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Strategies for Low Carbon Growth In India: Industry and Non Residential Sectors

Authors

Sathaye, Jayant
de la Rue du Can, Stephane
Iyer, Maithili
et al.

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Strategies for Low Carbon Growth In India: Industry and Non Residential Sectors

Jayant Sathaye, Stephane de la Rue du Can, Maithili Iyer, Michael McNeil, Klaas Jan Kramer

Environmental Energy Technologies Division

Joyashree Roy, Moumita Roy and Shreya Roy Chowdhury

Jadavpur University

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Industry experts

Mr.Ranjan Kumar Padhy, Junior manager, Joint Plant Committee

Mr.Pingal Das, Deputy Director, National Institute of Secondary Steel

Mr.Debashish Chatterjee, Deputy Director, National Institute of Secondary Steel

Mr.Pradip Kumar Batabyal, Technical Officer, The Fertiliser Association Of India

Mr.Tapan Chakraborty, Consultant Environment, (Ex)Tata Steel Limited And Steel Authority of India Limited.

Mr.Subir Kar, Consultant, Ex-GM SIEMENS India

Dr.Swadesh Bhattacharya, Indian Chamber Of Commerce

Prof.Siddhartha Datta, Pro-Vice Chancellor & Professor of Chemical Engineering, Jadavpur University.

Prof Shyamal Kanti Sanyal, VC and Prof of Chemical Engineering Department , Advisor WBPCB.

Mr.Debal Ray, Chief Environmental Officer, West Bengal Pollution Control Board

Mr.Sadhu, Vice President, Bengal Ambuja Cement

Mr.Mohanti, General Manager, Emami paper mills

Mr.Rabin Mukhopadhyay, Senior Vice President, Haldia Petrochemical Limited.

Mr.Kaushik Saha, Haldia Petrochemical Limited.

Mr.Kaustav Basak, Haldia Petrochemical Limited.

Mr.Partha Sur, Technology Cell, Haldia Petrochemical Limited.

Prof Samir Saha, Professor, Dept of Mechanical Engineering, Jadavpur University

Prof. Biswajeet Thakur, Professor, Civil Engineering Dept, Meghnad Saha Institute of Technology.

Prof.S.K.Sanyal, Professor, Central Pollution Lab

Dr.Suchandra Bardhan, Professor, Dept of Architecture, Jadavpur University

Dr.Asis Mazumdar, Professor, Dept of Mechanical Engineering, Jadavpur University

Dr.Biswanath Roy, Professor,Dept of Electrical Engineering, Jadavpur University

Dr. Tapas Gupta, Chief Engineer I, West Bengal Pollution Control Board

Dr.Tapan Kumar Ganguly, Secretary General, CREDAI Bengal

Mr. K.B.Deb, Consultant,TCE (TCE Consulting Engineers),

Mr.Jayanta Paul, SIEMENS India

Mr.Prabal Bose, SIEMENS India

Mr.P.K.Banerjee, Director, Phoenix Software Ltd

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List of Acronym and Symbols

AAGR	Average Annual Growth Rate
APEC	Asia-Pacific Economic Cooperation
BAU	Business-as-Usual
BBL	Barrel
BEE	Bureau of Energy Efficiency
BF	Blast Furnace
BTU	British Thermal Unit
C_2F_6	Hexafluoroethane
CBECS	Commercial Building Energy Consumption Survey
CC	Continuous Casting
CCC	Cost of Conserved Carbon
CDD	Cooling Degree Day
CDM	Clean Development Mechanism
CDQ	Coke Dry Quenching
CF4	Tetrafluoromethane
CFBP	Center-Feed Prebaked
CHP	Combined Heat and Power
CIDC	Construction Industry Development Council
CMA	Cement Manufacturers Association
CO_2	Carbon Dioxide
CRPRI	Central Pulp and Paper Research Institute
DR	Direct Reduction
DR-EAF	Direct Reduction- Electric Arc Furnace
DSCL	DCM Shriram Consolidated Limited
ECBC	Energy Conservation Building Code
ECO III	Energy Conservation and Commercialization
EF	Electric Furnaces
EFMA	European Fertilizer Manufacturing Association
EIL	Engineers India Ltd.
EMC	Energy Management Cell
EPS	Electrical Power Survey
EUI	Energy Use Intensity

FAO	Food and Agriculture Organization
FCC	Fluid Catalytic Cracker
GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
GHG	Greenhouse Gas
GJ/t	Gigajoule of tonne of output produced
HBI	Hot Briquette Iron
HPCL	Hindustan Petroleum Corporation Limited
HSS	Horizontal Stud Søderberg
IAI	International Aluminum Institute
IEA	International Energy Agency
IF	Induction Furnaces
IFA	International Fertilizer Association
IHIS	Indian Hotel Industry Survey
IISI	International Iron and Steel Institute
IOC	Indian Oil Corporation
IPCC	Intergovernmental Panel on Climate Change
IRR	Interest Rate of Return
ISP	Integrated Steel Plant
ISP	Other Integrated Steel Plants
Kg	Kilogram
Kt	Kilo tonne
kWh	Kilo Watt hour
kWh/t	Kilo Watt hour per ton of output produced
LPG	Liquefied Petroleum Gas
MBN	MBTU/BBL/NRGF
MDEA	Methyl Diethanolamine (N-methyl-diethanolamine)
MOS	Ministry of Steel
MOSPI	Ministry of Statistics and Program Implementation
MRPL	Mangalore Refinery & Petrochemicals Ltd
Mt	Million tonne
MTBU	Million British Thermal Unit
MtC	Million tonne of Carbon
MWh	Mega Watt hour

NBO	National Buildings Organization
NFCL	Nagarjuna Fertilizers and Chemicals Limited
NH_3	Ammonia
NPS	New Pricing Scheme
NRGF	Energy Factor
OBC	Oxygen Blown Converters
OECD	Organisation for Economic Co-operation and Development
OPC	Ordinary Portland Cement (OPC)
PBFSC	Portland Blast Furnace Slag Cement (PBFSC
PFCs	PerFluoroCarbons
PFPB	Point Feed Prebaked
PJ	Petajoule
PPC	Portland Pozzolana Cement (PPC)
RCF	Recycled Fiber Based
RINL	Rashtriya Ispat Nigam Limited
RR	Re-Rolling
Rs	Rupees
SAIL	Steel Authority of India
SEC	Specific Energy Consumption
SRRM	Steel Re-Rolling Mills
SSI	Small Scale Industries
TERI	The Energy and Resources Institute
TRT	Top Pressure Recovery Turbine
TSL.	Tata Steel Ltd
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USGS	U.S. Geological Survey
VRM	Vertical Roller Mills
VSS	Vertical Stud Soderberg
Yr	Year

Executive Summary

E.S. 1. Introduction

This report analyzed the potential for increasing energy efficiency and reducing greenhouse gas emissions (GHGs) in the non-residential building and the industrial sectors in India. The first two sections describe the research and analyses supporting the establishment of baseline energy consumption using a bottom up approach for the non residential sector and for the industry sector respectively. The third section covers the explanation of a modeling framework where GHG emissions are projected according to a baseline scenario and alternative scenarios that account for the implementation of cleaner technology.

E.S. 2. Non-Residential Buildings

Between 1990 and 2005, energy consumption increased by over 60% in the commercial building (including both public and private) sector. Key drivers affecting energy use and related emissions of the sector include population and economic growth, extreme temperatures, and energy prices. Space cooling and lighting are the two primary end-uses for the sector contributing to the overall energy use.

The main scope of the chapter comprised an estimation of the current commercial building stock with the proportion of public sector building and their distribution across activity types. The estimate of the size of the public buildings market in India is approximately 658 million square meters spread over 13 million buildings, as of 2005. The source for this estimate is the Economic Census of India 2005 and studies on space utilization in buildings. The limitations of this estimate are the uncertainties due to non-uniformity in space utilization across regions and building types. Sixteen percent of the non-residential building stock (number of buildings) in India is owned and operated by the public sector and it represents 30 percent of the nonresidential building floor space. The distribution further indicates that warehouses, offices, and schools account for the largest share of total floor area followed by health care and other services. From the perspective of ownership, bulk of the schools is in the public sector or government, while offices and health have an equal proportion in the public and the private sectors.

For the future, Indian commercial building floor space is expected to double by 2050, with retail establishments and large private offices showing the largest increases in new floorspace (31%, and 29% respectively of total new building space). By 2030, about half of the buildings are those in today’s stock, with the portion declining to about a third in 2050. The effects of modernization, with increased space conditioning and lighting loads, are reflected in the corresponding projection for total electricity consumption, which, absent intervention, is expected to more than quadruple from 35 TWh in 2005 to 147 TWh in 2030.

At the next level, the study aimed to profile energy consumption by various building types. Non-residential or commercial buildings are defined to include buildings such as offices (large and small), educational institutions, health care facilities, scientific and research establishments, sports facilities, and tourism and hospitality establishments. The study utilizes existing energy audit data and additional building data to profile public sector buildings. It describes the energy performance characteristics in public buildings for specific segments of the Indian public building population. We see a relatively wide range in energy consumption (20 – 500 kWh/sq.m), which is indicative of several factors, including levels of space conditioning, lighting, and other internal loads. Currently about 30% of the buildings are cooled. This percentage is expected to go up significantly in the future. However, for the sake of simplicity, we keep this percentage frozen for the analysis period in this study. One of the main limitations of the study is the lack of adequate data to accurately understand the existing building stock, technology mix and efficiency distribution of the installed equipment in the building stock. While the current study makes a significant attempt to get around the data limitation to assess the existing building stock through alternative means, systematic and regular data updates are essential to monitor and study energy consumption trends.

E.S. 3. Industry

The industry sector in India consumes 4.8 EJ in 2005, representing 35% of final energy consumption. The energy intensive industries represent 64% of the entire energy consumed in the sector in 2003-04 while only representing 32% of total industry value added. The scope of this study covers the six most energy intensive industry in India that are the iron and steel, fertilizer, cement, refining, aluminium and pulp and paper industries. Compared to all other sectors the industrial sector has recorded the maximum energy efficiency improvement since late eighties in India. Many factors explain this trend, amongst which the introduction of more competitiveness with the liberalization of the economy in the early 1990's, the increase in energy prices starting in the late 1990's, and the promotion of energy efficiency schemes through the Bureau of Energy Efficiency since the introduction of the "Energy Conservation Act" in 2001. However, barriers to energy efficiency improvement in India remain. They include lack of information and technical skills, especially for small and medium size industries; perception of risk towards adopting innovative technologies; the desire to minimize production disruptions and the access to capital for such improvements. If these problems can be overcome, there appear to be significant, potentially exploitable energy and emissions-saving opportunities in Indian industries. The approach used to develop a modeling framework for the industry sector is elaborated at the process level for each industrial sub-sector. Energy intensity is calculated as energy use per tonne of commodity produced and carbon intensity as CO_2 emission released per tonne of commodity produced. The following table shows the baseline emissions per industrial subsectors in 2007 and carbon intensity. The table also shows the total energy intensity potential resulting from the introduction of a \$20 CO_2 emission price.

Table ES1. Baseline Intensity Summary and Cost Curve results for \$20 $MtCO_2$

	2007 Baseline		Emissions Reduction with 20$/tCO2	
	tCO2equ	tCO2/t	tCO2/t	Frozen Eff
Iron and Steel, ISP plants	111	3.27	1.08	33%
Iron and Steel, Small plants	61	3.18	0.22	7%
Cement	144	0.82	0.11	14%
Aluminium	38	30.87	0.87	3%
Fertilizer	37	2.82	0.75	27%
Refining	45	0.29	0.03	11%
Pulp and Paper	19	4.43	1.21	27%

E.S. 3. 1- Iron and Steel

India is the seventh largest steel-producing country in the world. The small current per capita steel consumption let to believe that production will continue to grow fast over the near future. This sector is the largest consumer of energy in the industrial sector (28%). Over the last 20 years, specific final energy consumption has been reduced drastically, from 45 to 29 GJ/t today. The main factors influencing energy use are the size of the plant and the technology employed in the process. Information charactering the technology and energy use from Integrated Steel Plants (ISP) is well known. This is not the case for small scale industries (SSI). India is the largest producer of sponge iron in the world, representing approximately 20% of global production, but contrary to other countries, 70% of sponge iron produced in India is from small coal based SSI, which are less energy efficient. Small Scale Industries specific final energy is higher than the average, between 31 to 36 GJ/t, due to poor economy of scale, intermittent operation with 40-60% utilization of installed capacity and very low engineering base and use of obsolete technology. In term of CO_2 emissions per tonne of steel produced, ISP emits 3.1 tCO_2/t steel[1] and SSI emit 3.2 tCO_2/t steel in average. Data gathered on the cost of reducing carbon emissions in ISP show that about 1 tCO_2/t steel can be reduced economically if the price of CO_2 emissions saved is fixed at $20 per tonnes. Data describing the energy efficiency opportunities for SSI are lacking and did not permit to perform a similar estimation for this segment. Only a study on re-rolling steel mills shows that 0.2 tCO_2/t steel can be saved for $20 per tCO_2 saved. In the future, fuel switch represents a possible lower carbon growth for the iron and steel industry. The shortage of domestic metallurgical coal will continue to induce a shift to more sponge iron production. Natural gas based process, already in used in three plants allowing lower CO_2 emissions, provides a competitive alternative for ISP. Nevertheless, the Indian non-coking coals, suitable for SSI, have the opposite effect and stimulate the use of more coal. Future scenarios need to take into consideration the possible growth of SSI.

E.S. 3. 2- Aluminium

Production of primary aluminum in India is growing very rapidly, at an AAGR of 9.7% from 2000 to 2007 and is expected to continue its rapid growth. The sector consumed about 7% of total energy used in the industry sector in 2005 of which most is require under the form of electricity. The study estimates that primary aluminium production results in 30.8 tCO_2e (tCO_2 equivalent) per tonne of aluminium produced. These emissions come from three different sources: indirect CO_2 emissions from electricity generation, direct fuel combustion to produce heat and the process CO_2 emissions from chemical reaction and perfluorocarbons (PFCs) from anode effects. We estimate that Indian smelter uses in average only 8% more electricity than world best practice. Over the last 5 to 7 years, most Indian smelters have implemented energy efficiency measures that have reduced their energy intensity. Moreover, with a production capacity that has doubled in 7 years, modern and efficiency technology have been installed. However, potential for energy efficiency remains, especially in the first phase of aluminum production consisting in the alumina production, in the production of electricity that is met with captive power in all Indian smelters and in the final phase in the secondary aluminum industry. Finally, increasing the use of recycled aluminium allows considerable reductions in carbon

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[1] In this study, emissions per tonnes include emissions from electricity production

emissions, as production of secondary aluminium results in 30 time fewer emissions than primary aluminium production. Indian's smelter plants have specific electrical energy consumption ranging from 14,195 kWh/t aluminum to18,083 kWh/t, with an average of 14,765 kWh/t. The current best practice uses 13,600 kWh of electricity/t and consumes 400-440 kg of anode/t aluminum. The cost curve of emissions reduction shows that about 0.9 tCO_2e/t aluminium can be reduced with a tonne of CO_2 at $20, which represent a reduction of 3% compared to the 2007 baseline emissions intensity.

E.S. 3. 3- Cement

India is the second largest manufacturer of cement in the world. The cement industry comprises of 132 large cement plants with an installed capacity of 167 Mt per year and more than 365 mini cement plants with an estimated capacity of 11 Mt per year. With rapid expansion, the cement industry has made tremendous strides in upgrading and assimilating state-of-the-art technologies. Upgrading by converting wet process plants to semi-dry and full dry process has resulted in considerable economies in fuel and power consumption. Wet process capacity, which accounted for 97% in 1950, has been brought down to 3% in 2007 and 96% of the production capacity has modern, efficient, and environment-friendly dry process technology. Moreover, about 20% of fly ash generated by thermal power plants and almost all the granulated slag generated by steel plants in 2005-06 are currently used to produce blended cement, which reduce CO_2 emissions. It was estimated that the total CO_2 emission from the cement industry was to 1,441 $MtCO_2$ in 2007, which represents a carbon intensity of 0.82 tCO_2/t cement. Furthermore, Indian most efficient cement plant was found to emit 0.72 tCO_2/t cement while international practice is equal to 0.59 tCO_2/t cement. Areas of potential improvements remain. For example the use of fly ash can be increased. Cement plants relies heavily on captive power with efficiency often lower than the grid. Diesel generation unit have very low efficiency, averaging between 20 to 25%. Some cement plants are using non-fossil fuels, including agricultural wastes, sewage, domestic refuse and used tyres, as well as wide range of waste solvents and other organic liquids but potential to increase the share of energy needs from waste fuels remain large. When looking at the cost of reducing emissions, measures with a cost under $20 per tonne of CO_2 result in reducing emission by 0.11 tCO_2/t cement, which represents 14%.

E.S. 3. 4- Fertilizer

India is currently the second largest producer of nitrogenous fertilizer in the world with 65 large-sized fertilizer plants in India. The share of natural gas feedstock represents 66% of total nitrogen fertilizer production. The remaining production is based on naphtha for 30%, and fuel oil 4%. Most of the world ammonia produced from naphtha is in India (92%). The average energy use per tonne of ammonia has considerably decreased over the years. A recent study from the Fertilizer Association of India (FAI) estimates that the weighted average energy consumption of all ammonia and urea plants in 2007-08 was reduced by about 30% from the level of 1987-88. In 2007-08, average energy use was estimated at 37.5 GJ/t for ammonia plants and 26.3 GJ/t for urea plants. While selected modern Indian units display very high efficiency levels that are among the world best practices, some plants lag behind and have high energy intensity levels. The gap between the most energy intensive plant and the most efficient is a factor of two. However, the standard deviation is relatively small, meaning that plants energy intensity tend to be close to the average value. The total CO_2 emission from the fertilizer industry was estimated to 37 $MtCO_2$ in 2007, which represents a carbon intensity of 2.8 tCO2/tN. When looking at the cost of reducing emissions, measures with a cost under \$20 per tonne of CO2 result in reducing emission by 0.63 tCO2/tN. In the future, chemical fertilizer may be increasingly substituted with bio-fertilizers. The policy stresses the need for conversion of naphtha and FO/LSHS based units to gas-based units. The main reasons invoked are that NG/LNG is cheaper, cleaner and use a more energy efficiency process. To support the NG/LNG utilization, the government is continuing to construct pipeline that will bring the fuel to all units. Moreover, bio-fertilizers correspond to an alternative to chemical fertilizer to increase soil fertility and crop production in a sustainable manner.

E.S. 3. 5- Refinery

Production of petroleum products in India has doubled in 8 years, from 68 Mt in 1998 to 145 Mt in 2006. There are a total of 18 refineries in the country comprising 17 in the public sector, and one in the private sector. Total energy consumption in Indian refineries in 2002/03 was about 337 PJ, or about 3 PJ per million tonnes of crude oil throughput (Sathaye et al, 2005). Energy consumption per unit of input is a misleading indicator of the energy performance of refineries as it does not account for differences in type of crude processed, product mix (and complexity of refinery), as well as the sulfur content of the final products. In India, the energy performance of refineries is expressed in terms of specific energy consumption, measured as million BTUs per barrel per Energy Factor (MTBU/BBL/NRGF). This unit, commonly referred to as MBN, was developed by the Centre for High Technology. We estimated that current refinery emit 0.28 tCO_2 per tonne of petroleum product produced in average. The cost curve of emissions reduction shows that about 0.03 tCO_2/t petroleum product can be reduced with a tonne of CO_2 at \$20\$, which represents 11% savings compared to 2007 baseline.

E.S. 3. 6- Pulp and Paper

The Pulp and paper industry in India is highly fragmented industry. In total, there are about 666 units engaged in the manufacture of paper and paperboard out of which only 27 are large integrated mills representing 25% of total capacity. Energy use in this sector accounts for 3% of industrial energy use in 2004. The amount of energy used depends on the nature of the feedstock and the desired quality of the product. In India, about 38% of the total paper production is based on waste paper, 32% on bagasse and agriculture residues, and remaining 30% on wood. Coal and electricity are the two major sources of energy in Indian paper industries. Other fuels such as fuel oil are also used to fire boilers and diesel oil for small backup power generator. A comprehensive study was undertaken by CPPRI for the Bureau of Energy Efficiency in order to develop norms for various categories of mills, taking into account factors such as raw material, varieties & grades of pulp & paper produced, age of the plants, technology status, capacity of major equipment/machinery. Energy savings potentials in the pulp and paper industry in India are very large, in the order of 30 to 40%. We estimated the pulp and paper industry to emit about 4.43 tCO_2 per tonne of paper produced in average. According to the measure to reduce emissions collected in this study, about 1.21 tCO_2/t paper can be reduced with a carbon price of \$20, which represents 27% compared to 2007 baseline.

E.S. 4. Methodology and Scenarios

The methodologies are based on a bottom-up and demand-side approach, where energy use and GHG emissions at the sub-sectoral level are decomposed into activity drivers (floor space for the non residential building sector and commodities production for the industry sector) and energy/GHG emissions intensity. Scenarios are then based on the projection of activity drivers and the potential of reduction of intensity due to the implementation of cleaner technology. Potential reductions for each clean technologies identified are ranked according to their cost of implementation in a cost of conservation curve. The cost of conservation curve is then used to estimate what would be a necessary carbon price for the implementation of an efficiency target. Or inversely, the cost of conservation curve allows estimating what would be the efficiency reduction according to a specific carbon price. While cost is of course not a strict determinant of adoption of efficiency measures, it is taken to be a consistent one. In fact, it is well known that even highly cost effective measures are often not taken – this is the central market failure that efficiency policies are designed to address. Therefore, a scenario in which the cost of conserved energy of all measures taken is lower than the actual cost of energy may still be more efficient than the business as usual case. In high efficiency cases, we model that all measures up to a higher level of CCE will be taken. The specific mechanism by which the adoption threshold is raised is not specified. It could be a carbon tax, other tax incentives, rebates, credit payments from a cap and trade system, other subsidies, or increased consumer awareness.

In a scenario where carbon savings are valued \$20 per tonne of CO_2, non residential building sector emissions are reduced by 17% relative to the frozen efficiency case at an overall capital investment cost of 1.2 billion \$US in that year. Relative to the business as usual case, emissions savings is 9% and capital investment is \$552 million. In the industry sector, savings potentials are the highest in the Integrated Steel Plants (33%), the fertilizer (21%) and pulp and paper industries (27%). However, some sub-sectors are underrepresented partially due to the extreme scarcity of data that describe their savings. This is the case of SSI. When the carbon price reaches \$100, savings potential increases in all sectors, but to a small extend. For the highest case, it brings 5 percentage points of additional potential (steel and pulp and paper industries). A much higher carbon price does not imply much higher saving potential.

E.S. 4 Conclusion

For the industrial sector, this study shows that energy intensity for the six most energy intensive industry has reduced considerably over the last 20 to 30 years. The non-residential sector, on the other hand, does not show a similar trend as there are no historical estimates of the building stock and energy use to compare the current existing energy use intensities. The cement, fertilizer, iron and steel and aluminium industries have particularly performed well in reducing their energy use and are comparable with current average international level. However, a gap between current average and international best practices subsists, which suggests that room for energy efficiency improvement remains. The study found the pulp and paper to have the most potential reduction, followed by the steel industry and the iron and steel industry, then fertilizer industry. Nevertheless, these potential reductions come at a cost. The study looks at the cost of conserve energy and emissions reduction and rank measures according to their cost. When a carbon price of \$20 is considered, non residential building sector emissions are reduced by 9%, relative to business as usual. In the industry sector, savings potentials are the highest in the Integrated Steel Plants (33%), the fertilizer (21%) and pulp and paper industries (27%).

However, it is important to keep in mind some of the limitation of the study and outline areas where more work would improve the results in the future. While a cost curve provides a useful indication of the kind of reductions that are available to Indian society, we are cognizant that implementation are often limited by a variety of factors, or barriers to implementation. Removal of these barriers requires the adoption of policies such as those targeted at providing better information or financing to overcome the higher first costs of an efficiency technology. Additionally, the economic efficiency potential analyzed in this study was limited by the availability of data on cost implementation measures, specifically in the small scale industries and the non residential building. Hence, the total potential include in the cost curve is generally lower than the total potential compare to best practice. Moreover, the study did not estimate the cost of more substantial carbon reduction measures such as the switch to lower carbon fuel or the use of more recycled material. Instead, these measures and their implication were described in the text as potential low path growth options. Finally, estimating the rate of penetration of efficiency measures potential that remains for each technology was the most challenging part of this study. We rely on industrial experts and literature research. However, it is certain that the estimation provided in this study could be greatly improved if more time and resource were allocated in providing more information.

1. Introduction

Industrial and non-residential sectors account for nearly 50% of electricity consumption in India and thus are significant contributors to greenhouse gas (GHG) emissions. Significant GHG emission reductions can be achieved in both these sectors through implementation of efficiency measures and through adopting best practices.

Considering the vast potential of energy savings and benefits of energy efficiency, the Government of India enacted the Energy Conservation Act, 2001 (52 of 2001). The Act provides for the legal framework, institutional arrangement and a regulatory mechanism at the Central and State level to embark upon energy efficiency drive in the country. There are also several national level measures that try to address efficiency improvements in the industrial and buildings sectors. There is, however, tremendous potential for a coordinated implementation of efficiency programs in the larger industrial establishments and commercial buildings through specific policy measures. There have been several independent studies and energy audits performed on specific buildings, and the government has recently made the Energy Conservation Building Code (ECBC) mandatory, but there remains significant potential by way of integration of these efforts.

This study tries to bring together the individual and separate efforts already underway, and creates an integrative framework to establish baseline energy consumption and energy use-intensities for specific building types and process-level energy intensities for specific industrial sub-sectors. Information at this level can help users and other stakeholders including industries, builders, architects, code enforcing agencies to evaluate efficiency of performance and track improvement compared to other establishments. The information is also critical for setting benchmarks that can be used in the case of buildings for ECBC compliance, labeling of existing buildings, and recognizing the top performers through a systematic evaluation scheme.

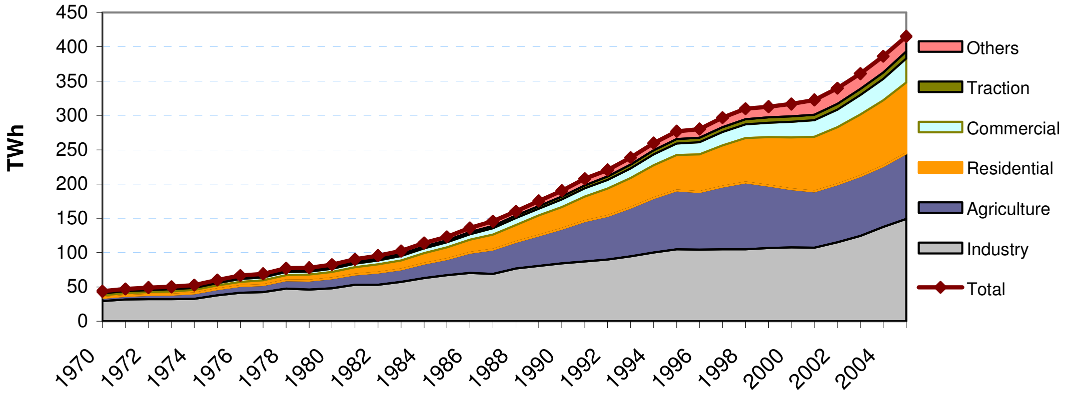
This report analyzed the potential for increasing energy efficiency and reducing greenhouse gas emissions (GHGs) in the non-residential building and the industrial sectors in India. While the both the non-residential building and the industrial sectors are a significant consumers of energy and emitters of energy related GHGs, primarily CO_2., the industrial sector has the additional burden of being an important emitter of non-energy derived GHGs occurring from industrial processes, from the use of GHGs in products, and from non-energy uses of fossil fuel carbon. The research and analyses supporting this study were organized around two major components for each sector. The first component consisted in collecting data and information to provide an assessment of the present energy use and GHG emissions at the sub-sectors level and to portray technologies that are currently in use. The second component consisted in the elaboration of a modeling framework where GHG emissions are projected according to a baseline scenario and alternative scenarios that account for the implementation of cleaner technology. The methodologies are based on a bottom-up and demand-side approach, where energy use and GHG emissions at the sub-sectoral level are decomposed into activity drivers (floor space for the non residential building sector and commodities production for the industry sector) and energy/GHG emissions intensity. Scenarios are then based on the projection of activity drivers and the potential of reduction of intensity due to the implementation of cleaner technology. Potential reductions for each clean technologies identified are ranked according to their cost of implementation in a cost of conservation curve. The cost of conservation curve is then used to estimate what would be a necessary carbon price for the implementation of an efficiency target. Or inversely, the cost of conservation curve allows estimating what would be the efficiency reduction according to a specific carbon price.

This report is organized in three chapters. The first chapter describes energy use and GHG emissions in the non residential sector, the second chapter describes six energy industry sub-sectors (iron and steel, cement, aluminum, fertilizers, pulp and paper and petroleum Refining subsectors) and finally the last chapter explains the methodology used and results found.

2. Non-residential buildings

As per the 17th Electrical Power Survey (EPS) of the Central Electricity Authority, the electricity demand is projected to increase by about 40% by 2012 over a five year period, and double over the subsequent decade reaching approximately 1,900 TWh by 2021-22 (MOP, 2007). The EPS's forecast is consistent with the growth in consumption across sectors in the recent past. Specifically in the buildings sector, the country has seen a near consistent 5% rise in annual energy consumption in the residential and commercial sectors. In 2004-05, residential and commercial sector together consumed about 135 TWh of electricity from the grid. presents the trend in sectoral electricity consumption. Building energy consumption has seen an increase in its share of 15% in the 1970s to nearly 33% in 2004-05. The growth has been particularly pronounced in the commercial sector with a growth rate of 8%. The 17th EPS forecasts an annual growth of 10.5% in the commercial sector over the next 5 years. Electricity use in both residential and commercial sectors is primarily for lighting, space conditioning, refrigeration, appliances and water heating.

Figure 1. Trend in Sectoral Electricity Consumption in India



As is also evident from looking at the construction sector, its contribution to total GDP has been rising rapidly since the past few years. In 2006–07, the sector registered an increase of 10.7% from the previous year. The share of the construction industry has grown significantly as is visible from Figure 2 below and is reflected in the share of construction in GDP, which has increased from 6.1% in 2002–03 to 6.9% in 2006–07. The reason for increased construction activity can be attributed to both an increased demand for residential, commercial and institutional spaces. Overall, the contribution of the sector has increased to 10.8% during the Tenth Five Year Plan from 7.5% during the Ninth Five Year Plan. Consequently, the projected investment in infrastructure in the Eleventh Plan is more than double the amount in the Tenth Plan (GOI 2008).

Figure 2. Trend in Value Added from the Indian Service Sector

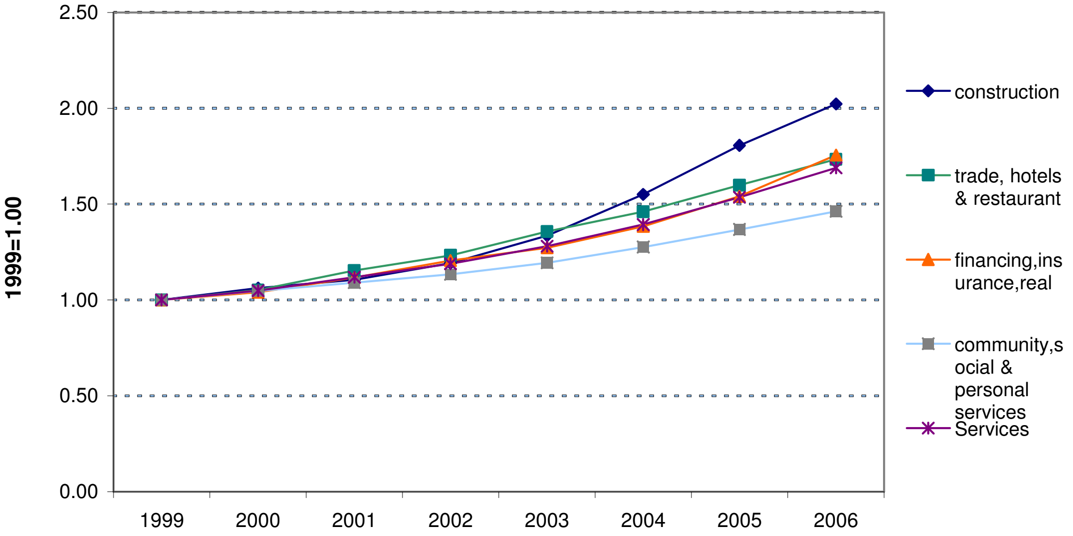
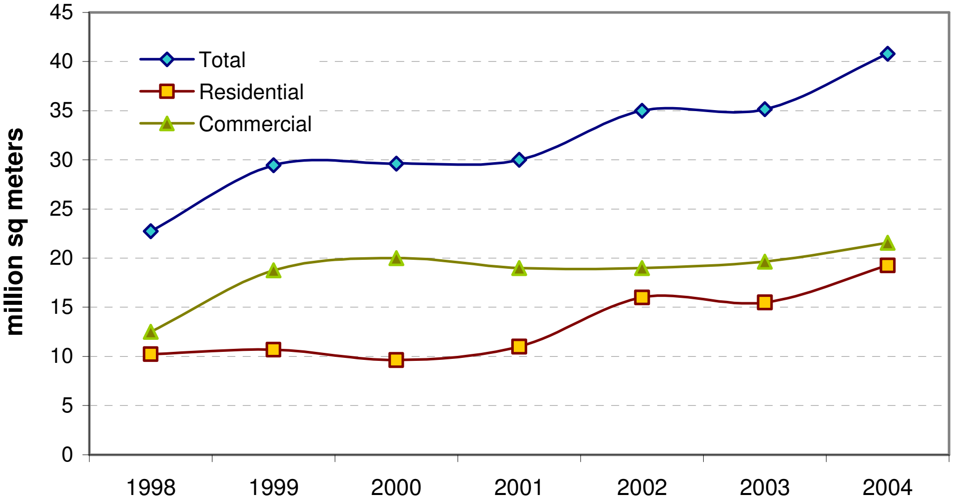


Figure 3 shows the growth in new construction over eight years.

Figure 3. Trend in New Construction



As per the estimates from the Construction Industry Development Council (CIDC), the total new construction floorspace added in the commercial and residential sectors was about 43 million square meters in 2004-05, of which about 23 million square meters is in the commercial sector. The new construction trend shows a consistent annual growth rate of about 10%. The Gross Fixed Capital Formation (GFCF) shows a similar trend with over 18% annual growth in the non-residential buildings during 2000-05, with bulk of the growth taking place in the private sector (MOSPI 2008). These numbers also point to an expectation that commercial sector construction will see a consistent growth in the next 5-10 years. It is therefore clear that commercial building stock will play a significant role in overall electricity consumption in the country.

2.1 *Methodology and Scope of Study*

In this study, non-residential or commercial buildings are defined to include buildings such as offices (large and small), educational institutions, health care facilities, scientific and research establishments, sports facilities, and tourism and hospitality establishments.

For the purposes of this study, buildings of all sizes are considered, from both rural and urban environments. Industrial buildings and multi-unit residential buildings are excluded to remain consistent with the definition used by the MOSPI (Ministry of Statistics and Program Implementation). The research and analysis contained in the report focuses on the energy consumption and carbon emissions generated during the operational life of the building since 45 – 80% of energy is consumed during this phase[2] (Thormak 2002). Construction and demolition phases of the life cycle are excluded from the analysis.

The main scope of the study comprised an estimation of the current commercial building stock with a reasonable sense for the proportion of public sector building and their distribution across activity types. At the next level, the study aimed to profile energy consumption by various building types. Understanding energy use is essential to identifying potential saving opportunities in this sector.

The research and analyses supporting this study have two major components:

1. Data Collection: The study utilizes existing energy audit data and additional building data to profile public sector buildings. It describes the energy performance characteristics in public buildings for specific segments of the Indian public building population. We estimate the current building stock and forecast the likely growth of the stock in this category of commercial buildings. Data was compiled from both primary and secondary sources. The secondary sources include BEE, CSO, ECO III, DSCL, and a range of Indian and international publications. LBNL also worked with architectural firms in India to collect building level data to profile energy consumption across building types and to assess the technology mix of the equipment used in buildings. These data were used to develop assumptions about the anticipated policy impacts on energy efficiency in commercial buildings for the economic modeling component of the report.
2. Modeling: The main driver of sector energy is economic growth. The World Bank's forecast has GDP growth at 8% till 2021, after which it drops to 7.5% till

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[2] The proportion of energy used during the operational life of a building is based on the level of conditioning in the building.

2026, and 7% till 2030. The main forecasting effort is to establish levels of activity that result in energy demand. For the buildings, the main activity variable is floor area, which will be affected by increases in GDP. The methodology takes a bottom-up and demand-side approach. The model is structured in sufficient detail to capture realistic efficiency options at the end-use level. Details of the model are discussed in Sections 4 and 5.

2.2 *Commercial Building Characteristics*

The non-residential or the service sector includes activities related to public administration, health, education, real estate, banking and finance, trade, and other services. Understanding energy consumption by this sector requires a reasonable sense of the share of the various activity types, building characteristics and detailed data on end-use equipment. Energy use in buildings is affected by the physical characteristics of the buildings, including building design, choice of location, structure and layout, as well as the efficiency of the equipment and the occupants' energy-related behavior. Specifically, the two most important parameters that determine the energy use in this sector are the building floorspace and the end-use technologies in place. These two measures provide different aspects of commercial building use, which allow energy analysis to focus on the characteristics of building use as they relate to either the building stock or the amount of floorspace.

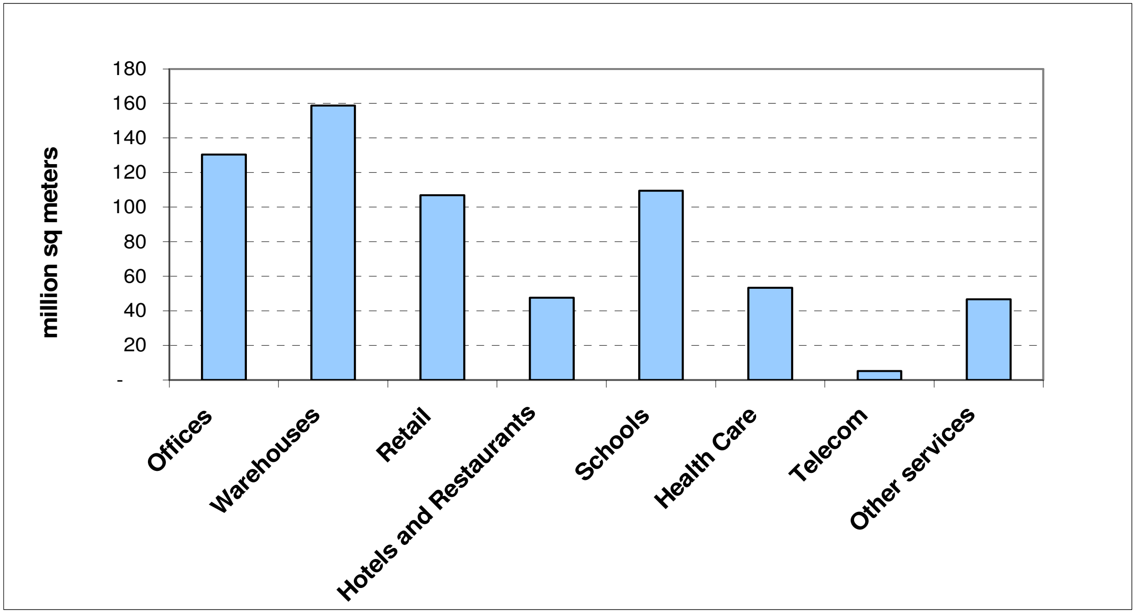
2.2.1 Existing Building Stock

Information at this level in India is very limited. There is no single source of data that provides an estimate of the building stock as a whole or by building types. The National Buildings Organization (NBO) under Ministry of Urban Employment and Poverty Alleviation is tasked with collecting and disseminating the building construction statistics. The organizational information suggests that the collected data includes current housing and building construction activity both from public and private sectors. In addition, NBO also collects data on building permits and completion certificates issued during a year from all towns with a population of 100,000 or more. This data would be useful to establish more accurately the new construction trend for forecasting purposes. At present, publications containing data are not readily available and thus, our study is unable to make use of it. It would be useful to incorporate these studies for improving the assumptions of this study and evaluating more aggressive efficiency measures in the sector in the future.

The Government of India conducts periodic economic census that provides a comprehensive account of major economic activities and their characteristics (MOSPI 2006). The scope of the census includes principal characteristics of the establishments and employment classified by major activity groups, type of establishments, ownership type, size class of employment, fuel used, source of finance, etc. The last economic census was conducted in 2005. The economic census data also categorizes employment statistics and establishments into those belonging public, private, and NGO sectors of the economy. In the absence of any official estimates of commercial building stock, we relied heavily on the economic census data to come up with rough preliminary estimates of the size and stock of the commercial building population. The economic census also provides disaggregated establishment and employment data by states, which may be used later for estimating regional or climatic distribution of buildings. Our study uses data from this publication and space utilization[3] rates to come up with a rough estimate of the existing building floor area and building stock by various economic activity groups.

We map the data further to specific building types in order to estimate the total commercial floorspace by building type. The following figures represent the estimated floorspace distribution by building type and ownership.

Figure 4. Distribution of Floorspace in by Building Type in 2005



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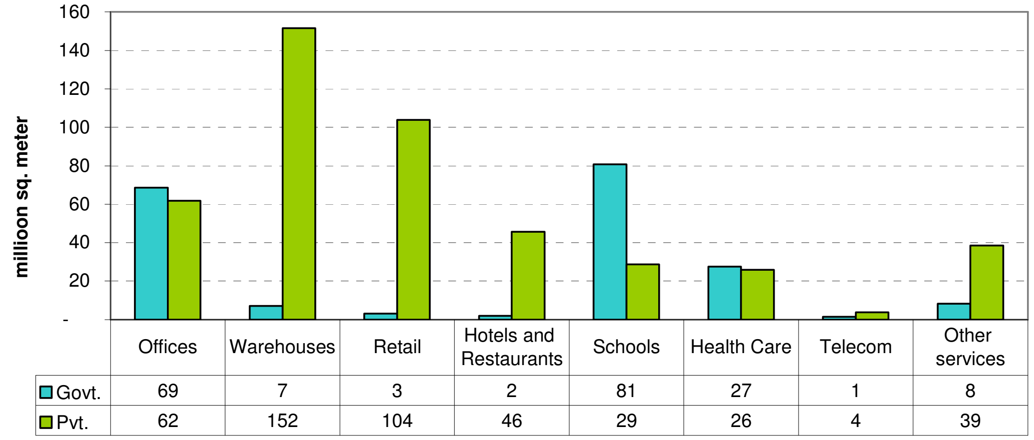
[3] We use space utilization factor from several sources, including Commercial and Industrial Floorspace Utilization Survey (CIFUS) from Hong Kong, code specifications, and discussions with experts. Assumptions on Space Utilization factor will be provided in the Appendix.

Figure 5. Distribution of Commercial Floorspace by Ownership in 2005



	Offices	Warehouses	Retail	Hotels and Restaurants	Schools	Health Care	Telecom	Other services
🟦 Govt.	69	7	3	2	81	27	1	8
🟩 Pvt.	62	152	104	46	29	26	4	39

Of the total commercial floorspace in the country, we find about 30% to be under public sector ownership. The distribution further indicates that warehouses, offices, and schools account for the largest share of total floor area followed by health care and other services. From the perspective of ownership, bulk of the schools is in the public sector or government, while offices and health have an equal proportion in the public and the private sectors. In the following sections, we will look further into offices, hospitals and hotels, as these three or the four building types that are major contributors to the overall energy consumption in the commercial sector and thus present a significant opportunity for energy savings. We have limited information on the retail sector and hence it is not presented here.

2.2.2 Offices

The characteristics of office buildings are of increasing interest from the energy perspective since office buildings account for over a fifth of all energy used in commercial buildings in most countries. The share of energy consumption is a function of the total floorspace they account for in the commercial sector.

In the absence of any official estimates of commercial building stock, such as the Commercial Buildings Energy Consumption Survey (CBECS) in the USA, we have relied heavily on the economic census data to come up with rough preliminary estimates. The economic census also provides disaggregated establishment and employment data by states, which may be used later for estimating regional or climatic distribution of buildings. At an aggregate level, new construction will be driven by economic activity, and urbanization.

The National Buildings Organization (NBO) under Ministry of Urban Employment and Poverty Alleviation is tasked with collecting and disseminating the building construction statistics. The organizational information suggests that the collected data includes current housing and building construction activity both from public and private sectors. In addition, NBO also collects data on building permits and completion certificates issued during a year from all towns with a population of 100,000 or more. This data would be useful to establish more accurately the new construction trend for forecasting purposes. At present, publications containing data are not readily available.

Estimates based on the Economic Census of India (GOI 2005) illustrate that offices account for about 35% of the total building floorspace in the country. The same estimate indicates that about 50% of the office floorspace is within the Government or Public Sector purview. In the public sector, offices account for more than a third of the floorspace. In the year 2006-07, the public sector, comprising administrative departments, departmental enterprises and non-departmental enterprises, contributed 21.4 per cent to the GDP and 22.3 per cent to gross domestic capital formation. shows an estimated office market of about 70 million sq. meters to be under government or public sector ownership.

2.2.3 Energy data

At the national or state level, end-use level energy consumption is not available for buildings either at the aggregate or by building type. As part of the mandate to initiate energy conservation, BEE commissioned energy audits in the Government-owned commercial buildings and selecting the methods to check energy leaks and efficient use of electricity in buildings. For the purpose of this study, we plan to use the energy audits commissioned by BEE.

Based on the audits conducted in several government buildings, studies estimate an overall energy savings potential of 760 GWh per annum (Singh and Michelowa 2004). The same studies also estimated that air conditioner facility improvement will require about 80% of the total investments whereas light will require 10% of the investments.

Nine government buildings and establishments including the *Rail Bhawan, Sanchar Bhawan, Shram Shakti Bhawan, Transport Bhawan, Research & Referral Hospital, Terminal I, II* and cargo section of *Delhi Airport, Prime Minister Office, Ministry of Defense Blocks, Rashtrapathi Bhawan* and *All India Institute of Medical Sciences* have been identified for the project. Below, we summarize the energy audit and recommended measures for efficiency improvement for one government building.

Shram Shakti Bhawan

The *Shram Shakti Bhawan* is located in central Delhi under New Delhi Municipal Council (NDMC) administered area. The metering of *Shram Shakti Bhawan* includes the electrical supply to *Transport Bhawan* as well. The total floor area of the six-storied *Shram Shakti Bhawan* building is 2356 m^2. *Transport Bhawan* is a five-storied building with a total floor area of 2280 m^2. The buildings have a connected load of 1.8 MW; annual average consumption is 2.1 GWh. The current consumption shows the share of lighting to be 28% and that of air conditioning to be 44% of the total electrical energy, respectively.

Table 1. Summary Results of Shram Shakti Bhawan

Area	Brief Description	Savings, US $	Investment, US$

Lighting	Retrofit based on Design and Technology for task lighting	18,533	26,222
Air Conditioning	Replacement of Window and Split ACs with Centrifugal Chiller based Central AC System	59,556	271,111
Total		78,089	297,333

The audit suggests a total savings potential of 26%.

2.3 *Hospitals*

Estimates based on the Economic Census of India (GOI 2005) illustrate that hospitals account for about 27% of the total building floorspace in the country. Of this, we estimate about 50% to be within the Government or Public Sector purview. As per the Central Bureau of Health Intelligence's National Health Profile, the total number of government hospitals in the country is 9,976 (GOI 2007).

National level energy consumption data in healthcare facilities is not available in the public domain. Nevertheless, estimates based on ECO-III study indicate a wide range in energy use pattern across hospitals based on their urban-rural setting and private or public ownership. The following table from the ECO-III study presents the electricity consumption.

Table 2. Estimated Electricity Consumption in Hospitals

Hospital	No. of Beds	Estimated (kWh/Bed/year)
Government Hospitals - Urban	328,491	750-1500
Government Hospitals - Rural	154,031	150-300
Private/NGO Hospitals and Nursing Homes	500,000	1000-2000
Total	982,522	-----
Source: USAID ECO-III Project, 2009		

2.4 *Hotels*

2.4.1 Overview

Hotels are large energy users and thus present a significant opportunity for efficiency. By identifying the strongest drivers of energy use in hotels, hotel energy use can be better understood. By identifying the relationship of these drivers to hotel energy use, energy efficiency and conservation potential can be more accurately assessed.

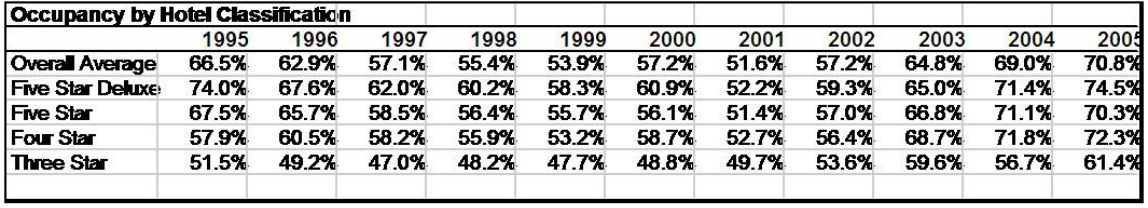
Hotels and restaurants together account for an estimated 528 million square feet of floor area based on the data from the Economic Census of 2005 (GOI 2005). The Commercial Building Energy Consumption Survey (CBECS) 2003, a survey of the US commercial buildings in 2003 suggest a total floor area of 1654 and 5096 million square feet in restaurants and lodging respectively. Assuming a similar proportion of split, we estimate that hotels and other lodging account for close to 390[4] million square feet.

2.4.2 Literature Review

Indian Hotel Industry Survey (IHIS) conducts periodic surveys of hotels in the country. The survey categorizes hotel into two main types: approved and unapproved. The Ministry of Tourism, Government of India grants approval to hotels at the project stage and then classifies them into one of the star categories. The majority of hotels and hotel rooms in India are included in the unapproved type, as many hotels, especially those that are equivalent to lower star category hotels; do not take part in the Government classification process.

The survey covers 252 hotels, representing a total of 1980 hotels covering various cities and class of hotels. The survey reports average occupancy rates historically for over 18 cities in the country. The following table summarizes the national averages.

Table 3. Occupancy Rates in Hotels



Occupancy by Hotel Classification											
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Overall Average	66.5%	62.9%	57.1%	55.4%	53.9%	57.2%	51.6%	57.2%	64.8%	69.0%	70.8%
Five Star Deluxe	74.0%	67.6%	62.0%	60.2%	58.3%	60.9%	52.2%	59.3%	65.0%	71.4%	74.5%
Five Star	67.5%	65.7%	58.5%	56.4%	55.7%	56.1%	51.4%	57.0%	66.8%	71.1%	70.3%
Four Star	57.9%	60.5%	58.2%	55.9%	53.2%	58.7%	52.7%	56.4%	68.7%	71.8%	72.3%
Three Star	51.5%	49.2%	47.0%	48.2%	47.7%	48.8%	49.7%	53.6%	59.6%	56.7%	61.4%

According to IHIS, based on ongoing construction, the next couple of years would see a addition of over 45000 rooms across ten cities. The survey report predicts a biggest growth in Hyderabad and Bangalore. The proposed construction numbers are useful for calibrating our new construction forecast of hotels.

2.4.3 Activity Variable

Variables that will impact the energy use include building construction, use, operational characteristics (such as the temperature norms for unoccupied rooms), weather variations, equipment types and controls including space cooling, water heating, lighting, etc. The building characteristics likely to have the strongest relationships to primary energy use in hotels are the number of lodging rooms, floor area, and occupancy rates. This is not unexpected, because these are all indicators of building size and occupancy, two dominant influences on energy use in most buildings. A plot of U.S. hotel total energy use as a function of gross floor area is shown in Figure 6. Plots of energy use as a function of lodging rooms and number of workers are very similar.

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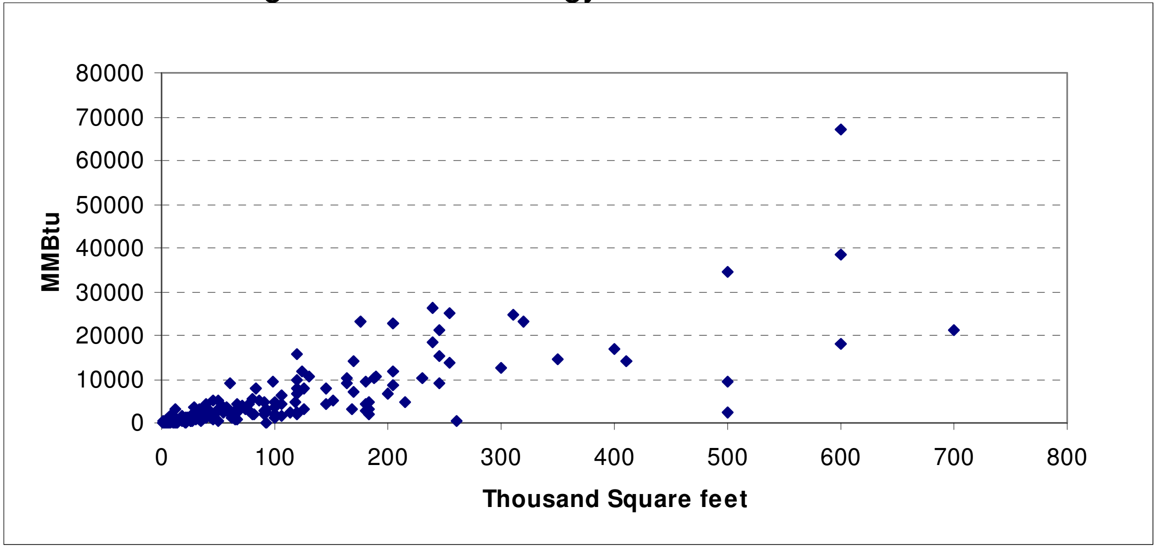
[4] 390 million square feet of building area for lodging is a conservative estimate, in the absence of sector specific data. The comparable figure for the United States is 5096 million square feet for a service sector GDP of 10.7 trillion US$, while India has 390 million square feet for a service sector GDP of 1.5 trillion US$ at PPP.

Figure 6. US Hotel Energy Use Versus Floor Area



Source: CBECS 2003

The U.S. data shows that correlation between total energy use and number of lodging rooms, floor area, and number of workers to be 0.60, 0.64, and 0.50 respectively. For hotels, number of lodging rooms is generally the dominant variable used for determining energy consumption. Since the correlation between these variables and total energy use are reasonably close, any one could be used as the primary normalization variable. In the current study, the normalization variable will depend on data availability.

An older benchmarking study on APEC countries provides data for select hotels in some Asian cities. The table below presents the summary of findings from the survey. Not surprisingly, the analysis of data in Hong Kong showed a high correlation between energy use and total floor area of the hotel.

Table 4. International Estimates of Energy Consumption in Hotels

	Hong Kong, China	Singapore	Chinese Taipei
Number of Hotels, and year of energy use	26,1998	25, 1993	5,1994
Gross Floor Area (m2)	3,120-64,212	2,604-87,082	30,887-277,704
Number of Workers, Range	29-750	50-250	258-1200
Number of Workers per Thousand M2	6.6-17.4	2.5-19.2	0.9-10.3
Energy Use Index Range (GJ/m2)	0.5-2.6	0.8-4.7	0.1-2.0

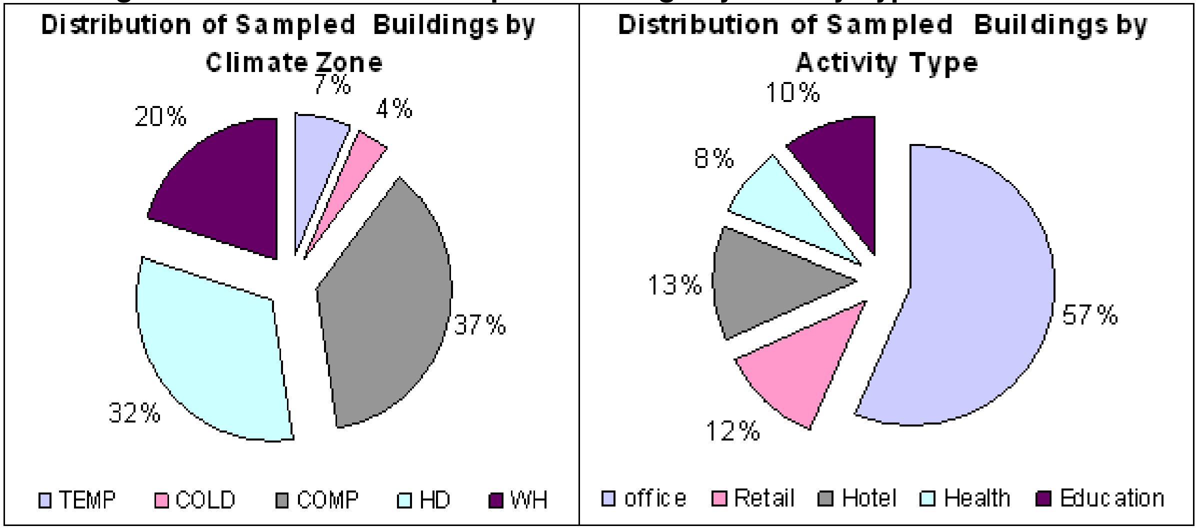
Source: APEC 1999.

2.5 *Data Used in the Study*

In order to analyze the savings potential, the study needed to baseline energy consumption of commercial buildings. This exercise required a set of buildings to profile building characteristics and energy use. LBNL created a sample set of buildings for this purpose, utilizing energy audits commissioned by BEE/GOI, data collected by the ECO-III project office, and LBNL's own effort to collect building level data through architectural firms based in India. This enabled the study to compile data on building characteristic and energy use for a total of 220 buildings in the commercial sector.

The information gathered included data on several owner and occupancy characteristics, physical building characteristics, types of energy technology in place, percentage conditioned, and energy bill information. The figure below shows the distribution of these building records across activity type and climate zones. Bulk of the compiled building data is in the category of offices followed by hotels, retail, educational institutions and hospitals. We acknowledge that the distribution of the sampled buildings is not entirely representative of the distribution of buildings as per the economic activity. However, the sampled buildings represent the climate zones reasonably well. The temperate zone is somewhat under-represented in this sample, due to lack of building data from that region. The sample is fairly representative for the remaining 4 climate zones.

Figure 7. Distribution of Sampled Buildings by Activity Type and Climate



Temp: temperate, Comp: composite, HD: hot and dry and, WH: warm and humid

2.5.1 Activity Variables

The main forecasting effort is to establish levels of *activity* that result in energy demand. In the case of buildings, the main activity variable is *floor area*. The other activity variables that are used for estimating energy savings potential from the public sector are climate variability, equipment use and penetration, and hours of operation.

Floorspace:

At an aggregate level, new construction will be driven by economic activity, and urbanization. In general, we model floor area either_as a function of the size of the economy or by forecasting construction as a function of economic growth. For specific sub-sectors, the factors driving the current rapid economic growth, such as retail and offices, floor area is modeled in terms of the contribution of the construction sector to the overall service sector GDP. Construction of government office buildings is expected to track with overall GDP of the country. In less dynamic sectors, such as education and health sectors, total floor area scales with population and/or per capita GDP. We take the number of beds per capita to be a proxy for health services overall. Health sector floor area is thus assumed to scale with the number of hospital beds. Education, on the other hand is assumed to scale by education levels – number of students enrolled in primary, secondary and post-secondary education. Additions in floor area implied is important, since new construction is expected to have different energy intensity properties, both in the business as usual, and in the policy scenario.

Climatic zones:

India has a reasonably diverse climate, ranging from extremely hot desert to high altitude locations with severe cold conditions, and therefore different energy usage patterns and demand. On the basis of hourly temperature, various climatic parameters and solar radiation data recorded at 233 weather stations, BEE divides the country into five climatic zones. These five climatic zones[5] with a representative city and corresponding Cooling Degree Day (CDD) are:

1. Hot & Dry (Ahmedabad, Gujarat; CDD_{18} of 3,514)
2. Warm & Humid (Mumbai, Maharashtra; CDD_{18} of 3,386)
3. Composite (New Delhi, Delhi; CDD_{18} of 2,881)
4. Temperate (Bangalore, Karnataka; CDD_{18} of 2,280)
5. Cold (Shillong, Assam; CDD_{18} of 287)

The factors that therefore will govern the energy usage inside the building can be classified as:

1. Energy consumption on the basis of climatic zones: Hot & Dry, Warm & Humid, Composite, Moderate, and Cold.
2. Energy consumption on the basis of building usage: Building Type
3. Energy consumption on the basis of conditioning: Conditioned and Non-conditioned buildings

However, bulk of the building population is in the hot & dry, warm & humid, and the composite climate zones.

Equipment Penetration and Hours of Operation

Energy use in an establishment is driven largely by the number and type of energy using equipment in use and the hours of operation of the building. The study collected data on the types of cooling equipment in use and their nameplate efficiencies in the buildings surveyed. This data is useful in establishing baseline efficiencies for end-uses such as cooling. Table 5 below presents the cooling equipment shares in specific building types based on surveyed data.

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[5] Climate Zone Map of India is included in Appendix A.

Table 5. Cooling Equipment Shares by Building Type

	Offices	Schools	Hospitals
CUAC - air-cooled	9%		5%
WRAC+Splits	5%	5%	34%
Multi-splits+Cassette	5%	0%	0%
Air-cooled Chiller	6%		20%
Water-cooled Chiller	6%		20%
None	69%	95%	21%

Fuels Considered

Energy consumption in commercial buildings include electricity used to run equipment and lights, LPG used for water heating and cooking, and diesel for back-up generation. In the current analysis, we consider only electric end-uses. Furthermore, diesel (high speed diesel and light diesel oil) used in back-up generation is accounted for in electrical demand. Our current data shows about 27% of electrical demand met through diesel.

2.5.2 Equipment Characterization

Air conditioning or space cooling and lighting are the top two energy end uses within the buildings sector. Space cooling, as an end-use, is significant also from the perspective that its saturation in the existing building stock is very low. Even with hot and humid climatic conditions, currently only about 30% of the buildings are cooled. With the changing construction practice, this percentage will likely go up significantly in the future. Studies have indicated that energy efficient lighting, air conditioning and electrical systems could save up to 20% of the energy used in existing buildings (Singh and Michaelowa 2004). In addition, some simulation studies also indicate that new buildings can save up to 40% of energy with design interventions and stronger building energy standards (BEE, 2007).

In our current analysis, we take a conservative approach to estimating savings potential. We consider only those efficiency measures for cooling and lighting end-uses that are commercially available and are cost-effective from a consumer's perspective. The cost-effectiveness of an efficiency measure is determined on the basis of a life-cycle cost analysis of a technology option using a marginal electricity rate. Table 6 and Table 7 show the efficiency options considered in the study and their cost of conserved energy, for cooling and lighting end-uses, respectively.

Table 6. Efficiency Options Considered for Cooling

Air-conditioning Equipment	**% improvement over baseline**	**CCE ($/kWh)**
AC - WRAC-msplit		
	13%	$0.02
	15%	$0.02
	19%	$0.02
	22%	$0.05
	30%	$0.07
AC - cassette units and multi-splits		
	8%	$0.03
	13%	$0.03
	18%	$0.06
	22%	$0.08
	40%	$0.12
	42%	$0.13
AC - Air-source packaged cooling AC (11TR)		
	4%	$0.02
	6%	$0.04
	19%	$0.13
AC - by Air-source packaged cooling HP (11 TR)		
	4%	$0.07
	5%	$0.07
	8%	$0.10
	14%	$0.16
AC - Air-source packaged cooling AC (17TR)		
	7%	$0.01
	9%	$0.01
AC - Air-source packaged cooling HP (17 TR)		
	9%	$0.09

Table 7. Efficiency Options Considered for Lighting

Fluorescent Ballasts	% Improvemen	CCE ($/kWh)
F40T12/ES w/ mag bal	Baseline	$0.00
Hi-perf T8 w/ elec bal	11%	$0.01
Max Tech (LED replacement)	22%	$0.03
Incandescent Lamps	% Improvemen	CCE ($/kWh)
Inc GS	Baseline	$0.00
CFL Replacement	66%	$0.01
Max Tech (LED Replacement)	87%	$0.10

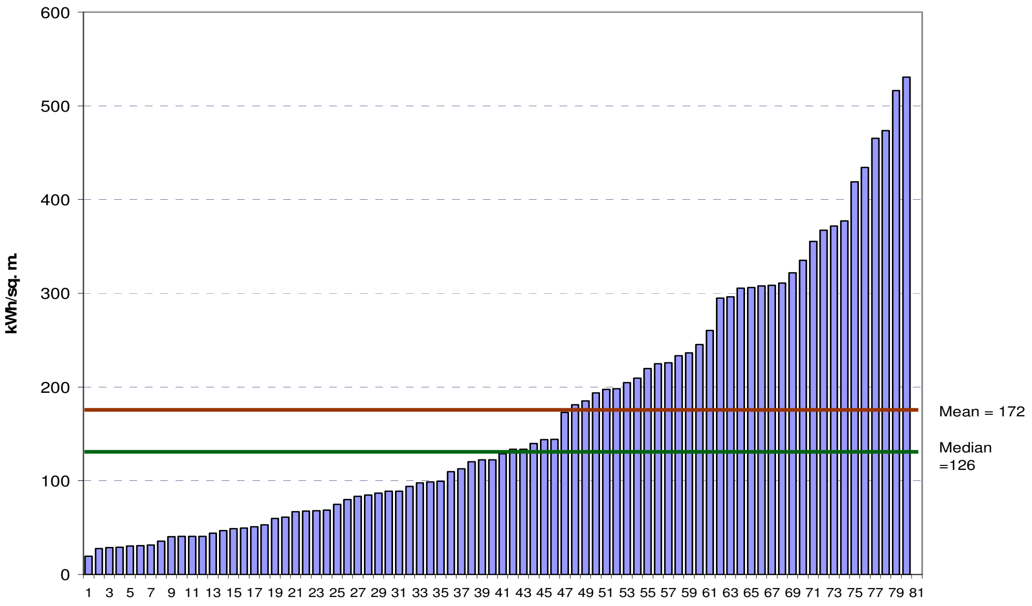
2.5.3 Estimates of Efficiency Improvements and Scenario for Savings Opportunities

In this section, we report on the aggregate energy use intensity, which is calculated using the total energy use and floorspace area reported in the previous data section. The efficiency scenarios covered in Section 4 include an improvement in energy efficiency of two end-uses – AC and lighting. The AC improvements are estimated for a subset of the equipment used for space cooling.

2.6 Aggregate Energy Use Intensity

The commonly used measure for assessing the energy performance of a building and for commercial end-use demand forecasting is the energy use intensity (EUI). Typically, energy-efficiency indicators for commercial buildings can be obtained by normalizing the energy use with floor area and/or operational hours. In this study we define EUI as the quantity of energy used per unit of floorspace. Climate adjustment of energy use data is performed when the degree-days information is available. By normalizing for primary determinants, the study utilizes the EUIs of existing building stock to calculate the potential improvement in the policy case for the new and surviving building stock. Figure 8 shows the range of EUIs found in the set of office buildings analyzed in this study. We see a relatively wide range in energy consumption (20 – 500 kWh/sq.m), which is indicative of several factors, including levels of space conditioning, lighting, and other internal loads. Currently about 30% of the buildings are cooled. This percentage is expected to go up significantly in the future. However, for the sake of simplicity, we keep this percentage frozen for the analysis period in this study.

Figure 8. Energy Use Intensity (EUI) in Offices



For estimating aggregate EUIs, we remove what we consider to be outliers from our building sample data[6]. Utilizing the building level energy consumption numbers, the study estimated aggregate EUIs for the whole building. Traditionally, median is used to appropriately represent the building sample in order to avoid biasing the estimates from being skewed towards very low or very high consuming fewer buildings. However, since we have a relatively small sample and evenly distributed set of buildings (with a balanced tail), we use the mean EUI as a measure aggregate EUI. Mean EUIs are also the appropriate measure when used to estimate consumption at the sectoral level. In order to further disaggregate the EUIs to specific end-use level, we had to rely on the combined wisdom of BEE energy conservation awards data[7], existing audits, and industry expert opinion.

Energy consumption in commercial buildings arises from diverse sources, and displays large variability. In order to provide a realistic assessment of efficiency potential, the study considers differences in end use consumption between distinct building types, and between new vs. existing buildings. The stock intensity is estimated simplistically, by taking an estimate of total energy consumption and dividing by an estimate of floor area by building type. For new construction, energy intensities are developed separately; generally, new building intensities are assumed to be higher, especially with regard to the presence of air conditioning.

Our estimates for End-use fractions for energy use and EUIs are detailed in the following two tables (Table 8 and Table 9).

Table 8. End-use Fractions of Energy Use in Commercial Buildings

End Use Fractions	Retail	Private Offices	Govt Offices	Schools	Private Hospitals	Govt Hospitals	Hotels	Other
Lighting	40%	30%	30%	45%	25%	25%	25%	23.8%
Cooling	45%	40%	40%	5%	40%	40%	55%	23%
Fans		10%	10%	45%	10%	10%		10%
Other	15%	20%	20%	5%	25%	25%	20%	43%
Total	100%	100%	100%	100%	100%	100%	100%	100%
Source: Based on Sampled Building Data 2009								

Table 9. Estimated Aggregate EUIs in Commercial Buildings

	Building Stock	New Construction
Retail	198	268
Offices	179	189
Government Offices	150	158
Schools	56	56
Private Hospitals	228	408
Government Hospitals	120	215
Hotels	267	280
Other	97	122
Source: Based on Sampled Building Data 2009		

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[6] The sample includes existing building energy data and LBNL's own survey.

[7] These data are available online on the BEE website.

In addition to this disaggregation, intensity variables have a time dependency that parameterizes the evolution of construction trends and equipment markets, as well as the diffusion level of high-efficiency equipment as a result of government or market-based initiatives.

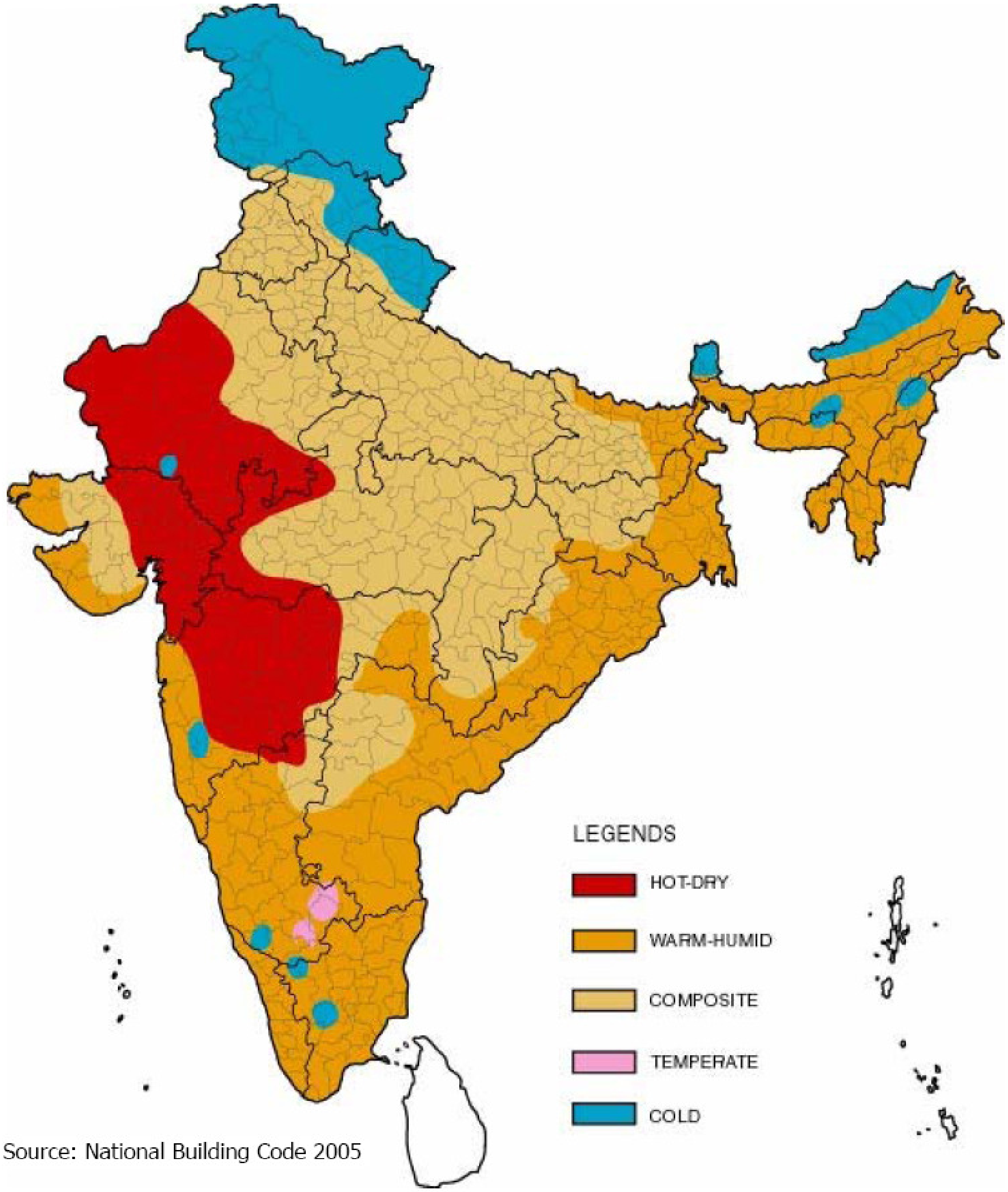
2.7 *Data Limitations*

One of the main limitations of the study is the lack of adequate data to accurately understand the existing building stock, technology mix and efficiency distribution of the installed equipment in the building stock. While the current study makes a significant attempt to get around the data limitation to assess the existing building stock through alternative means, systematic and regular data updates are essential to monitor and study energy consumption trends.

From a policy perspective, the effectiveness of investment in energy efficiency is contingent on the availability of reliable end-use data for buildings, availability of information rich databases such as CBECS, and analysis tools that accurately estimate cost-effective savings from implementing specific efficiency measures. Currently, dedicated collection of energy use information is not prevalent either at the national level or at the state level. Nevertheless, the growing momentum to build green and to benchmark buildings makes systematic data collection necessary. At a macro level, the Construction Industry Development Council (CIDC) produces construction statistics every couple of years. These could be improved through regular updates and greater disaggregation.

Annex

Climate Zone Map Of India



Source: National Building Code 2005

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3. Industry

3.1 *Overview*

The industry sector[8] in India consumes 4,771 PJ in 2005, representing 35% of final energy consumption. This sector is particularly energy intensive, as it requires energy to extract natural resources, convert them into raw materials, and manufacture finished products. The industrial sector can be broadly defined as consisting of energy-intensive industries (e.g. iron and steel, fertilizer, petroleum refining, cement, aluminum, and pulp and paper) and light industries (e.g. food processing, textiles, wood products, printing and publishing, metal processing). The energy intensive industries represent 64% of the entire energy consumed in the sector in 2003-04 while only representing 32% of total industry value added. The scope of this study covers the six most energy intensive industry in India that are the iron and steel, fertilizer, cement, refining, aluminium and pulp and paper industries.

Modern industry has advanced fairly rapidly in India since independence, and the industrial sector contributes 26% of the GDP in 2005 (MOSPI, 2007). Industrial value added augmented at an annual average rate of 5.6% in the 1990s and 7.3% during 2000 to 2005. Total industrial primary energy consumption increased at a slower rate of 3% over the period 1994-2004, inducing a decoupling in the relation of value added – energy consumption. This trend can be observed since the mid-1980s and is mostly the results of energy efficiency improvements. Table 10 shows final energy use and value added for energy intensive industrial sub sectors and other industries.

Table 10. Industrial energy consumption, India in 2003-04

	Final Energy Use (PJ)	% of Industry	% of Energy Cost on Total Production Cost	Gross Value Added (nominal Million US $)	% of value added of Industry
Iron & Steel	1,136	25%	30%	6,517	12%
Fertilizer	391	11%	55%	1,226	2%
Cement	488	9%	40%	1,376	2%
Refining	353	8%	20%	6,315	11%
Aluminum*	297	7%	40%	1,289	2%
Pulp & Paper	194	4%	30%	1,093	2%
Other	1,644	36%	-	38,588	68%

Source: de la Rue du Can, 2008; TERI, 2007 ; MOSPI, 2008

* Gross Value Added of all Manufacture of basic precious and non-ferrous metals (include other non-ferrous metal industries n.e.c. (e.g. copper, zinc, lead, nickel, manganese etc.)

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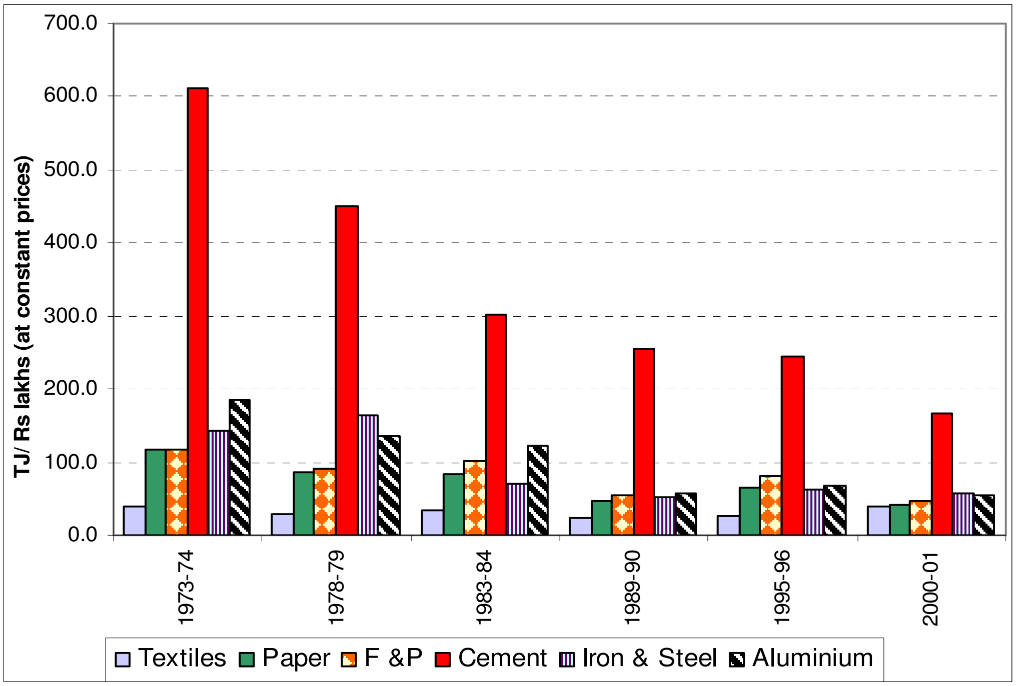
[8] including energy use in the refinery sector

Compared to all other sectors the industrial sector has recorded the maximum energy efficiency improvement since late eighties in India (Roy, 2007). Cement is by far the industry that has recorded the most impressive energy intensity reduction as shown in Figure 9.

Figure 9. Energy intensity of the six energy intensive industries

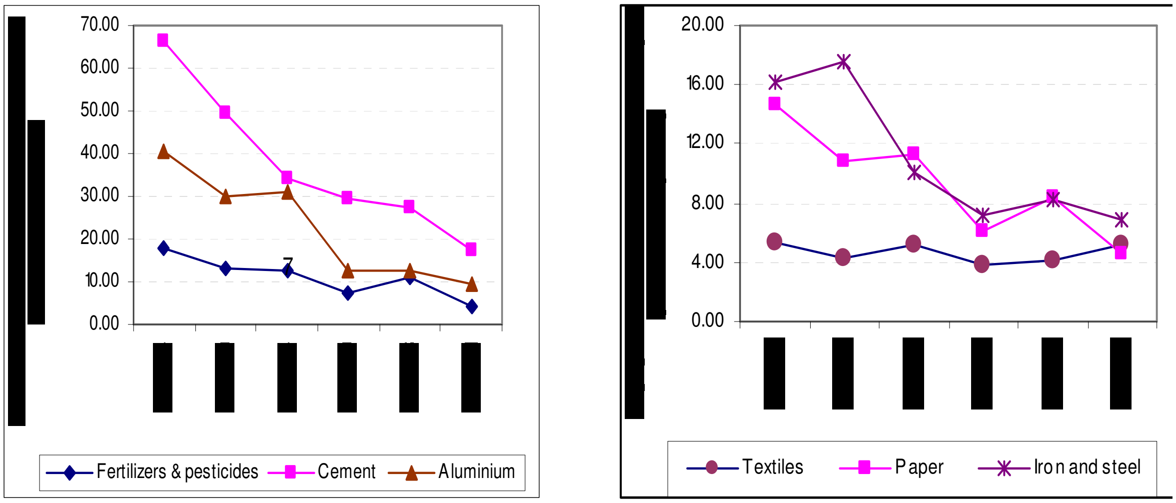


Source Dasgupta and Roy (2000, 2001), Dasgupta (2005)
Note: F&P: Fertilizer and Petrochemical Industries, Energy intensity at 1995 prices.

Many factors explain this trend, amongst which the introduction of more competitiveness with the liberalization of the economy in the early 1990's, the development of cleaner technologies, the increase in energy prices starting in the late 1990's, and the promotion of energy efficiency schemes through the Bureau of Energy Efficiency since the introduction of the "Energy Conservation Act" in 2001. However, barriers to energy efficiency improvement in India remain. They include lack of information and technical skills, especially for small and medium size industries; perception of risk towards adopting innovative technologies; the desire to minimize production disruptions and the access to capital for such improvements (Roy, 2007). If these problems can be overcome, there appear to be significant, potentially exploitable energy and emissions-saving opportunities in Indian industries. Panel data from steel companies in India using a fixed effect model (Dasgupta 2005) has shown that five factors could affect the technology upgradation or energy efficiency improvement in the steel industry. These are firm size, fuel prices, investment in plant and machinery, R&D, and environmental regulation. Of these environmental regulation, followed by fuel price, and investment in plant and machinery have been the statistically significant variables.

Looking at the individual industry's emission intensity (gigagrams of CO_2 per Rs lakhs of output at constant prices 1995 prices), it is found that all the industries are showing a declining trend (Figure 10). Industries achieving maximum reduction in emissions intensity are shown in left part of the graph. These are the aluminum, cement and fertilizer industries. The others, i.e. textiles, paper and iron and steel are shown in the other half of the graph.

Figure 10. Emissions intensity of the industries



Source: Dasgupta and Roy (2000, 2001), Dasgupta (2005)

The figures show that the cement industry's emission intensity has drastically reduced over the years and this has been a steady smooth decline. Since 1989-90, however, the emissions intensity has declined only marginally for all industries except in the case of cement where the significant decline has continued and in the case of textiles where the intensity has increased.

3.1.1 Approach

The approach used to develop a modeling framework for the industry sector is elaborated at the process level for each industrial sub-sector. Energy intensity is calculated as energy use per tonne of commodity produced and carbon intensity as CO_2 emission released per tonne of commodity produced. Energy intensity and carbon intensity of commodity production are estimated for existing plants and plants that show the most efficient level are, referred as best practice plants. Estimations were based on the breakdown in process, and on the efficiency of each process as detailed in the following chapters for each industrial sub-sectors. The model estimates average baseline intensity for production in the base year and considers the intensity likely to apply to new installation going forward, that is, the intensity of marginal production. In addition, efficiency improvements due to retrofits of equipment and processing in existing plants are included.

3.1.2 Data Source

As part of the initial stage of the project, we have conducted a review of the existing literature in several areas needed for the project. The main elements are process energy demand estimates in different industry sectors and establishment of baseline technologies. In addition, however, we identified studies specifically addressing the topic of the potential for efficiency improvement. The latter were typically industry studies, although a few of them were process oriented. The sources of data are referenced in each subsector chapters.

The main source use was the Bureau of Energy Efficiency (BEE). The BEE conducts a program called the National Energy Conservation Awards that reward companies that are the most active in implementing energy conservation measures. Under this scheme, industrial units are motivated to report on their energy conservation efforts and documents describing their energy use and the energy conservation measures implemented are available through the BEE website. The documents include the type of measure implemented, a description, the amount of energy consumed before and after the implementation of the measure per energy product type and the investment cost that was required to implement the measure. This information was used to construct energy conservation supply curve.

We also supplemented this source of data with individual companies annual report. Some large companies reports detail of their annual energy consumption as well as energy efficeicncy improvement implementations. Furthermore, we used data from Clean Development Mechanism (CDM) project documents available from the United Nations Framework Convention on Climate Change (UNFCCC) website. Some Indian industrial plants have implemented innovative technologies that have technologies that have been rewarded with carbon credit certificate under the CDM scheme. These plants have to provide detail analysis of the carbon savings resulting from the implementation of energy savings measure and sometime also provide investment cost analysis.

At last, but not at least, the study beneficiated from inputs from national experts. Two workshops were organized during the course of the study, one in New Delhi and one in Calcutta, during which national industry experts shared their knowledge of sector's energy use characteristics and efficiency improvement potentials.

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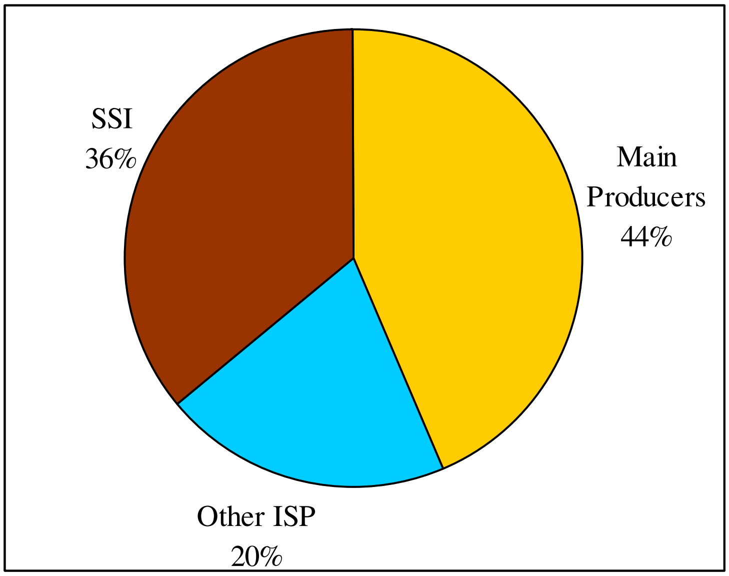
3.2 *Iron and Steel*

3.2.1 Overview

The iron and steel sector is the largest consumer of energy in the industrial sector in India, with a share of 28% of total energy use in industry (de la Rue du Can, 2008). The sector is highly concentrated with 9 companies producing 64% of total crude steel and the remaining 40% produced by small scale industries (SSI). Figure 11 shows the production of crude steel by type of producers. Main producers include the largest three companies: SAIL, RINL and Tata Steel Ltd (TSL). Other Integrated Steel Plants (ISP) include six plants of medium size and the SSI sector includes all the remaining steel produced by smaller size plants.

Figure 11. Production of crude steel in 2006-07 by producer category (Mt)



Source: JPC, 2008
ISP: Integrated Steel Plants
SSI: small scale industries

3.2.2 Activity Variable

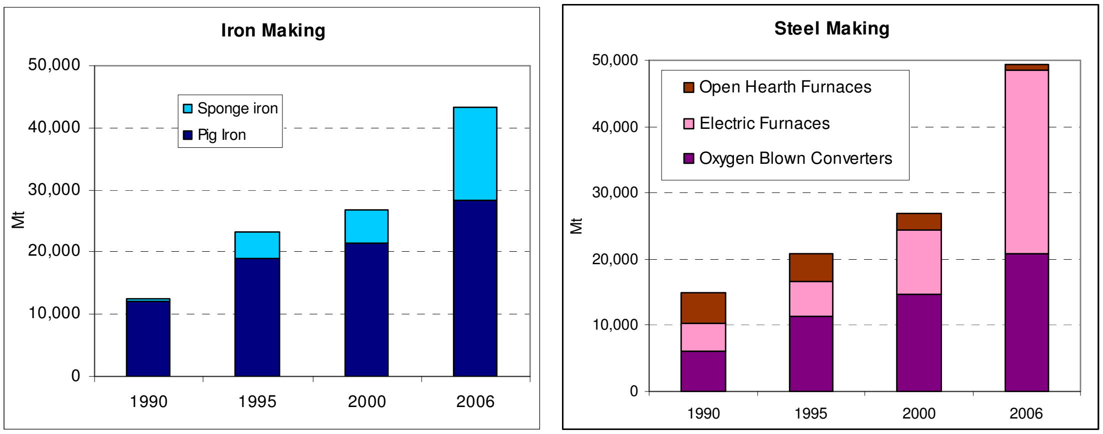
India is the seventh largest steel-producing country in the world. However, the per capita consumption is only about 43 kg as compared to global average of 202 kg, 295 kg in France, 425 kg in the US and 510 kg in Germany (IISI, 2007). Production is growing very rapidly, with an annual average of 11% over the period 2000 to 2006, mostly driven by domestic demand. The production of steel in India is expected to continue to grow fast to meet the country needs for its development. Industrialization drives an increase in materials demand for construction of basic infrastructure needs such as railways, buildings, power grids, etc. Furthermore, domestic steel demand is also driven by the rising automobile industry. If the steel production were to continue to increase at a similar rate, the world average per capita level would be reached by 2023 and level of developed countries such as the USA would be reached by 2030.

Process

Production of iron and steel consists in several steps, amongst which the most energy intensive are iron production, steel production, and finished product preparation. There is mainly three routes that can be followed: production of iron through blast furnaces (BF) followed by the steel production in oxygen blown converters (OBC); production of sponge iron through direct reduction (DR) followed by production of steel in electric furnaces (EF); and finally direct production of steel from scrap metal in electric furnaces. The latter is by far the less energy intensive as it avoids the production of iron.

In India, the steel industry is slowly diverting itself from the BF-OBC route in favor of the DR-EF route. Production of sponge iron has grown very rapidly over the last 16 years, from 0.6 Mt in 1990 to 16.9 Mt in 2006, representing 35% in 2006 (Figure 12). This results from the installation of three large natural gas based DR-EAF plants and the "mushrooming" growth of small coal based sponge iron plants starting after 2002 (JPC, 2006). Sponge iron from SSI is further processed into steel in small electric furnaces, either in EAF or for the most part in induction furnaces (IF), which correspond to a close version of EF more applicable to smaller melting capacity.

Figure 12. Iron and Steel Production by Process



Source: IISI, 2007

The recent growth in small coal-based sponge iron industry has been favored by the growth in domestic steel demand, the low cost of investment that these small plants require, the frequent problem of scrap availability, which can be supplemented or replaced by sponge iron and the availability of local coal of lower quality, which can be used in the DR process, while blast furnaces require coking coal that is mostly imported.

Steelmaking is followed by casting and shaping. Ingot casting is the classical process and is rapidly being replaced by the more energy efficient continuous casting process. The degree of penetration of continuous casting (CC) process increased from 12 % in 1990 to 66% in 2005 (IISI, 2007b).

3.2.3 Energy data

Specific final energy consumption in India has reduced considerably over the last 20 years. While in the 1980's final energy consumption had been on average 45 GJ/t crude steel (cs) (excluding energy used for coke making), in the early 1990s it had already declined to around 35 GJ/t cs (Schumacher and Sathaye, 1998) and has since further decreased to an estimated 29.1 GJ/t cs of crude steel produced. The main factors influencing energy use are the size of the plant and the technology employed in the process. Hence, a breakdown of energy intensity according to the size of the plants and the process route in use was done to project energy consumption and assess the reduction potentials.

Large Integrated Steel Plants

Table 11. Indian Large Integrated Steel Plants SEC (Final Energy)

	Production Of crude steel Mt	SEC GJ/t cs	Coal %	Elect %	FO %	LPG %	Gas %	SEC World Best Practices
ISP BF-OBC	25.4	32.0	88%	11%	-	-	-	17.8
ISP DRI natural gas-EAF	5.8	19.0	3%	11%	3%	11%	71%	18.6
ISP DRI coal-EAF	4.1	21.4	62%	23%	7%	9%		-

Source: Best practices data are based on Worrell et al, 2008.
cs: crude steel

There are 14 large integrated steel plants[9] (ISP) that produce about 64% of total crude steel in India. The vast majority (76%) are following the BF-OBC route, while the rest follow the DR/ Hot Briquette Iron (HBI)[10]–EAF route. Table 11 shows the specific energy consumption (SEC) and the total quantity produced by ISP per type process route. Data on energy use for seven of ISF are available in the Annual Report of Ministry of Steel (MOS, 2008a), while data for other ISF were collected from company annual reports. Annex 2 provides detailed data collected. Table 11 also provides SEC for best practices and demonstrates that large energy efficiency potential exist for ISP that are based on the BF-OBC route, while ISP DRI natural gas based provide very competitive energy intensity.

Small Scale Industries

SSI represents a very heterogeneous segment, where each production step is produced in different units. The sub sectors comprising mini blast furnace units, sponge iron producers, induction furnace, electric arc furnace units, re-rolling (RR) units (Basak G. K., 2008). A detailed production by sub sectors is given in Annex 3. SEC in small units is high due to poor economy of scale, intermittent operation with 40-60% utilization of installed capacity and very low engineering base and use of obsolete technology. Data

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[9] Owned by 6 companies.

[10] HBI is a compacted form of direct reduced iron (DRI), which facilitates its handling, storage, and use.

describing their energy use are scarce. The following paragraphs describe the different sub segments.

Sponge Iron Producer: India is the largest producer of sponge iron in the world, representing approximately 20% of global production (ISII, 2007), but contrary to other countries, 70% of sponge iron produced in India is from small coal based SSI, which are less energy efficient. There are about 319 sponge iron producers. Energy intensity in natural gas based DRI plants is 10.4 GJ/t DRI (IEA, 2007) while a typical small coal based DRI plant consumes between 20 to 24 GJ/t of sponge iron produced (Das and Kandpal, 1997). DR technologies take advantage of the local low-quality coal resource[11] and do not need coke production.

EAF/Induction furnaces: Electricity consumption per tonne of crude steel in the Scrap-EAF technology in India varies from 600 to 900 kWh as against 325 to 375 kWh in Japan. Other than electricity, a small quantity of petroleum products (6-16 kg/t of steel) is consumed in the process. (Das and Kandpal, 1997)

Re-rollers: There are about 1,200 re-rollers that roll out semis into finished steel products for consumer use, mainly by the construction industry. There are small and medium enterprises, whose reported capacity is around 15 Mt and capacity utilization was 55% in 2004/05. The energy consumption of the steel re-rolling mills is 1.8-2.3 times in comparison to that in developed countries for similar products (ENA, 2001).

Based on data collected from these different sources and estimates based on expert judgments, energy intensity by main steel production route are shown in Table 12.

Table 12. Characteristics of Iron and Steel Small Scale Industries in 2006

	Production of crude steel Mt	SEC GJ/t cs	Coal %	Elect %	Best Practices SEC (GJ/t cs)
SSI DRI coal	13.08	31.2	60%	40%	16.6
SSI Scrap-EF	3.5	3.5		100%	2.6
SSI BF-OBC	0.724	35.9	90%	10%	

Source: Scrap-EF Best practices data are based on Worrell et al, 2008.
cs: crude steel

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[11] the BOF-BF process requires higher level of coal that is for 70% imported

Resulting energy in the iron and steel industry use is presented in the following table:

Table 13. 2006 Estimated Final Energy Use in the Iron and Steel Industry

Average Energy Intensity	Gj/t cs	28.2
Energy Use	PJ	1,444
Integrated Plants	PJ	944
coal	PJ	727
electricity	PJ	103
Fuel Oil	PJ	21
Natural Gas	PJ	78
LPG	PJ	16
Small Scale Plants	PJ	500
coal	PJ	382
electricity	PJ	72
Fuel Oil	PJ	45

cs: crude steel

3.2.4 CO_2 Emissions

CO_2 emissions from the iron and steel industry are entirely due to consumption of fuel for energy purposes. Fuel consumption consists mainly of coal, and to some extent electricity, natural gas and fuel oil.

The quality of coal available in India is of a low grade with high ash content (25 to 30%). This poses environmental problems due to the production of fly ash (which is however, is getting increasingly recycled and used in cement industry) and contributes to lower energy performance and higher CO_2 emissions per unit of energy use. The National Policy reports that in 2004-05 about 27 Mt of coking coal, of which 70% was imported, and 13 Mt of non coking coal was consumed in the iron and steel sector (MOS, 2005). Moreover, the domestic coking coal requires intensive washing to lower its ash content.

Resulting CO_2 emissions in the iron and steel industry use is presented in the following table:

Table 14. 2006 Estimated CO_2 emissions from the Iron and Steel Industry

CO2 Emissions	ktCO2	160
Integrated Plants	ktCO2	102
Small Scale Plants	ktCO2	58
Emission Intensity	tCO2/tcs	3.14
Integrated Plants	tCO2/t	3.13
Small Scale Plants	tCO2/t	3.17

Cs: crude steel

3.2.5 Energy efficiency measures and associated costs

Energy conservation measures include a large variety of technology options, from capital intensive new machinery to simple process optimization. Several studies have looked at the potential to reduce energy use in the iron and steel industry, but only a few cover India and often focus on one process or one segment. Mishra (1998) looked at potential energy savings in ISP, Biwas et al (2003) focus on sponge iron units, ENA (2001) study the re-rolling industry and Pal and Nath (not dated) looked at cast iron. Moreover, information on ISP can also be gathered from the Bureau of Energy Efficiency (BEE). Most of the ISP industries submits to the BEE their top management commitments on energy conservation in order to participate to the National Energy Conservation Awards. Documents that describe their energy use and the energy conservation measures implemented are available through the BEE website. Often, the documents include investment detail and future perspectives. Several global studies also provide a description of energy efficiency options (Price, 2001; Bernstein et al., 2007; IEA, 2007). Worrell et al (1999) analyze the potential for reducing energy use and carbon dioxide emissions from steelmaking in the U.S., compiled information on the costs, energy savings, and carbon dioxide emissions reductions of a number of technologies and measures. However, potential to reduce energy use in small-scale enterprises is rarely analyzed in these studies.

Large Integrated Steel Plants

Past reduction in the iron and steel overall energy intensity is largely due to improvements from ISP. SAIL, the largest steel-making company in India, has reduced its SEC by 37% over the period 1990 to 2005. Some of the energy-efficient technologies adopted by the steel industry are as follows (TERI 2007):

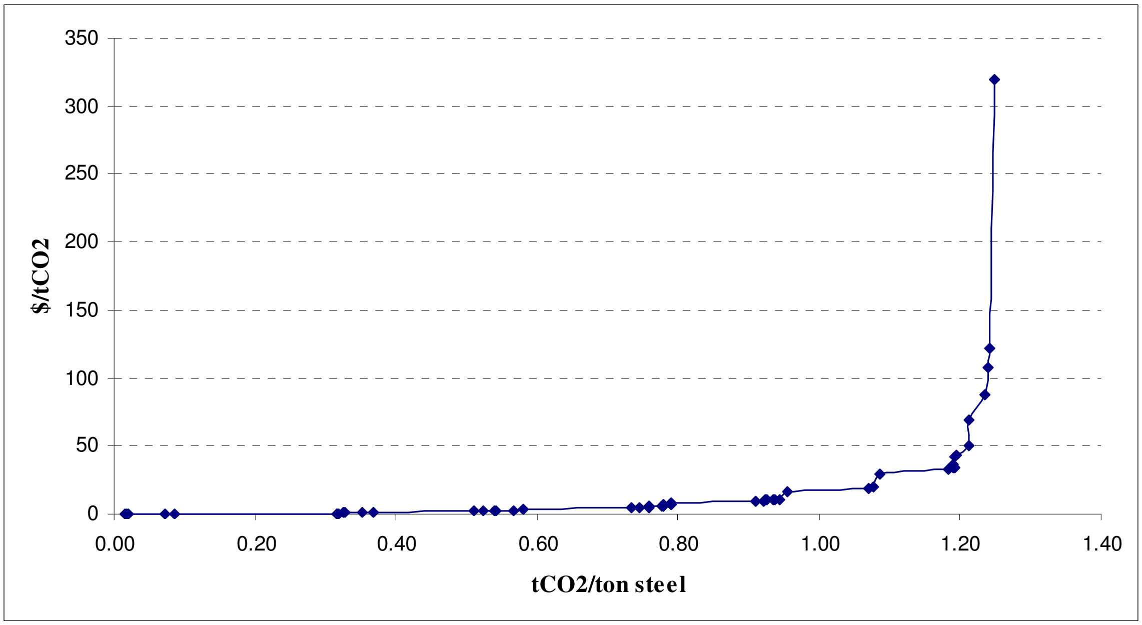
- Coke dry quenching (CDQ) in coke production
- Pulverized coal injection in pig iron making
- Natural gas injection in iron making
- TRT (top pressure recovery turbine) in iron making, and
- Utilization of blast furnace gas/ basic oxygen furnace gas for heat and/or power generation in steel production.

Other energy-efficient measures implemented by the steel industries include use of tar in blast furnaces, carbon monoxide firing in vertical shaft kilns, adoption of multi-slit burner; installation of variable frequency drives; installation of vapor absorption systems; use of high efficiency motors, pumps, and blowers; improved insulation of furnaces; and replacing electric heaters with fuel-fired heaters; and so on.

Figure 13 shows the CO_2 abatement cost curve for Indian integrated steel plants. A typical CO_2 abatement cost curve plots the marginal cost of mitigate carbon emissions by a measure or technology implementation against the total amount of greenhouse gases abated. Ranking investments according to their price per unit of GHG saved define the supply curve. CO_2 abatement cost curve is consistent with microeconomic theory which posits that a firm will invest in energy conservation up to the point where the marginal costs equal the marginal benefits, or the value of one unit of energy or greenhouse gas emissions or the energy/carbon price. (Martin et al., 2000). More information about estimating the cost of reducing emissions are available in the Methodology and Scenario Section. The vertical axis shows the cost of each abatement measure, in dollars per tonne of avoided greenhouse gas emissions, and the horizontal axis shows the amount of CO2-equivalents that can be avoided by that abatement measure, in tonnes of emissions per tonne of crude steel produced.

The cost curve is developed with various carbon saving measures. These carbon saving measures are derived from Indian case studies, CDM-projects and US carbon savings measures for the US iron and steel sector (Sathaye et al., 2009). The latter options are converted to the Indian situation. The accompanying spreadsheet model contains all carbon saving measures and lists the typical carbon savings, investment costs, lifetime, source etc.

Figure 13. CO_2 Abatement Cost curve for Indian Integrated Steel Plants



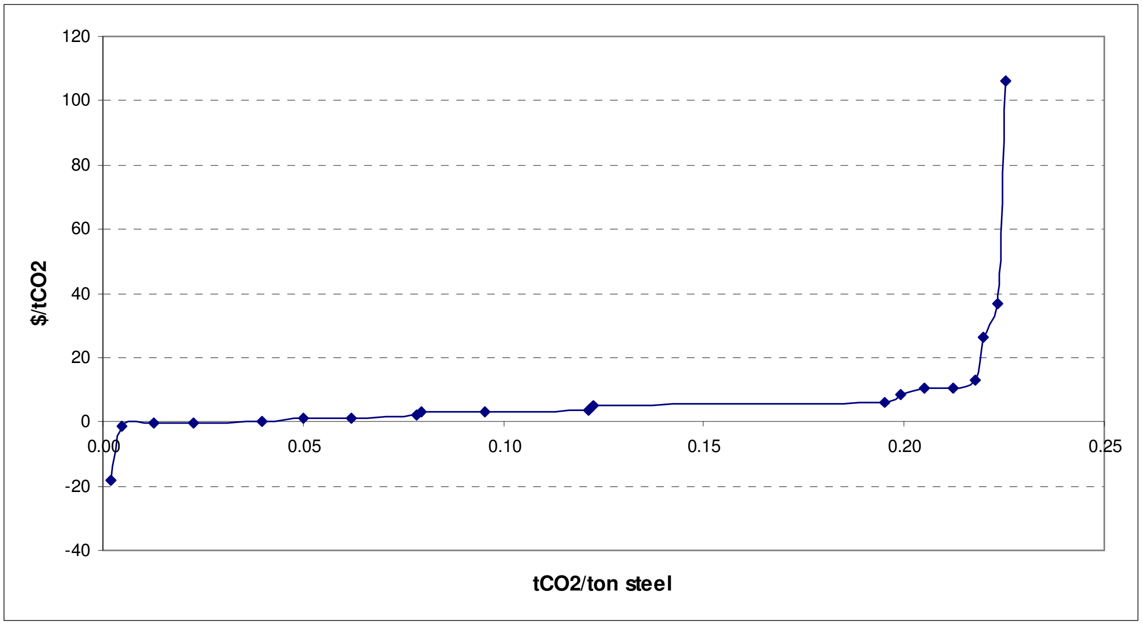
A list of energy efficiency improvement measures by process is included in Annex 4 and examples of investment and pay back periods are provided in Annex 5.

Small Scale Enterprises

With increasing competition in the steel sector, the small steel plants have started using upgraded technology, increasing the use of sponge iron through continuous feeding, scrap preheating and other modern and more efficient features. Furthermore, the secondary steel industry has more and more turned towards the combined use of mini blast furnaces (to supply hot metal) and electric arc furnaces. This combination basically presents a new approach to integrating steel production. However, data describing the energy efficiency opportunities for SSI are lacking in spite of their increasing share of total production and total energy use, approximately a third of energy use in the iron and steel sector. Only a detailed survey could be found for the Re-roller SSI.

The Ministry of Steel undertook a UNDP/GEF assisted project for identifying energy efficient and economically viable technology options in the Steel Re-Rolling Mills sector in India. A team of experts surveyed technology options in the area of combustion, mill-equipment and electrical equipment related to the SRRM sector. Thirteen options were identified for reheat furnaces and related opportunities to reduce fuel consumption, while five options were identified in the area of rolling mill and electrical machinery. The energy saving potential in GJ/t, cost of conserved energy with 30% hurdle rate of industry expressed in Rs100/GJ, along with interest rate of return (IRR) and paybacks period is summarized in Annex 6. Energy saving potential for these options with reference to defined baseline levels is in the range of 0.67 GJ/t to 2.5GJ/t. Figure 14 shows the cost curve for small plants in India. The individual measures that are based on Indian case studies and US reduction measures are listed in the accompanying spreadsheet-model.

Figure 14. CO2 Abatement Cost curve for Small Indian Steel Plants



3.2.6 *Future perspectives*

To meet the increased demand in India, BF-OBC route will continue to play a significant role, but its dominance is likely to be eroded largely because of a shortage of domestic metallurgical coal. Natural gas based DR process, already in used in three DR plants[12] allowing lower CO_2 emissions, provides a competitive alternative. Nevertheless, the Indian non-coking coals are suitable for treatment in small rotary kiln sponge iron making processes. Current trend in growth of SSI sector may continue to increase.

Projections from Ramachandran (2007) in Annex 1 shows potential demand increasing up to 180 Mt by 2019-20 with projected installed capacity of 289 Mt/yr by 2019/20, mostly from ISP installed capacity.

In integrated large plants retrofit is a very important candidate for efficiency improvement (Roy and Roy 2008a 2008b). In any investment decision industries for new plants vie for best technology in order to maintain a competitive edge, but for retrofits, high competitive demand for company's own investment fund means that funds do not get directed to retrofits due to lack of appropriate incentive and bulk investment need.

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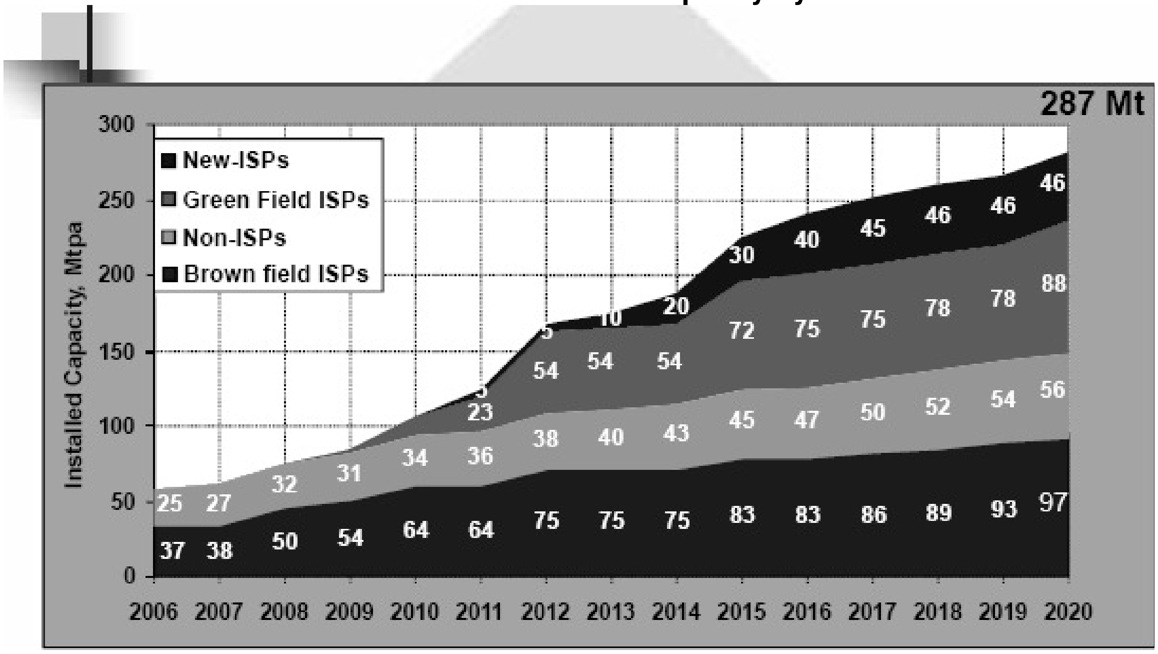
[12] ESSAR Steel Ltd., Ispat Industries Ltd. And Vikram Ispat Ltd

Annexes

Annex 1. Overall Indented Capacity by 2020



Source: Ramachandran V. 2007

Annex 2. Specific Energy Consumption per Indian ISP

Plants	Process	Output (Mt cs)	SEC GJ/ t cs
SAIL - BSP	BF-BOF/THF-IC/CC	4,799	33.0
SAIL - BSL	BF-BOF-CC	4,067	29.7
SAIL - DSP	BF-BOF-CC	1,869	29.6
SAIL - RSP	BF-BOF-CC	1,990	33.4
SAIL - I S P	BF-BOF-CC	472	38.9
SAIL - V I S L	BF-BOF	159	-
RINL	BF-BOF-CC	3,497	27.3
TATA Steel Ltd.(TSL)	BF-BOF-CC	5,174	34.9
JSW Steel Ltd.	BF-BOF-CC	2,643	34.6
Total Oxygen route		26,670	
SAIL - ASP	EAF	150	-
ESSAR Steel Ltd.	HBI/DR (nat gas)- EAF-CC	3,006	17.4
Ispat Industries Ltd.	HBI/DR (nat gas)- EAF-CC	2,761	20.7
Jindal Steel & Power Ltd.	BF and DR-EAF	803	25.5
Lloyds Steel Ltd	DRI-EAF- CC	537	21.2
Jindal Stainless Ltd	DRI-EAF- CC	585	16.7
Total EAF route		7,842	
Total ISP		32,512	

cs: crude steel

Annex 3. Secondary Producer Production

	Secondary Producers		Of Which SSI	
	kt	unit	kt	unit
Iron Production				
Mini Blast Furnace	10,463	36	7,820	35
pig iron	4,133		4,133	
Sponge iron	18,345	324	10,653	319
Ferro Alloys	1,845	69	1,845	69
Total	34,786		24,451	
Steel Production				
EAF	9,883	39	2,191	34
Induction Furnace	15,390	1,325	15,390	1,325
Corex/MBF	3,367	3	724	2
Total	28,640		18,305	
Finished Steel				
Re-rolling	19,831	2,288	9,496	2,288
Wire Drawing	539	100	539	100
HR Sheet/Coil	9,452	14	9,452	14
Cold Rolling	5,807	91	5,807	91
GP/GC Sheets	3,192	18	3,192	18
Total	38,821		28,486	

Source: Secondary Producers data comes from JPC, 2008
Notes: SSI = secondary producer minus other large steel plants

Annex 4. Energy Efficiency Measures in the India Iron and Steel ISF

1. Coke- Making

a. Pre-Carbonization of medium / poor coking coals (i.e. Partial Briquetting and Stamp Charging).

b. Maximum Recovery of Coke Oven Gas

c. Using Coke Oven Gas for achieving higher blast temperature

d. Using Coke Dry Quenching Technology

2. Iron-Making

a. Sinter Quality improvement and its use up to 80 % in BF burden

b. Computerized Control of Sinter Plant operations

c. Pulverized Coal / Coal Tar Injection in Blast Furnace

d. Bell Less Top Charging

e. Increasing Blast Pressure and Temperature

f. Cast House Slag Granulation

g. Steam / Electricity Generation from BF off-gases

3. Steel-Making

a. Pre- Treatment of Hot Metal, i.e. Desulphurization

b. Improvements in the BOF Steel-making like combined blowing, higher lining life, automation, etc.

d. BF top gas recovery and its use as fuel gas.

e. Replace Ingot casting with Continuous Casting.

4. Steel-Rolling

a. Replace large size pusher reheating furnaces with Walking Beam Type reheating furnaces

b. Direct Charging of hot slabs.

c. Rolling to close tolerances.

d. Near-net-shape casting of slabs and blooms.

Source: Mishra, 1998

Annex 5. Energy Savings Investment and Efficiency Potential

A. Automatic Ignition of Coke Oven Gas Flare

Units Equipped : 4 Coke Oven Batteries
Investment : Rs. 20 Million
Energy Recovered : 3 Mcal / TCS
Fuel Saved / Annum : 1962 Tonnes
Savings : Rs. 13.7 Million
Pay Back Period : 1.3 Years

B. Top Gas Recovery Turbines

Units Equipped : 2 Blast Furnaces
Investment : Rs. 1000 Million
Energy Recovered : 70 kWh / TCS
Electricity Saved / Annum : 387 Million units
Savings : Rs. 1150 Million
Pay Back Period : 1.00 Years

C. Hot Stove Waste Heat Recovery

Units Equipped : 2 Blast Furnaces
Investment : Rs. 150 Million
Energy Recovered : 15 Mcal / TCS
Fuel Saved / Annum : 9800 Tonnes
Savings : Rs. 68.6 Million
Pay Back Period : 3.5 Years

D. BOF Gas Recovery

Units Equipped : 3 BOF Vessels
Investment : Rs. 3000 Million
Energy Recovered : 200 Mcal / TCS
Fuel Saved / Annum : 130000 Tonnes
Savings : Rs. 910 Million
Pay Back Period : 5.7 Years

E. Double Insulation of Skids

Units Equipped : 3 Slab Reheating Furnaces
Investment : Rs. 50 Million
Energy Recovered : 10 Mcal / TCS
Fuel Saved / Annum : 6540 Tonnes
Savings : Rs. 45.5 Million
Pay Back Period : 1.4 Years

F. Coke Dry Quenching Unit

Units Equipped : 4 Coke Oven Batteries
Investment : Rs. 5500 Million
Energy Recovered : 150 kWh / TCS
Electricity Recovered/ Annum : 833 Million units
Savings : Rs. 2500 Million
Pay Back Period : 3.4 Years

G. Coke Oven Automatic Combustion Control

Units Equipped : 4 Coke Oven Batteries
Investment : Rs. 180 Million
Energy Recovered : 12 Mcal / TCS
Fuel (Coal) Saved / Annum : 17250 Tonnes
Savings : Rs. 52 Million
Pay Back Period : 6.0 Years

H. Sinter Cooler Sensible Heat

Units Equipped :2 Sinter Coolers
Investment : Rs. 1000 Million
Energy Recovered : 40 Mcal / TCS
Fuel Saved / Annum : 26250 Tonnes
Savings : Rs. 184 Million
Pay Back Period : 10 Years

I. Bled BF Gas Recovery

Units Equipped : 4 Coke Oven Batteries
Investment : Rs. 140 Million
Energy Recovered : 10 Mcal / TCS
Fuel Saved / Annum : 6540 Tonnes
Savings : Rs. 45 Million
Pay Back Period : 5.5 Years

J. BOF Sensible Heat

Units Equipped : 3 BOF Vessels
Investment : Rs 1000 Million
Energy Recovered : 30 Mcal / TCS
Fuel Saved / Annum : 20,000 Tonnes
Savings : Rs. 140 Million
Pay Back Period : 13 Years

Source: Mishra, 1998

Annex 6. Re-rolling technology options

No	EcoTech Option	Energy Saved$^{@}$(GJ/T)	CCE (Rs. 100/GJ)*	IRR (%)	Payback (Years)
1.	Re-vamping existing pusher hearth furnace	0.486	-1.73	255	0.42
2	LAP Oil Film Burners developed by IIP.	0.085	-1.67	166	0.58
3.	Replacement of the existing pusher furnace with EE furnace.	0.286	-1.67	61	1.50
4.	Variable Voltage Variable Frequency drives to control oxygen in combustion air.	0.015	-10.96	119	0.83
5.	Microprocessor based control system for regulating furnace zone temperature & pressure	0.438	-1.72	231	0.42
6.	Complete change of furnace lining	0.086	-1.46	115	0.83
7.	Ceramic fiber veneering	0.021	-1.46	115	0.83
8.	High Efficiency Metallic Recuperator	0.256	-1.91	355	0.25
9.	Application of Regenerative Burners	0.487	-3.29	195	0.50
10	Walking Beam reheating Furnace	0.486	-2.24	161	1.25
11.	Modification of grate type coal firing system into pulverized coal	2.445	-0.75	227	0.42
12.	Producer gas based re-heat furnace	1.222	-0.52	84	1.50
13.	Hot Charging in composite mills	0.342	-1.79	235	0.42
14.	Pre-requisite Re-rolling Mill Package (a/a)	0.166	-8.56	219	0.48
15.	Computerized Roll Pass Design	0.100	-6.03	204	0.50
16.	Anti-friction Roller Bearing	0.108	-2.48	185	0.58
17.	Energy Efficient Auxiliary Drives	0.029	-1.42	45	2.25
18.	Energy Efficient HT Motors (Main Drives)	0.108	+5.33	18	5.00

@: Energy savings are per tonne of annual production of crude steel
Source: ENA, 2001

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3.3 *Aluminum*

3.3.1 Overview

The Aluminum sector consumed about 7% of total energy used in the industry sector in 2005 (de la Rue du Can, 2008). India's share in world aluminum capacity represents about 3%. Indian reserves of bauxite, the key raw material in aluminum production, are abundant with deposits of about 3 billion tonnes or 5% of world deposits. The Indian aluminum sector is highly concentrated with only three large players: Hindalco, Sterlite Industries and the National Aluminum Company (Nalco). Table 15 shows primary aluminum production per producers in fiscal year 2007-08. The sector is also composed of secondary producers which process aluminum into rollers and extruders and either purchase from domestic producers or import the primary metal (billets and blooms). Such secondary metal producers include India Foils, Pennar Aluminum, and Century Extrusions, which together control over 70% of the market for extrusions and foils (ICRA, 2006). It is estimated that secondary producers produce about 600 kt of fabricated product (Metalworld, 2008).

Table 15. Primary Aluminum Production by Producer

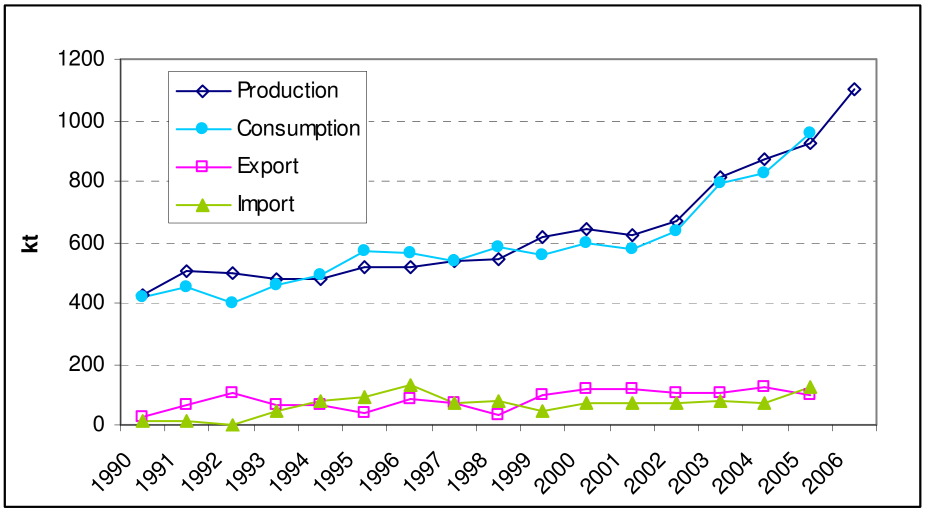
	2007-08	share
INDALCO	478	39%
Sterlite Industries	396	32%
NALCO	359	29%

Source: Murthy, 2007

3.3.2 Activity Variable

Production of primary aluminum in India grew at an average annual growth rate (AAGR) of 6.1% over the period 1990 to 2007 and has accelerated during the last 6 years of available statistics (2000-2007), with an AAGR of 9.7%.

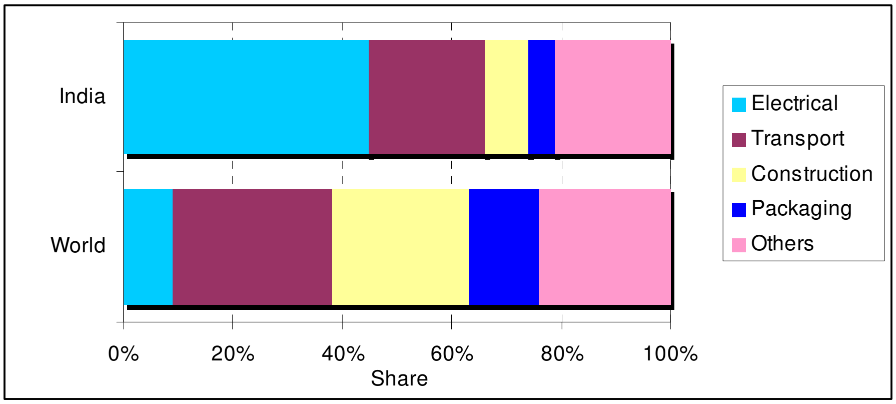
Figure 15. Primary Aluminum Supply



Source: UN, 2007; USGS, 2008.

The per capita consumption of aluminum in India continues to remain extremely low at 0.7 kg as against nearly 31.9 kg in the US, 32 kg in Japan, and about 6.5 kg in China. The main end-users of aluminum are the electrical, automobile, packaging, and construction sectors as shown in Figure 16. The usage pattern differs from the rest of the world where the sectors of construction, packaging and transport represent much larger shares.

Figure 16. End Use of Aluminum: India and World (%)



Source: Murthy, 2007

3.3.3 Energy data

The production of aluminum is a very energy intensive process, requiring large quantity of electricity. Energy cost represents on average 40% of total production cost. The main energy steps for primary aluminum production consist first in refining bauxite into alumina, then reducing alumina to aluminum by means of electrolysis and in rolling slab ingots into flat sheets. In 2007, an estimated amount of 111 PJ of energy was used in the production of aluminum in India, of which 65% was electricity (Table 16).

Table 16. Aluminum Energy Use in 2007

Primary[13] Energy Use (PJ)	303
Final Energy Use (PJ)	111
Coal Electricity Fuel Oil	31% 65% 4%
Alumina Production (ktonne)	2,835
SEC (GJ/t)	14.9
Primary Aluminum Production (ktonne)	1,233
SEC (kWh/t)	14,784
Secondary Aluminum Production (ktonne)	600
SEC (kWh/t)	1,183

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[13] Primary Energy are calculated by estimating a 25% efficiency for captive power in Primary aluminum production and 33% efficiency for electricity from the grid for alumina and secondary aluminum production (T&D losses of the grid are not included).

Specific energy consumption for alumina production was estimated to be equal to 14.9 while aluminum SEC was estimated equal to 14,784 kWh/t aluminium and only 1,183 kWh/t aluminium for secondary aluminum production.

Alumina Production

Alumina production requires energy in the form of steam for the refining process and in the form of heat for the calcining (drying) of the alumina. In India, there are 7 plants that refine alumina. Detailed data were collected for 3 plants, representing 83% of total alumina production (Annex 8.).

Primary Aluminum Production

The most energy intensive step in aluminum production is the electrolysis. Two main types of smelters are used for the electrolysis: the Hall-Héroult system with pre-baked (PB) anodes and the older Søderberg cell with in-situ baked electrodes. In India pre-baked system accounts for about 89% of aluminum production and Søderberg for the remaining share. Indian's smelter plants have specific electrical energy consumption ranging from 14,195 kWh/t aluminum to 18,083 kWh/t (see Annex 9 for more detail).

Smelters require an uninterrupted supply of power, and all plants own captive power plants that produce electricity from coal with a very low efficiency rate of around 25%. Generating power from a captive plant is more cost effective due to sourcing of coal from captive mines and since it is a more reliable source of power than from the grid.

Aluminum production from recycled material requires only 5% of the energy required by primary aluminum production. Recycled metal already satisfies around a third of world demand for aluminum and it is an ever growing proportion of total aluminum production in developed countries (IAI, 2001). The secondary aluminum industry imported about 190kt of scrap aluminum which is used through foundry and extrusion industry to produce various aluminum products including some for auto grades. Domestic recycling rate are very small (Metalworld, 2008).

Anode Production

Carbon anodes are a major requirement for the production of aluminum. About 0.5 tonne of carbon is used for every tonne of aluminum produced. Carbon anodes are formed and baked directly in the pot during the Søderberg process, while they are made before they are added to the pot in the Pre-baked process. Carbon anodes are a mixture of petroleum coke and pitch that require about 1.2 GJ/t (Worrell et al, 2008).

3.3.4 CO_2 emissions

The largest source of GHG emissions during the production of aluminum is the indirect CO_2 emissions from electricity generation, which represent about 60% of all emission in 2007. The other source of emissions consists in the direct fuel combustion to produce heat, the process CO_2 emissions from chemical reaction and the perfluorocarbons (PFCs) from anode effects. Table 17 shows CO_2 emission equivalent ($MtCO_2e$) details during the production of aluminum.

Table 17. 2007 GHG Emissions from aluminum Production ($MtCO_2e$)

	Emissions (MtCO2e/yr)	Intensity (tCO2e/t al)
Primary Aluminum Production	38.0	30.8
CO2 Energy Use (alumina production)	4.8	
CO2 Energy Use (smelters)	26.6	
CO2 Industrial Process	2.0	
PFC Industrial Process	4.7	
Secondary Aluminum Production	0.6	1.1

Note: CO_2 electricity factor from the grid is equal to 910.5 gCO_2/kWh, while it is equal to 1,457 gCO_2/kWh for captive power in average with an efficiency of 25%.

Direct and indirect CO_2 emissions from energy use

CO_2 emissions from fuel combustion arise mostly in the refining process of alumina. Most of the steam and heat required is based on coal consumption. During the production of aluminum, the bulk of the energy required is electric power supplied mostly by captive power plants which need to provide continuous current. In India, captive power plants use coal to generate the required electricity, resulting in considerable indirect CO_2 emissions.

Process CO_2 and PFC emissions from the industrial process

During electrolysis, CO_2 is produced as a byproduct of the chemical reaction between the carbon anode and alumina. Emission factors, measured in metric tonnes of CO_2 per tonne of aluminum produced, range from 1.5 for pre-baked cell technology to 1.8 for the Soderberg cell technology (IPCC, 1996). In addition, the electrolytic smelting process is also a major source of PFCs. PFCs have a very high global warming potential due to their extremely long atmospheric lifetimes (2,600–50,000 years). The PFCs are formed due to anode effects (see Annex 7). No specific emissions factors could be found for Indian smelters. However, Table 18 shows the average IPCC default emission factors with uncertainty ranges for CF_4 and C_2F_6 per tonne of aluminum produced for four technology types.

Table 18. IPCC Default Emission Factors (Tier1 method)

Cell Technology	CF4		C2F6	
	kg/t Al	Uncertainty Range	kg/t Al	Uncertainty Range
Centre Worked Prebaked	0.4	-99/+380	0.04	-99/+380
Side Worked Prebaked	1.6	-40/+150	0.4	-40/+150
Vertical Stud Søderberg	0.8	-70/260	0.04	-70/260
Horizontal Stud Søderberg	0.4	-80/+180	0.03	-80/+180

Source: IPCC, 2006

Note: global warming potential of 1 tonne of CF_4 is equal to 5,700 tonne of CO_2 and 1 tonne of C_2F_6 is equal to 11,900 tonne of CO_2

3.3.5 Energy efficiency and CO2 emission reduction measures and associated costs

Reduction of CO_2 emissions is possible during different stages of aluminum production. The most energy intensive step, which is the electrolysis, compares positively with world best standards. We estimate that Indian smelter uses in average only 8% more than world best practice. Over the last 5 to 7 years, most Indian smelters have implemented energy efficiency measures that have reduced their energy intensity. Moreover, with a production capacity that has doubled in 7 years, modern and efficiency technology have been installed.

However, potential for energy efficiency remains, especially in the first phase of aluminum production consisting in the alumina production and also in the production of electricity that is met with captive power in all Indian smelters. Annex 10 gives an overview of causes of energy losses during the production of aluminum, from refining to re-melting. The table also shows an approximate magnitude of the energy losses and the different energy conservation options that can overcome some of the energy lost in the process.

<u>*Alumina Production*</u>

In India, alumina production uses an estimated 14.9 GJ per tonne of alumina produced, of which about 90% is fuel use (13.52 GJ/t) and 10% is electricity (375 kWh/t). Most of the fuel use is meet with coal (91%). Energy intensity is much above the best practice found in the industry. Fuel consumption of a best practice alumina production Bayer plant is 9.7 GJ/t alumina, and electricity consumption is 203 kWh/t alumina, for a total consumption of 10.4 GJ/t alumina (Worrell et al. 2008). India's best practice is the Malco alumina plant, which uses 239 kWh/t and 12.35 GJ/t. This is still far from the world best practice and Malco's alumina production represents less than 3% of India's alumina total production.

As described by Basu et al (2005), most of the fuel energy is required to produce steam in the digestion process. Digestion of bauxite can either be carried out at low or high temperature ranging from 110°C to 300°C depending upon the mineralogy of the bauxite. In most alumina plants, a mixture of bauxite including trihydrate Gibbsite and monohydrate are pumped together into the high temperature digester. However, having a double digestion process improve considerably the energy efficiency of the digestion process as the trihydrate Gibbsite is digested at about 145°C (Geho, 2007). This technology is not common in India and requires a large investment. Hindalco is in the process of implementing this technology and has filed a CDM procedure to obtain CO_2 emissions reduction credits (UNFCC, 2008a). The investment is about 28.5 Million US$ and CO_2 emissions reduction are 630 $ktCO_2$ per year. In India about 80% of the bauxite reserves are predominantly gibbsitic in nature (Energy Manager, 2009). Hence increasing the share of this type of bauxite also reduces the heat needed.

Other energy efficient measures that are less capital intensive consist in improving heat integration, such as insulation maintenance, installation of a temperature controller unit, and heat recovery.

Annex 11 shows a list of energy conservation measures. Reducing the time spent on unit operations such as digestion and precipitation, increasing product yield, and adopting on-line instrumentation all make the overall refining process more efficient With existing technology, energy use in the key steps of alumina production can be reduced by 6 to 8% compared with current best practice. The replacement of existing rotary kiln with statutory calciner also reduces CO_2 emissions considerably. Table 19. shows potential options to reduce energy in the alumina production ranked by the cost of conserve GHG. Data presented in this table were gathered from many different source such as industry interview, CDM projects, BEE energy Awards, etc.

Table 19. Alumina GHG savings Measures and Cost

	GHG savings tCO2/t alumina	CGHG $/tCO2
Heat Integration	0.01	0.0
Heat Recovery	0.05	0.4
Insulation Maintenance	0.10	4.2
Replacement of existing rotary kiln with statutory calciner	0.18	18.5
Convert single digestion to double digestion	0.08	74.7
Total Savings	0.42	

Source: industry interview, CDM projects, BEE energy Awards, etc.

Primary Aluminum Production

The current best practice of Hall-Héroult electrolysis cells is the Center-Feed Prebaked (CFBP) process, which consumes 400-440 kg of anode/t aluminum, and uses 13,600 kWh of electricity/t (Worrell et al, 2008). Indian's smelter plants have specific electrical energy consumption ranging from 14,195 kWh/t aluminum to18,083 kWh/t, with an average of 14,765 kWh/t. Indian aluminum industry understands the importance of energy conservation and an energy management cell (EMC) has been set up in each aluminum plant.

Conversion from existing horizontal stud Søderberg (HSS) smelters to point feed pre-baked (PFPB) pots is a measure that allows considerable reduction of energy use and PFC emissions. However, it requires large investment. Hirakud smelter has done such a conversion recently (BEE, 2007) and obtained (UNFCC, 2008b). The replacement of HSS to PB pots resulted in reducing GHG emissions by 380 ktonne of CO_2e annually. The initial investment was Rs. 3,500 million (US $80 million) and has allowed direct energy saving of Rs. 100 million (US $2.3 million) per year.

Energy savings are also possible through many low cost retrofits that allow better electricity integration. These measures include:

- Dedicating an energy management unit to monitor energy use, identify potential for energy savings and keeping aware of latest technologies available.
- Improvements in bath chemistry to lower both the smelting temperature and heat losses and to increase the efficiency of the use of electrical current
- Improved insulation to reduce heat losses
- Improved baking technology for carbon anodes

- Reduced carbon anode consumption per kilogram of aluminum produced

Furthermore, measures considering reduction of PFC emissions include (EPA, 2008):

- Improving alumina feeding techniques by installing point feeders and regulating feed with computer control;
- Training operators on methods and practices to minimize the frequency and duration of anode effects (e.g., providing employees with measurement devices to monitor alumina feed rates and anode effects);
- Using improved computer controls to optimize cell performance; and
- Measuring PFC emissions and monitoring cell operating parameters to determine relationships between them

PFC emissions reductions of more than 70% have been achieved at plants in the United States and Western Europe using above options (IEA, 2007).

Over the last 7 years, Indian smelters have been proactive in reducing their energy intensity. Table 20. shows the number of measures implemented by Hindalco smelters, Renukoot and Hirakud, during the period 2004-05 to 2007-08 and 2002-03 to 2007-08. As reported by each company, simple payback period vary between 5 months to 16 years and 9 months. However, this is without accounting for CO_2 savings.

Table 20. Number of Measure Implemented at Renukoot and Hirakud

	No. of Measures Implemented	Investment (Million Rs.)	Energy Savings (Million Rs./yr)	Simple Pay Back Period*
Renukoot				
2004-05	67	16,920	3,429	4.9
2005-06	66	1,868	2,707	0.7
2006-07	68	915	789	1.2
2007-08	44	182	679	0.3
Hirakud				
2002-03	35	89	197	0.5
2003-04	36	806	712	1.1
2004-05	35	476	496	1.0
2005-06	30	15,048	889	16.9
2006-07	20	45,859	2,047	3.6
2006-07	15	21,304	2,076	10.3

Note: *data in brackets are calculated with estimates of CO_2 savings.

These investments have allowed considerable reduction in SEC but more initiatives are needed to reduce the gap between SEC of Indian plants and world best practices.

Aluminum recycling

Aluminum is a metal that can be easily recycled and its utilization generates substantial economies of energy. Energy requirement to process scrap in final secondary aluminum is only about 5 to 6% of the energy needed for the production of primary metal. However the availability of scrap in the country is dependent on earlier consumption levels and demand for aluminum is growing much more rapidly than the recycling potential. Considering an average lifetime of an aluminum product of 20 years, the aluminum consumed in 2002 shall become available in 2022. The potential of increasing use of recycled product also depend on public policy.

Captive Power

For entire India, the captive power generation capacity in aluminum industries was 2,023 MW in 2004-2005 and was entirely based on steam from coal inputs (CEA, 2004-05). All primary smelters have their own captive power. We estimated the average efficiency rate of converting coal to electricity to be around 25% based on data collected for the largest plants (HINDALCO, 2008, NALCO, 2008). The potential to improve captive power plant efficiency is large and is very cost effective. By improving equipment efficiencies, Hinalco has been able to reduce captive power plant coal consumption by an average of 3.5% per year, during the period 1995-2002 for a total investment of 1.15Million Rs (23 thousand US dollars).

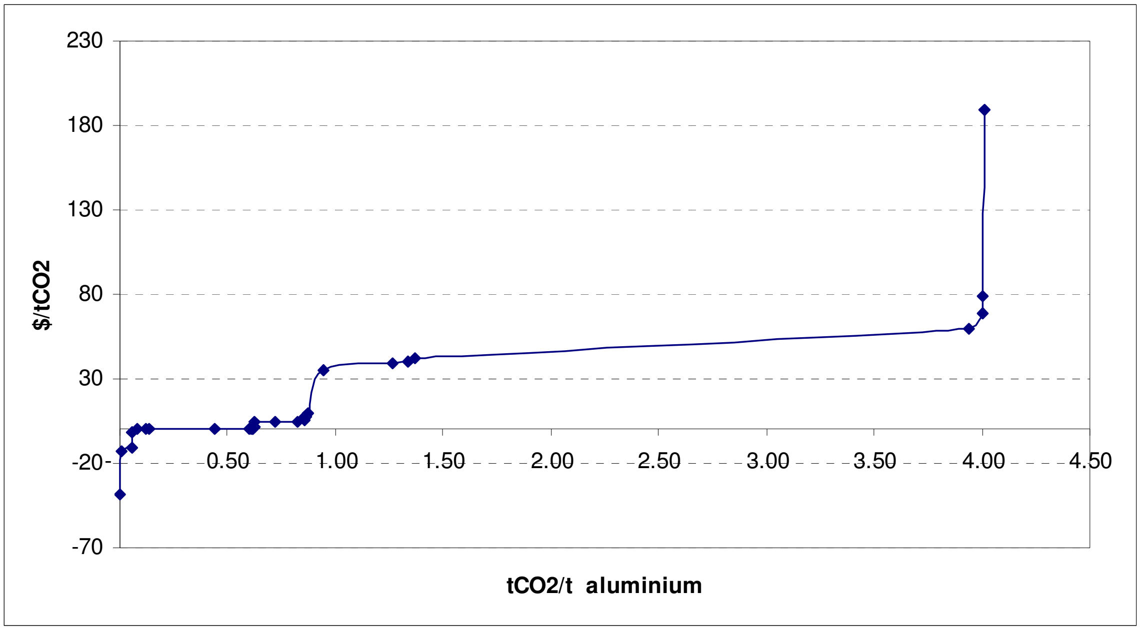
Installation of combined heat and power (CHP) systems also helps to reduce energy use. Electricity is used by motors and pumps. With time, coils of motors get damaged and draw more current. It is estimated that about 5% energy saving can be achieved through the replacement of such motors.

One of the most efficient and environmentally friendly options would be the use of a coal-gasification combined-cycle system to cogenerate electricity and process steam.

Cost Curve

The resulting cost curve is shown in Figure 17. The accompanying spreadsheet model contains information about the typical greenhouse gas emission savings of a measure as well as the investment costs, lifetime etc.

Figure 17. Conservation Supply Curve for Aluminum Production



3.3.6 *Future perspectives*

Planned capacity by the main two aluminum companies shows rapid increase of projected aluminum production in India (Table 21). Demand is driven by domestic demand and exports. Indian aluminum consumption pattern is gradually aligning to the global consumption pattern and the automobile and construction sector have become major demand drivers of this commodity.

Over the fiscal of 2007, Vedanta's new Lanjigarh alumina refinery has started production from a single stream operation and produced 267 ktonne of alumina. Capacity is expected to extend to 1.4 million tonne per year with associated 90 MW captive power plant. BALCO has increased its production from 173,743 tonnes in fiscal 2006 to 358,671 tonnes in fiscal 2008.

Table 21. Future Capacity Additions

Company	Year of Commissioning	Capacity ktonne/y
Alumina Refinery		
Hindalco		
Muri	2008	350
Belgaum		350
Utkal		1,500
Adityat	2011	1,500
Vedanta		
Lanjigarh (Orissa)	2007	1,400
Aluminum Smelter		
Nalco		
Extension	2008	100
Hindalco		
Hirakud Extension	2009	45
Adityat	2011	325
Mahan	2012	359
Bargawan		325
Vedanta		
Jharsuguda Phase I	2009	250
Jharsuguda Phase II		250
Balco III		650

Hidalco plans to increase the capacity of its Muri alumina refinery from 110,000 tonnes per year to 450,000 tonnes per year. Other major plants that increase capacity are for example Aditya Aluminum that plans an integrated aluminum project, encompassing 1 to 1.5 million tonne per year alumina refinery and Mahan Aluminum that plans a new aluminum smelter with a capacity of 359 ktonne per year with a captive power project of 900 MW. Vedanta Aluminum is building a greenfield 500,000 tonne per year aluminum smelter, together with an associated coal-based 1,215 MW captive power plant, in Jharsuguda in the State of Orissa. The project will be implemented in two phases. Also BALCO plans to build an aluminum smelter with a capacity of 650,000 tonnes per year at Chhattisgarh.

Annexes

Annex 7. Anode effect

Molten aluminum is produced while the anode is consumed in the reaction as follows:

$Al2O3 + 3/2\ C \Rightarrow 2\ Al + 3/2\ CO_2$

When the alumina ore content of the electrolytic bath falls below critical levels optima for the above chemical reaction to take place, rapid voltage increases occur, termed "anode effects". During an anode effect, carbon from the anode and fluorine from the dissociated molten cryolite bath combine, producing CF4 and C2F6. These gases are emitted from the exhaust ducting system or other pathways from the cell. The magnitude of PCF emissions for a given level of aluminum production depends on the frequency and duration of anode effects.

http://www.epa.gov/highgwp/aluminum-pfc/documents/pfc_rpta.pdf

Annex 8. Characteristics of Alumina Production in India

Company	Plants	Specific Energy Consumption	Production (kt)
Hindalco	Renukoot	444 kWh/t (1.6 GJ/t) 13.98 GJ/t	723 e
Hindalco	Belgaum		218 e
Hindalco	Muri*		20 e
Nalco	Angul	348 kWh/t (1.35 GJ/t) 78 Kg/t FO (3.14 Gj/t) 626 kg/t coal for steam (10.03 GJ.t) 4.60 kg/t oil for steam (0.18 GJ/t)	1,475
Sterlirte	Balco		219.4
Sterlirte	Maco	239 kWh/t (0.86 GJ/t) (2005) 12.35 GJ/t	76.4

* expansion planed to 450 in 2008
e: estimated based on each plant capacity and according to total Hindalco production
Source: BEE, 2007

Annex 9. Characteristics of Aluminum Production in India (2007)

Company	Plants	Technology	SEC kWh/t	Production kt
HINDALCO	Renukoot	PFPB	14,710	378
HINDALCO	Hirakud	PFPB	14,195	99
NALCO	Angul	PFPB	14,167	359
STERLIRTE GROUP	BALCO Korba I	VSS	18,083*	91
STERLIRTE GROUP	BALCO Korba II	PFPB		222
STERLIRTE GROUP	MALCO Mettur	VSS	17,437	38

* data for 1996
PFPB: Point Feed Prebaked
VSS: Vertical Stud Soderberg

Annex 10. Causes and amount of energy losses and savings options in aluminum industry

Causes of energy losses	Approximate losses (KJ/KG)	Energy saving options helping reducing loss shown in the previous column
1- Digestion of bauxite and evaporation of water for caustic:		
(a) Radiation and convection	700	Improvement of boiler efficiency by better combustion and draft control. Insulation maintenance Recovery of kiln flue gases.
(b) Heat in red mud	700	Heat recovery by a multiple flash system
(c) Heat removed in cooling	4,600	Unit rate of hydrate water to be kept as low as of aluminate solution possible to reduce evaporation load.
(d) Heat in vapor leaving	20,900	Operation modification for close control of wash evaporators water volume
2- Calcining		
(a) Heat in exit	3,250	Proper control of air/fuel ratio Use of gas in place of other fuels. Installation of temperature controller unit Complete heat recuperation
(b) Radiation and convection	930	Insulation maintenance.
(c) Heat in alumina	1,160	Operation modification to feed hot alumina to cells and design modification for complete heat recuperation.
3 - Electrolytic Reduction:		
Anode over voltage and resistance of electrical connection	4,650	Optimizing the cross section of bus bars resistance of electrical connection through changeover from bolted joints to welded joints to reduce voltage drops and power losses. Optimization of size, method of clamping, joint welding etc. Better control over current distribution in all anodes.
(b) Cathode resistance	4,650	Use of prebaked cathode block of better design.
(c) Electrolytic resistance	20,400	Optimization of anode-cathode spacing. Operation modification for lower current density. Control of the electrolyte composition
(d) Resistance between cells	1,850	Better control on cell operating parameters like bath temperature, anode-cathode distance, bath composition, ledge profile, crust feed and ore feed cycles, tapping frequency anode setting frequency and side break.
(c) Recombination of al.	8,100	Operation modification for closer control of cells.
(f) Excess carbon consumption	5,350	
4- Remelting and heat treatment		
(a) Heat in combustion gases	5,100	Proper control of air/fuel raw. Use of gas in place of other fuels. Installation of temperature controller unit. Complete heat
(b) Radiation and convection	930	Insulation maintenance
5- Overall process losses		
(a) Lack of aluminum	32,000	Waste utilization
(b) Hall-Heroult Process	25,000	Process modification
c) Radiation and convection losses	29,200	Insulation maintenance
(d) Heat in exit gases from electrolysis cell	14,900	Digestion modification for waste heat recovery.

Source: Basu et al., 2005

Annex 11. Energy Conservation in Alumina Plants

Recommendation	Benefit
Replacement of existing rotary kilns with stationary calciner	- Fuel oil saving to the extent of 30% - Low operation and maintenance cost - Better quality alumina - Greater plant availability
Adoption of tube digester for more hydrate bauxite	- Low heat consumption by improved heat transfer: 4-5 times/ unit heat transfer. - Low digestion time - Decreased evaporation equipment - Low operating cost
Removal of imperatives from plant liquor	- Better heat transfer co-efficient - Improved liquor productivity - Recovery of valuable by product - Improved quality
Adoption of dry disposal of red mud	- Lower pollution - Less area requirement - Lower cost of equipment in settling washing area and pond
Use of variable speed drives for major process pumps and large motors in the plant.	- Reduced requirement of electrical power
Provision of mechanical agitation or improved air agitation system in precipitation unit	- Reduces electrical power consumption - Lower compressed air consumption at reduced air pressure. - Better classification of Hydrate.

Source: Roy, 1998

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3.4 *Cement*

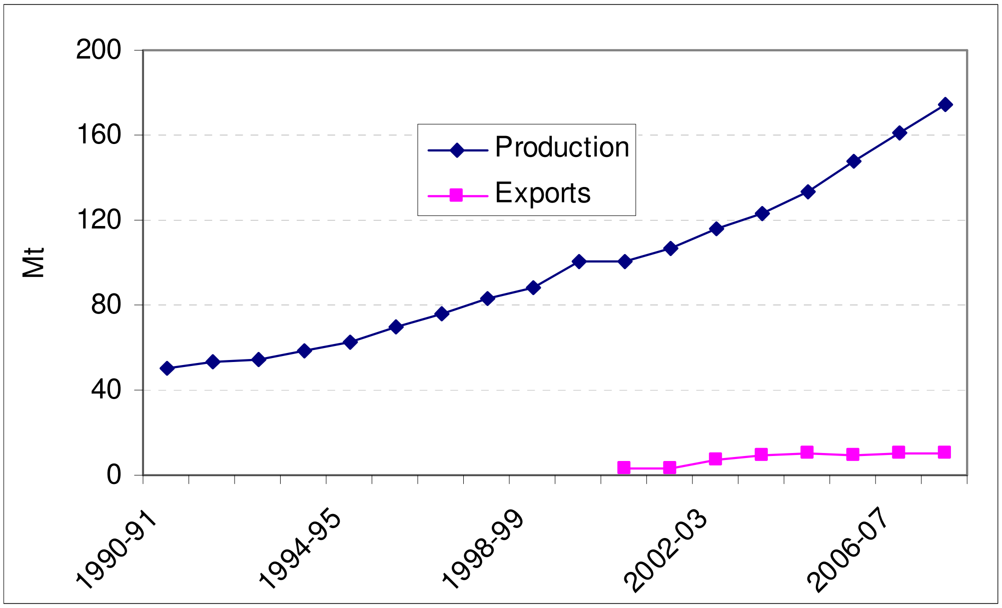
3.4.1 Overview

The cement industry is one of the most energy-intensive as well as high efficiency achievers within the Indian economy and is therefore of particular interest in the context of both local and global environmental discussions. The industry comprises of medium and large capacity cement plants, ranging in unit capacity per kiln from as low as 3.6 ktonne per year to as high as 2 Mt of cement per year. In 2006-07, the cement industry comprises of 132 large cement plants with an installed capacity of 167 Mt of cement per year and more than 365 mini cement plants with an estimated capacity of 11 Mt per year (CMA, 2008). Majority of plants in the country are in the private sector (nearly 93% of the industry capacity).

3.4.2 Activity Variable

India is the second largest manufacturer of cement in the world after China, accounting for about 6% of the world's production. In spite of its rapid growth, the per capita cement consumption in India still remains as one of the lowest in the world (about 130 kg). Global per capita consumption is about 260 kg and is about 450 kg in China. Cement production in India is on the rise due to demand from various sectors, notably housing construction and infrastructure expansion. Figure 18 shows the cement production and exports from 1990 to 2007.

Figure 18. Production and Exports of Cement



Source: India Stat, 2009 and CMA, 2008

The production of cement during 2007/08 was 174 Mt, registering a growth of 8.2% over the previous year 2006/07. India exported 10 Mt of cement. Along with production, capacity utilization in the industry has also increased with time. Overall, capacity utilization increased from 79% in 2005-06 to 90 % in 2006-07 (Planning Commission, 2008). However, the capacity utilization remains very low in the mini cement plants, with an average of 55% (CMA, 2009).

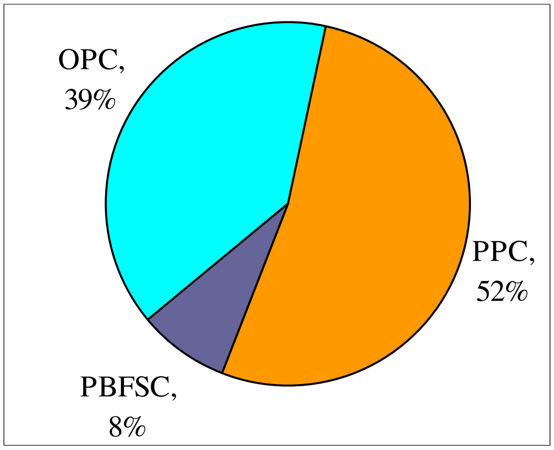
Technologies in cement manufacturing

With rapid expansion, the cement industry has made tremendous strides in upgrading and assimilating state-of-the-art technologies. The modern Indian cement plants are the state-of-the-art plants and comparable with the best in the world. Upgrading by converting wet process plants to semi-dry and full dry process has resulted in considerable economies in fuel and power consumption. Wet process capacity, which accounted for 97% in 1950, has been brought down to 3% in 2007 and 96% of the production capacity has modern, efficient, and environment-friendly dry process technology. The remaining 1% is based on semi-dry process. (Worrell et al., 2001)

Cement Varieties

At present the Indian cement industry produces 13 different varieties of cement employing three different process types. The basic difference among the different varieties of cement lies in the percentage of clinker[14] used. As shown in Figure 19, Portland Pozzolana cement (PPC) represents 52%, ordinary Portland cement (OPC) represents about 39%, and Portland blast furnace slag Cement (PBFSC) 8% (TERI, 2007).

Figure 19. Varieties of Cement Production in 2007



Production of clinker is responsible for the process emissions and most of the energy-related emissions. The use of blended cement, in which clinker is replaced by alternative materials, such as blast furnace slag and fly ash from coal-fired power stations, results in lower CO_2 emissions (IPCC, 2007). According to the Planning Commission (2008), cement plants in India utilized about 20% of fly ash generated by thermal power plants and almost all the granulated slag generated by steel plants in 2005-06. Minimum and maximum usage limits of fly ash in PPC have recently been raised from 10% to 15% and from 25% to 35% respectively in the Indian Standards. Further, addition of Fly-Ash, slag, limestone, rice husk ash, metakaolin or silica fume to the tune of 5% is also now permitted in OPC as Performance Improver.

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[14] The basic raw materials for cement production are ground and mixed to form raw meal, which is burnt in a rotary kiln to form cement clinker.

3.4.3 Energy data

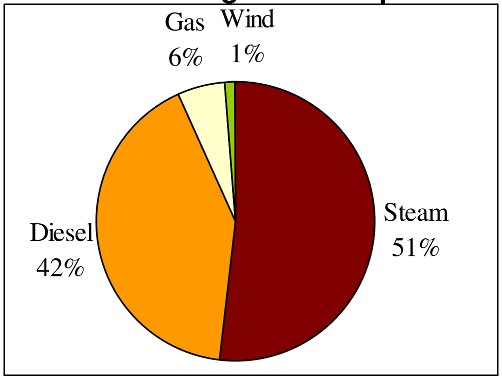
Cement making is a highly energy-intensive process. In India the annual energy cost in terms of sales turnover is in the range of 20% to 60% (BEE, 2003). Energy consumption per tonne of cement varies by technology. The dry process uses more electrical but much less thermal energy than the wet process (BEE, 2003). According to the Planning Commission (2008), the average thermal energy consumption during 2005-06 was 725 kcal/kg for producing clinker and the average electrical energy consumption was 82 kWh/t for producing cement. The best energy consumption achieved by an Indian cement plant was 667 kcal/kg of clinker in thermal energy and 68 kWh/t cement in electrical energy, which are comparable with 650 kcal/kg of clinker and 65 kWh/t of cement achieved in Japan. The next table (Table 22) shows the estimated final and primary energy use in India cement industry.

Table 22. Energy Use in Cement Production, 2007.

Total Primary Energy (PJ)	700
Total Final Energy (PJ)	580
Coal Electricity	91% 9%
Cement Production (Mt)	174
Thermal Energy Intensity (GJ/t) Electrical Energy Intensity (GJ/t)	3.03 0.30
Share of Electricity from Captive Plants Cpative Plants Efficiency	45% 27%

Since availability and quality of power supply from power utilities remains unreliable, increasing number of cement plants use captive power. In 2004-05, 48% of the total cement produced was by using captive power as against only 17% in 1985-86 (Planning Commission, 2008). Total captive power capacity was equal to 1,825 MW as on 31.12.2005 which generated 6,387 GWh of electricity (CEA, 2006). Figure 20 shows the breakdown by fuel type.

Figure 20. Captive Power Generation by Energy Source



Source: CEA, 2006

Hence about 45% of electricity used in the cement industry is from captive power. Efficiency of electricity production by captive power is often lower than from the grid. Diesel generation unit have very low efficiency, averaging between 20 to 25%.

According to the BEE (2003), the new generation cement plants in India have excellent energy efficiency norms comparable to the most efficient plants in the world. BEE further mentions that the energy management cell in the cement sector is well established and the R&D measures and technology absorption in the sector are also high. BEE has also developed specific energy consumption norms and benchmark tool that allow companies to assess their performance in term of energy efficiency.

3.4.4 CO2 Emissions

CO_2 emissions in cement manufacturing come directly from combustion of fossil fuels and from calcining of limestone in the raw mix. An indirect and significantly smaller source of CO_2 is from consumption of electricity. In India, most of the energy requirement in the cement industry is met by coal consumption directly and indirectly, in the production of electricity.

Concerning process emissions, the specific process CO_2 emission per tonne of cement depends on the ratio of clinker to cement. IPCC recommends using clinker data, rather than cement data, to estimate CO_2 emissions because CO_2 is emitted during clinker production (not cement production) (IPCC, 2006). However, the ratio of clinker in alternative types of cement, such as blended and natural cement, is highly variable and difficult to estimate. This ratio varies normally from 0.5 to 0.95. Considering the variety of cement produced in India, we estimated the ratio to be equal to 0.87; detailed calculations are available in Annex 12. The IPCC default emission factor for clinker production is equal to 0.507 tonnes of CO_2/tonne of clinker.

It was estimated that the total CO_2 emission from the cement industry was to 1441 $MtCO_2$ in 2007, which represents a carbon intensity of 0.82 tCO_2/tcement. Furthermore, Indian most efficient cement plant was found to emit 0.72 tCO_2/tcement while international best practice is equal to 0.59 tCO_2/tcement (based on data from Worrell et al, 2008).

3.4.5 CO2 emission reduction measures and associated costs

Indian cement plants are comparable with modern plants elsewhere in the World, However scope for further improvement in several areas remains. Annex 13 gives a list of energy conservation options in the cement industry with associated level of investment needed and potential energy savings. Some of the important energy-efficient technologies that can be adopted in different sections of the cement plants include:

- *Raw material preparation section:* Use of gyratory crushers and mobile crushers; use of VRM (vertical roller mills) in place of ball mills and external re-circulation systems in the VRMs; adoption of roller press technology; and use of high-efficiency separators in the grinding circuits.
- *Cement grinding:* Use of VRM with high-efficiency separators and high-pressure roller press in various modes of operation; use of static separators along with dynamic separators to improve energy efficiency.
- *Pyro-processing section:* Installation of pre-calcinators and five- or six-stage pre-heaters with low pressure drop cyclones; use of short kilns having lower L/D

(length/diameter) ratio; and use of new generation coolers with better heat recovery potential.

- *Blended cement production:* Production and use of 'blended cement' can reduce the heat energy consumption in pyro-processing, even though blended cement production meets higher electricity demand for cement grinding, which is too less as compared to heat energy savings.
- *Waste heat recovery:* Generation of power from the pre-heater or cooler exhaust gases using combined heat and power/ORC (organic Rankine cycle/Kalina cycle), and so on.

Use of Alternative Material

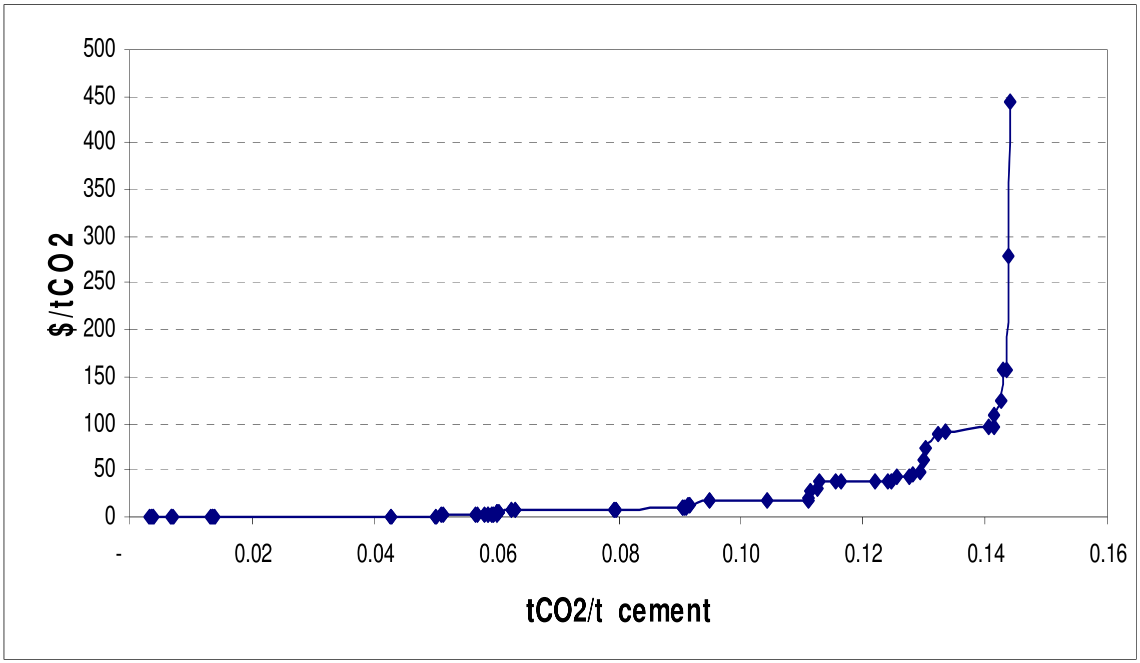
In addition, use of secondary materials such as slag and fly ash for manufacturing blended cement. Producing cement with alternative material is far less energy intensive than producing normal cement and avoids the process CO_2 emissions in the clinker production. A clinker ratio of 0.95 represents 100% production of Portland cement with 5% gypsum added, while lower values are achieved by increasing the share of blended cement types.

Use of Waste Material

Incineration of wastes (e.g., tyres, municipal and hazardous waste) in cement kilns offers the opportunity to reduce production costs, dispose of waste and in some cases reduce CO_2 emissions and fossil fuel use. Cement kilns are well-suited for waste combustion because of their high process temperature and because the clinker product and limestone feedstock act as gas-cleaning agents (IEA, 2007). Overall CO_2 emissions are reduced in the case where fossil fuels are replaced with alternative fuels that would otherwise have been incinerated or land filled. In India, some cement plants are using non-fossil fuels, including agricultural wastes, sewage, domestic refuse and used tyres, as well as wide range of waste solvents and other organic liquids; coupled with improved burners and burning systems (IPCC, 2007). European cement manufacturers increased the share of their energy needs from waste fuels from 3% in 1990 to 17% in 2005 (IEA, 2007).

Figure 21 shows the cost curve of carbon emissions reduction for the Indian cement industry.. The cost curve is developed using Indian case study data, Indian CDM-projects and US measures to reduce the greenhouse gas emissions in the US cement sector. US measures are converted to the Indian specific conditions, like emission factor electricity. The accompanying spreadsheet model lists all the mitigation options included in this curve and shows information about typical carbon savings, investment costs, lifetime, source etc.

Figure 21. CO2 Abatement Cost Curve for Cement Production



3.4.6 *Future perspectives*

The demand for cement has increased at the rate of 10% annually on account of buoyancy in the end-user industries. With capacity additions taking place at a slower pace, the demand–supply equation is expected to remain favorable, and this will lend support to current high prices.

Policy to encourage the use of PPC and slag cement is been considered by the Indian government. For example, the planning commission recommends modifying construction codes of Central and State Governments to allow use of PPC and slag cement, to lower excise duty by 25% for PPC manufactured with 25% or more fly ash and to give incentives for manufacturing composite cement using both fly ash and slag (Planning Commission, 2008).

Annexes

Annex 12. Clinker Ratio estimates

Overall Ratio	0.87
OPC	**39%**
clinker ratio	0.95
PPC	**52%**
clinker ratio	0.90
PBFSC	**8%**
clinker ratio	0.35

Annex 13. Cement Industry Energy Conservation Options

Options	Investment	Possible Savings
I- Housing-Keeping and Operational Control :		
Proper maintenance, monitoring and preventive maintenance to minimize downtime of machinery and plant.	Negligible	Depends on the extent of equipment availability and on stream days of the plants
Prevention of false air entry in the circuit	Negligible	Up to 10% on thermal energy and up to 2% on electrical energy depending on extent of false air.
Power Factor Improvement by regular inspection and maintenance of capacitor banks and installing additional banks, if required	Rs.200-300/KAVR	Depends on extent of power factor improvement
Regular inspection of interlocking arrangement to prevent idle running of motors and machinery	Negligible	
Effective load management	Negligible	Up to about 15% in maximum demand
Regular inspection of motors for identifying under loading, and reshuffling of the same	Negligible for reshuffling and depends on size of motor for replacement	Depends on extent of under loading and size of motor
II- Process Optimization :		
Proper pre-blending of raw materials to give optimum raw mix design	Nil	
Proper control over coal mix being fed into the kiln/precalcinator	Nil	
Proper control over process parameters for optimum and efficient operation	Nil	
Manufacture of blended cements like PPC, PSC	Nil	20% in case of PPC and 45% in case of PSC of heat energy in kcal/kg cement
III- Technological Upgradation :		
Conversion from wet to dry process	Rs. 1250-2700/ tonne of annual capacity	Around 700-800 kcal/kg Clinker installed
5/6 - stage preheaters	About Rs. 55 million per MW	30-40 kcal/kg Clinker
Waste heat utilization		About 4.5 MW for 3000 tonne

		per day plant
IV- Use of Energy Efficient Equipment / Systems :		
Gyratory crushers, mobile crushers and single stage crushers Vertical Roller Mills (VRM)	Rs. 10 million (VRM)	Up to 30% on electrical energy 15-30% compared to power consumption of ball mill
Roller press	Rs. 50 million	4-8 kWh/t of cement in pre-grinding system
High efficiency separators	Rs. 25 million	Up to 30% on electrical energy
Solid state motor up to controllers and soft starters	Rs. 0.2 million	Up to 2% on power consumption of the drive
Energy efficient motor	Rs. 0.4 million	Up to 5% on power consumption of the drive
Mechanical conveying systems over pneumatic conveying systems for dry raw meal and cement	Rs. 0.1 million	Up to 5% on power consumption of the drive
High efficiency fans	Rs. 4-5 million	10-30% on power consumption of the drive
Improved multi-channel burners		About 2% on heat consumption
V- Fuel Substitution		
Lignite Natural Gas Agricultural, industrial and other wastes Use of Renewable Energy Sources like Wind Power, Solar, Energy, etc		Fuel substitution to counter shortage of coal and utilization of waste.

Source: Karwa, 1998.

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3.5 *Fertilizer*

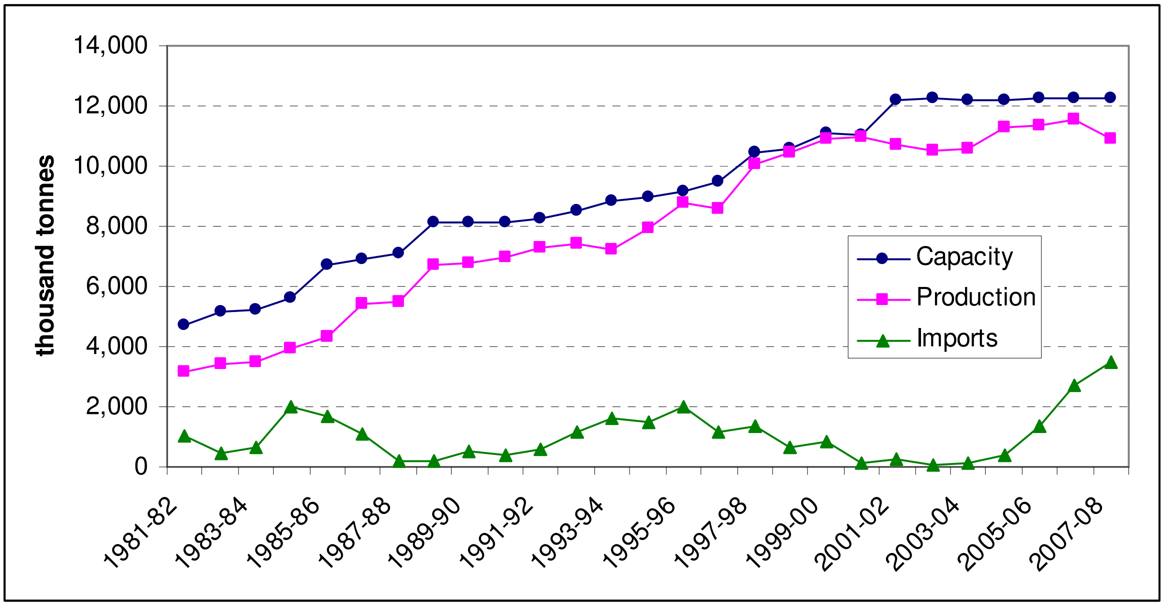
3.5.1 Overview

Chemical fertilizers played a major role in the accomplishment of India's green revolution. India is currently the second largest producer of nitrogenous fertilizer in the world, after China (USGS, 2009). Production has grown at an average rate of 6% annually since 1981. Presently, there are 65 large-sized fertilizer plants in India. Of these, 32 units produce urea, 20 produce di-ammonium phosphate (DAP) and complex fertilizers, and 13 manufacture ammonium sulfate (AS), calcium ammonium nitrate (CAN) and other types of fertilizers. Indian nitrogenous fertilizers are mostly composed of urea (88%); the remaining share consists of the complex fertilizer di-ammonium phosphate (10%) and different types of ammonium fertilizers (2%). The production of ammonia (NH3) represents the most energy intensive step in the production of nitrogenous fertilizer production.

3.5.2 Activity Variable

In spite of its rapid growth, the per capita nitrogenous fertilizer consumption in India still remains low compared to global average. Per capita consumption is 10 kg in India while it is about 24 kg globally. Fertilizer production has been constant over the last 5 years, causing imports to grow more rapidly during this period due to a constant increase in demand. Fertilizer production is expected to increase again with new capacity been build over the next few years.

Figure 22. Nitrogenous Fertilizer Production, Capacity and Imports



Process Description

In order to produce the raw material ammonia (NH3), which is needed for the production of nitrogenous fertilizers, a source of hydrogen (H2) is necessary. There are essentially two methods for the production of hydrogen: steam reforming of natural gas or other light hydrocarbons (natural gas liquids, liquefied petroleum gas, and naphtha), and partial oxidation of heavy fuel oil or vacuum residue. In the process of steam reforming, methane in the natural gas reacts with water vapor to form carbon monoxide and the oxygen combines with the CO to form CO_2 (Equation 1).

This is the most modern method, and it is also less energy intensive than the other approach. The partial oxidation process is used for the gasification of heavy feedstock such as residual oils and coal. Heavy feedstock and coal are first gasified and the synthesis gas is then processed as for other feedstock. Following the production of H2, ammonia is synthesized by reacting nitrogen (derived from process air) with hydrogen (Equation 2). Finally, liquid ammonia and CO_2 are sometimes reacted together to produce urea for nitrogen fertilizer production (Equation 3). Out of total energy consumed for the production of Urea, 80% is consumed in Ammonia production.

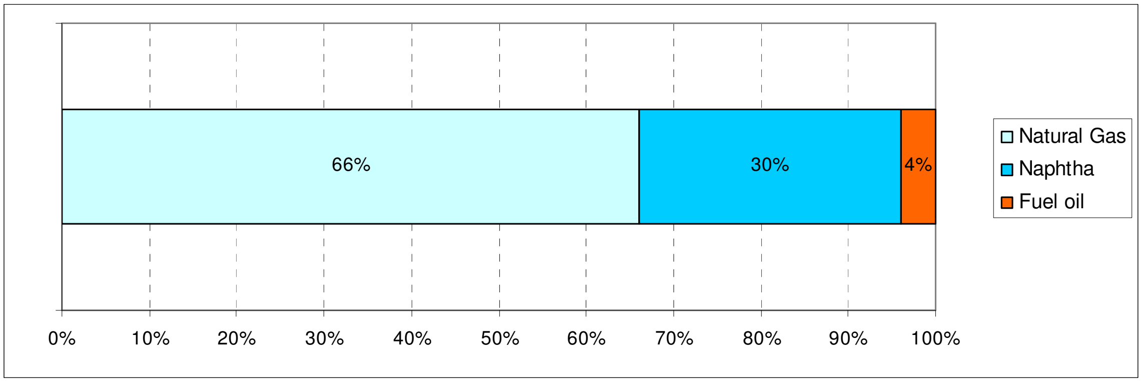
Equation 1: $0.88CH_4 + 1.26\text{ air} + 1.24H_2O \rightarrow 0.88CO_2 + 3H_2$

Equation 2: $N_2 + 3H_2 \rightarrow 2NH_3$

Equation 3: $2NH_3 + CO_2 \rightarrow H_2N\text{-}CO\text{-}NH_2 + H_20$

Today, over 67% of the world ammonia capacity is produced from natural gas (IFA, 2008). In India, the share of natural gas feedstock represents 66% of total nitrogen fertilizer production; the remaining production is based on naphtha for 30%, and fuel oil 4%. (see Figure 23). India represents 92% of world ammonia capacity produced from naphtha and 24% of world ammonia capacity produced from fuel oil (IFA, 2008).

Figure 23. 2007 Feedstock-Wise Share in Production of Nitrogen Fertilizer (%)



Source: MOCF, 2009

3.5.3 Energy Consumption and feedstock

In India, average energy use per tonne of ammonia has considerably decreased over the years. A recent study from the Fertilizer Association of India estimates that the weighted average energy consumption of all ammonia and urea plants in 2007-08 was reduced by about 30% from the level of 1987-88 (Nand S. and Goswami Manish, 2008). In 2007-08, average energy use was estimated at 37.5 GJ/t for ammonia plants and 26.3 GJ/t for urea plants. One explanation to the sharp decline in energy intensity is the shift towards the use of natural gas. In the early 80's, there were no nitrogen fertilizer production based on natural gas, the vast majority was based on naphtha (52%), while coal and coke oven gas represented 30%, and fuel oil 20%. Today, more that 65% of the capacity is based on natural gas, naphtha based capacity represents 30% and fuel oil 5%. Nand S. and Goswami Manish (2008) describe the different technology improvements that have also contributed to energy intensity reduction over the years. Among the most significant upgrades are the recovery of hydrogen with the installation of Purge Gas Recovery Unit (PGRU), the switch to better metallurgy for reformer tubes, the recovery of waste heat from the off-gases of reformer furnace and other types of heat integration improvements.

Table 23. shows energy use in the Fertilizer industry in India in 2007. Energy is mostly used in the form of heat and as mechanical power for compressing air and syngas. In energy efficient plants, the compressors are driven by steam turbines, utilizing steam produced from the excess process heat recovered from the reforming process. Hence no steam needs to be imported, and in some modern plant design, even a net steam export is possible.

Table 23. Fertilizer Energy Use in 2007

Primary Energy (PJ)	570
Final Energy (PJ)	519
Natural gas (%)	59%
Naphtha (%)	31%
Fuel oil (%)	5%
Electricity (%)	5%
Ammonia Production (ktonne)	10,903
From natural gas (%)	66%
SEC (GJ/t)	35.5
From naphtha (%)	30%
SEC (GJ/t)	41.2
From fuel oil (%)	4%
SEC (GJ/t)	49.1

Table 24. shows how energy is used in a modern steam reforming plant. Most of the energy used is consumed as hydrocarbon feedstock. The share of fuel used as feedstock increases when fuel used for energy purpose decreases. Hence, in less efficiency plants the share is much lower.

Table 24. Example for energy flows in an ammonia production plant (1350 tonnes/day, fired primary reformer)

Energy flow Share	%
Product ammonia (feedstock's)	71.9
Un-recovered process heat	10.5
Air compressor turbine	7.8
Syngas compressor turbine	5.7
Flue-gas heat	2.4
Refrigeration compressor turbine	1.8
Miscellaneous	0.6
Overall	100

Source: EIPCCB, 2007

The degree of energy integration in the partial oxidation process is lower than in the conventional steam reforming process. Separate auxiliary boilers are necessary to provide steam for mechanical energy and power generation.

3.5.4 CO_2 Emissions

The production of ammonia is associated with significant industrial source of CO_2 emissions. CO_2 emissions are released during the combustion of fuel and during the chemical reaction to produce ammonia. None of the carbon from the fuel is stored in the final products produced; as a result all the carbon from fuel used as feedstock is emitted. According to the IPCC guidelines (2006) Tier 1 method, emissions from energy use and industrial processes are calculated jointly.

Estimates of CO_2 emissions are based on ammonia production by fuel/process type. It is possible to subtract the amount of CO_2 recovered in urea production, as production of urea requires CO_2. However, this implies that emissions from urea are then accounted in after it is applied on the land. In this report we account for the full CO_2 emissions in the production of ammonia. The total CO_2 emission from the fertilizer industry was estimated to 37 $MtCO_2$ in 2007, which represents a carbon intensity of 2.8 tCO_2/tN.

In the production chain of nitrogen fertilizers the greenhouse gas nitrous oxide (N_2O) is emitted. The production process of the intermediate chemicals ammonia and nitric acid lead to these emissions. However, in this project we first focus on the energy-related greenhouse gas emissions and possible reductions.

3.5.5 National and International Benchmarking

While selected modern Indian units display very high efficiency levels that are among the world best practices, some plants lag behind and have high energy intensity levels. The gap between the most energy intensive plant and the most efficient is a factor of two. The major determining factors that explain divergence in energy efficiency are capacity utilization, feedstocks, plant age and technology. However, the standard deviation is relatively small, meaning that plants energy intensity tend to be close to the average value. This is especially the case for urea plants, see Annex 14 and Annex 15. The average energy intensity itself is closer to the best practices than the most intensive case.

In average, Indian nitrogen fertilizer energy intensity remains relatively higher than international level. Indian fertilizer industry reliance on non-natural gas-based plants explain partly its higher energy intensity as it requires more fuel to produce the same output as natural gas-based plants. Table 25 shows the specific energy consumption for the production of ammonia by fuel type. In 2007-08, natural gas plants used 35.5 GJ/t of energy for the production of ammonia, while naphtha plants used about 16% more energy with 41.2 GJ/t and fuel oil plants 38% more with 49.1 GJ/t. The use of coal is even more energy intensive but no plant exists today in India which produces ammonia from coal.

Table 25. India Specific energy consumption, including feedstock (GJ/t NH3)

	1990-91	1997-98	2007-08	India Best Practice	International Best Practice
Gas	40.2	37.1	35.5	30.3	28
Naphtha	49.9	45.8	41.2	34.0	-
Fuel Oil	63.1	55.7	49.1	47.9	-
Coal	163.8	201.5	NA	-	-

Source: TERI, 2007; Sathaye et al, 2005; Nand S. and Goswami Manish, 2008; Worrell, 2008.

When only the natural gas based plants are considered, Indian plants compare very favorably with international average. For the period 1994–1996, the average consumption in different regions in the EU was found to vary between 34.0 and 38.7 GJ/t (Phylipsen et al., 2002). However, when compared to Indian and international best practices, average energy intensity remains higher, denoting needs for energy efficiency improvements. With energy cost representing between 60% to 80% of total production cost, energy conservation is strongly pursued as one of the attractive options for improving the profitability in the Indian fertilizer industry.

3.5.6 CO2 emission reduction measures and associated costs

As feedstock use is an important factor in energy consumption in an Ammonia-Urea plant, some plants have switch to natural gas feedstock to reduce their energy intensity. Recently, Indian Farmers Fertilizer Cooperative Ltd (IFFCO) Phulpur ammonia plant has switched from naphtha to natural gas feedstock in their primary reformers and for use in gas turbine generators. The project has been registered under CDM activity with annual savings amounting to 186,637 tCO_2 (UNFCC, 2008). This represents considerable savings of 0.34 tCO_2/t of ammonia produced with moderate cost. The cost of reducing emission associated with this measure is equal to 4 \$/tCO_2 (considering a discount rate of 12%). As about 30% of fertilizer ammonia in India is produced from naphtha, saving of 0.10 tCO_2/t of ammonia in average are possible with this measure.

Technology-wise, three different process stages can be distinguished where energy improvements are possible (de Beer and Phylipsen, 2001):

- Steam reforming phase: This is the most energy intensive operation, with the highest energy losses. Better heat integration and heat recovery in old Indian plants has already proven their effects on reducing average energy intensity of fertilizer plants. However, there are still scope for a few plants to implement basic recovery upgrades and other more innovative low grade heat recovery systems to be implemented by more modern plants. For example IFFCO-Aonla I has recently reduced its SEC by 0.18 GJ/t by installed a natural gas heating coil to recover heat lost to atmosphere and reduce flue gas temperature to 160°C (Nand S. and Goswami Manish, 2006). Other measures include a better insulation, increasing pre-heating measures, lower the steam-carbon ratio, and recover waste heat from secondary reformer to primary reformer.

- CO_2 removal phase: Carbon Dioxide (CO_2) gas must be removed and recovered from ammonia process gas to make it fit for the synthesis reaction and later used for urea production. New technologies have dramatically improved the absorption rate efficiency, and lowered energy requirements for CO_2 regeneration. At IFFCO Kalol MEA CO_2 removal process was revamped to MDEA solution. Revamping of CO_2 removal section have increased the CO_2 absorption capacity and reduced the energy requirement with no capital cost. Another example is Indo Gulf Fertilizers Ltd has recently upgraded the originally designed CO_2 removal process of ammonia plant with more energy efficient process of high pressure and low pressure steam feeds. The plants has been able to save approximately 0.06 tCO_2/tNH3 for an estimated cost of 3$/$tCO_2$.
- Ammonia synthesis phase: Improved converter designs as well as improved catalysts allow reduction in energy use. For example, Nagarjuna Fertilizers and Chemicals Limited (NFCL) has installed a new converter of S-300 configuration, in parallel to the existing converter. This has resulted in reducing loop pressure leading to lower steam consumption in the synthesis gas compressor drive turbine. This project has been submitted and approved by the CDM project Executive Board for annual savings of 79.4 $ktCO_2$ from an initial investment of Rs 340 million (US $6.8 million).

Additionally, the optimization of operations and maintenance practices, by reducing waste heat and capturing excess heat to channel it back into the system, allows a better energy distribution and constitutes major energy efficiency improvements. Some plants in India have realized considerable energy savings by increasing awareness at all levels in the plant, monitoring energy consumption during production, and identifying potential energy-savings opportunities. As stated in chapter 5.4 the nitrous oxide emissions in the production chain of nitrogen fertilizers are not included in this project.

Table 26 gives the achievable improvement in energy intensity by selected retrofit measures in a steam reforming ammonia plant identified by Rafiqul et al. (2005) with applicability to India.

Table 26. Achievable Average Improvement

Retrofit measure	Improvement (GJ/t NH3)	Uncertainty (%)	Cost (€/t/yr)	Applicability in India (%)
Reforming large improvements	4.0	±1.0	24	10
Reforming moderate improvements	1.4	±1.0	17	15
Improvement CO2 removal	0.9	±0.4	20	25
Low ammonia synthesis pressure	0.5	±0.5	33	30
Hydrogen recovery	0.8	±0.5	67	90
Improved process control	0.7	±0.5	50	10
Process integration	3.0	±0.5	50	50

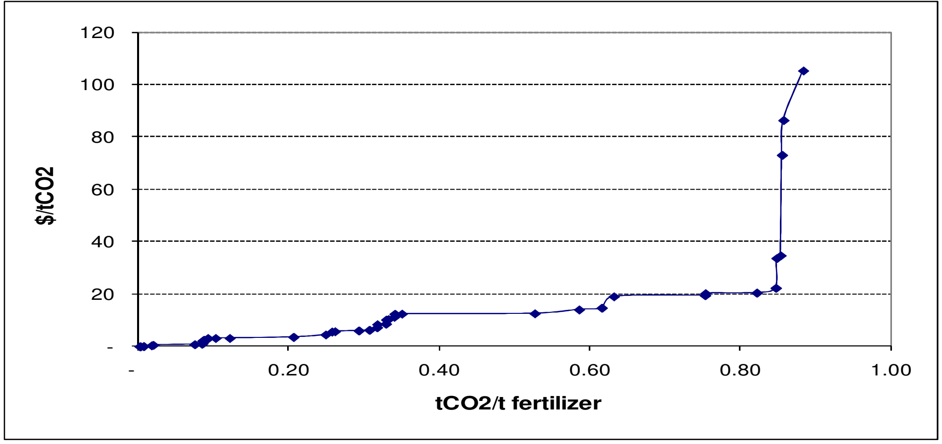
Source: Rafiqul et al. (2005)

For India , the study estimated that a typical energy efficiency revamp of a plant would reduce specific energy consumption for plants installed before 1980 by 5.02–13.4 GJ/t and for plants installed between 1981 and 1990 by about 3.3–4.2 GJ/t, depending on the feedstock used. Plants installed after 1991 are considered to be highly efficient and there is little scope for energy efficiency improvements.

Worldwide, the best practice energy intensity is 28 GJ per tonne of ammonia, and is a result of auto-thermal reforming technology process. Auto thermal reforming process is a mixture of partial oxidation and steam reforming technology. According to the European Fertilizer Manufacturing Association (EFMA), two plants of this kind are in operation and others are at the pilot stage (EFMA, 2000).

Figure 24 shows the conservation supply curve of carbon mitigation options for the Indian fertilizer industry. See chapter 2.5 for more information about assessing the cost of conserved carbon (CCC)-values. The CCC-values are assessed with information derived from Indian industrial case studies and CDM-projects. The accompanying spreadsheet-model shows more information about e.g. the typical carbon savings of a mitigation option, its investment costs and lifetime.

Figure 24. CO2 Abatement Cost Curve for Fertilizer Production



3.5.7 *Future perspectives*

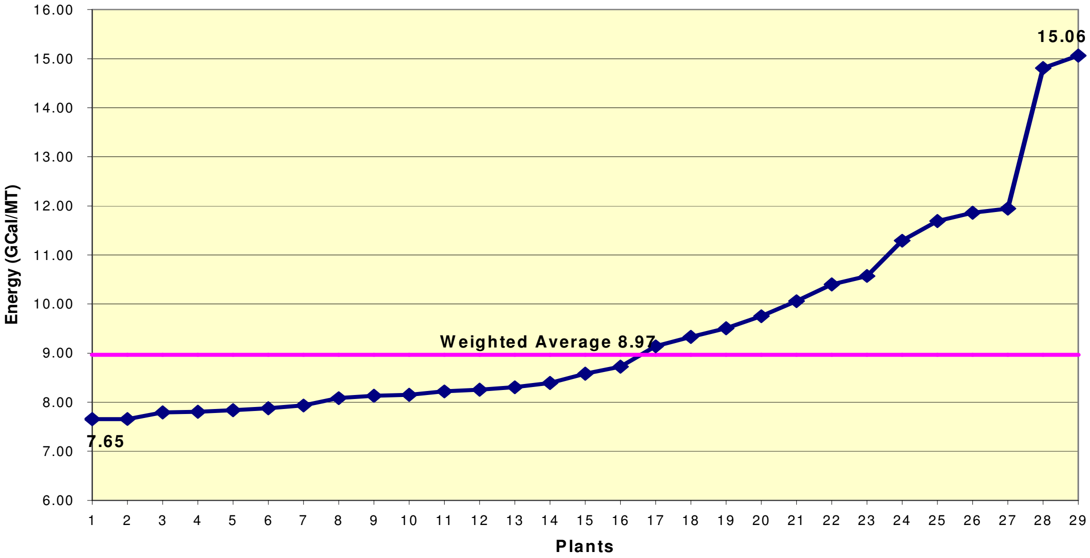
The fertilizer industry in India has long being subsidized by the government, with the objective of providing fertilizers to farmers at an affordable price without harming the interests of manufacturers (Sathaye et al., 2005). In 2003, the new pricing scheme (NPS) for urea manufacturing units took effect. Subventions are since allocated according to urea unit performances related to a pre-set energy norms to encourage energy efficiency improvements. The scheme aims at inducing the units to achieve internationally competitive levels of efficiency, besides bringing in greater transparency and simplification in the administration of subsidy.

The policy stresses the need for conversion of naphtha and FO/LSHS based units to gas-based units. The main reasons invoked are that NG/LNG is cheaper, cleaner and use a more energy efficiency process. To support the NG/LNG utilization, the government is continuing to construct pipeline that will bring the fuel to all units. Pipeline connectivity already exists in respect of 22 urea units and it is likely to be available in the next 3 to 4 years (Planning Commission, Nd).

In the future, chemical fertilizer may be increasingly substituted with bio-fertilizers. Bio-fertilizers correspond to an alternative to chemical fertilizer to increase soil fertility and crop production in a sustainable manner. They are low cost, renewable, and pollution free. In 2006, production of bio-fertilizer was still very small, of about 16 ktonne compared to 12,700 ktonne of chemical fertilizer consumed per year. However, bio-fertilizer production has increased by 78% over the last 5 years, representing an annual average growth of 15%. The Government of India has been trying to promote agricultural practices that use bio-fertilizers along with chemical fertilizers. The government encourages bio-fertilizer use in agriculture and also promotes commercial viability of its production.

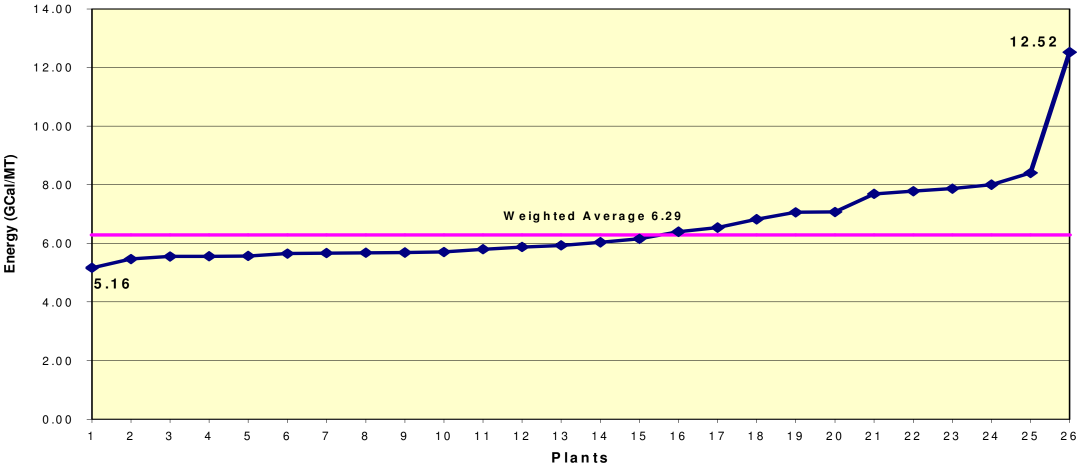
Annexes

Annex 14. Energy Intensity of Ammonia Plants (2007-08)



Source: Nand S., 2008

Annex 15. Energy Intensity of Urea Plants (2007-08)



Source: Nand S., 2008

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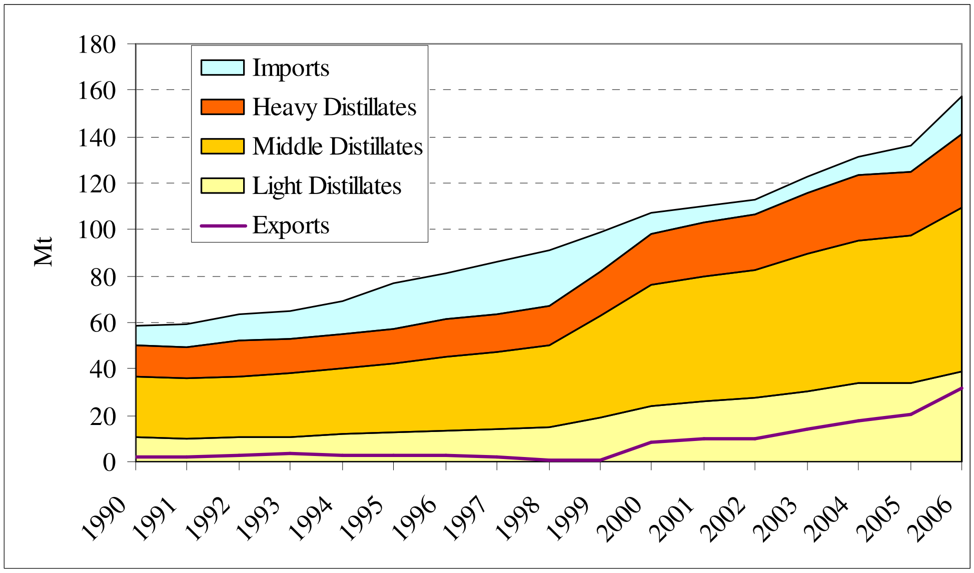
Worrell Ernst, Lynn Price, Maarten Neelis, Christina Galitsky, Zhou Nan. “World Best Practice Energy Intensity Values for Selected Industrial Sectors”, February 2008, LBNL-62806 Rev. 2

3.6 *Refinery*

3.6.1 Overview

Production of petroleum products in India has doubled in 8 years, from 68 Mt in 1998 to 145 Mt in 2006 (Figure 25). Over the last 5 years, average annual growth was 6% and it increased to 13% in 2006. Escalation of production is driven by domestic demand and exports which have increased rapidly over the period 2001 to 2006. There are a total of 18 refineries in the country comprising 17 in the public sector, and one in the private sector.

Figure 25. Refinery Throughput, Exports and Imports



Source: IEA, 2008; MOSPI, 2007.

3.6.2 Activity Variable

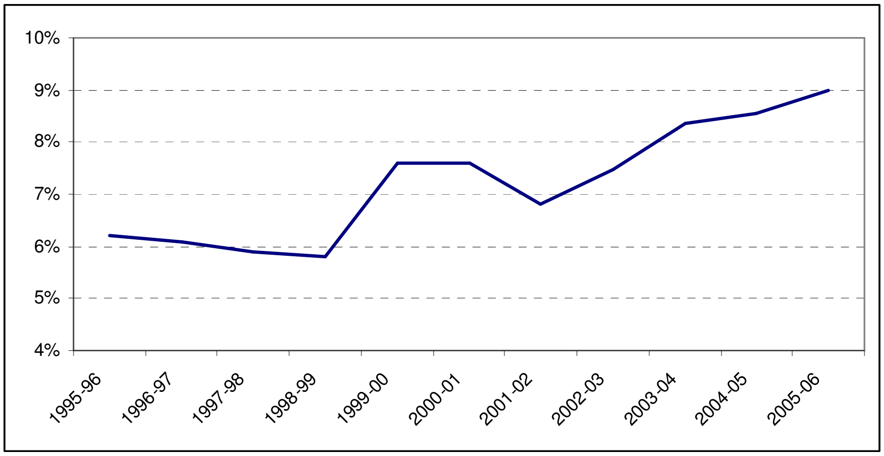
The main production step in a refinery consists in the distillation of crude oil into petroleum products. This is sometimes followed by conversion process using thermal and catalytic processes to further convert the oil streams from distillation and obtain lighter products. Conversion processes include catalytic reformer, where the heavy naphtha is converted to gasoline; the fluid catalytic cracker (FCC) where the gas oil from the vacuum distillation unit is converted; and the hydrocrackers, which are used to "crack" the molecules of heavy oil streams into lighter products such as gas oil. Refineries generally also include process units such as hydrotreaters or hydrodesulfurizers to treat products and improve their quality. Finally, ancillary units supporting the main process units include crude desalters (prior to distillation), hydrogen production, non-energy product units (asphalt, lubricants) and utilities (power and steam).

India has a fairly low overall cracking to distillation ratio (compares the ratio of primary upgrading capacity to crude distillation). Most large Indian refineries have a cracking-to-distillation ratio of less than 40%; the new large Reliance refinery ratio is the same as the average of the U.S. refining industry (56%) (Sathaye et al, 2005). One reason for this fairly low ratio is that Indian refineries use light crude oil, some of which is produced domestically. However, as imports increase (70% in 2005) and as crude oil prices rise, it is expected that Indian refineries will continue to expand their ability to process less expensive heavy, higher-sulfur grades of crude oil in the future.

3.6.3 Energy Consumption

The distillation process requires most of the energy use, then hydrotreater and the different conversion processes. Energy in refineries is consumed as direct fuel in process heaters, indirect fuel for raising steam and generating power, and power for drivers and cooling water circulation and lighting. Some refineries produce their own electricity in cogeneration power plants fueled by refinery byproducts such as refinery gas, though additional amounts of electricity beyond self-generation are often purchased from the grid. Thus, energy efficiency provides a double-benefit to refiners: not only does it lower energy consumption and processing costs, it also makes available additional amounts of fuel products for processing and sale (Sathaye, 2005). Aggregate refinery fuel use and losses (Figure 26) have increased over the years as refinery throughput has expanded and new upgrading units have been brought on line.

Figure 26. Fuel losses in tonne as a weight % of Crude Throughput



Source: Ministry of Statistics and Programme Implementation, 2007.

In 2005-06, the aggregate refinery fuel use and losses represented 9% of the total crude inputs, which is significantly higher than in developed countries where it is close to 4% (IEA, 2008). Total energy consumption in Indian refineries in 2002/03 was about 337 PJ, or about 3 PJ per million tonnes of crude oil throughput[15] (Sathaye et al, 2005). We estimated this consumption to have increased to 496 PJ in 2005-06, based on fuel loses. In the ten years since 1995/96, refinery throughput rose 180%, while energy consumption rose nearly 220%, leading to a 40% increase in energy consumption per unit of crude processed. This increase in unit consumption was due in part to the installation of more

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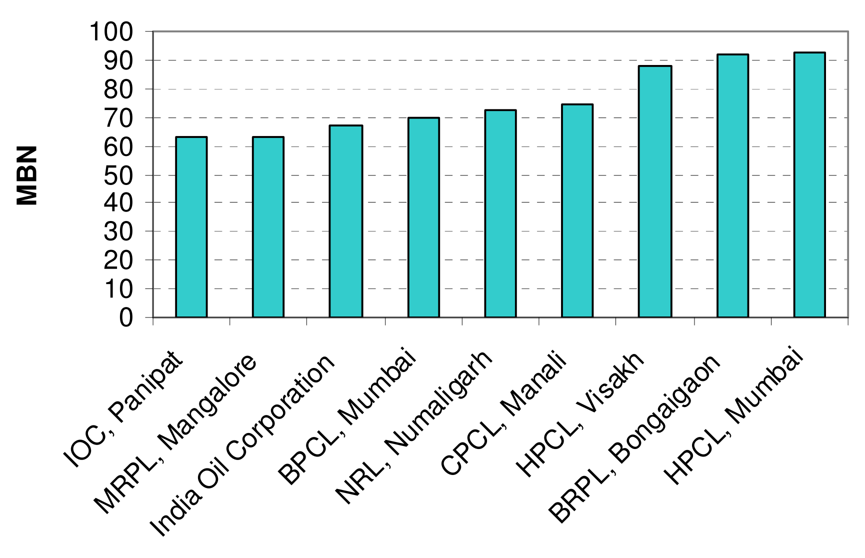
[15] These figures exclude externally purchased electricity. In 2000/01, external purchases of electricity for the entire Mineral Oil and Petroleum sector (including upstream and downstream) was about 6% of total power usage.

energy intensive processing units such as diesel hydro-desulfurizers after 1997 to improve the quality of Indian transport fuels.

However, energy consumption per unit of input is a misleading indicator of the energy performance of refineries as it does not account for differences in type of crude processed, product mix (and complexity of refinery), as well as the sulfur content of the final products. In India, the energy performance of refineries is expressed in terms of specific energy consumption, measured as million BTUs per barrel per Energy Factor (MTBU/BBL/NRGF). This unit, commonly referred to as MBN, was developed by the Centre for High Technology. It is based on the ratio of consumption for the same unit/operation and can be used as a tool to judge the relative unit performance with respect to the benchmark for that unit process. The MBN has been recently revised on new process unit benchmarking data from Engineers India Ltd. (EIL).

Figure 27. Indian Refinery Performance



Source: Individual Company Annual Report

Figure 27 shows MBN indicators amongst several Indian refineries, demonstrating considerable differences in energy intensity performance. Best performances are found for MRPL Mangalore and IOC, Panipat refineries, while the lowest performance is for HPCL, Mumbai with a difference of 30%.

3.6.4 CO_2 Emissions

CO_2 emissions from refineries originate from two main sources: fuel combustion and industrial processes. Industrial process emissions occur from production processes where CO_2 is a by-product of chemical reactions in the production of hydrogen. Hydrogen is used by oil refineries to meet limits on sulfur content in refined fuels and to convert heavy petroleum products into lighter products. Feedstocks used to produce hydrogen include natural gas, LPG, naphtha, and refinery fuel gas.

3.6.5 *Reduction measures and associated costs*

The key potential energy saving measures are:

- Co-generation: only 30% of the existing steam & power systems in Indian refineries employ gas turbine based co-generation systems.
- Revamp and replacement of low efficiency furnaces and boilers: quite a substantial proportion (30 to 50%) of the energy consumed in the refinery and petrochemical industry is used as fuel in the fired heaters.
- Process optimization
- Improved heat integration: installation of heat exchangers.
- control of compressed air
- use of efficient electrical devices

Experiences of various oil companies have shown that most investments are relatively modest. However, all projects require operating costs as well as engineering resources to develop and implement the project. Table 27shows the percentage energy efficiency from Indian refineries. These estimates were established by Gupta et al, from Engineers India Limited, during the calculation of MBN indexes.

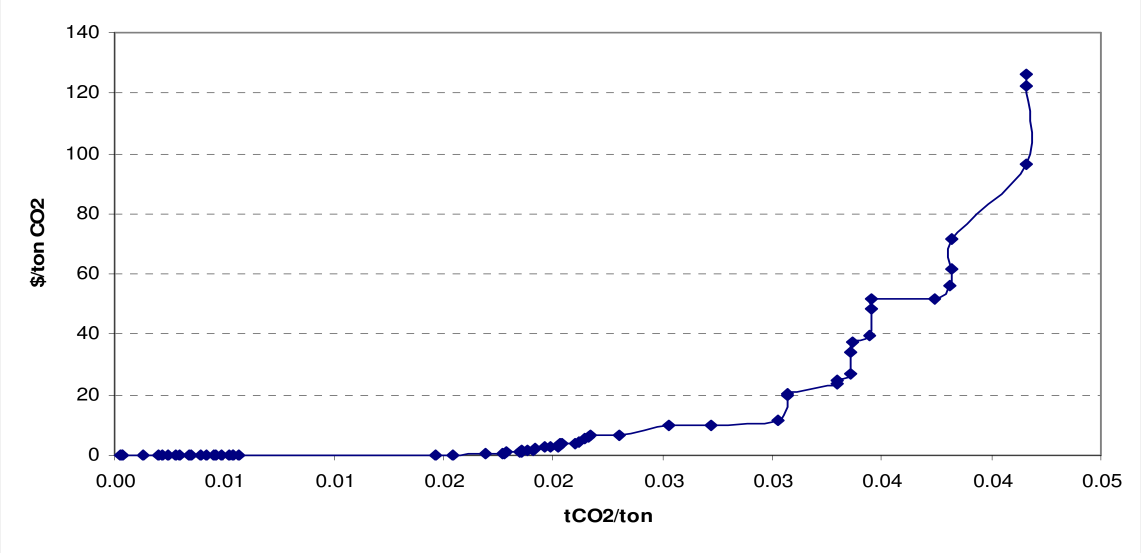
Table 27. Energy Saving Potential in Indian Refineries

Process Unit	20%
Power and Steam Plants	15-43%

Source: Gupta et al, not dated

With information from Indian case studies and CDM-project aimed at reducing energy use and/or emissions or greenhouse gases in the refinery sector a conservation supply curve was developed, see Figure 28.

Figure 28. Conservation Supply Curve for Refinery Production



3.6.6 Future perspectives

Petroleum production in India has grown fast over the last 15 years and is expected to continue increasing. Reliance Petroleum is currently constructing a second facility at the Jamnagar site, which is expected to have a capacity of 580,000 bbl/day when completed in 2008. When finished, Jamnagar will be the largest refining complex in the world.

Petroleum product demand is heavily concentrated on middle distillates (kerosene and diesel). In 2005/06, middle distillates (kerosene and diesel) accounted for 48% of consumption, down from 59% in 1990/91 while light distillates (LPG, motor gasoline, and naphtha) demand has increased from a share of 16% to 28%. In contrast, light gasoline accounted for 55% of oil consumption in the US, 52% in Korea, and 37% in China. It is highly probable that the demand for lighter petroleum products will increase with economic development.

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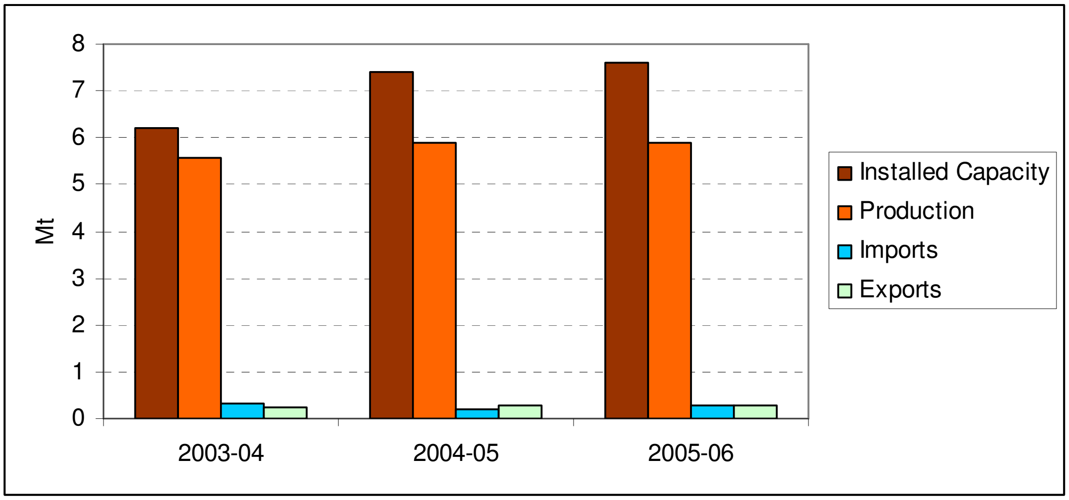
3.7 *Pulp and Paper*

3.7.1 Overview

The Indian pulp and paper industry is the sixth largest energy user in the Indian industrial sector, accounting for 3% of industrial energy use in 2004 (de la Rue du can, 2008). It is a highly fragmented industry. In total, there are about 666 units engaged in the manufacture of paper and paperboard out of which only 27 are large integrated mills representing 25% of total capacity (CRPRI, 2005). Paper mill capacities range from 1 to 200 ktonne/year, with an average of 11.5 ktonne/yr (Jain, 2005), compared to 300 ktonne/yr in Europe and North America. Thus, even large Indian mills are of only 'small' to 'medium' size by current international trends. The country is almost self-sufficient in manufacture of most varieties of paper and paperboard with a total production of 5.9 Mt in 2005-06. Production has increased at an annual rate of 6% over the last 10 years, 1995 to 2005. Import is confined only to certain specialty papers such as light weight coated variety of paper.

Figure 29. Paper & Paperboard Supply in Mt



3.7.2 Activity Variable

The pulp and paper industry converts fibrous materials, like wood, agro-residue and recycled paper into pulp, paper and paperboard. The most important process steps to produce paper and paperboard are pulp making, bleaching, in some case chemical recovery, pulp drying and paper making. The pulping process consists in the separation of fiber sources into fibrous constituents. After separation, the fibers are washed and screened. The pulp may then be used directly to make unbleached papers, or bleached for white papers. Pulp may be fed directly to a paper machine in an "integrated paper mill" or dried and pressed into bales to be used as a raw material by paper mills worldwide.

The amount of energy used depends on the nature of the feedstock and the desired quality of the product. In India, about 38% of the total paper production is based on waste paper, 32% on bagasse and agriculture residues, and remaining 30% on wood (TERI 2007).

Size of plant is correlated with the nature of the feedstock used. Large plants use wood, plants of a medium size generally use agro-waste and small plants use predominantly waste-paper (Table 28.).

Table 28. Share of Paper Produced per Fiber Input

	Sources of Resources	Paper Production (Mt)	Share (%)	No. of Mills	Share (%)	Average Mill Production (ktonne/unit)
Wood	Eucalyptus, Coniferous and other broad leaves	2.08	32	34	5.1	61
Agri-residues	Bagasse, rice and wheat	1.95	30	165	24.7	12
Waste paper	Domestic and imported waste	2.41	38	467	70.2	5

Source: Marthur, 2008.

The use of wood-based is gradually on the decline because of raw material availability constraints. Under the existing forest policy, the paper industry cannot use wood from any of the national forest reserves. The share of waste paper (secondary fiber), which is less energy intensive, has increased considerably over the last 10 years. Quantity of domestic recovered paper has more than doubled in the period 1995 to 2005 and imports of recovered paper increased by 24% annually over the same period (FAO, 2007).

3.7.3 Energy data

Paper industry is very energy intensive. About 75-85% of the energy requirement in the pulp and paper production is used as process heat and 15-25% for electrical power. Coal and electricity are the two major sources of energy in Indian paper industries. Other fuels such as fuel oil are also used to fire boilers and diesel oil for small backup power generator. Steam is primarily used in digesters and pulp making equipment, while electricity is mainly used in the paper making process.

Pulp making is one of the most energy consuming processes in the paper and paper board supply chain. Several processes exist to produce pulp: chemical, semi-chemical, mechanical and waste paper pulp making. The dominant form of pulp-processing in India is the chemical process using a variety of fibrous materials and caustic soda in a digester, although recycling paper is also very common. Chemical pulping uses heat and yields black liquor that can potentially be used to produce heat and electricity. Depending on its recovery efficiency and configuration, a pulp mill can be a net exporter of energy (IEA, 2007). However, the black liquor recovery in agro-residue pulping mills has a lower heating value. Consequently, many small mills lack a recovery unit and instead discharge the chemicals directly into the receiving water body, leading to environmental problems.

Pulp and paper industry in India is a mix of old and new plants having a diversified technology absorption pattern resulting in wide variation in specific energy consumption levels. Different varieties and grades of paper are being manufactured by the plants, which demand different process technologies affecting the energy requirements of the plants. A comprehensive study was undertaken by CPPRI (2005b) for the BEE to fully document how energy is used in the pulp and paper industry in India. Based on this study, we estimated the energy intensity shown in the following Table 29. The study also developed norms for various categories of mills, taking into account factors such as raw material, varieties & grades of pulp & paper produced, age of the plants, technology status, capacity of major equipment/machinery etc. The classification of wood, agro and recycled fiber (RCF) based mills was further disaggregated into subgroups to account for the difference in quality of paper produced. Annex 16 shows the main groups and

Annex 17 shows the norms developed for each group.

Table 29. Energy Intensity and Norms per Main Process (GJ/t)

	Current Average			Norms			Saving Potential
	Electricity	Steam	Total	Electricity	Steam	Total	
Wood Based	5.5	54.5	60.0	4.6	37.5	42.0	-30%
Agro based	3.7	28.7	32.4	2.7	18.2	20.9	-36%
RCF	3.5	20.6	24.1	2.1	12.1	14.2	-41%

Source: CPPRI (2005b)

Compared to best practices, there is a large scope for energy efficiency improvements. Best practices for wood based production are based on the thermo-mechanical process, which uses a large share of electricity.

3.7.4 CO_2 Emissions

CO_2 emissions from the pulp and paper industry are entirely due to consumption of fuel for energy purposes. Fuel consumption consists mainly of coal, and to some extent electricity. We estimated the pulp and paper industry to emit about 4.43 tCO2 per tonne of paper produced in average. Wood biomass is used as an input to the production process but can also be used for its heating value and hence burned. CO_2 from biomass combustion are not counted as greenhouse gas emissions unless it is contributing to deforestation. In this case, information about the sustainability of the biomass use should be gathered. With the implementation of central and state government policy towards forest protection and afforestation, pulp and paper mills now have to take responsibility for the reduction of forest material consumption and afforestation efforts. The government is encouraging he industry to create plantations on degraded forest and waste land.

3.7.5 CO2 emission reduction measures and associated costs

As shown in Table 29, we estimated that if all mills met the norms in their sub group category based on the CPPRI study (2005b), 30 to 40% of energy could be saved. Energy savings potentials in the pulp and paper industry in India are very large. Table 30. presents measures to reduce the use of energy in the Indian pulp and paper sector.

Table 30. Mitigation Options in Indian Pulp and Paper Industry

Energy Efficiency Measures	Efficiency Potential per energy type	Payback Period	Applicability in India	Source
Cogeneration	20% to 100% (total)	-	Wood and agro-residue	Estimates
Biopulping: natural wood decay	30% (heat)	-	Wood and agro-residue	Shukla, 2004
Increase of heat transfer area in the blow heat recovery system	15% (heat)	6 months	All	Teri, 2006; Ballarpaper, 2006
Variable frequency drives	-	1 year	All	Ballarpur, 2006
Lighting	-	2 year	All	Ballarpur, 2006
Fiber recovery system	2% (heat)	-	All	Teri, 2006;
Oxygen de-lignification	2% (heat)	-	All	Teri, 2006;
Replacement of turbine with DC drive	3% (elec.)	-	All	Teri, 2006;
Press section re-building/long nip (shoe) press	3% (heat)	-		Teri, 2006;
Hot dispersion	11% (elec.)	-		Teri, 2006;
Drum chipper	1% (elec.)	-	Wood mills	Teri, 2006;
Long tube failing-film evaporators		-	Wood mills	Teri, 2006;
High concentration of black liquor	47% (heat)	-	Wood mills	Teri, 2006;
Continuous digester	26% (heat)	-	Wood mills	Teri, 2006;

According to Schneider at al. (2009) the energy and carbon saving measures can be classified in three categories:

- input related measures: energy and raw materials supply,
- process related measures: material and energy efficiency (heat and electricity) measures,
- output related measures: measures to reduce or re-use waste or waste heat flows.

Most measures included in this project are process related saving measures. Below a few of these measures are described briefly.

Input-related measures: Pulp and paper mills can reduce their use of energy and emissions of greenhouse gases through a more efficient energy conversions and/or using less carbon-intensive fuels (Schneider et al., 2009). Schneider et al. (2009) showed that CDM projects related to cogeneration of agricultural residues, mainly rice husk, at Indian pulp and paper mills is the most important measure to reduce the greenhouse gas emissions of these plants. Electricity and heat generated by cogeneration where biomass is used as fuel lead to significant reduction compared to plants that use electricity from the grid that is generated with fossil fuels. The carbon savings per tonne of paper varies per plant and can range from 0.9 kg CO_2e per tonne paper to about 2.3 kg CO_2e per tonne. Higher price of eg. rice husk compared to the price for coal can in some cases lead to a higher the price for electricity generated with biomass cogeneration units than with fossil fuel generated electricity.

Process related measures: After paper is formed, it is pressed to remove as much water as possible. Normally, pressing occurs between two felt liners pressed between two rotating cylinders. Extended nip presses use a large concave shoe instead of one of the rotating cylinders. The additional pressing area allows for greater water extraction, (about 5-7% more water removal) to a level of 35-50% dryness. Greater water extraction leads to decreased energy requirements in the dryer, which leads to reductions in steam demand. Furthermore, reduced dryer loads allow plants to increase capacity up to 25% in cases where production is dryer limited. Published estimates for the steam savings achievable through the installation of extended nip presses range from 2% to around 15%, depending on product and plant configuration For example, the application of the X-NIP T shoe press in tissue plants is estimated to reduce drying energy use by 15% (Baubock and Anzel, 2007).

Variable speed drives. Variable speed drives offer good opportunities to better match speed to local requirement for motors, pumps and or compressors. The application of variable speed drives lead to reduction of the use of electricity. Another possible benefit, is that adjusting the adjustable speed drives can have a positive effect on lowering maintenance costs on motors, pumps and or compressors by less worn out of these equipments. The payback period of installing the variable speed drives is in most of the times less than one year (Kramer et al, 2008).

Heat recovery from blow down. Boiler blow down is important for maintaining proper steam system water properties. However, blow down can result in significant thermal losses if the steam is not recovered for beneficial use. Blow down steam is typically low grade, but can be used for space heating and feed water preheating. In addition to energy savings, blow down steam recovery may reduce the potential for corrosion damage in steam system piping. A study in the United States shows that the period of payback for blow down heat recovery systems in the pulp and paper industry is between 12 to 18 months (Kramer et al., 2008).

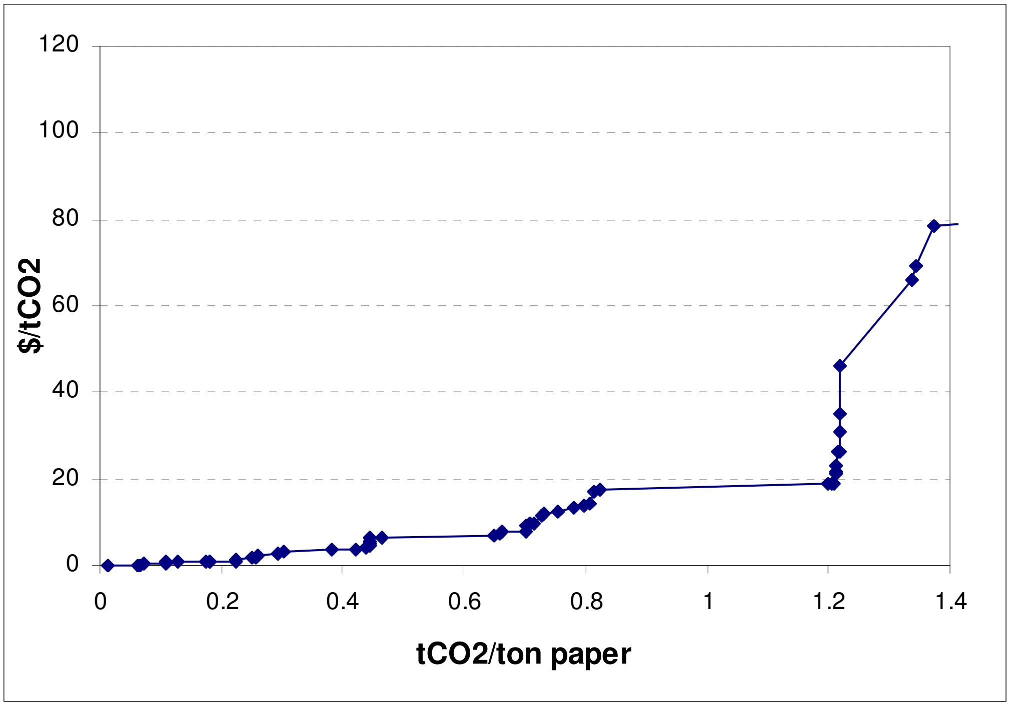
Continuous digesters. There are two primary types of digesters, batch digesters and continuous digesters, which can cook fiber containing materials, like wood, on batch and continuous bases. In continuous digesters there is a continuous flow of woody materials into the digester and pulp streams out of the digester. Continuous digesters slightly use more electricity but this is by far compensated by reduced steam consumption. The continuous flow within the digester allows the recovery of heat from one part of the process to another part of the process. An Indian pulp and paper plant (300 tonne paper production per day) reduced the annual use of coal by about 9,000 tonnes of coal with batch digesters were replaced with a continuous digester (Andra Pradesh, 2007). In terms of greenhouse gas emissions per tonne of paper, the plant reduced the greenhouse gas emission by 0.13 kg CO_2e per tonne of paper. The replacement of batch digesters (that are cheaper) is a capital-intensive measure, with period of payback of several years.

Output related measures. Several measures are available to reduce waste or waste heat flows in the pulp and paper industry. For example heat can be recovered from flash steam recovery at boilers blowdown, heat recovery at bleach plants, but also waste effluent sludge can be used as fuels in boilers. A Indian pulp and paper mill reduced the use of coal by 1,900 tonnes by using about 13,000 tonnes sun-dried sludge in its boiler.

The period of payback of the necessary investment was about 4 months (Tamil Nadu, 2006).

Figure 30 shows the conservation supply curve for the Indian pulp and paper sector. The individual reduction options are included in the accompanying spreadsheet-model. Information about typical carbon savings are derived from Indian case studies, CDM-projects and some US carbon saving measures that are converted to Indian pulp and paper production characteristics.

Figure 30. Conservation Supply Curve for Paper Production



3.7.6 Future perspectives

Contrary to other energy intensive material production, the consumption of paper per capita continues to grow with income after industrialization. Today, per capita consumption in India is very low (

Table 31.). It was 4.5 kg per annum in 2004. With India's per capita income on the rise, the per capita paper consumption is expected to increase to 8 kg by 2010 and 8.75 kg by 2015 (Bhati and Jha 2006). An improvement in the standard of living has also resulted in a gradual shift towards better quality papers.

Table 31. Per Capita Consumption of Paper in 2004

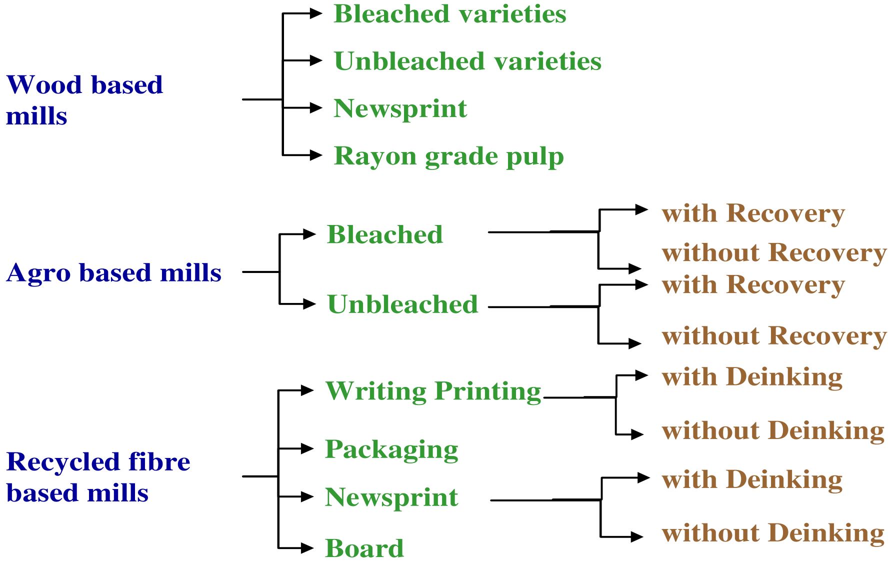
Country/Region	Kg/ca
India	4.5
China	30
South East Asia	40
Japan	260
USA	334
World Average	53

Source: Jana S (2005)

Growth in paper production requires available fiber resources. However, India has limited forest with rules that restrict its exploitation. Large integrated mills are encouraged to plant their own forest of bamboo to overcome this barrier. Over time the share of wood based paper production has been declining significantly and is expected to further decrease. On the other side, the share of agricultural residues shows a steadily increasing trend from 1980 to today and is expected to further rise in the future. At the same time wastepaper use has risen fast and will continue to play a major role. The overall constraint of raw materials may also force the paper industry in future to rely more and more on imports of pulp or final paper products.

Annexes

Annex 16. Norms Sub-Sectors Breakdown



Annex 17. Specific Energy Consumption Norms

I) Summary Table for Specific Energy Consumption Norms - Wood Based Mills

Wood Based Mills (Integrated)	Bleached	Unbleached	Newsprint	Rayon (Pulp)
Purchased Energy, M kcal/t	7.0	5.6	7.0	3.0
Steam, t/t of finished paper	9.0	7.0	5.0	8.0
Power, kWh/t of finished paper	1300	1150	2100	800

II) Summary Table for Specific Energy Consumption Norms -Agro Based Mills

Agro Based Mills	Bleached		Unbleached
	With Recovery	Without Recovery	
Purchased Energy, M kcal/t	7.0	5.5	5.0
Steam, t/t of finished paper	7.5	4.9	3.3
Power, kWh/t of finished paper	1050	925	500

III) Summary Table for Specific Energy Consumption Norms-Recycled Fiber Based

Recycle Fiber Based Mills	Writing Printing (*)	Newsprint (*)	Unbleached	Board
Purchased Energy, M kcal/t	4.0	6.0	3.0	4.0
Steam, t/t of finished paper	3.2	3.0	2.2	2.0
Power, kWh/t of finished paper	800	750	450	400

(*) With Deinking

Source: CPPRI (2005b)

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4. Methodology and Scenarios

The methodology takes a bottom-up and demand-side approach. The model is elaborated in sufficient detail to allow realistic efficiency scenarios. This means a disaggregation to the end use level in the case of non-residential buildings, and to the process level for industrial sub-sectors.

The model allows for the construction of multiple scenarios, both in terms of economic growth, and adoption of high efficiency technologies. The reference scenario for economic growth is given by the World Bank. The impact of overall economic growth is twofold: first, economic growth is the main (indirect) driver of energy demand growth in all sectors. Therefore, a higher growth scenario will correspond to higher demand in both the base (business as usual) case and the efficiency cases. On the other hand, efficiency improvement in years late in the forecast will be achieved by the adoption of lower intensity equipment or industrial processes. Diffusion of efficiency technology is likely to be more rapid for new equipment and production capacity – therefore higher economic growth cases will see an accelerated improvement of the stock. In the high-efficiency scenarios, the degree and rapidity of adoption of efficient technologies are parameterized in terms of an effective cost of carbon or cost of conserved energy**.**

In most cases, forecasts of proximate drivers of sectoral energy consumption (floorspace or commodity production) are not available. Therefore, these drivers are modeled according to more aggregate variables (GDP), in combination with relations taken from historical data, either global, or India-specific. The main driver of sector energy is economic growth and population growth. The World Bank's forecast has GDP growth at 8% till 2021, after which it drops to 7.5% till 2026, and 7% till 2030.

This chapter first describes how activity forecast for each sector and sub sectors were derived. Then the methodology used to construct scenarios using cost of conserve energy curves is explained in detail. Finally, results of the model are depicted for each sectors and key subsectors.

4.1 *Activity Forecast*

The main forecasting effort is to establish levels of *activity* that result in energy demand. In the non-residential building sector, the main activity variable is *floorspace*. In the industrial sector, it is *commodities production*. Increases in GDP and population generally affect both floorspace and commodity production. The main analytical input to the model is to establish the relation between sub-sectors growth and overall economic growth. This amounts to modeling the evolution of the structure of energy consumption.

4.1.1 Non Residential Building

In general, we model floorspace as a function of the size of the economy for subsectors that are driving the current rapid economic growth, retail and private offices. In less dynamic sectors, education, health sectors and hotels, total floorspace scales with population and/or per capita GDP, but reaches a saturation point. Implied additions in floorspace are important, since new construction is expected to have different energy intensity properties, both in the business as usual, and in the efficiency scenarios.

Total floorspace in year y is given as a function of driver variables by:

$$F(y) = f(F(y_0),G(y),a\ldots)$$

These equations express the main dependences on total floorspace. These are: total floorspace or construction in the base year $F(y_0)$ or $\Delta F(y_0)$, macroeconomic parameters $G(y)$ and other determined model parameters a. In each year the remaining floorspace which was present in the base year is given by

$$F^0(y) = F(y_0) \times (y-y_0)^{1-b}$$

In this equation, b expresses the demolition rate and is assumed to be 1 percent per year. In this way, the base year stock is gradually taken out of service over time. As a result of these relations, the new floorspace is given by

$$F_{new}(y) = F(y) - F^0(y)$$

The components of floorspace F_{new} and F^0 have distinct energy intensities, due to the evolution of building and workspace design (especially with regard to lighting and HVAC systems). Total energy demand is given by:

$$E(y) = F^0(y)\times I^0(y)+F_{new}\times I_{new}(y) \qquad \textbf{Eq. 1}$$

Both I^0 and I_{new} have a time dependency, due to the replacement of equipment in new buildings.

In general, GDP value added from the commercial sector should be a main driver of commercial floorspace. While a forecast for GDP growth through 2030 is provided by the World Bank, commercial sector value added is not. Therefore, we develop a model for the growth of the commercial sector as a function of the size of the economy as a whole.

Office and Retail– Private sector office and retail space are among the most dynamic subsectors of non-residential buildings. Floorspace increases in this subsector are assumed to scale with commercial sector GDP value added, with the constant of proportionality determined by the ratio in the base year.

$\Delta F = \varepsilon \times \Delta GDP_{Comm}$, where

$$\varepsilon = \frac{\Delta GDP(y_0)_{Comm}}{\Delta F(y_0)}$$

Using historical data from the Construction Industry Development Council, the elasticity ε is found to be 0.56. This is scaled by a factor of 70% to arrive at an elasticity of 0.39. Due to the relative dynamism of the private sector, 80% of the new office space is assumed to be privately owned.

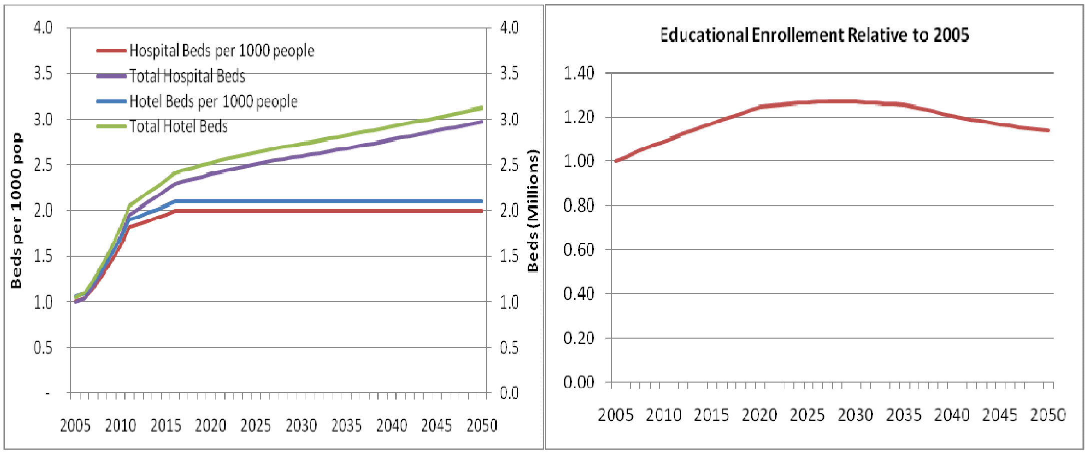
Hospitals– The amount of floorspace in the health sector (hospitals and clinics) is expected to grow gradually as the level of health services improve with economic development. We take the number of beds per capita to be a proxy for health services overall. According to Ministry of Health data, this indicator is forecast to rise at a rate of 5.6% per year until 2015, at which point it stabilizes at 2 hospital beds per capita. The total number of beds is then calculated to be

$$Beds = Beds\ per\ Capita\ (y) \times Population(y)$$

Health sector floorspace is then assumed to scale with the number of hospital beds. The evolution of number of hospital beds over time is shown in Figure 31.

Schools– Floorspace in education is assumed to scale according to education levels – number of students enrolled in primary, secondary and post-secondary education.

Figure 31. Trends in number of hospital beds, hotel beds and educational enrollment.



Hotels – Recent trends in the number of hotel rooms are provided by The Federation of Hotel & Restaurant Association, and forecast to 2016. After this, the number of hotel rooms per capita is assumed to stabilize.

4.1.2 Industrial Sector

The energy required to produce one unit (tonne) of industrial commodity is given by:

$$E(y) = P^0(y) \times I^0(y) + P_{new} \times I_{new}(y)$$

This equation distinguishes between production from facilities existing in the base year P^0 (tonnes), and those installed in subsequent years P_{new}. The energy intensity of production in existing plants I^0 (GJ per tonne) is averaged over the entire base year production, while the intensity of production in new plants I_{new} is estimated independently. Production by existing plants is given by:

$$P^0(y) = P(y_0)\ x\ (y-y_0)^{1-\lambda}$$

In this equation, λ expresses the plant retirement rate. Accordingly, production in plants installed after the base year is given by

$$P_{new}(y) = P(y) - P^{0}(y)$$

Imports and Exports

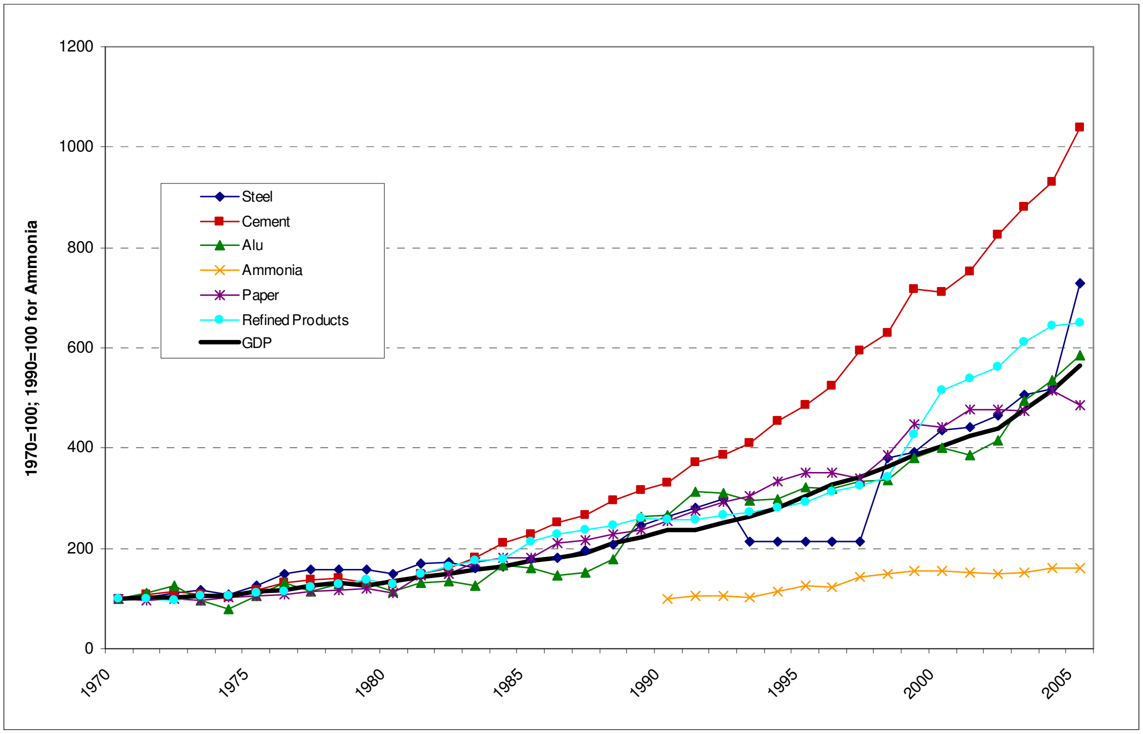
Commodity production in the industrial sector is driven largely by the internal demands of the country as the economy grows. Commodity exports and imports can be significant, however, affecting energy production differently than models based solely on GDP can capture. For instance, the development of a large steel exporting industry in India would create higher production rates per unit of GDP than what are currently observed. The model considers commodity trade externally to the GDP driver model, as the demand for steel depends on other according to government and industry projections, as well as models of international trade of commodities. In the baseline scenario we have considered the percentage of imports and exports to remain the same over time.

Commodity Demand

Determining the future trend of commodities production is a challenging task as many factors can contribute in shaping this trend. However, historical trends and experience from countries across the world can help understanding and estimate the most probable path. Historical trends show that the importance of industry within an economy varies by its stage of economic development. At an early stage of development, the share of the agriculture sector in the economic activity is the largest. With income growth, the share of the industry sector increases to satisfy a growing demand for infrastructure such as roads, railways, buildings, power grids, etc. As development continues, the need for basic infrastructure declines and consumer demand shifts increasingly towards services. This trend is often refereed as "dematerialization" and has been studies by a large body of research, Groenenberg (2005) provides an overview of the dematerialization literature.

Data on production (Figure 32) and trade were gathered for each of the six energy intensive industries studied in this report. We then calculated commodities demand or consumption as equal to production plus imports minus exports. Commodity demand for each subsectors were then used to calculate the material intensity of use defined as the ratio of commodities demand to GDP. This ratio was analyzed over time and used to estimated future growth. The resulting material consumption per capita projections were calculated and then compared to current level from India and other countries.

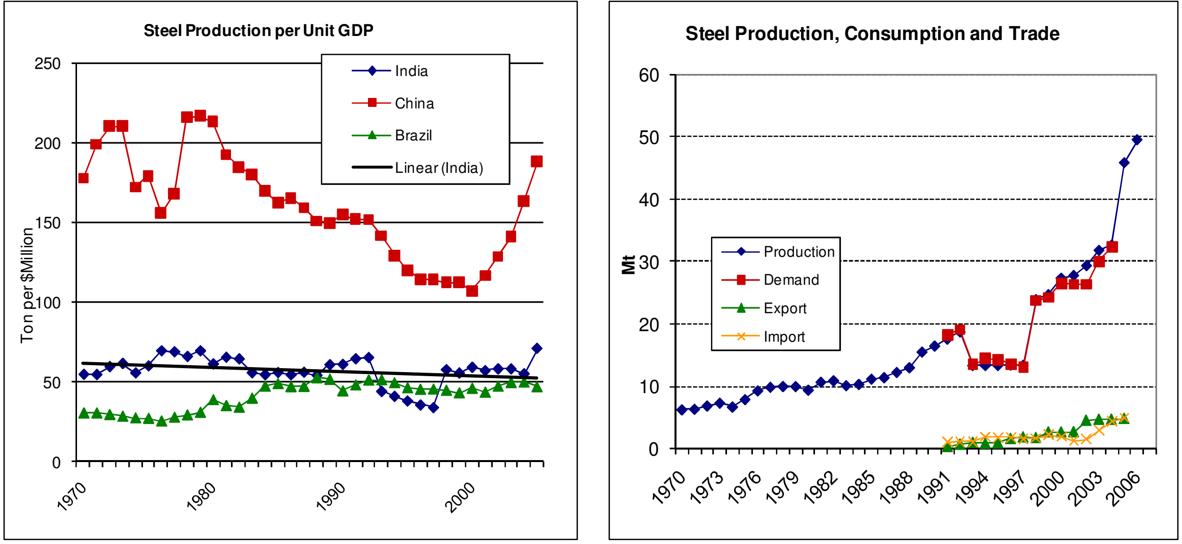
Figure 32. Historical Commodities Production Growth (1970=100; 1990=100 for Ammonia)



Iron and Steel

The relation between iron and steel production is modeled as a function of GDP is investigated from historical data. The historical data show a correlation between rates of steel production and economic development. Steel seems to be a relatively constant input to each unit of GDP. Figure 33-a shows steel production per unit GDP (tonnes of steel per million 2000 US dollars of GDP) in India, China and Brazil. Indian steel production rates are similar to those of Brazil, at about 61 tonnes per million of 2000 US $ GDP (World Bank, 2009). Though there are some fluctuations over time in the Indian case, there is no clear trend. The comparison with China is striking, however. First of all, China's steel intensity is much higher than the other two countries, using the same metric. In addition, the Chinese data shows a discontinuous and dramatic rise in steel production over the past few years, starting in 2000. This indicates that China has become a qualitatively more steel-intensive economy, and also shows clear evidence of China's recent construction boom. Net exports of steel from China remain very low, representing only 6% of production in 2006. Signs of such a boom are becoming apparent in India as well. Whether a similar future is in store for India will dramatically influence energy consumption of the steel sector. Therefore, by default we model steel consumption as constant per unit GDP.

Figure 33. Trend in Steel Production and Consumption in India



As shown in Figure 33b, growth in domestic consumption of iron and steel follows closely the production trend since net imports tend to be small. Average ratio of tonnes of steel used per million dollars of GDP produced is equal to 54.6 over the period 1991 to 2007. This ratio was used to forecast domestic consumption of iron and steel. In the baseline scenario, we considered the percentage of imports and exports to remain constant over time. The iron and steel production projections result in an average annual growth rate (AAGR) of 6.6% over the period 2007 to 2030. Steel consumption per capita will increase from 42 kg today to 152 kg in 2030. This estimation can be considered as conservative as it remains lower than the world average of 178 kg per capita and much lower than the OECD rate of 253 kg per capita and China which is 322 kg per capita today.

Cement, Aluminum. Paper and Refined Products

Over the past few decades, cement, aluminium, paper and refined products productions in India has grown steadily. Figure 34 shows the trend in production, exports, imports and consumption for these 4 industries. In each case, consumption follows closely production. The rate of material use per unit of GDP was then calculated. Figure 35 shows the variation of intensity of material use per unit of GDP. The variation is contained in a range of -20% to + 40% and no trend can be seen. Therefore, we model cement, aluminum, paper and refined products consumption as constant per unit GDP produced, similar as for steel consumption.

Cement consumption increases by an average of 171.3 tonnes per million dollars of GDP, aluminum consumption increases by 1.39 tonnes per million dollars of GDP, paper consumption increases by 9.1 tonnes per million dollars of GDP and finally refined product consumption increases by 191.1 tonnes per million dollars of GDP.

Figure 34. Production, Consumption and Trade in India

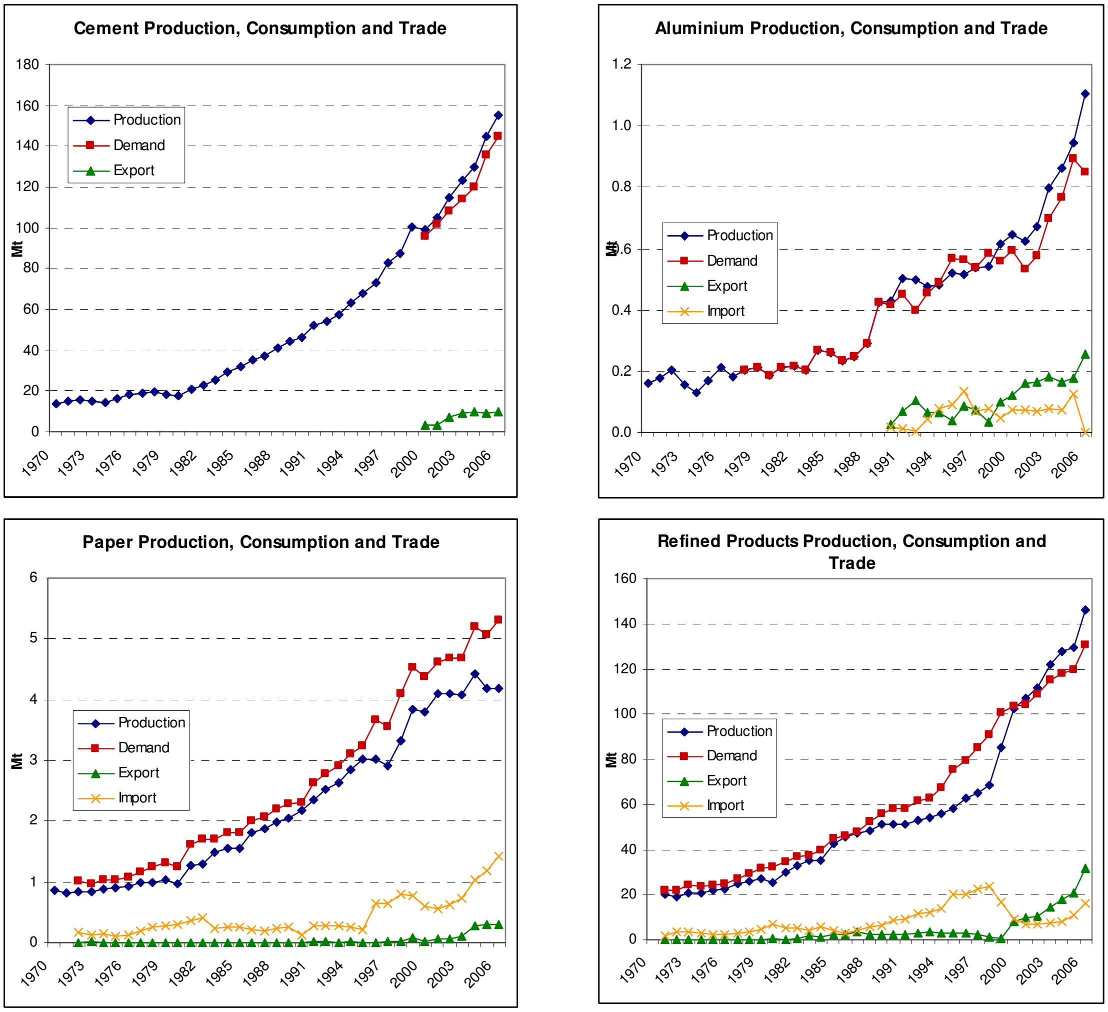
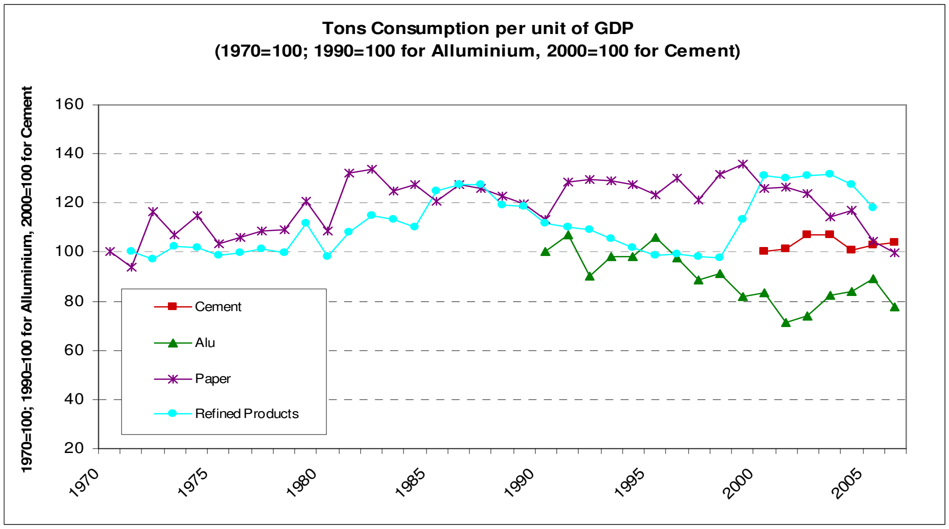


Figure 35. Intensity of Material Use



The resulting AAGR for cement, aluminum, paper and refined products production are as follow: 6.8%, 7.6%, 8.5% and 7.6% as shown in Table 1. Table 1 also provides per capita consumption level for India in 2005 and 2030 and for China in 2006. It was not possible to provide per capita consumption for other countries but per capita production is shown as a rough guide. 2030 projection of cement per capita consumption (500 kg) comes close to the present OECD level of per capita production (506 kg) but is well below the level of China (915 kg). Trade of Cement is very small in China; net exports are about 3% of production. In the case of aluminium, paper and refined products, the level of per capita consumption remains low in 2030, below the world average, but well above the Indian current levels.

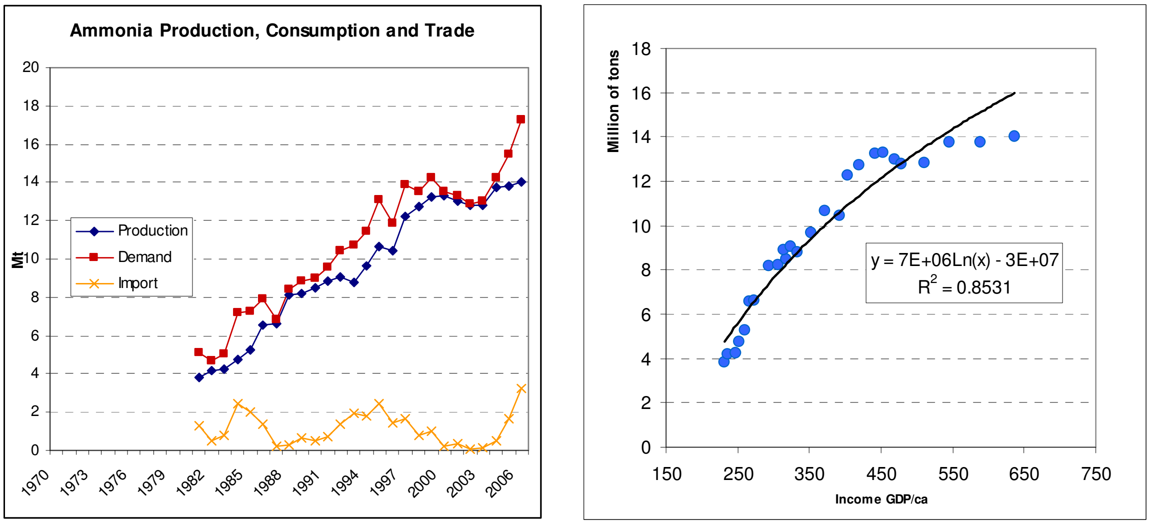
Table 32. Commodities Forecasts

	Historical Growth - India		Projections - India	Per Capita Consumption			Per capita Production	
	1981-2006	2000-2006	2007-2030	India, 2005	India, 2030	China, 2006	World, 2006	OECD, 2006
Cement	8.3%	7.7%	6.8%	122	500	886	390	506
Aluminium	6.8%	9.4%	7.6%	0.8	3.9	7.0	5.2	6.8
Paper	4.5%	1.6%	8.5%	4	23	55	57	197
Refined Pdts	6.6%	6.1%	7.6%	106	503	217	582	1,793

Ammonia

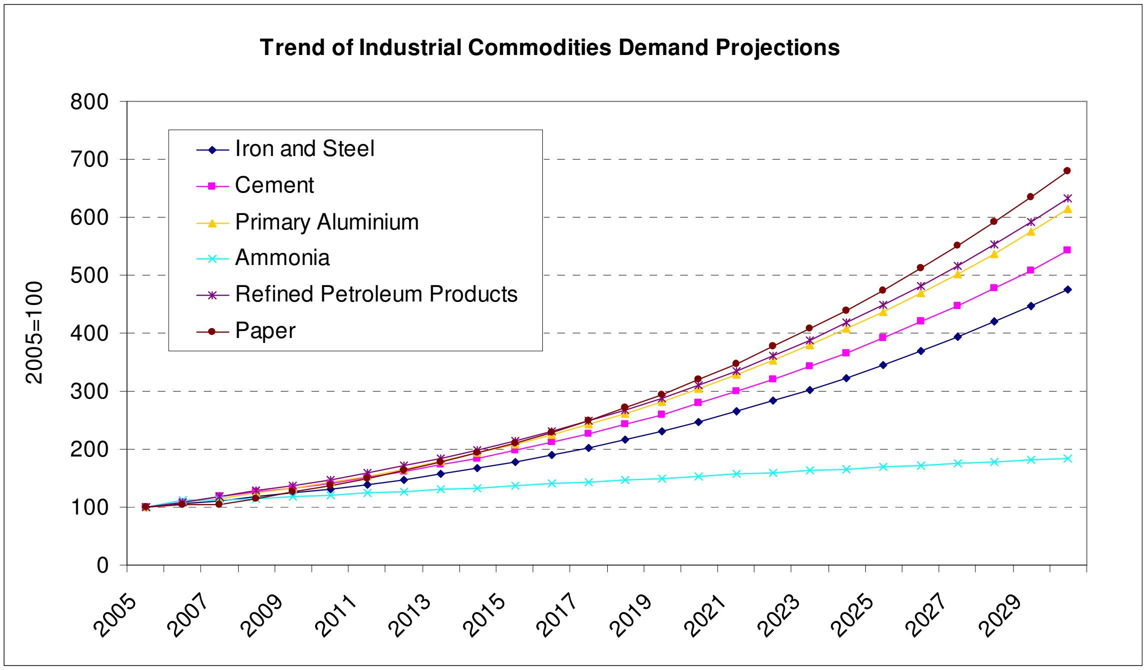
We found ammonia production, largely used for fertilizer, not to be driven directly by overall economic growth of the country, but by amount of agricultural production and population growth. For this reason, ammonia production is forecast using a regression over income level, i.e. GDP per capita. In order to capture the trend of ammonia expansion, we track ammonia consumption for 1981-2006, and showed its evolution against income growth (Figure 36). The logarithmic equation was used to forecast future projection of ammonia according to GDP growth and income.

Figure 36. Ammonia Production and Consumption Trends



Resulting projections of material demand for each of the 6 energy intensive industries are shown in Figure 37. The percentage of imports and exports are assumed to remains constant over time in this scenario. Therefore, production follows a similar trend.

Figure 37. Commodities Demand Projections



4.2 *Energy Intensity Baseline Forecast*

The energy intensity baseline forecast consists of two components: current technology and new technology. Energy intensity is broken into two 'market segments': equipment in operation in the base year and equipment installed after the base year.

4.2.1 Non Residential Building Intensity

Energy consumption in non-residential buildings arises from diverse sources, and displays large variability. In order to provide a realistic assessment of efficiency potential, the model considers differences in end use consumption between distinct building types, between new vs. existing buildings, and between public and private sector buildings.

Climate Zones

Due to lack of data on specific building types disaggregated by climate zone, climate zone-dependent cooling loads are not considered in the model. Instead, national average loads are used.

Electricity Intensity

In general terms, building electricity intensity (in GJ per square meter) is given by

$$I(y) = Lighting + AC + Fans + Other \qquad \textbf{Eq. 2}$$

Each term in this equation corresponds to an end use. *Other* is an end use specific to building type, such as office equipment, food preparation or refrigeration. Base year end use intensities are differentiated according to the following variables:

1. Building type
2. New vs. Existing Buildings
3. Public vs. Private Sector Buildings (offices, and schools, hospitals – all schools are considered public - and hotels)

Base year end use intensities (EUI) are provided in Section 3. The 'Other' category is a residual category. EUIs for this category are an average over all other building types, weighted by floor space in the base year.

In order to ensure consistency with current sector electricity consumption, total electricity demand of each building type is calibrated to government statistics collected by the International Energy Agency (IEA)[16]. Individual electric end use intensities are determined according to estimates of the breakdown of the total electricity load. The percentage load for each end use for each building type is multiplied by total electricity intensity to yield end use intensity, in kWh/year/m^2. End use load percentages are provided in Section 3.

Other Fuels

As mentioned above, diesel fuel consumption in the commercial sector is assumed to be used entirely for back-up electricity generation. The fraction of electricity demand that is provided by diesel generators is assumed constant in the forecast. Detailed statistics for LPG in the commercial sector were not available. Therefore, LPG use was allocated between the building types, and LPG intensity was calculated using the base year floor space of each. The allocation and resulting intensity of LPG is given in

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[16] In this estimate grid electricity is added to diesel electricity generation. All commercial sector diesel consumption is assumed to be used for backup electricity generation, with an efficiency of 25%.

Table 33. LPG intensity by building type is assumed constant in the forecast.

Table 33. LPG allocation and intensity by building type.

	Share	Intensity (MJ/m2)
All Buildings	100%	45
Retail	0%	0
Private Office	5%	21
Government Office	5%	19
School	0%	0
Hotel	25%	247
Private Hospital	29%	268
Public Hospital	21%	228
Other	15%	27

Carbon Dioxide Emissions

Once floorspace and intensity of new and existing buildings are determined, total commercial sector energy consumption by fuel are given according to Equation 1. CO_2 emissions resulting from site consumption of LPG and diesel fuel are calculated according to IPCC conversion factors. Emissions from grid electricity are calculated according to a time series of conversion factors provided by the World Bank.

4.2.2 Industrial Production Intensity

Energy intensity (GJ per tonne) of commodity production is estimated for existing plants and plants to be installed in future years. This depends on the breakdown in process, and on the efficiency of each process. The model estimates average baseline intensity for production in the base year and considers the intensity likely to apply to new installation going forward, that is, the intensity of marginal production. In addition, efficiency improvements due to retrofits of equipment and processing in existing plants are included.

Energy intensity is estimated (GJ/tonne) for each of the following processes, for existing and new plants. Intensity is time dependent in each case, to express gradual improvements in the BAU case.

Iron and Steel

I. Finished Steel
    A. Blast Furnace - Oxygen Blown Converters
        1. Integrated Steel Plant
        2. Small Scale Plants
    B. Direct Reduction (natural gas) - Electric Furnace (ISP only)
    C. Direct Reduction (coal) - Electric Furnace
        1. Integrated Steel Plant
        2. Small Scale Plants
II. Scrap Steel – Electric Furnace
    A. Integrated Steel Plant
    B. Small Scale Plants

Cement

- I. Dry Kiln
- II. Semi-Dry
- III. Wet Kiln

Aluminum

- I. Primary Aluminum
  - A. Alumina Production
  - B. Primary Aluminum
    - 1. Pre-Baked
    - 2. Vertical Stud Soderberg
- II. Secondary Aluminum

Fertilizer (Ammonia)

- I. Ammonia Production
  - i. Natural Gas Feedstocks
  - ii. Oil Feedstocks
  - iii. Coal Feedstocks

Refinery

- I. Petroleum Refining

Pulp & Paper

- I. Wood-Based
- II. Agro-Based
- III. Waste Paper Pulping

4.3 *Efficiency Scenarios*

High-efficiency (low-carbon) scenarios in the model can be driven by target efficiency levels (or percentage improvement), or alternatively by assumptions of carbon market prices. The model spreadsheet allows for the selection of target technology levels for specific technologies. The scenarios generated by the model are:

- **Frozen Efficiency Scenario (non-residential sector only)** – Assumes no change in efficiency (intensity) by end use over time.
- **Business as Usual Scenario** – Market-driven efficiency improvement only.
- **High Efficiency Scenario** – End use intensity determined by user-selected technology targets or carbon prices.

4.3.1 Energy Conservation Supply Curve

The main determinant of adoption rates of high efficiency technologies in this study is likely to be the cost of conserved energy (CCE)[17]. While cost is of course not a strict determinant of adoption of efficiency measures, it is taken to be a consistent one. In fact, it is well known that even highly cost effective measures are often not taken – this is the central market failure that efficiency policies are designed to address. Therefore, a scenario in which the cost of conserved energy of all measures taken is lower than the actual cost of energy may still be more efficient than the business as usual case. In high efficiency cases, we model that all measures up to a higher level of CCE will be taken. The specific mechanism by which the adoption threshold is raised is not specified. It could be a carbon tax, other tax incentives, rebates, credit payments from a cap and trade system, other subsidies, or increased consumer awareness.

A typical CCE plots the marginal cost of conserved energy or conserved carbon emissions by a mitigation option or technology implementation against the total amount of energy or greenhouse gases conserved. Ranking investments according to their price per unit of GHG saved define the supply curve. CCE is consistent with microeconomic theory which posits that a firm will invest in energy conservation up to the point where the marginal costs equal the marginal benefits, or the value of one unit of energy or greenhouse gas emissions or the energy/carbon price. (Martin et al., 2000).

Cost curves are necessarily specific to processes and equipment type. A main objective of the detailed study of the non-residential building and industrial sectors was to develop the datasets that allowed the construction of these relationships. In the industry sector CCEs are constructed for the six industrial energy intensive sectors, and the energy savings have been translated into corresponding greenhouse gas emissions reductions. Cost of Conserved Energy is expressed as the increment (increase) in cost of technology, divided by the energy saved by that measure over the lifetime of the technology/installation:

$$CCE = \frac{I \times q}{S}, \qquad \textbf{Eq. 3}$$

where I is the annualized capital cost, q is the capital recovery factor, and S is annual energy savings. The capital recovery factor q is given by:

$$q = \frac{d}{(1-(1-d)^{-n})}$$

In this equation, d is the discount rate, and n is the lifetime of the equipment. Detailed CCE relationships for non-residential end uses and industrial process were developed in for the project. An example of these is shown in Figure 38, for cassette and multi-split type air conditioning (non-residential sector).

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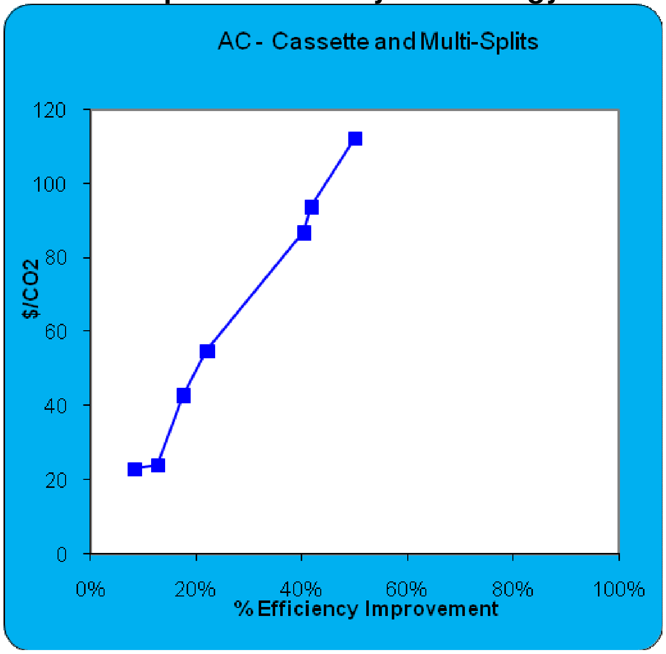
[17] Life Cycle cost savings, Payback Period or Internal Rate of Return are other possible metrics describing the net value of efficiency improvements

Figure 38. Example of Efficiency Technology Cost Curve



Non Residential Building End Use Equipment

In order to construct a high-efficiency scenario, the user may choose efficiency targets from a list provided on the spreadsheet's 'cost curve' page via a series of pull-down menus. On this page, efficiency and capital investment costs are given by technology, type, not by end-use. For example, a different cost-efficiency relationship is provided for room air conditioners and packaged cooling units, because these are distinct technologies with different design options for improving efficiency. For each technology design option (efficiency level), percentage efficiency improvement is given. This is the main output of the cost-curve model.

Industrial Process Technologies

Efficiency improvements in the industrial sector are modeled at the process level according to specific measures with well-defined energy saving levels and associated costs. Each efficiency improvement measure reduces the consumption of a particular input fuel. In some cases, due to the nature of the data, savings are estimated directly in terms of carbon emissions[18]. Measures are then combined and rolled up to the sub-sector level in order to generate one cost curve. Efficiency scenarios are generated in one of two ways, designated 'Model 1' or 'Model 2'. Using Model 1, the user sets a definite price of carbon. The spreadsheet then uses the cost curves to identify the corresponding efficiency level for each sub-sector. The 'target efficiency' determined in this way is then compared to the business as usual case to calculate savings (details of scenario accounting are given below). The second option is designated 'Model 2'. In this scheme,

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[18] This is true in the case of data from CDM projects.

the user selects the target emissions reduction percentage directly, e.g. 20% or 30% reduction in emissions. This fractional reduction is applied over all industry sub-sectors. Costs of implementation are then determined from the cost curves in a manner complimentary to Model 1.

4.3.2 Business-as-Usual Case

Non-Residential Buildings

In the BAU Case, efficiency improvements are assumed to be driven by market-effects only. Lighting and air conditioning are assumed to gain efficiency at a constant growth rate, which is a user-defined parameter. Intensity in this case is given by

$$I_{b,enduse}(y) = I^{0}_{b,enduse} \times (1+r)^{y-2010}$$

In this equation, *b* denotes the building type. The parameter r is the *exogenous annual efficiency improvement rate* set by the user. By default, *r* is set to 0.7%. Exogenous improvement of end use efficiency is assumed to begin in 2010, and continue throughout the forecast. The exogenous improvement rate applies to all new building installations. Efficiency also improves in existing buildings, but at a much slower rate, to take account for the fact that installations in these buildings only occurs when equipment is worn out and replaced.

Industry

In the Business-as-Usual (BAU) case, new industrial plants accommodating production growth and replacing old plants are assumed to follow current best practices. In some cases, this will be the most efficient technology currently employed in new Indian plants; in others it will be taken from international examples. In the BAU for industry, the intensity of existing plants does not change. The overall intensity of the industry decreases over time, however, due to the process of replacement of older plants with new ones. The growth of new production is quite fast in India, so that a large fraction of production in 2030 will be from new plants (Table 34).

Table 34. Share of new Plants

Share of new Plants	2030
Steel	79%
Aluminum	80%
Cement	83%
Ammonia	24%

4.3.3 High-Efficiency Case

Non-Residential Buildings

For non-residential buildings, intensity in the high-efficiency case is defined in terms of reduction of intensity versus the frozen efficiency case according to user-chosen target end use technologies. This efficiency improvement is modeled as the result of government policies, which could include: efficiency regulations (standards), incentives, taxes, the existence of a carbon market, etc. The target efficiency of various policies will be different. For this reason, the selection of the target by the user allows for modeling of a variety of policies. The resulting end use intensity is given by:

$$I_{b,enduse} = \left[1 - \sum_{tech} W_{b.tech} \times \left(\frac{\Delta E}{E}\right)_{tech} \times AdoptionRate\right] \times I^{BAU}_{b,enduse}$$

In this equation, I^{BAU} is the BAU case intensity, given for each building type and end use. The index *b* denotes building type, and the index *tech* denotes technology type. The weighting factor $W_{b,tech}$ is the percentage of each technology type used in each building type (see Section 3). The *AdoptionRate* factor accounts for incomplete adoption of the target technology. For a regulation, this could be the compliance rate. For voluntary programs, it could be the uptake rate.

Because the efficiency improvement applies to BAU, and not frozen efficiency case intensity, the equation takes into account market-driven effects. It assumes, for example, that if a stepwise improvement occurs due to, e.g. an efficiency standard, after the standard is imposed, efficiency will continue to improve as it would have in the BAU case.

High-efficiency case efficiency improvements are assumed to take effect in 2010. Efficiency target improvements are implemented in new buildings only. In existing buildings, only the exogenous efficiency improvement is accounted for. This difference in modeling takes into account that, while new equipment in existing buildings may be affected by efficiency policies, these improvements may be offset by increased installation or usage patterns, as these buildings "modernize". By default, the adoption rate is set to 80%.

Industry

In the high-efficiency case, the intensity of both new and existing industrial plants change over time. In the industry model, the efficiency improvements are assumed to take effect in 2010 but the intensity is assumed to evolve gradually to its new level. Intensity during the years between 2010 and 2030 is calculated with an exponential growth between the reference level in 2010 and the new level in 2030. Efficiency improvements mean that the target intensity is lower than the existing plant intensity, which is the base line. Existing plants will therefore become less intensive over time at any level improvement. The situation for new plants is somewhat different, since the target level is potentially less efficient than in the BAU case. If that is the case, new plant efficiency in the high-efficiency case will remain at the BAU level.

4.3.4 Financial Impacts

In general, high efficiency equipment is more expensive than inefficient equipment. It is useful to policymakers and analysts to evaluate the total incremental investment associated with a high-efficiency scenario. The model calculates financial impacts from electricity savings according to cost of conserved energy. The relationship established by Equation 3 allows for the calculation of annualized capital investment *I* from savings *S*, and CCE.

CCE for each end use is calculated according to technology CCE and the technology weighting factors $W_{b,tech}$. This factor is multiplied by savings for each end use for each building type to yield total capital investment.

4.4 *Discussion of Scenarios*

In our model, efficiency improvement is determined according to the cost and savings of particular technologies. The resulting efficiency scenarios should be interpreted as the *economic efficiency potential*, as they are based on societal discount rates and do not take into account the barriers to implementation of efficient technologies. This is the general discount rate considered when evaluating societal investments, such as used by international lending institutions. As compared to this discount rate, consumer or business discount rates may be higher. In the industry model, discount rate was fixed at 12%.

While the economic efficiency potential provides a useful indication of the kind of reductions that are available to Indian society, we are cognizant that the more likely outcome of efficiency programs, which can be characterized as the *market efficiency potential* for improvement is limited by a variety of factors, or barriers to implementation.

Some of these barriers to high-efficiency technology adoption include:

Market

- Unstable market situations which hinder international technological investments;
- Difficulty of market entry for new firms and technologies;
- Low level of competitiveness;
- Small size of markets; and
- Low income consumers;

Financial

- Lack of financial resources;
- High level of debt;
- Incompatible prices, subsidies, tariffs, taxes and insurance;
- Lack of incentives;
- Lack of access to credit;
- High up-front and transaction costs; and
- Low economic productivity;

Informational

- Lack of access to information;
- Lack of access to relevant technical data;
- Lack of awareness about climate change related issues, options for mitigation and adaptation and advanced technologies; and
- Lack of information about potential donors and project developers;

Legal

- Inappropriate systems of intellectual property rights;
- Inappropriate allocation of liabilities for environmental damage; and
- Inappropriate litigation systems;

Regulatory and policies

- Existing laws and policies that may not be compatible with climate change mitigation and adaptation related measures; and
- Lack of necessary policies, regulations, standards and codes;

Human resources

- Lack of skill/expertise in dealing with various aspects of climate change related projects; and
- Lack of skilled personnel for the installation and operation of environmentally sound technologies;

Infrastructural

- Lack of minimal technological infrastructures;
- Inflexible city and settlement designs; and
- Infrastructure obsolescence;

Organizational and Institutional

- Lack of compatible or adequate organizational and institutional frameworks (legal, financial, regulatory, enforcement, etc.); and
- Lack of coordination among activities of existing organizations and institutions;

Social and cultural

- Social practices, beliefs and norms that prevent acceptance of climate change mitigation/adaptation options;
- Lack of awareness of environmentally sound technologies and energy efficiency benefits; and
- Inefficient life-styles; and

Political

- Lack of public mechanisms that support technology transfer;
- Ineffective governance; and
- Lack of freedom of speech and information.

The mix of barriers that are most relevant to the penetration of an efficiency technology will vary with location, market structure and the political and policy environment in place. Removal of these barriers will require the adoption of policies such as those targeted at providing better information or financing to overcome the higher first costs of an efficiency technology. Quantification of such barriers is in its infancy, and is beyond the scope of work of this project.

4.5 *Sample Results*

Finally, we present some results provided as an output of the model for demonstrative purposes. For both sectors modeled, scenarios are essentially user-determined, either by setting a price of carbon, or by choosing specific target efficiencies or efficiency improvement levels. We did not attempt to determine a most-likely high-efficiency level, or technically-achievable level.

Non-Residential Buildings

For non-residential buildings, the high efficiency scenario is created by the user choosing efficiency levels for each technology. As an example we created a scenario in which the highest efficiency level was created that did not exceed \$20 per tonne of CO_2. The result is shown in Figure 39. Table 35 provides the details of this scenario. In this scenario, sector emissions are reduced by 17% relative to the frozen efficiency case at an overall capital investment cost of 1.2 billion \$US in that year. Relative to the business as usual case, emissions savings is 9% and capital investment is \$552 million.

Figure 39. High-Efficiency Scenario Emissions - \$20 per tonne of CO_2.

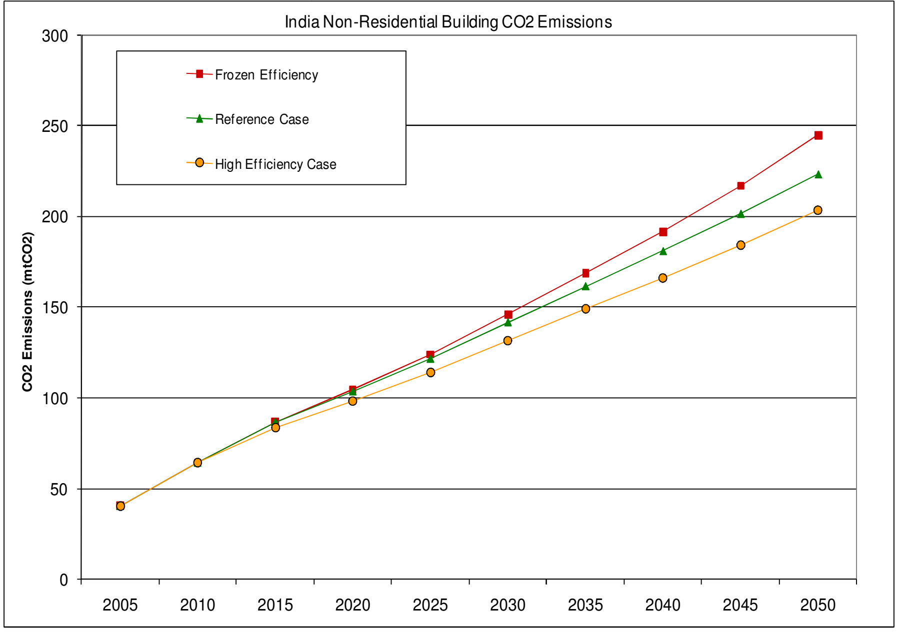

Table 35. High-Efficiency Scenario Emissions - $20 per tonne of CO_2.

	2020	2030	2040	2050
Emissions (mt CO2)				
Reference (Frozen Efficiency)	105	146	192	245
Business As Usual	104	142	181	223
High Efficiency Scenario	98	132	166	204
Mitigation (mt CO2)				
Business As Usual	1	4	11	22
High Efficiency Scenario	6	14	26	42
Mitigation (%)				
Business As Usual	1%	3%	6%	9%
High Efficiency Scenario	6%	10%	13%	17%
Capital Investment ($Millions)				
Business As Usual	29	125	306	616
High Efficiency Scenario	178	405	718	1168

Figure 40. High-Efficiency Scenario Emissions – Max Tech

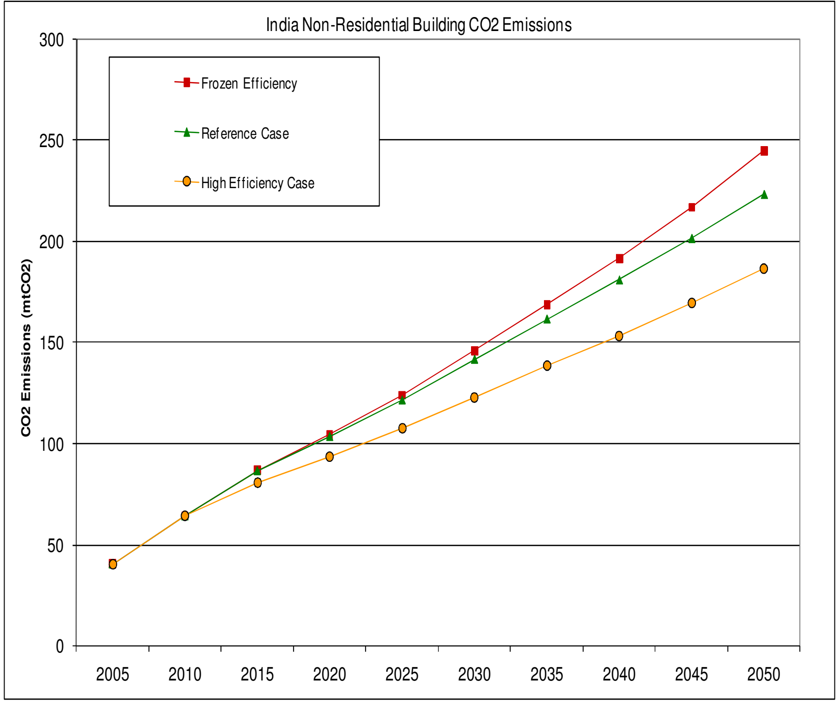

Table 36. High-Efficiency Scenario Emissions – Max Tech

	2020	2030	2040	2050
Emissions (mt CO2)				
Reference (Frozen Efficiency)	105	146	192	245
Business As Usual	104	142	181	223
High Efficiency Scenario	94	123	153	186
Mitigation (mt CO2)				
Business As Usual	1	4	11	22
High Efficiency Scenario	11	23	38	59
Mitigation (%)				
Business As Usual	1%	3%	6%	9%
High Efficiency Scenario	10%	16%	20%	24%
Capital Investment ($Millions)				
Business As Usual	130	550	1354	2727
High Efficiency Scenario	1377	2902	4821	7366

<u>Industry</u>

Model 1 allows for the calculation carbon emissions savings potential after the introduction of a carbon price. Baseline emissions per industrial subsectors and carbon intensity are shown in Table 37. The table also shows the total energy intensity potential resulting from the introduction of a $20 CO_2 emissions. The savings represent efficiency potentials from the baseline.

Table 37. Baseline Intensity Summary and Cost Curve results for $20 $MtCO_2$

	2007 Baseline		Emissions Reduction with 20$/tCO2	
	tCO2equ	tCO2/t	tCO2/t	Frozen Eff
Iron and Steel, ISP plants	111	3.27	1.08	33%
Iron and Steel, Small plants	61	3.18	0.22	7%
Cement	144	0.82	0.11	14%
Aluminium	38	30.87	0.87	3%
Fertilizer	37	2.82	0.75	27%
Refining	45	0.29	0.03	11%
Pulp and Paper	19	4.43	1.21	27%

The next table,

Table 38, describes the results of two scenarios constructed in Model 1. The first one calculates the savings potential after the introduction of a $20 carbon price and the second after the introduction of a $100 carbon price.

Table 38. Industry Model 1 Scenarios

	Emissions (Mt CO_2)			Percentage Savings (%)		
	2010	2020	2030	2010	2020	2030
Reference Scenario						
Iron and Steel, ISP plants	132	249	479			
Iron and Steel, Small plants	72	136	262			
Cement	169	318	606			
Aluminium	46	89	172			
Fertilizer	39	47	54			
Refining	57	120	243			
Pulp and Paper	31	72	153			
Saving Potential ($0 - $20)						
Iron and Steel, ISP plants	129	202	321	-2%	-19%	-33%
Iron and Steel, Small plants	72	131	244	0%	-4%	-7%
Cement	168	308	568	-1%	-3%	-6%
Aluminium	45	81	151	-3%	-9%	-12%
Fertilizer	38	40	43	-2%	-14%	-21%
Refining	56	111	211	-1%	-7%	-13%
Pulp and Paper	30	61	112	-1%	-15%	-27%
Saving Potential ($20 - $100)						
Iron and Steel, ISP plants	129	194	297	-2%	-22%	-38%
Iron and Steel, Small plants	72	131	244	0%	-4%	-7%
Cement	168	305	544	-1%	-4%	-10%
Aluminium	45	79	147	-3%	-12%	-15%
Fertilizer	38	40	41	-2%	-15%	-23%
Refining	56	109	204	-1%	-9%	-16%
Pulp and Paper	30	59	104	-2%	-18%	-32%

The results differ between Table 37 and

Table 38 as the model 1 calculate savings from the business as usual scenario, where new plant installed have a better efficiency level than current existing average. Moreover, we assumed that the introduction of a carbon price increase the level of performance of the new plant installed.

In the first scenario, savings potentials are the highest in the Integrated Steel Plants, the fertilizer and pulp and paper industries. According to the table, the lowest potential is situated in the small-scale steel industries. However, this is partially due to the extreme scarcity of data that describe savings potential in this sub sector. In the second scenario, where the carbon price is set higher, at $100, savings potential increases in all sectors, except fertilizer and small scale steel industries. This indicates than in the case of the fertilizer industry, most of the savings are available at a lower carbon price. In the case of small-scale steel industries, again this is mostly due to the lack of data in this sector. A much higher carbon price does not imply much higher saving potential. For the highest case, it brings 5 percentage points of additional potential (steel and pulp and paper industries).

In Model 2, instead of setting a carbon price, a carbon intensity reduction target is set. In the scenario shown in Table 36, the level is set to 15% carbon intensity reduction. The first part of the table shows the resulting carbon reduction and the second part shows the carbon price necessary to achieve this result. The carbon reduction differs from the target in the case of steel and cement sectors because the reduction is only applied to old plants.

Table 39. Industry Model 2 Scenarios

	2010	2020	2030
Reference Scenario (Mt CO_2)			
Iron and Steel, ISP plants	132	249	479
Iron and Steel, Small plants	72	136	262
Cement	169	318	606
Aluminium	46	89	172
Fertilizer	39	47	54
Refining	57	120	243
Pulp and Paper	31	72	153
Efficiency Scenario (Mt CO_2)			
Iron and Steel, ISP plants	131	229	407
Iron and Steel, Small plants	72	131	244
Cement	168	307	558
Aluminium	45	79	147
Fertilizer	39	43	47
Refining	56	110	208
Pulp and Paper	30	66	130
Efficiency Scenario (%)			
Iron and Steel, ISP plants	-1%	-8%	-15%
Iron and Steel, Small plants	0%	-4%	-7%
Cement	-1%	-4%	-8%
Aluminium	-3%	-12%	-15%
Fertilizer	-1%	-8%	-13%
Refining	-1%	-8%	-15%

Pulp and Paper	-1%	-8%	-15%
Cost (\$/tonne CO_2)			
Iron and Steel, ISP plants	0.1	0.1	1.6
Iron and Steel, Small plants	-1.2	3.3	36.6
Cement	0.0	0.3	7.6
Aluminium	9.4	41.8	188.7
Fertilizer	0.5	3.6	12.4
Refining	0.0	6.4	126.3
Pulp and Paper	0.1	3.4	8.0

The cost of conserved carbon to achieve 15% intensity reduction of old plant is relatively low in the case of steel while it is very high in the case of the aluminum industry. The remaining energy-intensive industries have a relatively low cost of conserved carbon, all under $13.

References

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5. Conclusion

This study shows that energy intensity for the six most energy intensive industries in India has considerably reduced over the last 20 to 30 years. The cement industry has particularly performed well in reducing its energy use to a level comparable with current average international level. All other sectors have performed well in reducing their energy intensity, but a gap remains compared to international best practice. This is the case for example of heteroclite industries like the iron and steel industry which is composed of modern large integrated plant that perform well and smaller scale plants that have large energy efficiency potential. The fertilizer industry is also composed of some efficient natural gas based plants and to a lesser extend of naphtha and fuel oil based plants which have higher energy intensity. In the case of aluminum, the sector is highly concentrated with only three large players which all have worked toward reducing their highest cost of production which is electricity use. The refining industry is a more complicated industry to assess as energy consumption per unit of input is a misleading indicator of the energy performance of refineries as it does not account for differences in type of crude processed, product mix (and complexity of refinery), as well as the sulfur content of the final products. The sector is growing rapidly and potential to reduce its energy use exists. Finally, the sector where the most potential exist is the pulp ad paper industry, with estimated potential of 30 to 40%. Across all sectors, the use of captive power to supplement unreliable supply from the grid has increased. These captive plants are rarely cogeneration plants and generally use coal with low efficiency conversion rate. Potential emission reductions lie also in the use of increasing waste and recycled materials. Production of steel and aluminium based on recycled products leads to large savings potentials. Use of fly ash from coal power plant in cement plants is another example of use of recycled material for a low carbon alternative pathway. In the pulp and paper sector, the India industry has shown ingenious way in developing the use of agricultural waste to reduce wood demand. It is to believe that additionally to energy efficiency improvements, a better use of recycled material across industries can lead to significant emissions reductions.

In the case of the non-residential sector, commercial building floor space is expected to double by 2050, with retail establishments and large private offices showing the largest increases in new floorspace (31%, and 29% respectively of total new building space). By 2030, about half of the buildings are those in today's stock, with the portion declining to about a third in 2050. The effects of modernization, with increased space conditioning and lighting loads, are reflected in the corresponding projection for total electricity consumption, which, absent intervention, is expected to more than quadruple from 35 TWh in 2005 to 147 TWh in 2030.

The study observes a relatively wide range of energy consumption (20 – 500 kWh/sq.m), in the building population. This range is indicative of several factors, including levels of space conditioning, lighting, and other internal loads. Currently about 30% of the buildings are cooled. This percentage is expected to go up significantly in the future. However, for the sake of simplicity, we keep this percentage frozen for the analysis period in this study.

Data on the cost of reducing GHG emissions and conserve energy were assessed in this study based on Indian case studies, CDM-projects and some US carbon saving measures that were converted to Indian production characteristics. Based on these data, the study found that considerable potential remains but these come at a cost. When a carbon price of $20 is considered, non residential building sector emissions are reduced by 9%, relative to business as usual. In the industry sector, savings potentials are the highest in the Integrated Steel Plants (33%), the fertilizer (21%) and pulp and paper industries (27%).

However, it is important to keep in mind some of the limitation of estimating the economic potential and outline areas for improvement and future work. While a cost curve provides a useful indication of the kind of reductions that are available to Indian society, we are cognizant that implementation are often limited by a variety of factors, or barriers to implementation. Removal of these barriers requires the adoption of policies such as those targeted at providing better information or financing to overcome the higher first costs of an efficiency technology. Additionally, the economic efficiency potential analyzed in this study was limited by the availability of data on cost implementation measures, specifically in the small scale industries and the non residential building. Hence, the total potential include in the cost curve is generally lower than the total potential compare to best practice. This is in part due to the limit of conversion of the existing infrastructure and the excessive cost that this would involve. Moreover, the study did not estimate the cost of more substantial carbon reduction measures such as the switch to lower carbon fuel or the use of more recycled material. Instead, these measures and their implication were described in the text as potential low path growth options. Finally, estimating the rate of penetration of efficiency measures potential that remains for each technology was the most challenging part of this study. We rely on industrial experts and literature research. However, it is certain that the estimation provided in this study could be improved if more time and resource were allocated in providing more information.

One of the main limitations of the study is the lack of adequate data to accurately understand the existing building stock, technology mix and efficiency distribution of the installed equipment in the building stock. While the current study makes a significant attempt to get around the data limitation to assess the existing building stock through alternative means, systematic and regular data updates are essential to monitor and study energy consumption trends.