculations of the costs of a project that are not addressed here. For example, see (18, 36).
b. The WHO database provides only these two options for the internal discount rate used in DALY calculations.

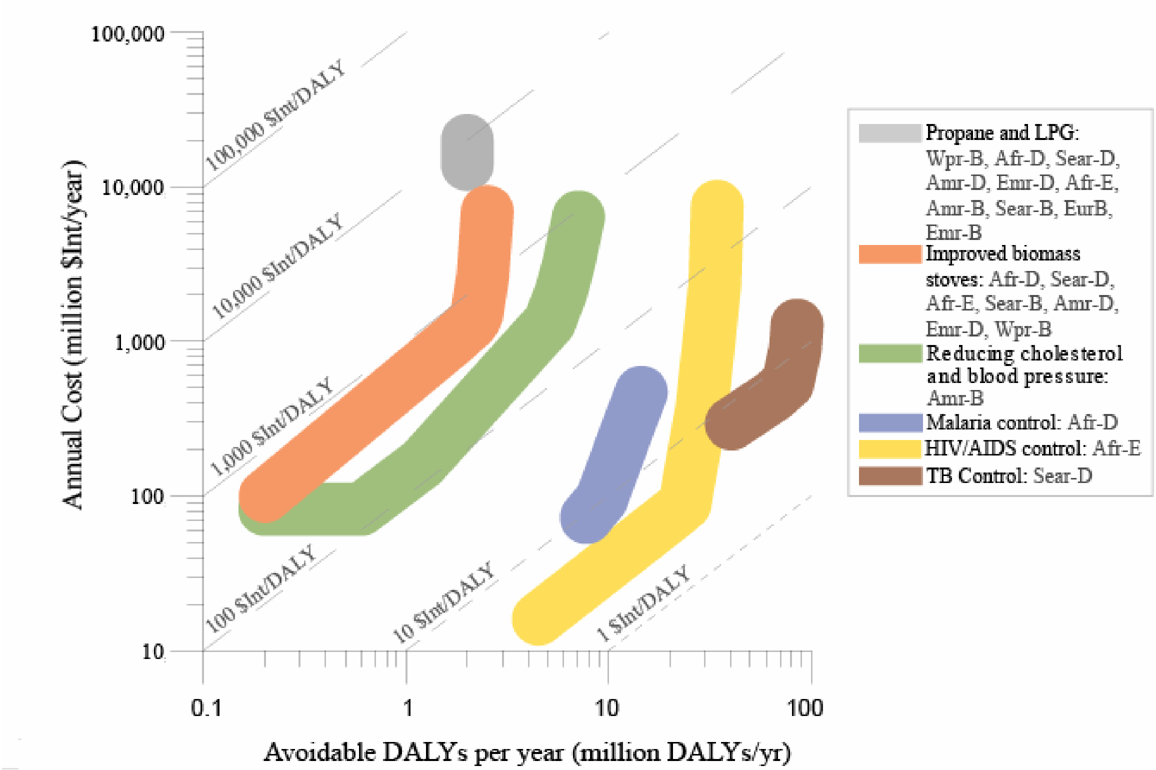


Figure 1. Total cost, total benefit in DALYs, and cost effectiveness of a range of health interventions.

1. From WHO-CHOICE: (5, 27, 45, 47, 49). Each band represents the incremental cost effectiveness of several approaches and coverage levels for each category of health intervention.

Example: A Household Fuel Intervention in China

The poorest half the world's households cook with solid fuels, mainly as biomass or coal. This traditional household use accounts for nearly 10% of global energy use and, because biomass contains less energy per unit carbon than fossil fuels, it accounts for some 13% of direct global carbon emissions from all human fuel use, although less of net emissions (22). Although agricultural residues and much of the wood burned in households is harvested renewably and thus is CO_2 neutral, the poor combustion typical in simple devices results in substantial releases of the Kyoto GHG, methane, as well as the second-level GHGs carbon monoxide and hydrocarbons and the tertiary GHP, black carbon particles (78). A significant, but poorly known, fraction of the fuelwood is not renewable harvested, however, and thus, like coal, is a net emitter of CO_2 when burned. Given the poor combustion and efficiency, and the resulting high pollutant emissions and exposures, GHG and health impacts per unit useful energy are high compared to other energy sectors, leading to high potential co-benefits (4, 7, 62, 63, 71, 78). Costs per unit energy are also relatively high, however, and thus the overall cost-effectiveness is not obvious.[43]

The poor combustion and lack of good ventilation typical in simple household stoves, results in high indoor and near-household air pollution exposures. This in turn has been associated with a range of diseases, with best evidence for pneumonia (acute lower respiratory infections) in children and COPD (chronic obstructive pulmonary disease) in women, the two groups receiving the highest exposures (64). See Table 2.

To illustrate how variations in the analysis parameters affect the results, we use the example of a major substitution possible today, a switch from household use of coal for cooking in rural China to use of advanced biomass "gasifier" stoves that achieve dramatically lower emissions of health-damaging and methane emissions through better combustion efficiency and a cleaner fuel source, crop residues, as well as lower CO_2 emissions because a non-renewable fuel, coal, is replaced by crop residues, which are by definition renewable. As shown in Table 4, in the Kyoto Case, the cost-effectiveness as either a health intervention ($370/DALY) or a carbon intervention ($5.6/ tCO_2e) is well below the "market" thresholds ($1500/DALY and $10/ tCO_2e, respectively). According to the analysis, the full health and climate value of an introduced stove is about $300, 69% as health benefits. Based on present value calculations, the benefit/cost ratio is about 6.

Table 4. Cost-effectiveness on the basis of health, climate, and combined of shifting from a coal to a biomass gasifier cookstove in Chinese rural areas, using the standardized information in Tables 1-3.

Case	$/DALY	$/$tCO_2e$	Health (at $1500/DALY)	Carbon (at $10/$tCO_2e$)	Total ($/stove)	% Health
Kyoto	$374	$5.64	$205	$91	$295	69%
Base	$479	$4.93	$160	$104	$264	61%
Financial	$411	$4.23	na	na	na	na

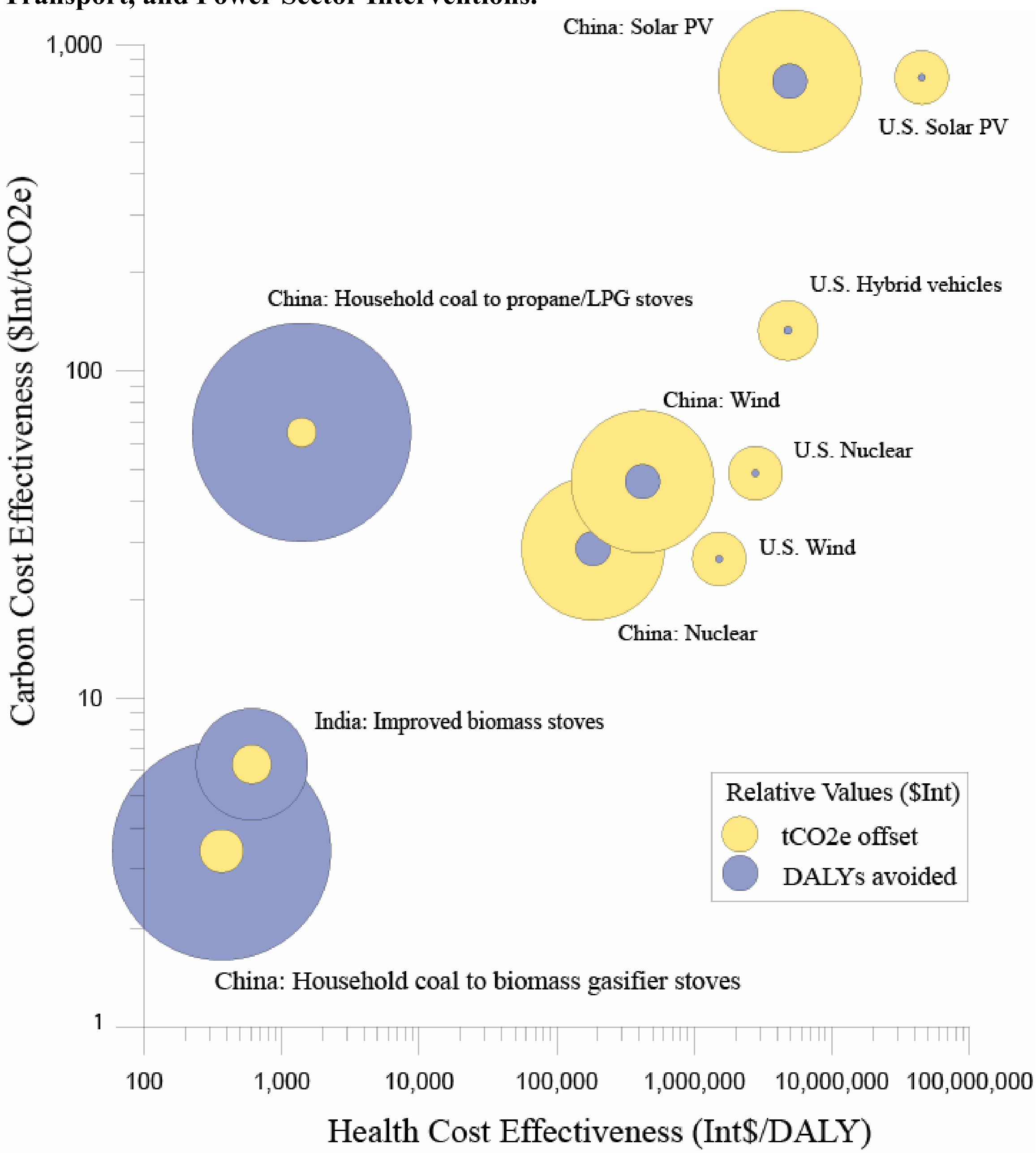
Assumptions: $60 average per stove installed (50% more than retail price of $40 to account for program costs and losses); costs are front loaded to allow for start up investments in the program; effectiveness is 50%, i.e., carbon and DALYs only go down by 50% of their full impact per installed stove; 10-year dissemination program introducing 100,000 stoves starting at 5000/y and ending at 12,000/y, with 10% of those in place each year needing to be replaced – approximate half-life of 7 years; extra fuel processing costs balanced by fuel savings to households. Undiscounted totals: $6 million program cost; 17.8 thousand DALYs; 830 thousand tCO_2e.

Although these are the results of a scoping procedure and would need local information to be made more precise, given the methods used, probably represent fairly conservative estimates. As such, they would seem to call attention to this class of interventions for co-benefits investments.

[43] Standard methods have been developed by WHO to deal with the health and economic benefits of interventions in this sector (30, 31).

This kind of calculation can be placed against others as shown in Figure 2, which is based on estimates in the literature adjusted as best as possible to consistent methods and assumptions. Here, for international comparison, we have used the mean world GDP/capita for the DALY evaluation to be parallel to the global carbon price. In this way, the "like is like" principle is not violated, i.e., all health impacts are valued in a common metric within the systems boundaries of the analysis (50).

Figure 2: Comparison of the Health and Climate Cost-Effectiveness of Household, Transport, and Power Sector Interventions.



1.Area denotes the total 'Social Benefit' in International Dollars from the combined value of carbon offsets (valued at 10$/ tCO_2e) and averted DALYs ($7450/DALY, which is representative of valuing each DALY at the avg. World GDP (PPP) per capita). DALYs for China, India, and the United States are calculated based on populations in 2000 relative to WHO subregions Wpr-B, Sear-D, and Amr-A, respectively.
2.The Nuclear, Wind, and Solar Photovoltaic (PV) scenarios estimate the average annual value of cobenefits realized by replacing excess coal demand between 2000 and 2020 with each technology. Carbon cost-effectiveness estimates are from (61), and ambient PM2.5 source apportionment from coal in China and the U.S. are roughly, yet conservatively, estimated to be 20% (50% less than values in (38)).
3.The stove scenarios for propane/LPG (liquefied petroleum gas) in China and improved biomass in India use estimates of stove-program costs and avoided DALYs from (45), a WHO-CHOICE publication. The China gasifier scenario is from Table 4., but notably assumes $7450/DALY for comparability. For all three cases emissions factors are from(65) and IPCC defaults, fuel consumption is assumed to be typical, and all biomass is assumed to be 60% renewable.
4.The Hybrid scenario is a thought experiment in which it is assumed the U.S. fleet rapidly transitions to hybrid technology between 2008 and 2015. For rough calculations it is assumed hybrids cost $3,000 extra per unit, use 30% less fuel (valued at 2$/gallon) and emit 30% less GHGs and PM2.5 than standard automobiles. 19% of ambient PM2.5 is from 'mobile sources' (38).

Conclusion: Value of Standard Methods

With the Kyoto Protocol and growing national and local actions, the world is inexorably moving toward shared responsibility for climate change. The IPCC and UNFCC are the UN-related organizations charged with developing standard methods for assessing the climate protection benefits of alternate activities, among their many other tasks. Although international shared commitments in health and development are older, well considered and vetted methods for analysis of alternative interventions are only just this decade coming to fruition through the WHO and other UN-related organizations (WHO-Choice, Commission on Macroeconomic and Heath, the WHO Comparative Risk Assessment, World Bank Disease Priorities Project). Although not without remaining uncertainties and ambiguities, the work in these documents was conducted by significant numbers of the world's most prominent experts in relevant fields and extensively peer-reviewed. It thus probably represents the best possible compilation of knowledge of how to conduct fair, balanced, and meaningful assessments of actions to protect health and climate.

For guidance in doing co-benefits analysis, we have thus briefly laid out some of the main features of the methods for assessing interventions for climate mitigation and health promotion. We then offer ways to combine them together into common coherent analyses of co-benefits in the energy sector. We touch upon related issues in financial analysis, but these extend further than we can follow in the space here.

Our short example in household energy illustrates that first-level scoping indicates that co-benefits from targeted interventions in the energy sector can be highly cost-effective for protecting health and climate.

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Base Case Co-benefits: Coordinating and Systemizing Evaluation Methods with Examples from China

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Presentation at the IGES Scoping Consultation
The Developmental Co-Benefits of Climate Policies in Asia
Bangkok, Aug 3, 2007

Major Co-benefits Questions

1. Is it possible to simultaneously achieve both significant carbon credits as well as progress toward development goals?
   i. "Significant" statistically
   ii. "Significant" substantively
2. What methods are available to estimate, measure, and confirm these benefits?
   i. Should be robust and easy to apply
   ii. Should be traceable to international norms

And,

- How does one handle trade-offs between the two, that is,
  - Make a decision to go with a project that achieves more progress toward development goals, but costs more per ton of carbon?
- Context: Scoping methods for UNDP MDG-Carbon Facilities (Beijing/New York)

Background to Central Premise

- Methods for determining benefits in terms of carbon credits, health improvements, economic development, etc. are complex and in flux, and vary according to a range of explicit and implicit assumptions made by the analyst. e.g.:
  - Basic metrics for health, economic development, etc.
  - Economic valuation approaches
  - Discount rates
- Nevertheless, there has been much progress in recent years within the context of major international collaborative assessments for some of the benefits being considered

International Collaborative Assessments

- IPCC/UNFCCC: Metrics and procedures for calculating carbon credits
- Millennium Development Goals: 8 MDGs with ~30 explicit indicators and metrics
- Commission on Macro-economics and Health: established health burden metrics and standard methods for cost-effectiveness analysis
- WHO Comparative Risk Assessment: Metrics of exposure and health burden with estimated exposure –response relationships and uncertainties

Premise

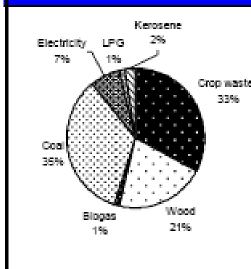
- The first scoping of benefits should use the methods and metrics established by the international collaborative assessments –base case
- Elaboration can be made in additional analyses (cases) based on particular needs or local conditions

Examples will be drawn from the rural energy sector in China

- The energy sector is where most GHG emissions derive
- Rural areas are where energy is most closely tied to household health and development
- China is in a position to implement a range of projects soon

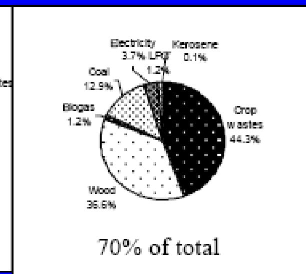
Rural Energy in China: 2004

Total



Ministry of Agriculture

Households



National Bureau of Statistics

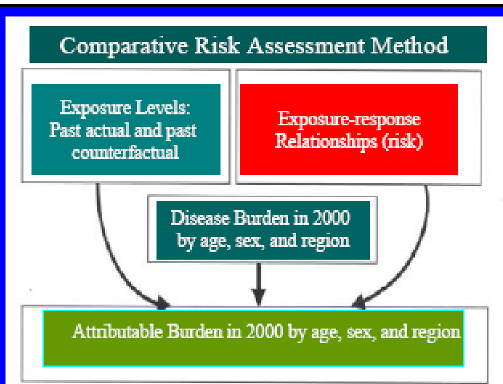
Comparative Risk Assessment (CRA) 2-year 30-institution project organized by the World Health Organization

Disease, injury, and death due to 26 major risk factors calculated by age, sex, and 14 global regions.

Fully published in late 2004 in two volumes by WHO

WHO CRA

- Standard methods and metrics
- Common databases
- "Consensual Discipline"
- Uncertainty explicitly ascertained
- Heavily peer-reviewed
- Published in detail
- Regular update
  - Next update starting Sep 2007



Health Effects of Indoor Solid Fuel Combustion*

Use of biomass fuels in households increases risk of

- Chronic Obstructive Pulmonary Disease in adult women by a factor of 3.2 (95% CI: 2.3-4.8).
- Pneumonia in children under 5 years old by a factor of 2.0 (95% CI: 1.7-2.5).
- Lung cancer in women, coal only

*Review of many dozen studies worldwide by World Health Organization (WHO, 2002,2004)

Health Benefits of Fuel/stove Intervention

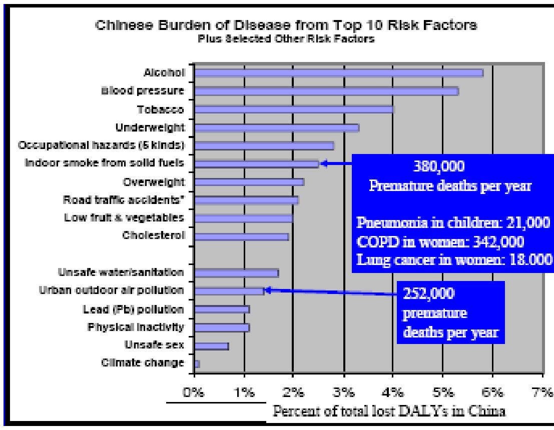
Best published studies in the world were done by examining introduction of improved coal stoves in China

Improved Stoves Brought to Xuanwei County in early 1980s

- The reduction in particle levels was ~a factor of about three.
- Reduction in lung cancer was ~40% in men and ~45% in women. (*Journal of the National Cancer Institute)*
- Reduction in COPD rates was also significant at about 50% in both men and women (*British Medical Journal*)
- Reduction in lung cancer and COPD took 10 years to fully develop after IAQ improvement.

Metric Used for Comparative Risk Assessment

- Lost life years only type of unit ever proposed that systematically includes premature mortality and morbidity
- And puts everyone on Earth on an equal basis, i.e., we all share the right and capability of the same length of healthy life
- The Disability Adjusted Life Year, DALY, one such metric, is the only one with systematic, worldwide databases that allow consistent comparisons across age, sex, disease, risk factor, and region the world.



MDG 4. Reduce child mortality.

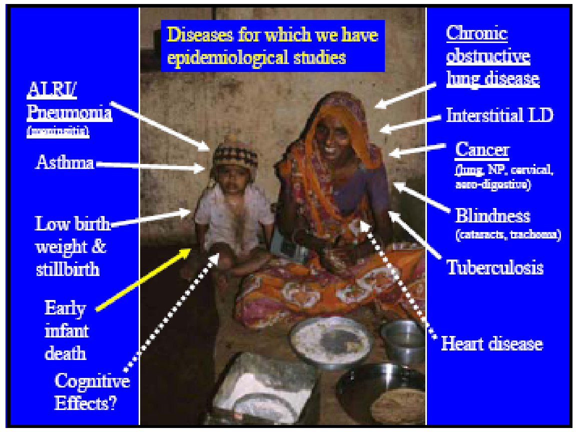
- **Official Indicators**
  - 13. Under-five mortality rate
  - 14. Infant mortality rate
- **Rural Energy – closely related indicators**
  - **Mortality/morbidity from pneumonia**
  - **Incidence of low birth weight**

MDG 5. Improve maternal health.

- **Official Indicators**
  - 16. Maternal mortality ratio
- **Rural Energy – related indicators**
  - Mortality/morbidity from chronic obstructive pulmonary disease (COPD) and lung cancer in women
  - TB, cataracts and heart disease in women

MDG 6: Reduce TB, HIV, Malaria

- Official indicator
  - 23. Prevalence and Death Rates Associated with Tuberculosis
- **Rural Energy – related indicators**
  - **<u>Pneumonia as chief fatal outcome of HIV in children</u>**
  - **TB as chief fatal outcome of HIV in adults**



Absolute impact depends on

1. Exposure difference
2. Risk (exposure-response relationship)
3. Background disease rate

As all depend on local conditions, the impact of a risk factor, such as air pollution, will not be the same in different populations

Indoor and Outdoor Air Pollution Risk Factors in China

	Population	Exposure Metric	Relative risk per unit	DALYs/ exposurea
Outdoor		1000 people		3% DALY
Cardiovascular	Adults>30	10 µg/m3 PM2.5	1.059	1.56E-01
Lung Cancer	Adults>30	10 µg/m3 PM2.5	1.082	2.26E-02
ALRI	Children<5	10 µg/m3 PM10	1.01	1.64E-02
Indoor		Household (HH)		
COPD	Adults>30	Solid fuel use	3.2	1.17E-02
Lung Cancer	Adults>30	Solid fuel use	1.9	5.03E-03
ALRI	Children<5	Solid fuel use	2.3	7.58 E-03

WHO CRA, 2004

How to quantify, verify, and value? Mothers' and Children's Health

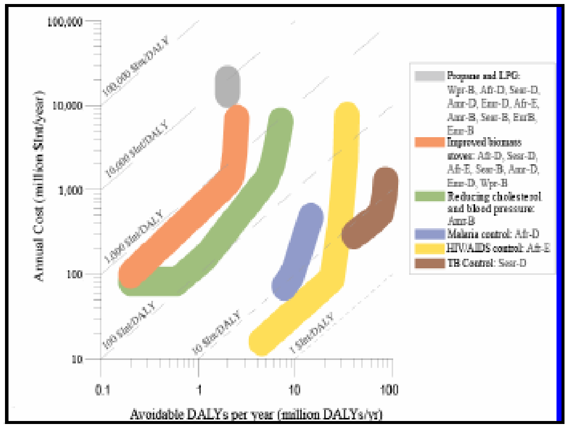
- Apply peer-reviewed results of meta-analyses of health benefits from household energy improvements using standard epidemiologic risk techniques in the WHO CRA to estimate DALYs for each population group
- How to determine economic value? WHO/IBRD has developed methods and recommendations

Commission on Macro-economics and Health, 2001

- Recommended methods and criteria for setting priorities among health interventions based on
  - DALYs: saved healthy life years
  - Cost: in terms of local income levels
- Adopted by World Health Organization and World Bank

Recommendations

- **"Very Cost-Effective":** Less than the local $GDP/capita per DALY should be considered part of primary health promotion and be undertaken as quickly and widely as possible.
- **"Cost-Effective" :** Between one and three times the local $GDP/capita-DALY, interventions should be seriously considered and with appropriate attention to the needs of special populations, regions, etc; the cheaper ones should generally be undertaken first.
- **"Not Cost-Effective" :** More than three times the local $GDP/capita-DALY, interventions should be left to private markets and not be part of government or donor activities.



Cost-Effectiveness Analyses

- Need to apply consistent criteria
- Need to stick to UNFCCC rules for CDM
- No need to depart from recommendations by WHO/IBRD for health analyses
- Need to reflect standard financial analysis methods
- Is need to adjust discount rates and other protocols to bring the three types of analysis together
  - DALYs - health
  - Global Warming Commitments – climate change – including use of GWPs for combining GHGs
  - Costs – financial analysis

Summary metrics for use in co-benefits scoping.

	Health	Climate Change	Money	
Metric	DALYs (Disability-Adjusted Life Years)	GWC (Global Warming Commitment)	International Dollars	
Unit	Years	Tons CO_2 equivalent	US Dollars	
Formulation	Years lost from premature death plus weighted years lost to disability	Tons CO_2 plus tons other GHGs multiplied by their global warming potentials (GWPs)	Local currency adjusted by its capability to buy standard market basket of purchases	
Discount Rates	DALYs	GWPs	Benefits	Costs
Kyoto Case	0%	100-year ~ 0.7%	1%	3%
Base Case	3%	20-year ~ 4.3%	3%	3%
Financial Case	3%	20-year ~ 4.3%	3%	6%

Health Impact in China

- Indoor air pollution from household solid fuel use – 2002 (WHO)
  - Children: 21,000 deaths from pneumonia
  - Women: 342,000 from COPD
    18,000 from lung cancer
  - Burden = 3.2 million DALYs
- If half reduced, at $4500/DALY (3x GDP/cap) = $7.2 billion/yr
- Without credit for poisonous coal

Carbon from Rural Coal

- Ministry of Agriculture: 167 million tons coal used in 2005
- If half could be saved: 260 million tCO2 at $15 = $3.9 billion/yr
- If combustion efficiency could be increased so that the methane emissions are reduced from the remainder, depending on GWP, perhaps an additional $2 billion/yr could be had

A Chinese Biomass Gasifier Stove

Tests show PIC emissions nearly at LPG levels.

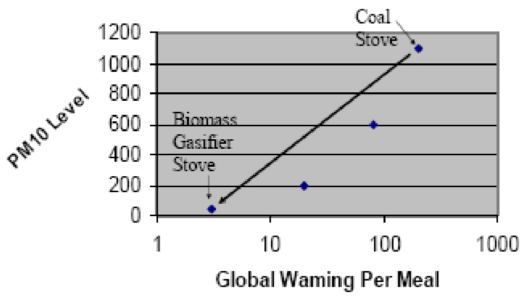
Winner of Chinese national contest
announced March 2007 for best stove meeting
emissions and reliability criteria: cost 300Y

Three Co-benefits Cases for Chinese Rural Energy Sector: Substitution of Biomass Gasifier Stoves for Coal Stoves

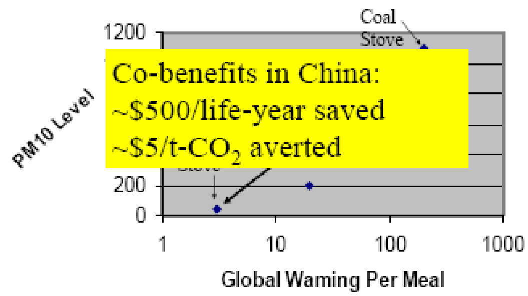
Case	$/DALY	$/tCO2e	Health (at $1500/DALY)	Carbon (at $10/tCO2e)	Total ($/stove)	% Health
Kyoto	$374	$5.64	$205	$91	$295	69%
Base	$479	$4.93	$160	$104	$264	61%
Financial	$411	$4.23	na	na	na	na

Source: Smith & Haigler, in press

Health and Greenhouse Gas Benefits of Biomass Stove Options



Health and Greenhouse Gas Benefits of Biomass Stove Options

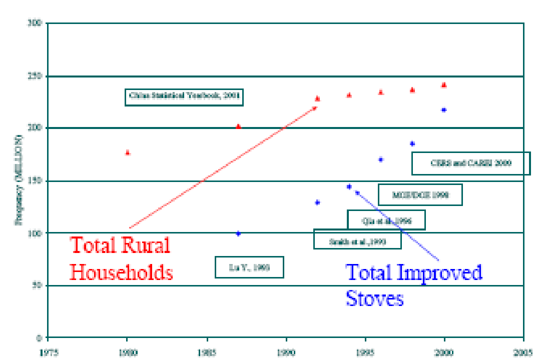


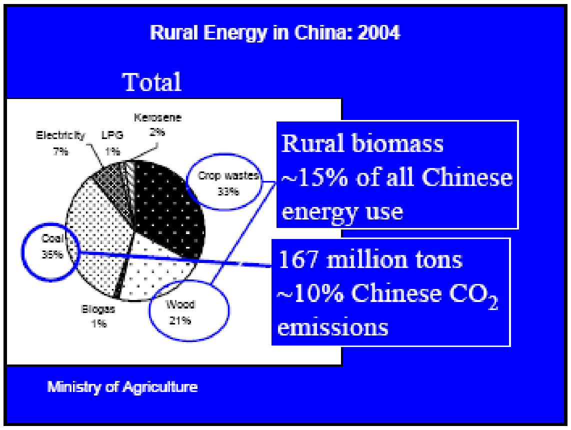
China has shown itself capable of major achievement in rural energy, including one of the largest rural development Programs in human history and, purportedly, the most cost-effective Energy efficiency measure undertaken in China.

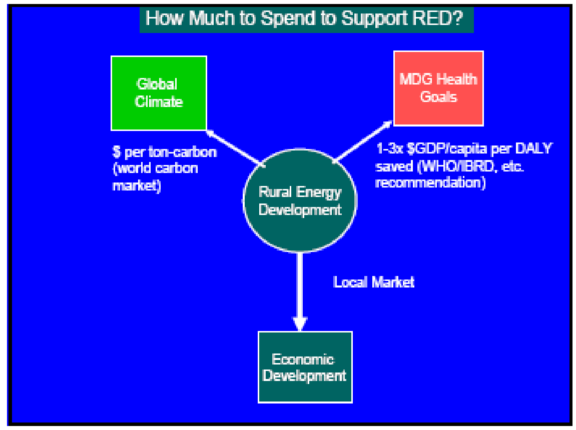
Improved Biomass Stoves in China

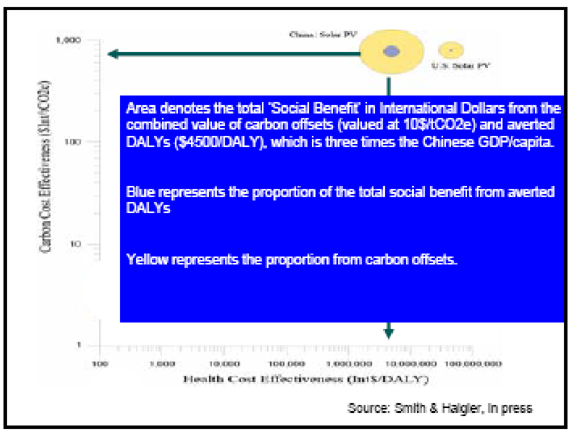
More than 180 million introduced 1981-1998

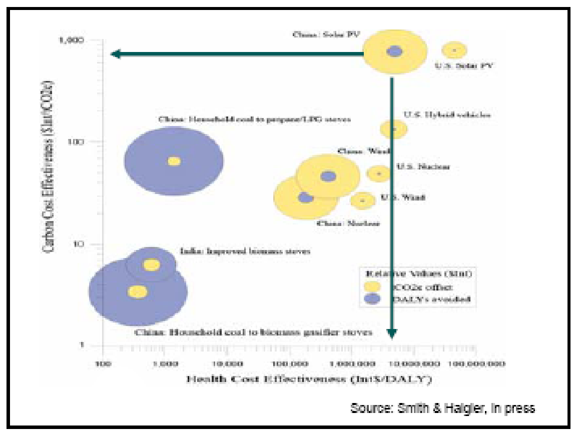
China's National Improved Stove Program (NISP)











What about non-health co-benefits?

- Several of the other MDG goals offer indicators that could serve in base case analyses for other development co-benefits
- Two examples follow

MDG 1. Eradicate extreme poverty and hunger.

- **Official Indicators**
  - 1. Proportion of population below $1 (PPP) per day
  - 2. Poverty gap ratio [incidence x depth of poverty]
  - 3. Share of poorest quintile in national consumption
  - 4. Prevalence of underweight children under-five years of age
  - 5. Proportion of population below minimum level of dietary energy consumption
- **Rural Energy – other possibilities as well**
  - Fuel costs per person-meal.
  - Time spent cooking.
  - Time spent obtaining and preparing fuel
  - Economic modeling of the effects of expanding rural energy activities

MDG 7.Environmental Sustainability

- Official Indicators
  - 25. Forested land as percentage of land area;
  - 27. Kg oil equivalent per $1,000 (PPP) GDP;
  - 28. Carbon Dioxide Emissions (per capita)
  - 29. Proportion of population using solid fuels
  - 30. Proportion of the Population with Access to Improved Water Source;
- Rural Energy – other possibilities as well
  - **Carbon storage;**
  - **CO2-equivalent GHG emissions;**
  - **biodiversity preservation;**
  - **fraction of renewable energy;**
  - **reduction of diarrhea rates**

Conclusion

- The first scoping of benefits should use the methods and metrics established by the international collaborative assessments
  - they represent a consensus of world expert opinion on how best to navigate through the complexity of such analyses
  - This would represent in all analyses, the **Base Case**
- Elaboration can be made in additional analyses (cases) based on particular needs or local conditions
  - Departures from Base Case to be clearly stated
  - Restricted, however, to peer-reviewed methods in published literature

Need, however

- To slightly adjust the methods proposed by the different groups to be consistent with one another, e.g.
  - Discount rates
  - Valuation techniques
  - Time periods
- Must be verifiable at reasonable cost
  - "You don't get what you expect, you get what you inspect"

The presentation based on

Smith KR and Haigler E, "Co-benefits of climate mitigation and health protection in energy systems: Scoping methods" Symposium on Climate Change and Health Ed, KR Smith, *Annual Review of Public Health*, 29 (forthcoming, 2008).

Full list of CO-benefits publications since 1992: http://ehs.sph.berkeley.edu/krsmith/page.asp?id=5

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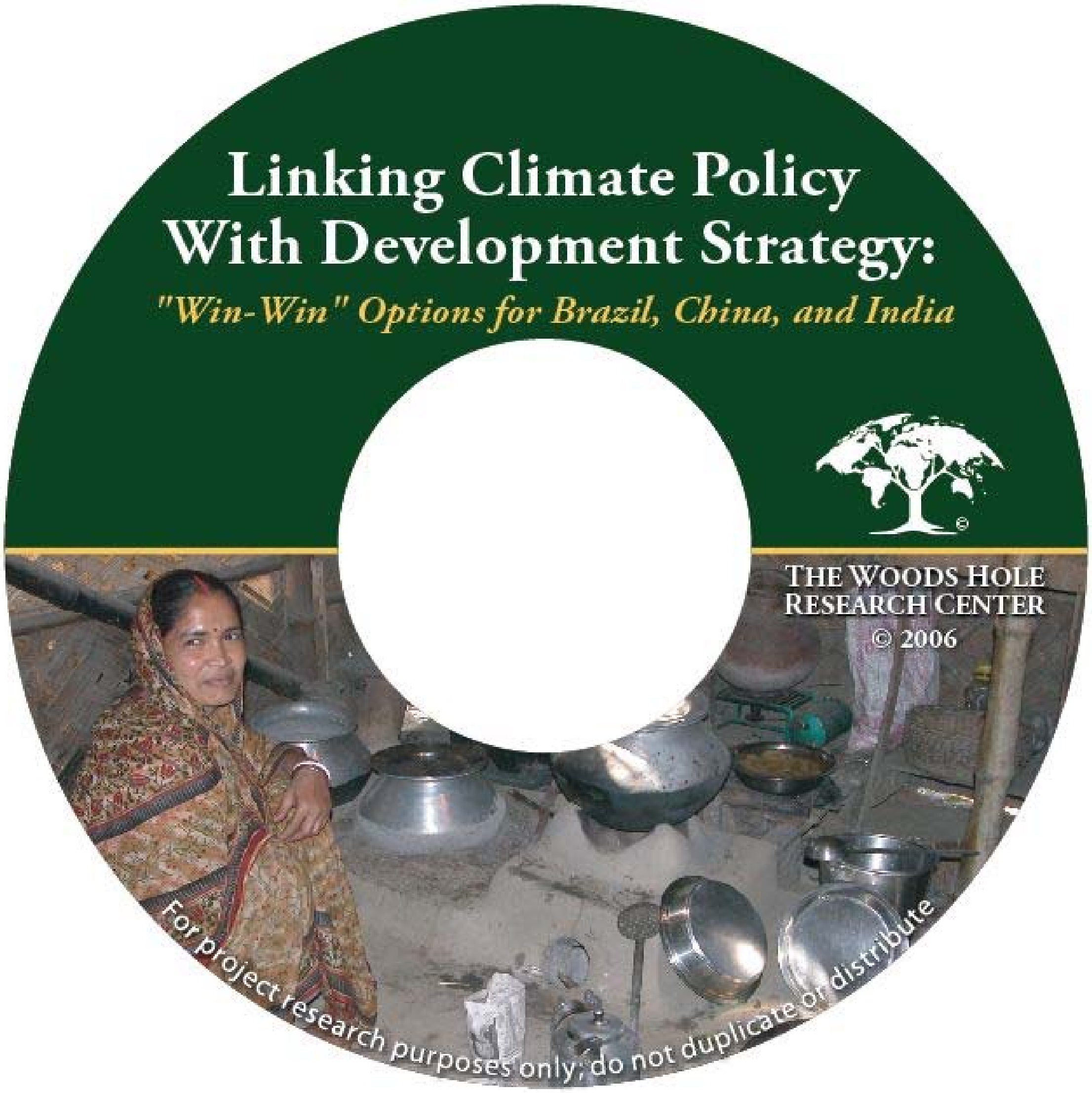
Thank you



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**Linking Climate Policy with Development Strategy:
in Brazil, China, and India**

Updated List of Resources—November 2007

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[i] Actual projections of China's total urban population in 2020 vary but most estimates have settled within a range of 50 to 70 percent urban by 2020. See Wang (2004) for a discussion of the parameters germane to urbanization-related policy discourse in China.

[ii] China's *Electricity Statistical Yearbook* classifies electricity generation as "thermal," "hydro," "nuclear," or "other"; fossil fuel-based generation is not disaggregated. Electricity(include heat)'s share of total CO2 emissions and total CO2 emissions data is from Climate Analysis Indicators Tool (CAIT) Version 4.0(Washington, DC: World Resources Institute, 2007). And coal-fired generations share of these emissions, were calculated by using energy input/output tables and heating values in the *Energy Statistical Yearbook* (NBS, 2004).

[iii] Energy Statistical Yearbook (NBS, 1995-2006)

[iv] Source: Chinese statistic book, 2006

[v] Source: IEA, Energy consumption by sector, 2005

[vi] Source: Chinese statistic book, 2006

[vii] Source: Tsinghua University, Background report of vehicle fuel economy, 2002

[viii] Source: Zhao Lifeng, Economic Assessment of Deploying Advanced Coal Power Technologies in Chinese Context; National statistic year book 2006; The future of Coal, MIT

[ix] Discount rate used in this study is 10%, and the depreciation period is 15 years

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[xi] NDRC & SEPA. 11th Five-year Plan on SO2 Emission Treatment for Existing Coal-fired Power Plants. 2007

[xii] Lifeng Zhao, et al. 2007. Recent Progress and Remaining Challenges for Advanced Coal Technology in China

[xiii] Source : Chinese 863 plan report on electrical vehicles, MOST, 2006

[xiv] Source: This table is from engineers of some Chinese automobile manufacturers.

[xv] Source: NDRC, China Medium and Long Term Energy Conservation Plan, 2004.

[xvi] Source: NDRC, the "11th Five-Year Plan" on Ten prioritized energy-saving projects implemented views, 2006

[xvii] Source: Fusha, 2006, Master thesis, Renmin university of China