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# Assessment of Energy Use and Energy Savings Potential in Selected Industrial Sectors in India

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## List of Abbreviations and Acronyms

ARRPEEC: Asian Regional Research Program in Energy, Environment and Climate
ATC: Agreement on Textiles and Clothing
ATIRA: Ahmedabad Textile Industry Research Association.
BEE: Bureau of Energy Efficiency
BTRA: Bombay Textile Research Association.
GOI: Government of India
IDBI: Industrial Development Bank of India
LBNL: Lawrence Berkeley National Laboratory
NITRA: Northern India Textile Research Association.
RPS: Retention Price Scheme
SMI: Small and Medium Industries
SITRA: South Indian Textile Research Association.
TPD: tons per day

# 1. Introduction

Indian industry uses energy more intensively than is the norm in industrialized countries. While selected modern Indian units often display very high efficiency that approaches world best practice levels, the average intensity lags world best levels. Indian industry has undergone a transformation since 1991, the year the economy was opened to foreign investment and competition. Energy per unit of valued added in the industrial sector has declined since then. However, there still remains considerable scope for continued improvement of energy efficiency in Indian industry, and for learning from both worldwide and Indian best practices.

**Table 1-1. Industrial energy consumption, India, 2001.**

| | Net Value Added M Rs | % of Industry | Final Energy (PJ) | % of Industry | Primary Energy ( PJ) | % of Industry |
|---|---|---|---|---|---|---|
| Total Industry | 1,443,021 | 100% | 4,477 | 100% | 5,270 | 100% |
| Cement | 42,137 | 3% | 352 | 8% | 466 | 9% |
| Refineries | 71,844 | 5% | 316 | 7% | 316 | 6% |
| Fertilizers | 50,430 | 3% | 524 | 12% | 561 | 11% |
| Textiles | 145,767 | 10% | 113 | 3% | 163 | 3% |
| Chlor-alkali | NA | NA | 29 | 1% | 47 | 1% |

Source: Annual Survey of Industries, 2001-2002; IEA, 2004; CEA, 2001; India Ministry of Coal, 2003; India Ministry of petroleum & Natural Gas, n. d.; Teri, 2001.
Note: Primary electricity calculated using an electricity conversion efficiency of 33%.

This scoping study assesses the intensity of energy use in Indian industry, identifies national and worldwide best practice energy intensity levels, and on the basis of the above assessment provides guidance on areas for improving energy efficiency. This work focuses on five energy-intensive industrial sectors -- fertilizers, textiles, chlor-alkali, cement, and petroleum refining. The intent of the scoping study is to increase knowledge and sector-specific understanding about industrial energy use in order to assist Indian industry, the Bureau of Energy Efficiency, and concerned stakeholders in efforts to improve energy efficiency in this sector in the country.

The approach used involves assessing the current trends in output and value added in Indian industry, energy use by fuel type and electricity use in the above sectors, and indicators of energy intensity. In addition, Lawrence Berkeley National Laboratory (LBNL) assessed the types of energy conservation measures that industry could adopt to improve efficiency, and compared these with worldwide best practices in each of the above sectors. It is recognized that cement and chlor-alkali sectors have limited numbers of technologies and are easier to assess, while fertilizers and refining are more difficult because of more complex plants, and finally textiles is even more difficult because of the large numbers of plants in the unorganized sector and the diversity of processes used.

LBNL has relied largely on published literature for this assessment. Earlier studies have reported extensive potential for improving energy intensity in these sectors (Sethi and Pal, 2001), and a recent report by USAID corroborates these findings (Deneb, 2002).

Lawrence Berkeley National Laboratory (LBNL) has previously evaluated energy efficiency potentials for the Indian fertilizer sector (Schumacher and Sathaye, 1999a), the cement sector (Schumacher and Sathaye, 1999b), and energy-intensive industries overall (Mongia and Sathaye, 1998a and 1998b; Mongia, Schumacher, and Sathaye, 2001, Roy et al., 1999). In addition, LBNL staff assisted the Industrial Development Bank of India (IDBI) in setting benchmarks for 12 industrial sectors in order to select enterprises that would be worthy of modernization loans from the Asian Development Bank (Sathaye, Gadgil and Mukhopadhyay, 1999).

This assessment is organized by industrial sectors. We begin with the cement sector, and then focus on the refining, fertilizer, textiles, and chlor-alkali sectors, in that order. For each sector, we report on the basic production processes, economic and energy characteristics of that sector in India, its potential for energy efficiency improvement, and scenarios of future energy use. This is followed by a short summary of the future directions for efficiency improvement. In the final section, we provide some examples of policies that have been used in other countries that could be pursued in India for efficiency improvement. The length of each section depends on the complexity of the industry, and the material available for the assessment. We had access to more material on the cement and refining industry, which are reviewed more in-depth, while chlor-alkali is both an industry with limited number of products, and limited availability of studies, and hence its description is shorter than others.

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# 2. Cement Industry

## 2.1 Cement Production Processes[1]

Cement acts as a bonding agent, holding particles of aggregate together to form concrete. Cement production is highly energy intensive and involves the chemical combination of calcium carbonate (limestone), silica, alumina, iron ore, and small amounts of other materials. Cement is produced by burning limestone to make clinker, and the clinker is blended with additives and then finely ground to produce different cement types. Desired physical and chemical properties of cement can be obtained by changing the percentages of the basic chemical components (CaO, $Al_2O_3$, $Fe_2O_3$, MgO, $SiO_2$, etc.).

Most cement produced is portland cement: other cement types include white, masonry, slag, aluminous, and regulated-set cement. Cement production involves quarrying and preparing the raw materials, producing clinker through pyroprocessing the materials in huge rotary kilns at high temperatures, and grinding the resulting product into fine powder.

### 2.1.1 Raw Materials Preparation

Raw materials preparation involves primary and secondary crushing of the quarried material, drying the material (for use in the dry process) or undertaking a further raw grinding through either wet or dry processes, and blending the materials. The energy consumption in raw materials preparation accounts for a small fraction of overall primary energy consumption (less than 5%) although it represents a large part of the electricity consumption.

### 2.1.2 Clinker Production

Clinker production is the most energy-intensive step, accounting for about 80% of the energy used in cement production. Produced by burning a mixture of materials, mainly limestone (CaCO3), silicon oxides (SiO2), aluminum, and iron oxides, clinker is made by one of two production processes: wet or dry; these terms refer to the grinding processes although other configurations and mixed forms (semi-wet, semi-dry) exist for both types.

In the wet process, the crushed and proportioned materials are ground with water, mixed, and fed into the kiln in the form of a slurry. In the dry process, the raw materials are ground, mixed, and fed into the kiln in their dry state. The choice among different processes is dictated by the characteristics and availability of raw materials. For example, a wet process may be necessary for raw materials with high moisture content (greater than 15%) or for certain chalks and alloys that can best be processed as a slurry. However, the dry process is the more modern and energy-efficient configuration.

Once the materials are ground, they are fed into a kiln for burning. In modern kilns, the raw material is preheated (in four to six stages) using the waste heat of the kiln, or it is

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[1] Excerpt from Levine et al., 1995.

pre-calcined. During the burning or pyroprocessing, the water is first evaporated after which the chemical composition is changed, and a partial melt is produced. The solid material and the partial melt combine into small marble-sized pellets called clinker.

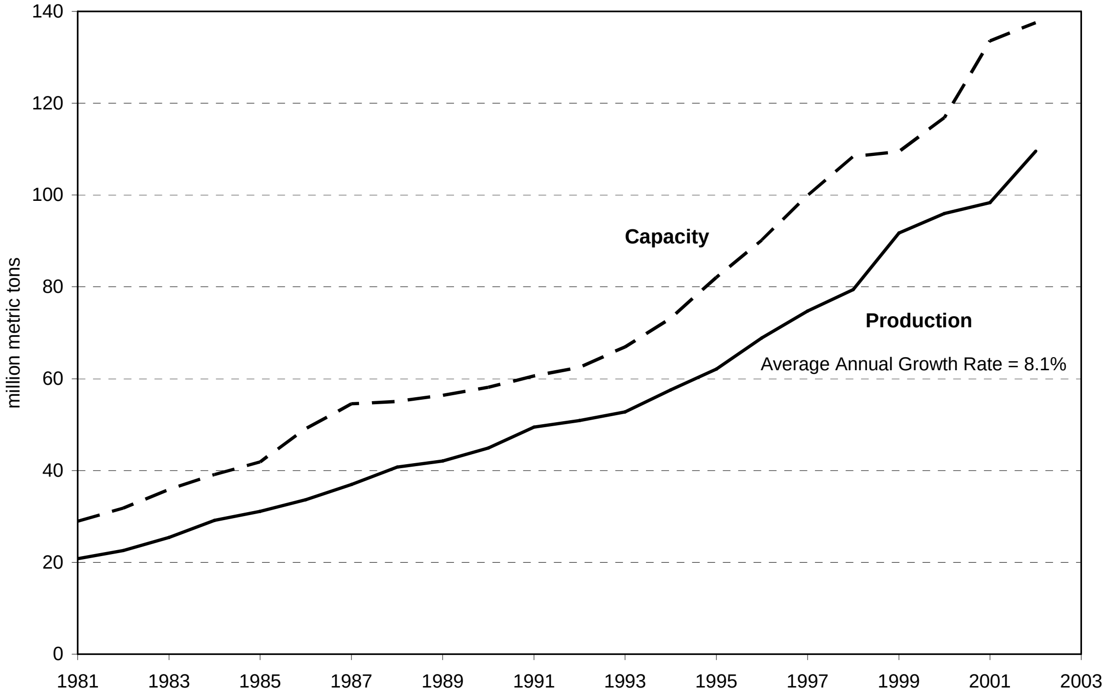
### 2.1.3 Finish Grinding

Cooled clinker is ground in tube or roller mills and blended by simultaneous grinding and mixing with additives (e.g., gypsum, anhydrite, pozzolana, fly-ash or blast furnace slags) to produce the cement. Drying of the additives may be needed at this stage.

## 2.2 Cement Production in India

India is the second largest producer of cement in the world. In 2003, India produced 115 million metric tons (Mt) of cement, behind China (750 Mt), but ahead of the U.S. (93 Mt) and Japan (72 Mt) (UNESCAP, 2004; van Oss, 2004). India's cement industry – both installed capacity and actual production – has grown significantly over the past three decades, with production increasing at an average rate of 8.1% per year between 1981 and 2003 (see Figure 2-1).

**Figure 2-1. Annual Cement Capacity and Production in India, 1981-2003.**



Sources: The India Cements, Ltd, n.d.; UNESCAP, 2004.

### 2.2.1 Cement Industry Characteristics

The Indian cement industry is comprised of 125 large cement plants and 300 mini-cement plants, with installed capacities of 148.28 and 11.10 million metric tons, respectively (Indian Ministry of Commerce & Industry, 2004). The cement plants can be grouped into 12 general clusters serving specific areas of India (see Figure 2-2 and Table 2-1). Appendix 2-A provides a list of Indian cement plants.

**Figure 2-2. Indian Cement Plant Clusters**

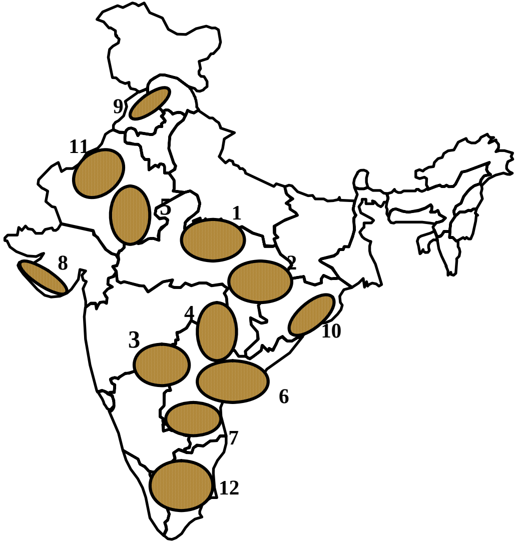


**Table 2-1. Indian Cement Plant Clusters and Annual Capacity in 2000.**

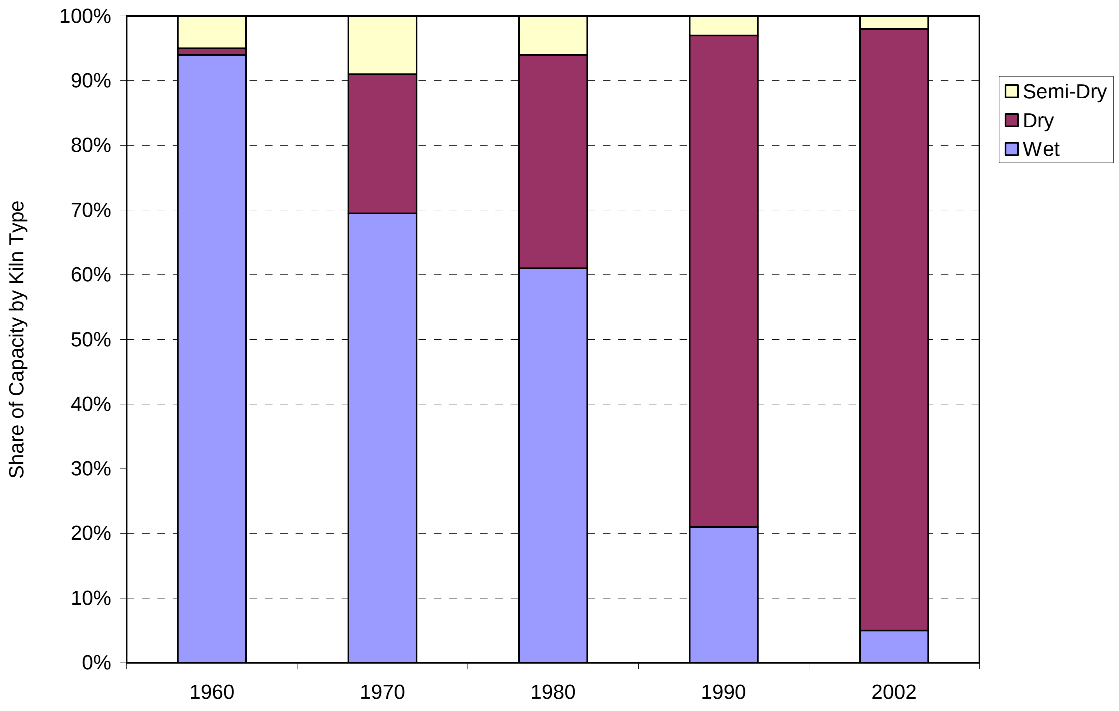
| No. | Name | Location | 2000 Annual Capacity (million tons) | % |
|---|---|---|---|---|
| | Cluster | | | |
| 1 | Satna | North MP | 12.2 | 11% |
| 2 | Bilaspur | Chhattisgarh plants | 11.2 | 10% |
| 3 | Gulbarga | North Karnataka and East AP | 9.0 | 8% |
| 4 | Chandrapur | North AP + East Maharashtra | 7.5 | 7% |
| 5 | Chanderia | South Rajasthan + Jawad & Neemuch in MP | 9.3 | 8% |
| 6 | Nalgonda | Central AP | 6.4 | 6% |
| 7 | Yerraguntla | South AP | 5.4 | 5% |
| 8 | Gujarat | South Gujarat | 11.5 | 10% |
| 9 | Himachal Pradesh-Punjab | HP + Punjab | 5.0 | 5% |
| 10 | Orissa | Orissa | 2.7 | 2% |
| 11 | North Rajasthan | Rajasthan plants excl. listed in 5 above | 8.2 | 7% |
| | Total | | 88.3 | 80% |
| | Non cluster | | | |
| 12 | Tamil Nadu + Kerala group | All plants in TN and Kerala | 8.0 | 7% |
| 13 | Others | All plants not considered above | 13.9 | 13% |
| | Grand Total | | 110.0 | 100% |

Source: Crisil Advisory Services, 2000.

Figure 2-3 shows that 94% of the cement plants in the Indian cement industry used wet process kilns in 1960. These kilns have been phased out over the past 42 years and now 93% of the kilns are dry process, 2% are semi-dry, and only 5% are wet process. Dry process kilns are typically larger, with capacities in India ranging from 300 to 8000 metric tons per day, while capacities in semi-dry kilns range from 600 to 1200 tons per day and capacities in wet process kilns range from 200 to 750 tons per day (Kumar, 2003).

About 56% of the cement produced in India is Ordinary Portland Cement (OPC), 31% is Pozzolana Cement (PPC), 12% is Portland Blast Furnace Slag Cement (PBFS), and the remaining 1% are special cements (Kumar, 2003). Blended cements, where energy use and associated emissions are reduced because a portion of the clinker is replaced by other materials such as fly ash or blast furnace slag, are only a very small portion of the Indian cement production (Jayaraman, G., n.d.). Indian cement plants have begun to look into the use of alternative fuel such as lignite, petroleum coke, rice husks, groundnut shells, and municipal and industrial wastes (Jayaraman, G., n.d.).

**Figure 2-3. Share of Indian Cement Kiln Capacity by Process Type**



Source: Karwa, 1998; Kumar, 2003; TERI, 1994

### 2.2.2 Cement Industry Energy Consumption

In 1992, the Indian cement industry produced about 58 million metric tons of cement and consumed approximately 195 PJ of final energy and 261 PJ of primary energy.[2] In 2002,

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[2] Primary electricity calculated using an electricity conversion efficiency of 33%.

cement production almost doubled to 110 million metric tons but, due to increases in energy efficiency, annual final energy consumption only increased to approximately 352 PJ of final energy and 466 PJ of primary energy.

Energy efficiency improvements are the result of the combined effects of shifting away from inefficient wet kilns toward more efficient semi-dry and dry kilns, as well as adoption of less energy-intensive equipment and practices. Implementation of advanced technology has reduced both energy and materials consumption in Indian cement plants (Indian Ministry of Commerce & Industry, 2004).

Table 2-2 compares the average energy intensity of dry, semi-dry, and wet kilns in India in 1992 to the average for those used in 2002. In all cases, both the thermal and electrical energy required per unit of cement produced declined over this period. In addition, as previously shown in Figure 2-2, the share of production by inefficient wet kilns declined, shifting the bulk of production to the more energy-efficient dry process kilns. Overall, total final energy consumption per metric ton of cement produced in India dropped from 3.6 to 3.1 GJ/t between 1992 and 2002. Similarly, total primary energy consumption dropped from 4.8 to 4.2 GJ/t over this period.

**Table 2-2. Energy Use for Cement Production in India, 1992 and 2002.**

| Process | | Thermal Energy | | Electricity | | Share | Production | Final Energy | Primary Energy |
|---|---|---|---|---|---|---|---|---|---|
| | | kcal/kg clinker | GJ/t cement | kWh/t cement | GJ/t cement | % | Mt | PJ | PJ |
| 1992 | Dry | 829 | 2.89 | 113 | 0.41 | 82% | 44.4 | 146.33 | 201.01 |
| | Semi-dry | 944 | 3.29 | 116 | 0.42 | 2% | 1.1 | 4.01 | 5.38 |
| | Wet | 1359 | 4.74 | 107 | 0.39 | 16% | 8.7 | 44.37 | 54.47 |
| | Total | | | | | | 54.1 | 194.72 | 260.86 |
| 2002 | Dry | 800 | 2.68 | 95 | 0.34 | 93% | 102.3 | 309.16 | 415.15 |
| | Semi-dry | 911 | 3.05 | 95 | 0.34 | 2% | 2.2 | 7.47 | 9.75 |
| | Wet | 1300 | 4.36 | 90 | 0.32 | 5% | 5.5 | 25.73 | 31.13 |
| | Total | | | | | | 110.0 | 342.36 | 456.03 |

Sources: Holtec, 2003; Karwa, 1998; Kumar, 2003; Raina, 2002; Schumacher and Sathaye, 1999; Sethi, 2004; TERI, 1994. Note: 1992 process shares are for 1993; clinker cement ratios of 0.833 and 0.8 used for 1992 and 2002, respectively; primary electricity calculated using an electricity conversion efficiency of 33%.

## 2.3 Future Development of the Cement Industry

### 2.3.1 Ongoing Changes in the Cement Industry

There have been significant improvements in the Indian cement industry over the past four decades, as more efficient equipment and energy-saving management practices have been adopted. Figure 2-4 and Figure 2-5 illustrate the trends of electrical and thermal energy consumption in the Indian cement industry, respectively, noting the specific technologies that have been incorporated by the industry since 1960 (Raina, 2002).

**Figure 2-4. Trend of Electrical Energy Consumption in Indian Cement Industry.**

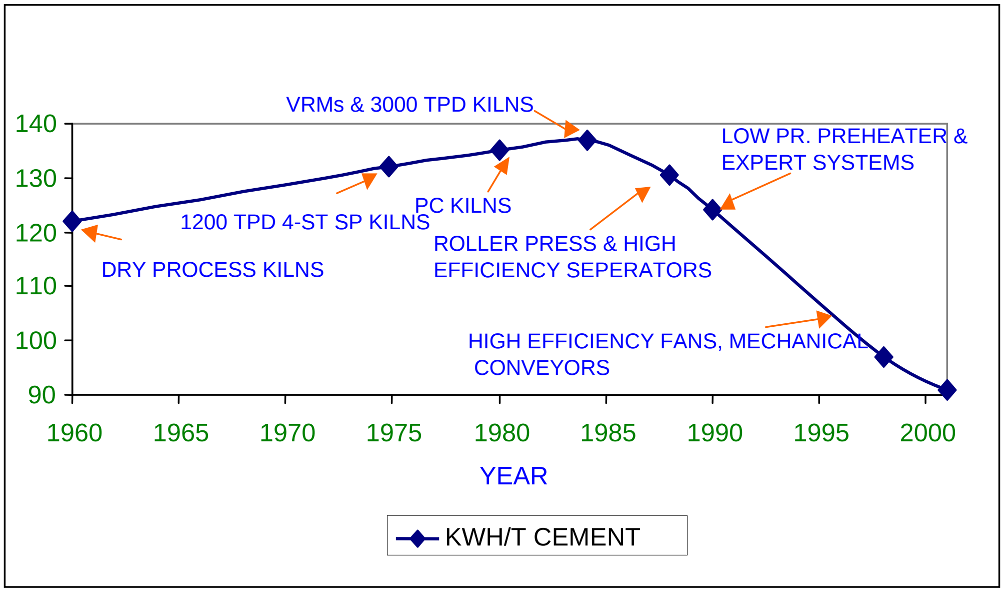
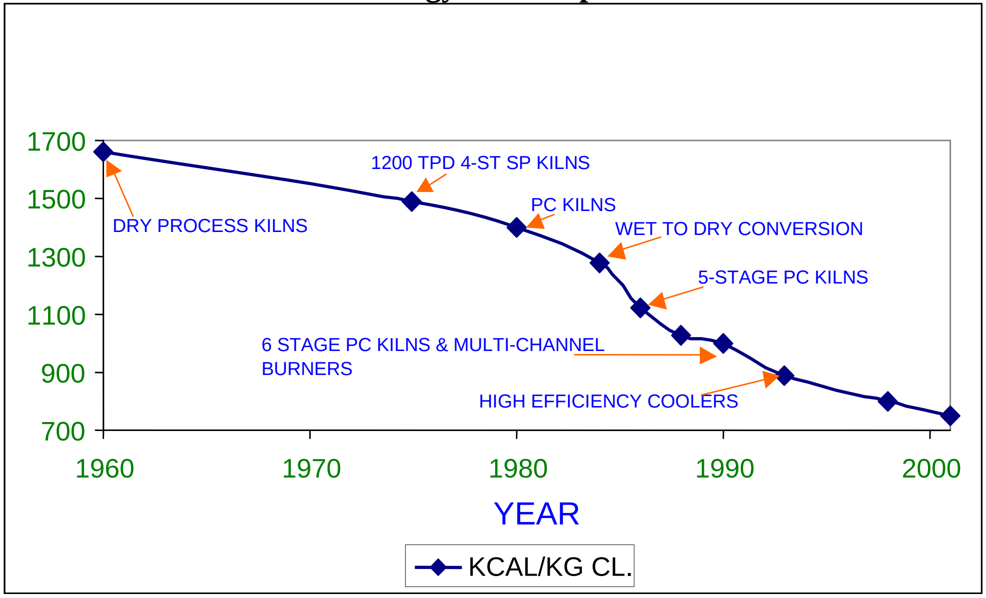


**Figure 2-5. Trend of Thermal Energy Consumption in Indian Cement Industry.**



### 2.3.2 Potential for Energy Efficiency Improvement

While a number of cement plants in India approach world best practice levels in terms of energy efficiency, average Indian cement plants are relatively inefficient (Engineering Staff College of India, 2003). Table 2-3 provides average energy consumption values by process for Indian cement plants.3 In almost all cases, the average energy consumption

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[3] A recent report on 41 energy-efficient cement plants in India found an energy consumption range of 667 to 882 Kcal/kg clinker and 62 to 106 kWh/t cement (NCCBM, 2004).

value is significantly higher than the best practice value, indicating a strong potential for energy efficiency improvement in many plants.

**Table 2-3. Average and Best Practice Energy Consumption Values for Indian Cement Plants by Process.**

| Process | Unit | India Average | World Best Practice |
|---|---|---|---|
| Raw Materials Preparation | | | |
| Coal mill | kWh/t clinker | 8 | 2.4 |
| Crushing | kWh/t clinker | 2 | 1.0 |
| Raw mill | kWh/t clinker | 28 | 27 |
| Clinker Production | | | |
| Kiln & cooler | Kcal/kg of clinker | 770 | 680 |
| Kiln & cooler | kWh/t clinker | 28 | 22 |
| Finish Grinding | | | |
| Cement mill | kWh/t cement | 30 | 25 |
| Miscellaneous | | | |
| Utilities: mining & transportation | kWh/t clinker | 1.6 | 1.5 |
| Utilities: packing house | kWh/t cement | 1.9 | 1.5 |
| Utilities: misc. | kWh/t cement | 2.0 | 1.5 |
| Total Electric | kWh/t cement | 95 | 77 |

Source: Cement Manufacturer’s Association, 2003; Worrell, 2004.

India’s National Council for Cement and Building Materials reports that “some of the cement plants by their pioneering efforts have reduced energy consumption by 25-30% by incorporating/retrofitting energy-efficient equipment/systems during the last 7-8 years giving them competitive advantage over others.” In addition, sponsored energy audits of about 50 cement plants in India have found savings of up to 164 kcal/kg clinker and 16.4 kWh/t cement on average, leading to potential cost savings Rs. 4.40 million to Rs 66.20 million annually (Raina, 2002).

### 2.3.3 Categories of Energy Efficiency Improvement

Numerous technologies and measures exist that can reduce the energy intensity of the various process stages of cement production. Table 2-4 provides a list of a number of these technologies and practices by process stage, the associated typical specific fuel and electricity savings, the primary energy savings, the simple payback period, and the level of penetration of these technologies and measures in Indian cement kilns (Martin et al., 1999; Raina, n.d.; Worrell and Galitsky, 2004). Numerous case studies exist illustrating the energy and cost savings from adopting energy-efficient technologies and measures in Indian cement plants (BEE, 2004a; NCCBM, 2004).

Trends in adoption of energy-efficient equipment in India cement kilns were shown in Figures 2-4 and 2-5. These trends continue today and some types of energy-efficient equipment currently being adopted in India include slip power recovery systems, variable voltage and frequency drives, grid rotor resistance, soft starter for motors, high efficiency fans, high efficiency separators, vertical roller mills, pre-grinder/roller presses, low pressure preheater cyclones, multi-channel burners, bucket elevators in place of pneumatic conveying, fuzzy logic/expert kiln control system, mechanical seals in kilns, improved ball mill internals, and high efficiency grate coolers (BEE, 2003; Raina, 2002).

In addition to adoption of energy-efficient technologies, energy management and process control optimization, which often require little financial investment, can lead to significant energy savings. Various Indian cement plants are exploring the following management and optimization techniques: plugging of leakages in kiln and preheater circuit, raw mill and coal mill circuits; reducing idle running; installation of improved insulating bricks/blocks in kilns and preheaters; effective utilization of hot exit gases; optimization of cooler operation; optimum loading of grinding media/grinding mill optimization; rationalization of compressed air utilization; redesigning of raw mix; installation of capacitor banks for power factor improvement; replacement of over-rated motors with optimally rated motors; optimization of kiln operation; and changing from V-belt to flat belt (BEE, 2003; Raina, 2002).

The use of waste heat from the exit gases of preheaters and grate coolers can be used for on-site cogeneration of electricity. A recent analysis by the National Council for Cement and Building Materials found a potential for generation of 3 to 5.5 MW in 20 surveyed cement plants and concluded that in 45 plants producing 1 million tons per year or more, the total cogeneration potential is about 200 MW (Raina, 2002).

The use of blended cements, in which blast furnace slag, fly ash from thermal power plants, or other agents are inter-ground with cement clinker, is an important option for further reducing the energy required for clinker production. Blended cements are commonly used in Europe and produce the same quality of cement while using less clinker, leading to reductions in energy consumption, costs associated with energy, and emissions of greenhouse gases. It appears that blended cements are being used by the more modern cement facilities in India (Sethi, n.d.) and the share of blended cement was 43% in 2002 (BEE, 2003). While significant increases in blended cement capacity may not be realistic due to distances from sources of blending materials as well as technical limits (CRIS INFAC, 2003), it is a viable option for improving energy efficiency in some plants and promotion of blended cements has been recommended by the Bureau of Energy Efficiency as a proposed energy policy for India (BEE, n.d.). A current Natural Resources Canada project in partnership with the Confederation of Indian Industries is focused on the introduction of the use of high-volume fly ash either as a partial replacement for ordinary portland cement in concrete or by an increased use of blended cements (Government of Canada, 2003).

Indian cement plants are also beginning to explore the use of alternative and waste fuels, such as lignite, pet coke, tires, rice husks, groundnut shells, etc., to replace the use of coal in cement kilns (Jayanraman, n.d.). The Central Pollution Control Board has proposed that the Indian cement industry increase its use of high calorific value hazardous wastes as fuels in cement kilns. The cement industry has requested further information on the instrumentation required to monitor emissions from waste fuel burning as well as details of the location of such wastes (CMA, 2004). CMA is pressing the government to allow the cement industry to use waste-derived fuels and its recent international seminar for the cement industry highlighted alternate and hazardous waste derived fuel (CMA, 2005; Sethi, 2004).

## 2.4 Scenarios of Future Energy Use

### 2.4.1 Future Trends in Cement Production

Historically, cement production in India grew at an average annual rate of 8.1% between 1981 and 2003. Despite some significant single-year jumps, such as the 11.4% growth that was experience between 2001 and 2002, annual growth since 1990 was 7.5% per year and since 2000 was 6.2% per year (India Cements Ltd., n.d.; UNESCAP, 2004).

The Indian Planning Commission's Working Group on Cement Industry predicts cement production in India to grow at a rate of 10% during the tenth five year plan (2002-2007) (Indian Ministry of Commerce & Industry, 2004). The India cement industry itself projects a growth rate of 8% to 10% over the 2003 to 2007 period (India Cements Ltd., n.d.).4

Growth of 8% per year from 2003 to 2020 would result in cement production of 425 million metric tons in 2020; 10% growth would lead to production of 580 million metric tons that year. China, the world's largest producer of cement, has seen sustained cement production average annual growth of 10% since 1980 (van Oss, 2004), mostly due to the enormous infrastructure development that country has experience over this period. Similarly, India has plans to lay 13,000 kilometers of roads for the Golden Quadrilateral and North South East West projects, as well as to use cement for the Rural Road Scheme, rail projects, construction of power plants, coastal ports, rural housing, etc. (India Cements Ltd., n.d.; Sethi, 2004). In addition, it is reported that almost 50 million homes and 24,500 kilometers of new roads are currently needed and over 22,000 kilometers of single-lane highways need to be widened, 2000 kilometers of expressway needs to be constructed and 635 bridges need to be constructed or repaired (Sharma, 2004).

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[4] Note that the Planning Commission states that its projected 10% growth will result in "creation of additional capacity of 40-62 million tonnes" (Indian Ministry of Commerce & Industry, 2004), which would be 159 to 181 million tonnes in 2007, while we calculate that a 10% growth rate will result in production of 225 million tonnes that year.

## Table 2-4. Cement Production Energy Efficiency Technologies and Measures: Energy Savings, Simple Payback Period, and Penetration in Indian Cement Plants.

| Energy Efficiency Technology or Measure | Specific Fuel Savings | Specific Electricity Savings | Primary Energy Savings | Simple Payback Period[5] | Penetration in Indian cement plants |
|---|---|---|---|---|---|
| | GJ/t cement | kWh/t cement | GJ/t cement | years | # of plants |
| Raw Materials Preparation | | | | | |
| Raw meal (slurry) blending and homogenizing systems | - | 1.5 - 3.9 | 0.02 – 0.04 | N/A | |
| Fuel preparation: roller mills | - | 0.7 – 1.1 | 0.008 – 0.012 | N/A | |
| Raw meal process control – vertical mill | - | 0.8 – 1.0 | 0.009 – 0.011 | 1 | <10 |
| Switch from pneumatic to efficient mechanical transport systems | - | 3.2 | 0.04 | > 10 | |
| Replace ball mills with high efficiency vertical roller mill (VRM) (dry) | - | 10.2 – 11.9 | 0.11 – 0.13 | > 10 | >20 |
| High efficiency classifiers/separators (dry) | - | 4.3 – 5.8 | 0.05 – 0.06 | > 10 | >20 |
| Clinker Production | | | | | |
| Indirect firing | 0.13 - 0.19 | - | 0.14 – 0.20 | N/A | |
| Kiln shell heat loss reduction | 0.09 – 0.31 | - | 0.095 – 0.327 | 1 | |
| Efficient mill (kiln) drives | - | 0.8 – 3.2 | 0.009 – 0.035 | 1 | |
| Use of waste-derived secondary fuels | > 0.5 | - | > 0.53 | 1 | |
| Seal replacement | 0.02 | | | < 1 | |
| Optimization of heat recovery/upgrade clinker grate cooler | 0.06 – 0.12 | -1.8 – 0.0 | 0.044 – 0.127 | 1-2 | >20 |
| Conversion to reciprocating grate cooler | 0.23 | -2.4 | 0.22 | 1-2 | |
| Energy management and process control systems | 0.1 – 0.2 | 1.2 – 2.6 | 0.12 – 0.24 | 1-3 | 10-20[6] |
| Kiln combustion system improvement | 0.1 – 0.4 | - | 0.1 – 0.4 | 2-3 | >20 |
| Heat recovery for power generation (cogeneration) | - | 18 | 0.2 | 3 | |
| Installation or upgrade of a preheater to a preheater/precalciner kiln | 0.12 – 0.54 | - | 0.13 – 0.57 | 5 | >20 |
| Low-pressure drop cyclones for suspension preheaters | - | 0.5 – 3.5 | 0.01 – 0.04 | > 10 | > 20 |
| Conversion of long dry kiln to multi-stage preheater | 0.36 – 0.73 | - | 0.38 – 0.77 | > 10 | |
| Conversion of long dry kiln to preheater/precalciner kiln | 0.55 – 1.10 | - | 0.58 – 1.16 | > 10 | |
| Improved refractories[7] | | | | | >20 |

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[5] Simple payback periods are calculated on the basis of energy savings alone. In reality many investments may be driven by other considerations than energy efficiency (e.g. productivity, product quality), and will happen as part of the normal business cycle or expansion project. Under these conditions the measure will have a lower payback period depending on plant-specific conditions.

[6] Expert systems.

[7] Energy savings are difficult to quantify, as they will strongly depend on the current lining choice and management (Worrell and Galitsky, 2004).

## Table 2-4. Cement Production Energy Efficiency Technologies and Measures: Energy Savings, Simple Payback Period, and Penetration in Indian Cement Plants (continued).

| Energy Efficiency Technology or Measure | Specific Fuel Savings | Specific Electricity Savings | Primary Energy Savings | Simple Payback Period8 | Penetration in Indian cement plants |
|---|---|---|---|---|---|
| | GJ/t cement | kWh/t cement | GJ/t cement | years | # of plants |
| Finish Grinding | | | | | |
| Energy management and process control – grinding mills | - | 1.6 | 0.02 | <1 | 10-209 |
| Improved grinding media in ball mills | - | 1.8 | 0.02 | 8 | |
| High pressure roller press | - | 7 – 25 | 0.08 – 0.27 | >10 | 10-20 |
| High-efficiency classifiers | - | 1.7 – 6.0 | 0.02 – 0.07 | >10 | |
| General Plant-Wide Measures | | | | | |
| Preventative maintenance | 0.04 | 0 – 5 | 0.04 – 0.06 | <1 | |
| High efficiency motors and drives | - | 0 – 5 | 0.06 | <1 | |
| Adjustable or variable speed drives | - | 5.5 – 7 | 0.06 – 0.08 | 2-3 | |
| Optimization of compressed air systems | - | 0 – 2 | 0.02 | <3 | |
| Efficient lighting | - | 0 – 0.5 | 0.01 | N/A | |
| Product Changes | | | | | |
| Blended cement | 1.21 | -15 | 1.11 | <1 | |
| Limestone Portland cement | 0.30 | 3.0 | 0.35 | <1 | |
| Low alkali cement | 0.16 – 0.4 | - | 0.17 – 0.42 | <1 | |
| Reduced fineness of cement for selected uses | - | 0 - 14 | 0.15 | <1 | |
| Use of steel slag in clinker (CemStar) | 0.16 | - | 0.17 | <2 | |

Sources: Martin et al., 1999; Raina, n.d.; Worrell and Galitsky, 2004.

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[8] Simple payback periods are calculated on the basis of energy savings alone. In reality many investments may be driven by other considerations than energy efficiency (e.g. productivity, product quality), and will happen as part of the normal business cycle or expansion project. Under these conditions the measure will have a lower payback period depending on plant-specific conditions.

[9] Expert systems.

India's 2003 per capita cement production of 0.1 tonne/capita is significantly below the world average of 0.3 tonne/capita and China's production of 0.58 tonnes/capita (van Oss, 2004; World Bank, 2004). If India's per capita production increases to world average levels by 2020, then – based on the United Nation's medium variant population projection – total cement production would increase to 390 million metric tonnes (United Nations, 2003). If India's per capita production increases to China's current level then total cement production in India in 2020 would rise to 765 million metric tonnes.

### 2.4.2 Future Trends in Energy Consumption for Cement Production

From the above discussion, it appears that cement production in the range of 400 to 600 million metric tonnes in India by 2020 is likely. Assuming average energy intensity values reach today's best practice levels, this leads to energy consumption for production of cement in India of between 1,100 and 1,700 PJ of final energy and 1,500 to 2,100 PJ of primary energy in 2020.

## 2.5 Summary and Future Directions

The Indian cement industry has grown rapidly over the past few decades and there have been significant investments in new cement kilns and associated production equipment. This has led to a situation where India's cement industry in made up of both some of the world's most energy-inefficient plants as well as some of the world's best practice facilities. The challenge for the Indian cement industry is to modernize or phase out the older, inefficient plants while acquiring the best possible cement production technology as production inevitably expands in the coming decades.

The Bureau of Energy Efficiency is currently leading the Indian Industry Programme for Energy Conservation. The activities of this project related to the cement industry include formation of a Cement Task Force, energy audits, identification of best practices, and development of energy consumption norms (BEE, 2004b). A benchmarking tool being developed through the Indo-German Energy Efficiency & Environment Project will provide cement manufacturers with information regarding their relative energy consumption level compared to their peers and to industry average (IGEEP, n.d.). A number of cement plants have set their own targets for energy efficiency improvement (BEE, 2003; Sethi, 2004).

Once a cement plant has participated in a benchmarking exercise, it requires more detailed information about the energy savings and costs of specific energy-efficiency improvement measures that can be adopted in order to set ambitious, yet achievable, targets. Information from the Indian case studies and best practice examples, combined with international information on energy-efficiency technology energy savings and costs, could be provided to Indian cement manufacturers in the form of an energy management guide (similar to those produced by the U.S. Environmental Protection Agency's Energy Star Industry program) or could be integrated into a benchmarking tool in order to provide projected savings for an individual cement plant given the adoption of a chosen set of energy-efficient technologies and practices.

Policy-related recommendations for increasing energy efficiency of the Indian cement industry include 1) institutional reforms in which there is demonstrated commitment to energy conservation by senior cement company management, 2) establishment of a dedicated "energy management cell" within a cement company that includes a full-time energy manager with regular reporting, monitoring, training, and auditing responsibilities, 3) establishment of realistic short term and long term targets for reducing energy consumption, accompanied by a budget for reaching the targets, 4) initiation of employee awareness programs to involve the plant operators and foremen in energy efficiency activities, and 5) increased promotion of blended cements through incentives to manufacturers for producing blended cements, education of cement consumers, awareness campaigns for the general public, developing categorization scheme for blended cements, and promoting the use of blended cement in large construction project through such mechanisms as government procurement (BEE, 2003; Sethi, n.d.).

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## Appendix 2-A. List of Indian Cement Plants

| Dry Process Plants | | | | |
|---|---|---|---|---|
| **Sl. No.** | **Company/Group** | **Location** | **State** | **MnT** |
| **A. Capacity Upto 0.5 MnT** | | | | |
| 1 | CCI, Bokajan | Bokajan | Assam | 0.20 |
| 2 | CCI, Rajban | Rajban | HP | 0.20 |
| 3 | Mangalam Cement | Morak | Raj | 0.40 |
| 4 | CCI, Adilabad* | Adilabad | AP | 0.40 |
| 5 | CCI, Akaltara* | Akaltara | CTG | 0.40 |
| 6 | CCI, Neemuch* | Neemuch | MP | 0.40 |
| 7 | Andhra Cement, Sri Durga Nadikudi | Nadikudi | AP | 0.50 |
| 8 | Kanoria Industries | Bagalkot | Kar | 0.33 |
| 9 | J & K Cement, works | Khrew | J & K | 0.20 |
| 10 | Lafarge Cement Sonadih | Sonadih | CTG | 0.40 |
| 11 | L & T, Narmada Cement Works | Jafrabad | Guj | 0.40 |
| 12 | Priyadarshini Cement, Unit-II | Racherla | AP | 0.40 |
| 13 | Malabar Cements | Palghat | Kerala | 0.42 |
| 14 | Tata Chemicals | Mithapur | Guj | 0.44 |
| 15 | Diamond Cement-II | Damoh | MP | 0.50 |
| 16 | Tancem, Ariyalur Cement Works | Ariyalur | TN | 0.50 |
| 17 | ACC, Lakheri | Lakheri | Raj | 0.60 |
| 18 | Chettinad-Karur | Karur | TN | 0.60 |
| 19 | Neershree Cement | Morak | Raj | 0.70 |
| 20 | Birla Cement Works | Chittorgarh | Raj | 0.72 |
| 21 | Satna Cement Works | Satna | MP | 0.75 |
| 22 | India Cements, Yerraguntla | Yerranguntla | AP | 0.77 |
| 23 | Birla Vikas Cement | Satna | MP | 0.80 |
| 24 | Sikka New | Sikka | Guj | 0.88 |
| 25 | J.K. Udaipur Udyog* | Udaipur | Raj | 0.90 |
| 26 | IDCOL Cement, ACC | Bargarh | Orissa | 0.96 |
| 27 | ACC, Gagal | Gagal | HP | 0.98 |
| 28 | ACC, Chanda | Chanda | Mah | 1.00 |
| 29 | Maihar Cement-I | Maihar | MP | 1.00 |
| 30 | Maihar Cement-II | Maihar | MP | 1.00 |
| 31 | CCI, Tandur | Tandur | AP | 1.00 |
| 32 | Ambuja Cement Eastern | Bhatapara | CTG | 1.00 |
| 33 | Panyam Cement* | Bugganipalle | AP | 0.53 |
| 34 | Diamond Cement-I | Damoh | MP | 0.53 |
| 35 | Mysore Cement | Ammasandra | Kar | 0.57 |
| 36 | KCP | Macherla | AP | 0.58 |
| 37 | J.K. Cement Works | Mangrol | Raj | 0.75 |
| 38 | UPSCCL, Dalla* | Dalla | UP | 0.86 |
| 39 | ACC, Jamul | Jamul | CTG | 0.90 |
| 40 | OCL India | Rajgangpur | Orissa | 1.00 |
| 41 | Chankaya Cements | Ganeshpahd | AP | 1.00 |
| 42 | Priyadarshini Cement, Unit-I | Ramapuram | AP | 1.00 |
| 43 | Kalyanpur Cements | Banjari | Bihar | 1.00 |
| 44 | Kesoram Cement | Basantnagar | AP | 0.9 |

| | | | | |
|---|---|---|---|---|
| 45 | Grasim South | Reddipalayam | TN | 1.03 |
| 46 | Visaka Cement | Tandur | AP | 1.15 |
| 47 | Ambuja Cement, Himachal Unit | Darlaghat | HP | 1.16 |
| 48 | Century Cement | Tilda | CTG | 1.20 |
| 49 | Chettinad-Karikkali | Karikkali | TN | 1.20 |
| 50 | Chittor Cement Works | Chittorgarh | Raj | 1.28 |
| 51 | India Cements, Dalavoi Works | Trichy | TN | 1.30 |
| 52 | India Cements, Chilamkur Works | Chilamkur | AP | 1.34 |
| 53 | India Cements, Sankarnagar | Tirunelveli | TN | 1.45 |
| 54 | Manikgarh Cement | Manikgarh | Mah | 1.50 |
| 55 | Ambuja Cement | Kodinar | Guj | 1.50 |
| 56 | Ambuja Cement Rajasthan | Pali | Raj | 1.50 |
| 57 | ACC, Kymore | Kymore | MP | 1.70 |
| 58 | ACC, Gagal | Gagal | HP | 1.72 |
| 59 | Aditya Cement | Shambhupura | Raj | 1.75 |
| 60 | Grasim Cement | Raipur | CTG | 1.90 |
| 61 | Ambuja Cement, Maratha | Chandrapur | Mah | 2.00 |
| 62 | ACC, Wadi | Wadi | Kar | 2.11 |
| 63 | Rajashree Cement | Malkhed | Kar | 2.30 |
| 64 | India Cements, Rassi | Wadapally | AP | 2.30 |
| 65 | ACC, Wadi (New) | Wadi | Kar | 2.60 |
| 66 | Vasavdatta Cement | Sedam | Kar | 1.20 |
| 67 | Madras Cement, R R Nagar | R R Nagar | TN | 1.10 |
| 68 | L & T, Arakonam Cement Works | Arakonam | TN | 1.20 |
| 69 | Gujarat Sidhee Cement | Veraval | Guj | 1.20 |
| 70 | Penna Cement | Tadipatri | AP | 1.20 |
| 71 | Sri Vishnu Cement | Sitapuram | AP | 1.20 |
| 72 | Saurashtra Cement | Ranavav | Guj | 1.30 |
| 73 | Orient Cement, Devapur | Devapur | AP | 1.30 |
| 74 | My Home Cement | Kodak | AP | 1.40 |
| 75 | Lafarge Cement, Arasmeta | Bilaspur | CTG | 1.60 |
| 76 | Madras Cement, Jayantipuram | Jagayyapeta | AP | 1.60 |
| 77 | Jaypee Bela Cement | Bela | MP | 1.70 |
| 78 | L & T, A P Cement Works | Tadipatri | AP | 1.90 |
| 79 | L & T, Himri Cement Works | Hirmi | CTG | 1.90 |
| 80 | Zuari Cement | Yerraguntla | AP | 2.20 |
| 81 | Lakshmi Cement | Sirohi Road | Raj | 2.40 |
| 82 | Gajambuja Cement | Kodinar | Guj | 2.50 |
| 83 | J. K. Cement Works | Nimbahera | Raj | 2.50 |
| 84 | Jaypee Rewa Cement | Rewa | MP | 2.50 |
| 85 | Prism Cement | Satna | MP | 2.51 |
| 86 | Sanghi Industries | Kutch | Guj | 2.60 |
| 87 | Shree Cement, Unit 1 & 2 | Beawar | Raj | 2.60 |
| 88 | Vikram Cement | Khor | MP | 3.00 |
| 89 | L & T, Awarpur Cement Works | Chandrapur | Mah | 3.00 |
| 90 | Madras Cement, Alathiyur I, II | Alathiyur | TN | 3.12 |
| 91 | L & T, Gujarat Cement Works | Pipawa | Guj | 5.20 |
| 92 | Dalmia Cement | Trichy | TN | 1.23 |

**Wet Process Plants**

| Sl. No. | Company/Group | Location | State | Mnt |
|---|---|---|---|---|
| 1 | ACC, Chaibasa | Chaibasa | Jhk | 0.61 |
| 2 | CCI, Kurkunta* | Kurkunta | Kar | 0.20 |
| 3 | CCI, Mandhar* | Mandhar | CTG | 0.38 |
| 4 | Shri Digvijay Cement* | Sikka | Guj | 0.20 |
| 5 | HMP, Porbander* | Porbander | Guj | 0.20 |
| 6 | HMP, Shahabad* | Shahabad | Kar | 0.47 |
| 7 | India Cement Ltd., Sankari-West | Sankaridurg | TN | 0.70 |
| 8 | Kistna Cements* | Guntur | AP | 0.22 |
| 9 | Lemos Cements* | Khalari | JHK | 0.11 |
| 10 | Mawmluh Cherra | Cherapunju | Megh | 0.20 |
| 11 | Shriram Cement Works | Kota | Raj | 0.20 |
| 12 | Sone Valley Cements* | Jalpa | JHK | 0.25 |
| 13 | Tancem, Alangulam Cement Works | Alangulam | TN | 0.40 |
| 14 | UPSCCL, Churk Cement Factory | Churk | UP | 0.48 |
| 15 | UPSCCL, Dalla* | Dalla | UP | 0.43 |

**Semi-Dry Process Plants**

| Sl. No. | Company/Group | Location | State | Mnt |
|---|---|---|---|---|
| 1 | ACC, Madukkarai | Madukkari | TN | 0.96 |
| 2 | ACC, Mancherial | Mancherial | AP | 0.33 |
| 3 | CCI, Charkhi-Dadri* | Charkhi-Dadri | Har | 0.17 |
| 4 | ACC, Jamul | Jamul | CTG | 0.60 |

**Grinding Units**

| Sl. No. | Company/Group | Location | State | Mnt |
|---|---|---|---|---|
| 1 | Andhra Cement, Sri Kanaka Durga* | Vijaywada | AP | 0.24 |
| 2 | Andhra Cement, Sri Visakha Cement | Vizag | AP | 0.50 |
| 3 | ACC, Sindri Cement | Sindri | JHK | 0.60 |
| 4 | Acc, Tikaria | Tikaria | UP | 0.75 |
| 5 | ACC, Damodar Cement | Purulia | WB | 0.53 |
| 6 | Birla Cement | Raebareli | UP | 0.63 |
| 7 | Durgapur Cement | Durgapur | WB | 0.60 |
| 8 | CCI, Delhi* | Tughlakabad | Delhi | 0.50 |
| 9 | Birla Super Cement | Hotgi | Mah | 1.35 |
| 10 | Vikram Cement | Bhatinda | Pub | 1.00 |
| 11 | Gujarat Ambuja, Bhatinda Unit | Bhatinda | Pub | 0.50 |
| 12 | Gujarat Ambuja, Ropar Unit | Ropar | Pub | 1.34 |
| 13 | Ambuja Cement Eastern | Sankrail | WB | 1.00 |
| 14 | Indo Rama Cement | Raigad | Mah | 1.00 |
| 15 | Jaypee | Sadva Khurd | UP | 0.60 |
| 16 | Lafarge India, Jojobera Cement | Singhbhum | JHK | 3.00 |
| 17 | L & T, Jharsuguda Cement | Jharsuguda | Orissa | 0.80 |
| 18 | L & T, West Bengal Cement | Durgapur | WB | 1.00 |
| 19 | L & T, Magdalla | Magdalla | Guj | 0.70 |
| 20 | L & T, Ratnagiri | Ratnagiri | Mah | 0.40 |
| 21 | Madras Cement, Mathod | Mathad | Kar | 0.29 |
| 22 | Diamond Cement | Jhansi | UP | 0.50 |
| 23 | Orient Cement, Jalgaon Cement | Jalgaon | Mah | 0.70 |
| 24 | UPSCC, Chunar Cement Factory* | Chunar | UP | 1.68 |

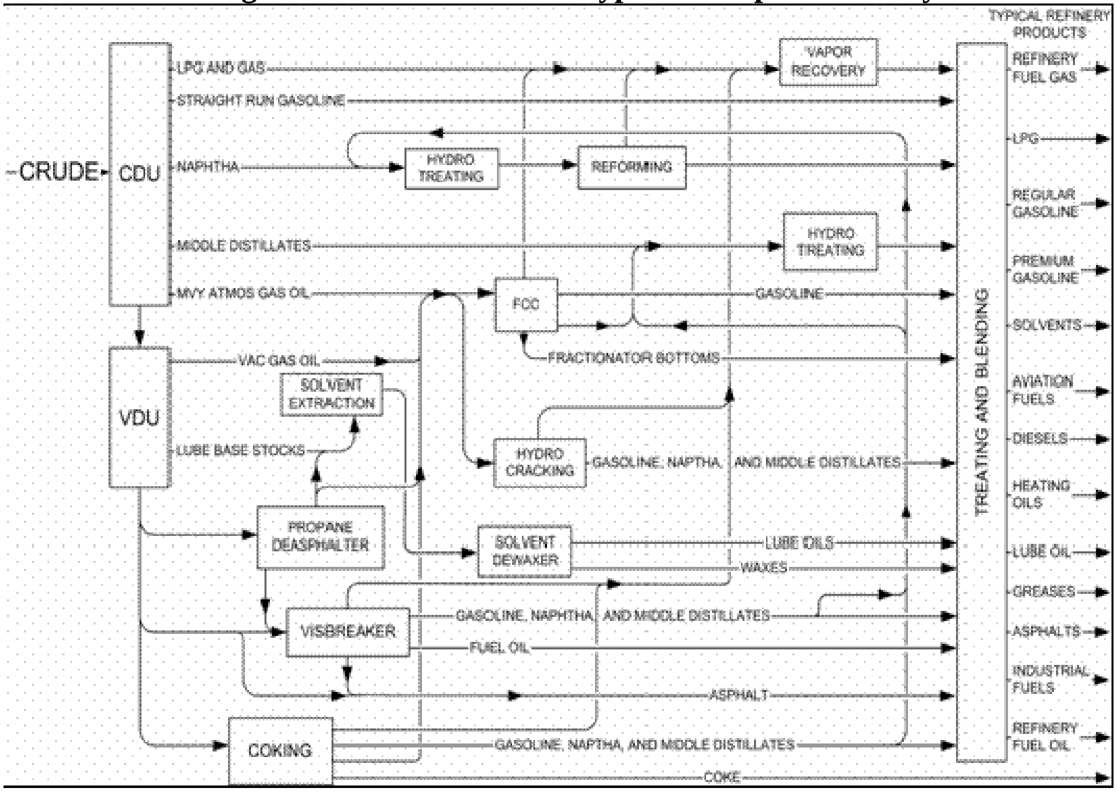
Source: BEE, 2004c.

# 3. Refining Industry

## 3.1 Refinery Production Processes[10]

Refineries typically consist of a number of parallel and serial processes used to transform crude oil into a range of final products such as gasoline, diesel, and asphalt. Modern refineries range from the simple to the very complex, though the trend is towards increased complexity as the requirements for higher-quality final products increase. In all refiner89ies, including smaller simple refineries, crude oil is first distilled into its basic components; these component streams are sent for further conversion in the more complex refineries. The most important distillation processes are the crude or atmospheric distillation, and vacuum distillation. Secondary conversion processes generally use thermal or catalytic processes to further convert the oil streams from distillation. Among the most important are the catalytic reformer, where the heavy naphtha, produced in the crude distillation unit, is converted to gasoline; the fluid catalytic cracker (FCC) where the gas oil from the vacuum distillation unit is converted; and the hydrocrackers, which is used to “crack” the molecules of heavy oil streams into lighter products such as gas oil.

**Figure 3-1. Flowchart of a Typical Complex Refinery.**



Source: Worrell and Galitsky, forthcoming.

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[10] This section is drawn largely from Worrell and Galitsky, forthcoming.

Refineries generally include process units such as hydrotreaters or hydrodesulfurizers to treat products to improve their quality. 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).

A summary of the main process units appears in Table 3-1.

**Table 3-1. Summary of Major Refining Units**

| Unit | Main Use |
|---|---|
| Crude Distillation | Fractional distillation of crude oil into light, middle, and heavy streams. |
| Vacuum Distillation | Separation of the heaviest streams from crude distillation into middle and heavy fractions |
| Hydrotreater | Desulfurization of naphtha for reforming; desulfurization of middle distillates |
| Catalytic reformer | Production of high-octane reformate for gasoline blending from naphtha |
| Fluid catalytic cracker | Conversion of vacuum unit gas oil to gases, gasoline, and diesel blendstocks. |
| Hydrocracker | Conversion of vacuum unit gas oil to gasoline and diesel, improvement in diesel quality |
| Coker | Conversion of heavy feedstocks to diesel blendstocks, light products, and coke |
| Visbreaker | Reduction of heavy feedstock viscosity for fuel oil production |
| Alkylation/Polymerization | Combination of gas molecules to produce high-octane gasoline blending materials |
| Hydrogen Unit | Production of hydrogen from natural gas, naphtha or other feedstocks for process unit use |
| Gas Processing/Fractionation | Separation of gas streams by weight and removal of sulfur and impurities |

Energy is used in refineries in the form of fuel, steam, and electricity mainly for heating, process energy, pumping, and lighting. The major energy consuming processes are crude distillation, hydrotreating, reforming, vacuum distillation, and catalytic cracking. Actual energy use will vary based upon the loading of units, the quality of the feedstock, the severity of the operation, and other operational factors. Some refineries produce their own electricity in cogeneration power plants fueled by refinery byproducts such as dry gas, though additional amounts of electricity beyond self-generation are purchased from the grid. Except for refineries with access to natural gas externally, the balance of fuel needs in a refinery is met internally from process streams and byproducts. Thus, energy efficiency provides a double-benefit to refiners: not only does lower energy consumption lower processing costs, it also makes available additional amounts of fuel products for processing and sale.

## 3.2 Refinery Production in India

### 3.2.1 Refining Industry Characteristics

Refining capacity, as measured by primary distillation capacity, has expanded rapidly in recent years. At the end of the 1998/99 fiscal year, refining capacity stood at 67.5 million tonnes (mmt), compared to 119 mmt at the beginning of the 2003/04 fiscal year, a rise of over 75% in five years. Many existing refineries were expanded over this period, but more than half the increase was accounted for by the commissioning of the 27 mmt Reliance grassroots refinery at Jamnagar in 1999 (see Table 3-2). India now has 19 refineries, owned among five major corporate groups, the largest of which is Indian Oil Corporation. Since 2001, a number of smaller refining companies have been consolidated into the Indian Oil Group and Bharat Petroleum Corporation. In 2003, the Oil and Natural Gas Corporation, India's major upstream oil and gas producer, entered the downstream market though the acquisition of the majority shares of the 9.7 mmt Mangalore refinery.

India's refineries are relatively simple (see Table 3-3). Comparing the ratio of primary upgrading capacity to crude distillation ("cracking to distillation ratio"), most large Indian refineries have a cracking-to-distillation ratio of less than 40%; only the new large Reliance refinery meets the average of the U.S. refining industry (56%) (Worrell and Galitsky, 2004).

## Table 3-2. Primary Distillation Capacity by Refinery (million tonnes/year)

| Company | Refinery | State | Yr Est. | 1999-00 | 2000-01 | 2001-02 | 2002-03 | 2003-04 |
|---|---|---|---|---|---|---|---|---|
| Indian Oil Corporation, Ltd. | | | | | | | | |
| | Barauni | Bihar | 1964 | 3.3 | 3.3 | 4.2 | 4.2 | 6.0 |
| | Digboi | Assam | 1901 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| | Gujarat | Gujarat | 1965 | 9.5 | 12.5 | 13.7 | 13.7 | 13.7 |
| | Guwahati | Assam | 1962 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| | Haldia | West Bengal | 1975 | 4.6 | 4.6 | 4.6 | 4.6 | 4.6 |
| | Mathura | Uttar Pradesh | 1982 | 7.5 | 7.5 | 8.0 | 8.0 | 8.0 |
| | Panipat | Haryana | 1998 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| Hindustan Petroleum Corporation, Ltd. | | | | | | | | |
| | Mumbai | Maharashtra | 1954 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 |
| | Visakh | Andhra Pradesh | 1957 | 4.5 | 7.5 | 7.5 | 7.5 | 7.5 |
| Chennai Petroleum Corporation, Ltd. (subsidiary of IOCL from 2001) | | | | | | | | |
| | Manali | Chennai | 1969 | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 |
| | Cauvery Basin | Tamil Nadu | 1993 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 |
| Bharat Petroleum Corporation, Ltd. | | | | | | | | |
| | Mumbai | Maharashtra | 1955 | 6.9 | 6.9 | 6.9 | 6.9 | 9.0 |
| Bongaigaon Refining & Petrochemicals Ltd. (IOCL Group Company) | | | | | | | | |
| | Bongaigaon | Assam | 1974 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| Kochi Refineries Ltd. (subsidiary of BPCL from 2001) | | | | | | | | |
| | Ambalamugal | Kerala | 1963 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 |
| Numaligarh Refinery Ltd. (subsidiary of BPCL from 2001) | | | | | | | | |
| | Numaligarh | Assam | 1999 | - | 3.0 | 3.0 | 3.0 | 3.0 |
| Mangalore Refinery & Petrochemicals, Ltd. (subsidiary of ONGC from 2003) | | | | | | | | |
| | Mangalore | Karnataka | 1996 | 3.7 | 9.7 | 9.7 | 9.7 | 9.7 |
| Reliance Industries, Ltd. | | | | | | | | |
| | Jamnagar | Gujarat | 1999 | 22.5 | 27.0 | 27.0 | 27.0 | 27.0 |
| ONGC | | | | | | | | |
| | Tatipaka | Andhra Pradesh | 2001 | - | - | 0.1 | 0.1 | 0.1 |
| National Total | | | | 92.4 | 111.9 | 114.6 | 114.6 | 119.0 |

Source: India Ministry of Petroleum & Natural Gas, 2004; company websites.
Note: Figures shown are licensed design capacities based on design crude types.

**Table 3-3. Secondary Processing Units in Indian Refineries**

| | Crude Distillation | Catalytic Cracking | Delayed Coking | Hydro-cracking | Catalytic Reforming | Secondary/Primary |
|---|---|---|---|---|---|---|
| RPL, Jamnagar | 27.0 | 9.0 | 6.8 | | ▨ | 59% |
| IOCL, Baurauni | 6.0 | 1.3 | 1.1 | | ▨ | 40% |
| IOCL, Panipat | 6.0 | 0.7 | | 1.7 | ▨ | 40% |
| IOCL, Mathura | 8.0 | 1.2 | | 1.2 | ▨ | 30% |
| MRPL, Mangalore | 9.7 | | | 2.2 | ▨ | 23% |
| IOCL, Gujarat | 12.0 | 1.5 | | 1.2 | ▨ | 23% |
| BPCL, Mumbai | 6.9 | 1.0 | | | ▨ | 14% |
| HPCL, Visakh | 7.5 | 1.0 | | | | 13% |
| KRL, Ambalamugal | 7.5 | 1.0 | | | ▨ | 13% |
| CPCL, Manali | 6.5 | 0.6 | | | ▨ | 9% |
| HPCL, Mumbai | 5.5 | 0.4 | | | | 7% |
| IOCL, Digboi | 0.7 | | ▨ | | ▨ | |
| IOCL, Guwahati | 1.0 | ▨ | ▨ | | | |
| IOCL, Haldia | 4.6 | ▨ | | | ▨ | |
| CPCL, Cauvery Basin | 1.0 | | | | | |
| BPPL, Bongaigaon | 2.4 | | ▨ | | ▨ | |
| NRL, Numaligarh | 3.0 | | ▨ | ▨ | | |
| ONGC, Tatipakam | 0.1 | | | | | |

Note: Shaded cells indicate the presence of the unit or process; capacities are given only for the largest refineries. The Secondary/Primary calculation excludes reforming capacity.
Source: GOI, 2002; IOC

Despite the relative lack of cracking and upgrading units, Indian refiners produce a fairly light slate of products. For less sophisticated refineries, producing such a slate of products would require processing of more expensive light crudes. In contrast, the Reliance refinery, which accounts for nearly a quarter of Indian refining capacity, has a high level of cracking and upgrading capacity, allowing it considerable flexibility to optimize its slate of imported crudes and to process heavier, less expensive crudes. In 2002/03, light distillate production accounted for 22% of output (on a throughput basis), while middle distillates totaled nearly 50%. Heavy products (fuel oil, coke, bitumen, etc.) constituted the remaining 21% of products. Aggregate refinery fuel use and losses have increased over the years as refinery throughput has expanded and new upgrading units have been brought on line (see Table 3-4). Expansion of secondary cracking capacity at the less complex refineries would be necessary, however, to expand the ability of Indian refineries to process less expensive heavy, higher-sulfur grades of crude oil, to meet the pattern of Indian domestic demand.

Most Indian refineries are located in or near coastal areas in order to facilitate the receipt of imported and offshore crude oil (see Figure 3-2 **Error! Reference source not found.**). A number of long-distance product pipelines distribute products to other regions.

Because of the stagnation of Indian domestic crude oil production—at about 33 mmt since 1990--the expansion of the refining system since then has increased reliance on crude oil imports, much of which come from the Middle East. In 2002-03, 73% of the crude processed in Indian refineries was imported, up from 40% in 1990 (see Table 3-5).

**Table 3-4. Refinery Throughput and Output (million tonnes per year)**

| | **1995-96** | **1996-97** | **1997-98** | **1998-99** | **1999-00** | **2000-01** | **2001-02** | **2002-03** |
|---|---|---|---|---|---|---|---|---|
| Throughput | 58.74 | 62.87 | 65.17 | 68.54 | 85.96 | 103.44 | 107.27 | 112.56 |
| Output: | | | | | | | | |
| LPG | 1.54 | 1.60 | 1.67 | 1.72 | .49 | 4.09 | 4.78 | 4.90 |
| Motor Gasoline | 4.46 | 4.70 | 4.85 | 5.57 | 6.23 | 8.07 | 9.70 | 10.36 |
| Naphtha | 5.98 | 6.12 | 6.10 | 6.08 | 8.17 | 9.91 | 9.18 | 9.65 |
| Kerosene | 5.27 | 6.24 | 6.70 | 5.34 | 5.74 | 8.71 | 9.68 | 10.03 |
| Jet Kerosene | 2.13 | 2.12 | 2.15 | 2.29 | 2.29 | 2.51 | 2.60 | 3.05 |
| High-speed Diesel | 20.66 | 22.20 | 23.35 | 26.72 | 34.79 | 39.02 | 39.77 | 40.11 |
| Light Diesel | 1.35 | 1.29 | 1.25 | 1.34 | 1.62 | 1.48 | 1.70 | 2.08 |
| Fuel Oil | 9.58 | 10.30 | 11.08 | 11.03 | 11.35 | 11.39 | 12.23 | 12.17 |
| Lubricants | 0.63 | 0.62 | 0.59 | 0.59 | 0.73 | 0.68 | 0.65 | 0.68 |
| Petroleum Coke | 0.26 | 0.25 | 0.28 | 0.29 | 0.47 | 2.47 | 2.78 | 2.66 |
| Bitumen | 2.03 | 2.28 | 2.16 | 2.42 | 2.49 | 2.72 | 2.56 | 2.94 |
| Paraffin Wax | 0.04 | 0.03 | 0.03 | 0.04 | 0.05 | 0.05 | 0.05 | 0.04 |
| Other Waxes | 0.06 | 0.06 | 0.05 | 0.06 | 0.07 | 0.06 | 0.04 | 0.00 |
| Others | 1.09 | 1.20 | 1.06 | 1.06 | 2.93 | 4.44 | 4.29 | 5.46 |
| Total | 55.08 | 59.01 | 61.31 | 64.54 | 79.41 | 95.61 | 100.00 | 104.14 |
| | | | | | | | | |
| Refinery Fuel & Loss | 3.66 | 3.86 | 3.86 | 3.99 | 6.55 | 7.83 | 7.27 | 8.42 |
| % Throughput | 6.2% | 6.1% | 5.9% | 5.8% | 7.6% | 7.6% | 6.8% | 7.5% |

Source: India Ministry of Petroleum & Natural Gas, 2004.

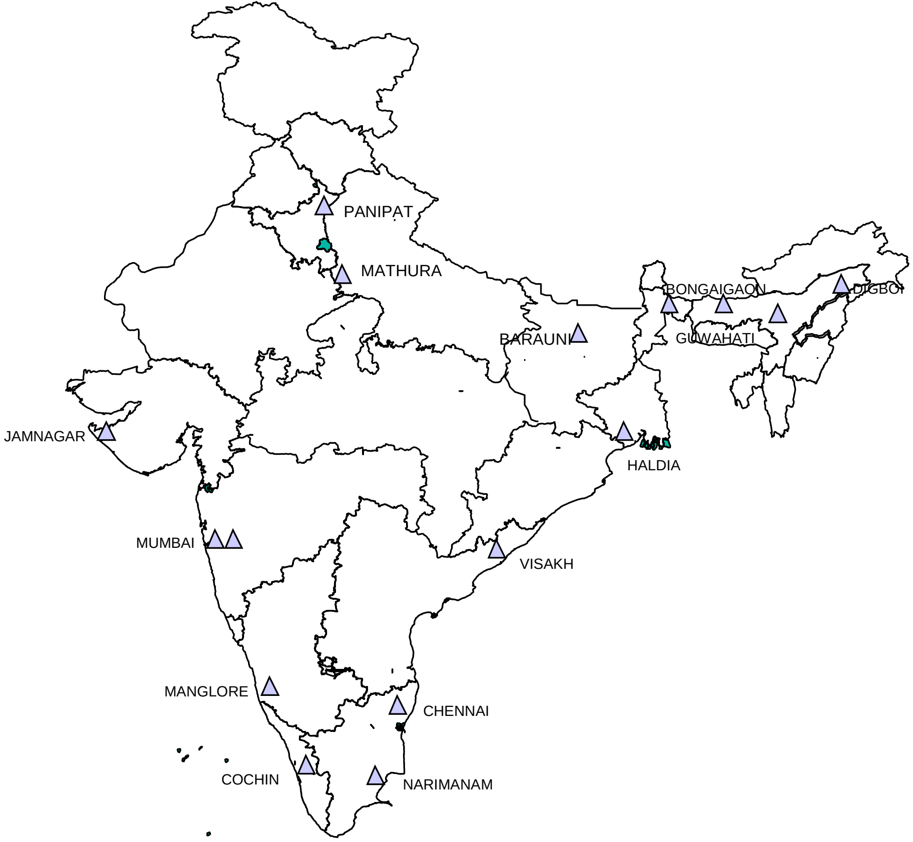
**Table 3-5. India Crude Production and Oil Trade (million tonnes)**

| | **Crude Production** | **Net Crude Imports** | **Crude Import Dependency*** | **Net Product Imports** |
|---|---|---|---|---|
| 1990-91 | 33.02 | 20.70 | 40% | 6.01 |
| 1991-92 | 30.35 | 23.99 | 47% | 6.51 |
| 1992-93 | 26.95 | 29.25 | 55% | 7.56 |
| 1993-94 | 27.03 | 30.82 | 57% | 8.04 |
| 1994-95 | 32.24 | 27.35 | 48% | 10.70 |
| 1995-96 | 35.17 | 27.34 | 47% | 16.90 |
| 1996-97 | 32.90 | 33.91 | 54% | 17.10 |
| 1997-98 | 33.86 | 34.49 | 53% | 20.59 |
| 1998-99 | 32.72 | 39.81 | 58% | 23.05 |
| 1999-00 | 31.95 | 57.81 | 67% | 15.86 |
| 2000-01 | 32.43 | 74.10 | 72% | 0.90 |
| 2001-02 | 32.03 | 78.71 | 73% | (3.50) |
| 2002-03 | 33.04 | 81.99 | 73% | (3.55) |

*as a percentage of refinery throughput

Source: India Ministry of Petroleum & Natural Gas, 2004.

**Figure 3-2. India Refinery Distribution**



Source: Malhotra, 2002

The increase in refining capacity has made India virtually self-sufficient in the supply of refined products; indeed, India became a net product exporter (motor gasoline and diesel) in 2001 and is expected to maintain this status in the near term.

Petroleum product demand is heavy concentrated on middle distillates (see Table 3-6. India Oil Consumption) In 2002/03, middle distillates (kerosene and diesel) accounted for 49% of consumption, down from 59% in 1990/91. In contrast, motor gasoline, a major transport fuel in many countries, accounted for only 7% of consumption in 2002/03. In contrast, gasoline accounted for 35% of oil consumption in Australia, 16% in China and Japan, and 15% in Thailand in 1999 (GOI, 2002)

Consumption of LPG and naphtha has recorded the fastest growth since 1990. LPG is a major home cooking fuel, and remains subsidized by the government. Naphtha is a major petrochemical and fertilizer sector feedstock, and consumption jumped in the late 1990s with the completion of several large petrochemical plants. In the 12 years to 2002/03, oil demand grew at an average 5.4% per year, but this fell to 3% after 2000/01 owing to the slowdown of the economy, improved transportation infrastructure and the introduction of more efficiency vehicles (GOI, 2002).

**Table 3-6. India Oil Consumption**

| Sales Million tonnes | 1990-91 | 1995-96 | 1998-99 | 1999-00 | 2000-01 | 2001-02 | 2002-03 | AAI 90-02 |
|---|---|---|---|---|---|---|---|---|
| LPG | 2.42 | 3.92 | 5.35 | 6.42 | 7.02 | 7.73 | 8.34 | 10.9% |
| Motor Gasoline | 3.55 | 4.68 | 5.51 | 5.91 | 6.61 | 7.01 | 7.57 | 6.5% |
| Naphtha/NGL | 3.45 | 4.15 | 9.22 | 10.89 | 11.68 | 11.76 | 11.47 | 10.5% |
| Kerosene | 8.42 | 9.93 | 12.24 | 11.90 | 11.31 | 10.43 | 10.39 | 1.8% |
| Jet Kerosene | 1.68 | 2.08 | 2.11 | 2.20 | 2.25 | 2.26 | 2.27 | 2.6% |
| High-speed Diesel | 21.14 | 32.26 | 37.22 | 39.30 | 37.96 | 36.55 | 36.56 | 4.7% |
| Light Diesel | 1.51 | 1.31 | 1.28 | 1.51 | 1.40 | 1.59 | 2.06 | 2.7% |
| Fuel Oil | 8.99 | 11.16 | 12.51 | 12.45 | 12.65 | 12.98 | 12.64 | 2.9% |
| Lubricants | 0.89 | 0.96 | 1.10 | 1.24 | 1.04 | 1.14 | 1.25 | 2.9% |
| Petroleum Coke | 0.29 | 0.32 | 0.39 | 0.33 | 0.45 | 1.80 | 0.34 | 1.2% |
| Bitumen | 1.58 | 2.01 | 2.41 | 2.88 | 2.71 | 2.58 | 2.99 | 5.4% |
| Paraffin Wax | 0.07 | 0.08 | 0.04 | 0.05 | 0.04 | 0.05 | 0.04 | -4.4% |
| Other Waxes | 0.05 | 0.06 | 0.08 | 0.09 | 0.06 | 0.05 | 0.01 | -10.2% |
| Others | 1.02 | 1.92 | 1.11 | 1.92 | 4.89 | 4.52 | 7.50 | 18.1% |
| Total | 55.04 | 74.83 | 90.56 | 97.09 | 100.07 | 100.43 | 103.42 | 5.4% |

| **Consumption Pattern** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1990-91** | **1995-96** | **1998-99** | **1999-00** | **2000-01** | **2001-02** | **2002-03** |
| LPG | 4% | 5% | 6% | 7% | 7% | 8% | 8% |
| Motor Gasoline | 6% | 6% | 6% | 6% | 7% | 7% | 7% |
| Naphtha | 6% | 6% | 10% | 11% | 12% | 12% | 11% |
| Kerosene | 15% | 13% | 14% | 12% | 11% | 10% | 10% |
| Jet Kerosene | 3% | 3% | 2% | 2% | 2% | 2% | 2% |
| High-speed Diesel | 38% | 43% | 41% | 40% | 38% | 36% | 35% |
| Light Diesel | 3% | 2% | 1% | 2% | 1% | 2% | 2% |
| Fuel Oil | 16% | 15% | 14% | 13% | 13% | 13% | 12% |
| Lubricants | 2% | 1% | 1% | 1% | 1% | 1% | 1% |
| Petroleum Coke | 1% | 0% | 0% | 0% | 0% | 2% | 0% |
| Bitumen | 3% | 3% | 3% | 3% | 3% | 3% | 3% |
| Paraffin Wax | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Other Waxes | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Others | 2% | 3% | 1% | 2% | 5% | 4% | 7% |
| Total | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

Source: India Ministry of Petroleum & Natural Gas, 2004.

### 3.2.2 Refining Industry Energy Consumption

Total energy consumption in Indian refineries in 2002/03 was about 337 PJ, or about 3 PJ per million tonnes of crude oil throughput[11] (see Figure 3-3). In the ten years since

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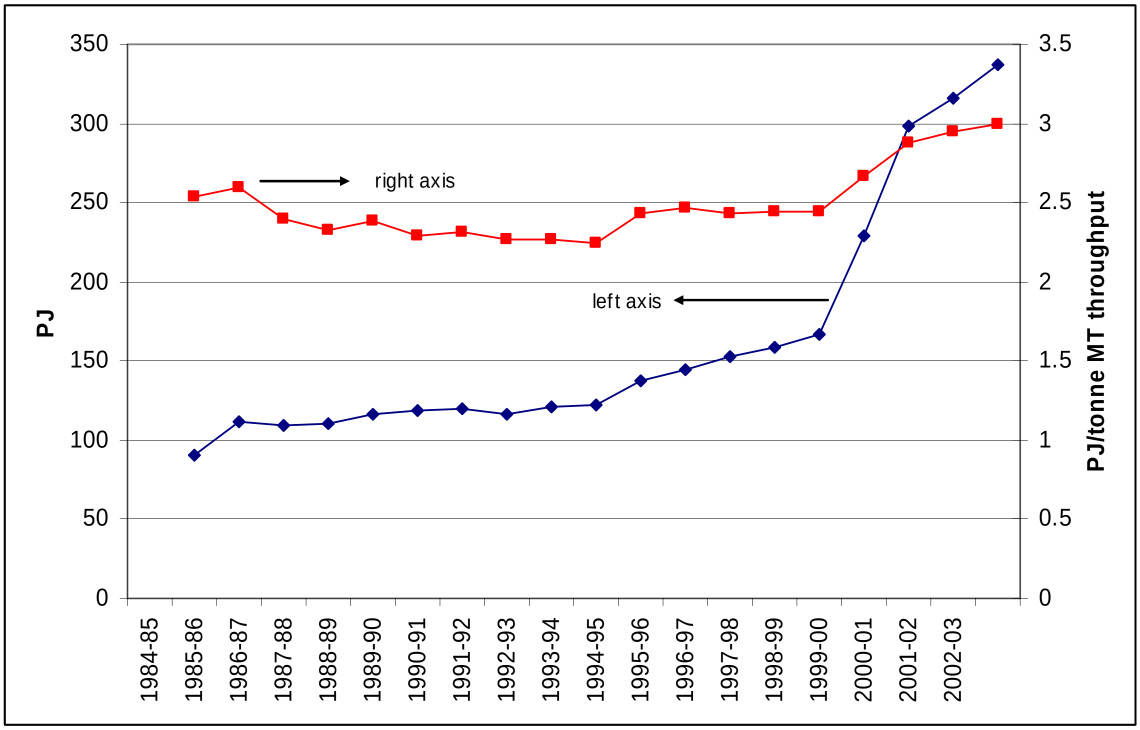
[11] These figures exclude externally purchased electricity. In 2000/01, external purchases of electricity for the entire Mineral Oil and Petroleum sector (including upstream and

1992/03, refinery throughput rose 110%, while energy consumption rose nearly 180%, leading to a 32% increase in energy consumption per unit of crude processed. This increase in unit consumption was due in part to the installation of more energy intensive processing units such as diesel hydrodesulfurizers after 1997 to improve the quality of Indian transport fuels. After 1997, primary distillation capacity began to grow rapidly as well, and the commissioning and "shake-down" of these new units, along with the construction of new ancillary equipment such as hydrogen production units in support of the hydrodesulfurizers contributed to the increase in unit fuel consumption as well.

**Figure 3-3. Energy Consumption in Indian Refineries**



Source: India Ministry of Petroleum & Natural Gas, 2004.

Energy consumption per unit of input, however, is a misleading indicator of the energy performance of refineries as it does not account for differences in complexities, output slates, or type of crude processed. A simple topping unit, for example, will always have a lower specific energy consumption than a complex refineries—sometimes one-fourth as much—but may not be able to produce blended gasoline or to remove sulfur from 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 (sponsored by the Ministry of Petroleum & Natural Gas) to provide a comparable basis to compare energy performance of refineries of different configurations by accounting for the throughput of secondary units. Although the MBN is

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downstream) was about 6% of total power usage. Separate figures for refining alone are not available at this time (CEA, 2001).

currently being revised based on new process unit benchmarking data from Engineers India Ltd. (EIL), the current unit remains the basis of refinery reporting (with the exception of the Reliance refinery, which employs the Shell Benchmark and Energy Intensity Index, or EII). Table 3-7 shows selected series from reporting refineries, demonstrating a general trend towards improved energy performance of refineries over a period when higher energy intensive secondary processing units were being added.

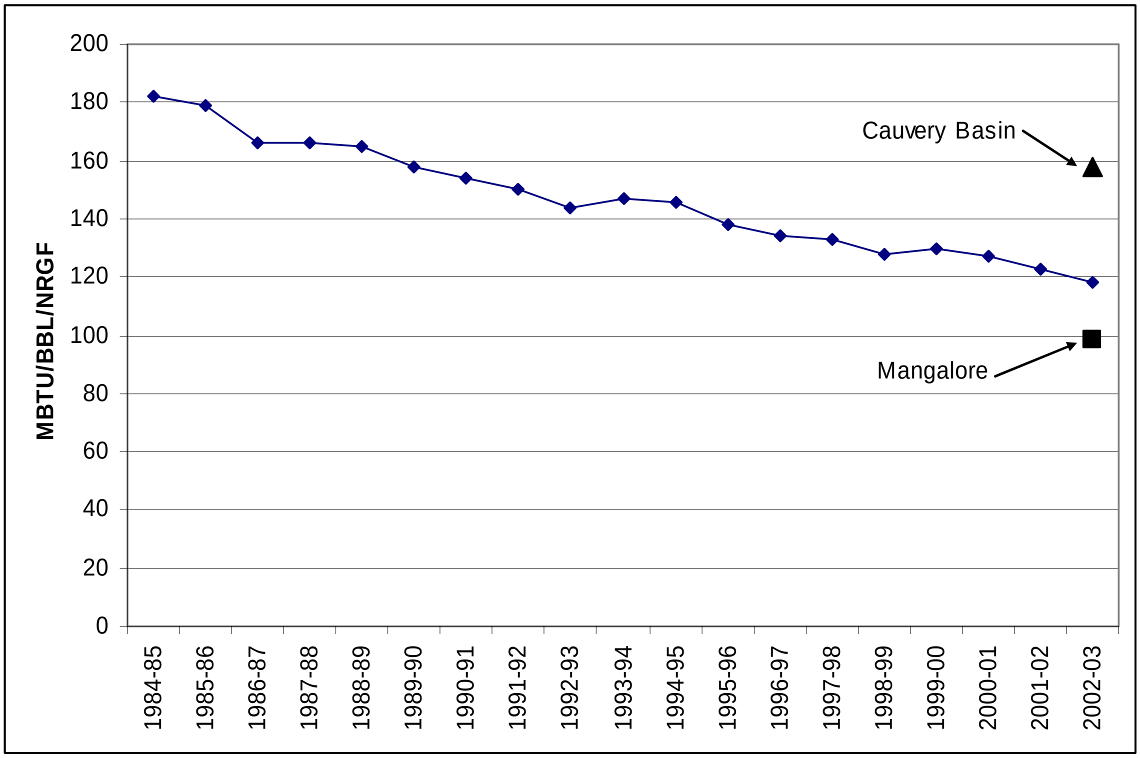
**Table 3-7. Energy Performance of Indian Refineries (MBTU/BBL/NRGF)**

| | 1999-00 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | Notes |
|---|---|---|---|---|---|---|
| Indian Oil Corporation, Ltd. | | | 116.0 | | | |
| Baurauni | 137.0 | | 135.4 | 146.1 | 136.8 | 03/04 to August |
| | 133.0 | | | | | EII |
| Digboi | | ~170 | | | | |
| Gujarat | 110.4 | 107.3 | 105.6 | 104.5 | | |
| Guwahati | | | | | | |
| Haldia | | | | | | |
| Mathura | | 135.9 | 121.7 | 111.6 | | |
| Panipat | 171.0 | 127.0 | 110.0 | 105.0 | 102.0 | |
| Hindustan Petroleum Corporation, Ltd. | | | | | | |
| Mumbai | 125.5 | | 120.4 | | | |
| Visakh | 121.5 | | 132.2 | | | |
| Chennai Petroleum Corporation, Ltd. | | | | | | |
| Manali | | 124.5 | 128.1 | 118.9 | 118.7 | |
| Cauvery Basin | | 211.6 | 200.5 | 157.9 | | revised calculations in 2002-03 |
| Bharat Petroleum Corporation, Ltd. | | | | | | |
| Mumbai | | | | | | |
| Bongaigaon Refining & Petrochemicals Ltd. | | | | | | |
| Bongaigaon | | 149.9 | 132.2 | 128.7 | | |
| Kochi Refineries Ltd. | | | | | | |
| Ambalamugal | | 128.3 | 124.0 | 123.4 | 123.0 | |
| Numaligarh Refinery Ltd. | | | | | | |
| Numaligarh | | | | | | |
| Mangalore Refinery & Petrochemicals, Ltd. | | | | | | |
| Mangalore | | 102.8 | 109.4 | 98.6 | | |
| Reliance Industries, Ltd. | | | | | | |
| Jamnagar | | 95.6 | 93.9 | 88.7 | | Shell Benchmarking |
| | | | | 64 | | EII |

Note: EII is the Energy Intensity Index.

Figure 3-4**Error! Reference source not found.** displays the historical MBN of the entire sector to 2002/03. In that year (excluding the Reliance refinery), Cauvery Basin refinery reported the highest MBN at 157.9, while Mangalore Refinery was lowest, at 98.6, compared to the national average of 118.

**Figure 3-4. Specific Energy Consumption in Indian Refineries**



Source: CHT, n.d.

The Reliance refinery is India’s most energy efficient. In terms of the Energy Intensity Index12 Reliance ranks in the top 5% of worldwide refineries, with an EII of 64 in 2002, and it ranked highest of all participating refineries in the Shell Benchmark of energy and loss performance (Bokare, n.d.).

Figures 3-5 shows the ranking of selected Indian refineries in terms of their MBN rating (excluding the Reliance refinery, which does not report an MBN index). Based on an

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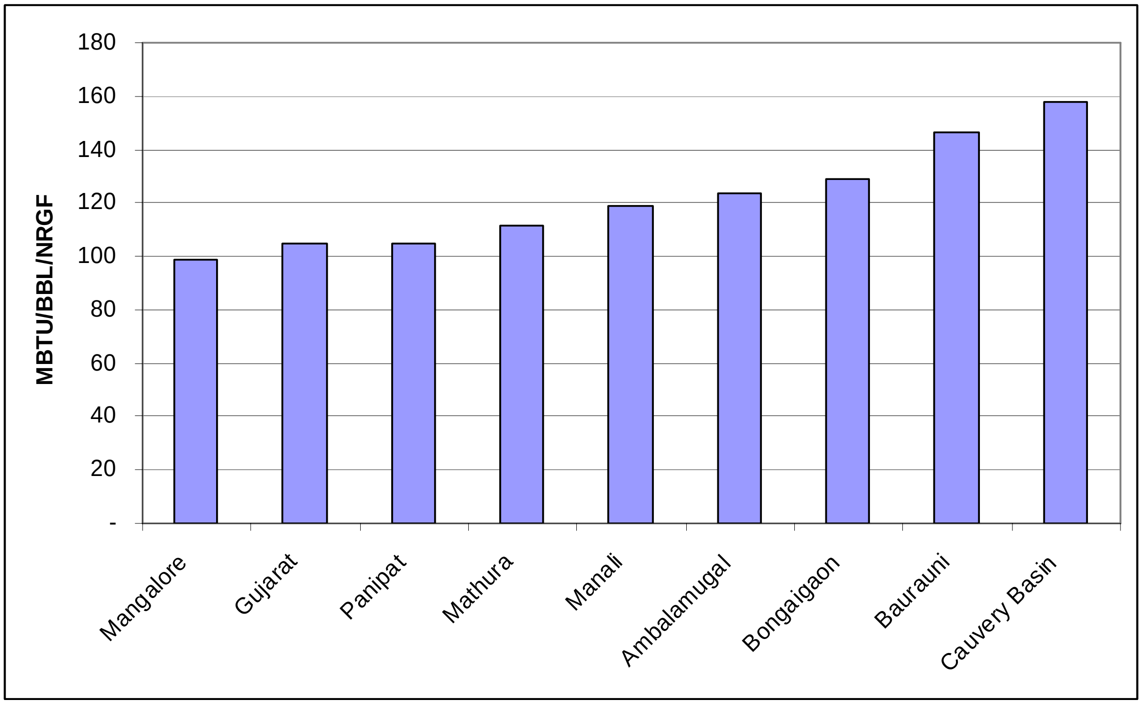
[12] The Solomon EII is a unit-by-unit benchmarking methodology that adjusts the unit consumption coefficients for some units based on feedstock or operational parameters. For example, distillation energy coefficients are a base consumption per barrel plus a coefficient times the crude gravity. Catalytic cracking energy coefficients are computed from a base plus a function of coke deposited on the catalyst. Hydrocracking energy consumption is calculated from the severity. Cat reforming is calculated as a function of the RON of the output. The Solomon study of 1994 resulted in an average worldwide EII of 92 for participating refineries, ranging from a low of 62 to a high of 165. The standard is set at 100 (EC, 2003).

index of 100[13], this ranking shows that the majority of Indian refineries have a substantial potential for overall efficiency improvement.

**Figure 3-5. MBN of Selected Indian Refineries, 2002/03**



Source: Table 3-7.

The government supported a Study on Energy Benchmarking and Targeting of PSU (Public Sector Undertakings) Refineries to identify areas in which energy efficiency improvements could be made. The results of the study are shown in Table 3-8. In some technologies, the surveyed refineries met or exceeded benchmarks, while the gap for some refineries exceeded 100% in the case of vacuum distillation, naphtha splitters, fluid catalytic cracking, and propane deasphalting. The study indicated that overall there was at least a 20% potential for improvement in the PSU refineries in terms of process unit operations, and 15-43% improvement possible in the steam and power systems (Prasad, n.d.)

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[13] Assumed calculation basis, based on parallels with EII.

**Table 3-8. Benchmark and Actual Consumption of Process Units**

| Unit | Benchmark | Actual (1994/95) | Efficiency Gap |
|---|---|---|---|
| | (BTU/BBL) | | vs Benchmark |
| Crude distillation | 73,600-78,650 | 74,640-123,900 | 0-68% |
| Vacuum distillation | 65,330 | 86,200-198,400 | 32-204% |
| Crude/Vacuum integrated unit | 88,000-109,000 | 104,900-155,700 | 0-77% |
| Naphtha splitter | 102,150 | 102,660-236,740 | 0-132% |
| FCC (with coke) | 250,400 | 256,675-505,000 | 3-102% |
| Delayed coker | 316,710 | 370,100-421,140 | 17-33% |
| Aromatics recovery | 505,840 | 654,175 | 29% |
| Hydrocracker (once-through) | 262,320 | 433,300 | 65% |
| Hydrogen | 66,930 | 87-387-110,850 | 31-66% |
| Propane Deasphalting | 261,640 | 454,380-573,255 | 74-119% |

Note: The figures in this table were compiled by the Centre for High Technology, developers of the Indian MBN measure, and thus use the same units—BTUs—as the MBN index.
Source: Prasad, n.d.

## 3.3 Future Development of the Refining Industry

### 3.3.1 Ongoing Changes

One of the largest challenges to the Indian refining sector is the requirement to improve fuel quality, particularly of motor gasoline and diesel. During the 9th Plan period, refineries invested about US$2.5 billion in secondary processing equipment and other measures to bring gasoline and diesel up to the BIS 2000 standards, equivalent to Euro I specifications. Of the US$2.5 billion, US$1.5 billion alone was expended on the construction of 9 diesel hydrodesulfurization (DHDS) units in 9 refineries (GoI 2003). These investments allowed the:

- Elimination of lead from gasoline
- Increase in gasoline octane to 88 RON
- Reduction in gasoline sulfur from 2000 ppm to 1000 ppm (500 max in 4 cities)
- Reduction in diesel sulfur from 10,000 ppm to 2500 ppm (500 ppm in 4 cities)
- Increase in diesel cetane number to 48
- Reduction of benzene content of gasoline to 5% vol max (3% vol max in 4 cities)

The Auto Fuel Policy adopted by the Government of India in 2002 set further targets for reductions in sulfur content, improvement in quality, and new constraints on aromatics, benzene and olefin content in gasoline (Table 3-9). The roadmap for quality improvements includes the adoption of Bharat Stage II standards nationally from 1 April 2005 and the Euro III standards nationally from 1 April 2010. In Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur and Agra, the Bharat Stage II standards already went into effect in 2000-2001 (Delhi, Mumbai, Kokata and Chennai) and 2003. In these cities, Euro III standards will take effect in 2005 and Euro IV standards in 2010.

**Table 3-9. Upcoming Transport Fuel Quality Requirements**

| Gasoline: | | | |
|---|---|---|---|
| | Bharat Stage II | Euro III | Euro IV |
| RON | 88 | 91 | 91 |
| Sulfur | 500 ppm | 150 ppm | 50 ppm |
| Benzene | 5% (3% April 2005) | 1% | 1% |
| Aromatics | | 42% max | 35% max |
| Olefins | | 21% max | 21% max |
| Oxygenates | n.a. | 2.7wt% max | 2.7wt% max |
| Diesel: | | | |
| Cetane number | 48 | 51 | 51 |
| Sulfur | 500 ppm | 350 ppm | 50 ppm |

By 2010, refiners will be required to reduce sulfur by up to 95-98% below current allowable levels, in face of expected increases in imports of high-sulfur crude. The government estimates that existing refiners will have needed to invest about US$3.2 billion to achieve the Bharat Stage II standards for the country, and a further US$2.1 billion to reach Euro III standards. A further US$2.1 billion would be needed to move to Euro IV standards (GOI, 2002).

The difficulties of refiners to meet these new quality standards differ in terms of location, existing technology base, crude quality, and current margins. The incremental costs of producing Bharat Stage II gasoline is estimated to range from US$0.04 to US$0.23 per gallon, and US$0.05 to US$0.32 per gallon to achieve Euro III levels. Bharat Stage II diesel may increase costs by US$0.02 to US$0.27 per gallon, and US$0.03 to US$0.33 per gallon for Euro III standards (GOI, 2002).

Increasing product quality alone is likely to have substantial energy impacts on refiners. Raising product quality will primarily rely on investment in additional processing units, including light naphtha isomerization, diesel hydrotreating, diesel hydrodesulfurization, naphtha hydrotreating, benzene extraction, mercaptan extraction, alkylation, hydrocracking, continuous catalytic reforming, fluid catalytic cracking (including resid fluid catalytic cracking), and FCC and reformate splitters, depending on the original configuration of the refinery. (GOI, 2002; Acharya, 2003). All of these processes increase the energy intensity of processing. As a result, refiners are likely to see their aggregate energy consumption per unit of throughput rise further, as happened after 1998.

### 3.3.2 Potential for Energy Efficiency Improvements

As part of the plan for the refining sector in the 10th Five-year Plan, the government has encouraged domestic refineries to benchmark their energy performance to best international levels in order to provide a guidepost for their energy efficiency gains. Internal benchmarking (MBN) has been used extensively in Indian refineries, but now that the sector has been delicensed and opened up for foreign investment, crude and product imports and exports have been liberalized, and distortions on domestic product prices lifted with the abolition of the Administered Pricing System (APS), Indian refineries now face direct international competition. External benchmarking based on EII, Shell, or other processes would allow Indian refiners to measure their performance against their international peers and allow more transparent comparisons internationally.

Higher oil prices, government incentives and penalties under the APS to reduce fuel use and hydrocarbon losses, and the need to improve competitiveness led to series of energy audits and the development of energy conservation ("EnCon") projects in refineries throughout the 1990s. Table 3-10 summarizes the range of efficiency opportunities in petroleum refineries (Worrell and Galitsky, forthcoming), and the investment programs of the Indian refineries in the late 1990s and early 2000s contained a number of the elements as noted on the chart. Despite the higher specific energy consumption in the refineries owing to the installation of energy-intensive processing units in the late 1990s, refineries were able reduce their MBN, which takes into account the configuration changes over this period. Two examples are presented; in both cases, investment measured resulted in the savings of 0.6-1% of total fuel use and loss in the refinery.

Table 3-10. Energy Efficiency Opportunities in Petroleum Refineries

| Process | Energy Management | Cogeneration | Gas Expansion Turbines | High-Temperature Cogeneration | Gasification | Flare Gas Recovery | Power Recovery | Boilers | Steam Distribution | Process Integration | Process Heaters | Distillation | Hydrogen Management | Motors | Lighting | Other Opportunities |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Desalting | X | | | | | | | | | | | | | | | |
| CDU | X | | | X | | X | | | X | X | X | X | | X | | |
| VDU | X | | | X | X | | | | X | X | X | X | | X | | |
| Hydrotreater | X | | | X | | | | | X | X | X | X | X | X | | X |
| Cat.Reformer | X | | | X | | X | | | X | X | X | X | X | X | | X |
| FCC | X | | | X | | X | X | | X | X | X | X | | X | | X |
| Hydrocracker | X | | | X | | X | X | | X | X | X | X | X | X | | |
| Coker | X | | | X | X | X | | | X | X | X | X | | X | | |
| Visbreaker | X | | | X | X | X | | | X | X | X | X | | X | | |
| Alkylation | X | | | | | | | | X | X | X | X | | X | | |
| Hydrogen | X | | | X | X | | | | X | X | X | | X | X | | |
| Utilities | X | X | X | | X | X | | X | X | X | X | | X | X | X | X |

Note: “X” indicates that relevant energy fficiency measures are possible in these areas. Lighting and boilers, used throughout refineries, are all included under Utilities.
Source: Worrell and Galitsky, forthcoming.

#### *3.3.2.1 Haldia Refinery*

Haldia is a 4.6 mmt refinery, part of the Indian Oil Corporation chain. In 2002/03, it processed 4.06 million tonnes of crude. It is a cracking refinery, with fluid catalytic cracking (FCC) and catalytic reforming as its main process units.

As a result of the installation of diesel hydrodesulfurization, FCC, microcrystalline wax unit, and catalytic isodewaxing unit, specific energy consumption of both electricity and thermal energy rose. Electricity use jumped from 53.5 kWh/tonne in 2000/01 to 57.14 kWh/tonne in 2002/03. Thermal energy rose from 0.77 million kcal/tonne in 2000/01 to 0.94 mmkcal/tonne in 2001/02. However, as a result of the refinery's EnCon projects, thermal energy consumption fell in 2002/03 to 0.88 million kcal/tonne.

The refinery oversees and manages energy consumption through a Energy Conservation and Technical Audit Cell and develop proposals for improving energy efficiency in process units, the thermal power station, heaters, heat exchangers and other areas, and the cell works as well to reduce leaks and increase insulation effectiveness. The refinery benchmarks its performance on a international best practices basis and implements projects that are economical and feasible (BEE, 2003).

Recently implemented projects that led to the reduction in the specific consumption of thermal energy in 2002/03 included:

- Preheat recovery though crude distillation unit heat (CDU) integration using pinch technology
- Fuel savings through use of soaker technology in the visbreaker
- Pinch technology in the solvent dewaxing unit
- Fuel savings in the CDU through improved refractory coating
- Power savings through use of supercritical extraction for separation of solvent in propane deasphalting unit
- Power savings through motor replacements
- Fuel savings from high-efficiency furnace installation in the hydrofinishing unit
- Fuel savings from selection of gas turbine in new power plant.

The refinery's action plan is to reduce energy consumption further through a variety of schemes currently planned or under implementation. The refinery estimates total investment of about US$800,000 will result in savings of about 3720 tonnes of refinery fuel, equivalent to about 1% of the total thermal energy consumption in 2002/03. These measures include:

- Replacement of motors with turbo driver in cooling system pump
- Replacement of insulation in the steam header
- Recovery of medium-pressure steam condensate in the naphtha stabilizer reboiler in the CDU
- Replacement of old air compressors with high-efficiency centrifugal air compressors
- Installation of steam trap in steam tracing line
- Pinch modification of kerosene hydrodesulfurization unit

- Improved insulation in the catalytic reformer
- Improved insulation in the tank farm

#### *3.3.2.2 Mathura Refinery*

Mathura has a rated crude distillation capacity of 8.0 million tonnes and is part of the Indian Oil Corporation system. It is a cracking refinery containing both an FCC and a hydrocracker, in addition to visbreaking, bitumen, and sulfur recovery units. Units designed for improving product quality include the catalytic reformer and a diesel hydrodesulfurization unit.

As was the case with the Haldia refinery, the Mathura refinery experienced higher energy consumption as a result of the installation of the energy-intensive secondary processing units for product quality. In 2000/01, fuel use and loss equaled 4.82% of throughput and rose to 6.56% of throughput in 2002/03. The MBN, however, fell during those years from 135.9 to 111.6 (BEE, 2003).

The refinery manages energy conservation projects through an Energy Conservation Cell, which monitors energy consumption on a daily basis. The Cell has implemented a range of energy conservation projects, including:

- Preheating of air in furnances
- Optimization of heat exchangers
- Installation of high-efficiency burners
- Fuel savings through use of low-pressure gas that was otherwise flared
- Loss reduction through control and monitoring of flares
- Use of soaker technology in the visbreaker
- Installation of advance process control
- Installation of gas turbines for power generation/heat recovery steam generation
- Heat integration among units
- Use of high-efficiency pumps
- Use of low pressure steam in vacuum unit and reformer
- Insulation improvement

In 2002/03 alone, a series of projects, including optimization of steam to carbon ratio in the hydrogen unit, use of secondary seals in gasoline/naphtha tanks, installation of efficient centrifugal compressors, and routing of hydrogen rich gas from the reformer to the hydrogen unit achieved savings of 3447 equivalent tonnes of refinery fuel, equivalent to about 0.6% of total fuel and loss in 2002/03.

Among the conservation and efficiency projects the refinery has planned for the near term include the revamp of the atmospheric and vacuum unit at a cost of about US$9.5 million, resulting in a fuel savings of about 20,000 equivalent-tonnes of fuel per year.

## 3.4 Scenarios of Future Energy Use

### 3.4.1 Future Trends in Refinery Production

According to the 10th Five-Year Plan (2002-2007), petroleum product demand is expected to grow to 120.4-134.6 million tonnes, or 3.7% to 5.7% per year on average. Under the lower growth scenario, refining capacity additions would be limited to expansions at existing refineries, and capacity would reach 138 million tonnes. Under the higher-growth scenario, one or two new grassroots refineries may become necessary in addition to expansions at existing refineries, to bring total capacity up to 155 million tonnes. By the end of the 11th Plan in 2012, demand may grow further to 172 million tonnes, with commensurate increases in refining capacity expected (India Planning Commission, 2002).

During the 10th Plan period, however, domestic production of crude oil is expected to remain flat at about 33 million tonnes per year. As a result, incremental crude oil supplies to refineries will be imported, and India's external dependency on crude will rise.

### 3.4.2 Future Trends in Energy Efficiency

The installation of new energy-intensive processing units in refineries to meet the targets of nation-wide implementation of Euro III/IV product standards by 2010 will inevitably lead to a rise in refinery specific energy consumption and thus total sector energy consumption. The continuation of programs on energy conservation and efficiency improvements in refineries will thus be critical to moderating the increase.

Assuming that domestic oil demand of 172 million tonnes in 2012 is met entirely through expansion of domestic refining capacity, efficiency measures implemented by then could substantially cut total energy consumption in the sector. As shown in Figure 3-3, specific energy consumption rose nearly 23% from 2.44 PJ/tonne in 1998/99 to 3.00 PJ/tonne in 2002/03 owing in part to the large increase in secondary processing units for product quality improvement required to achieve BIS 2000 gasoline and diesel standards. Achieving Bharat Stage II, Euro III and Euro IV standards will require extensive use of these and other processing technologies before 2010 and may result in further increases in specific energy consumption. Assuming a further 15% rise in this measure to 3.44 PJ/tonne in 2012, total energy consumption in the sector could reach 640 PJ. However, if the implementation of refinery efficiency measures could maintain specific energy consumption at the 2002/03 level, total energy consumption would total 553 PJ, nearly a 14% decrease, and a savings of 88 PJ. This represents both a substantial savings in costs as well as a substantial volume of fuel that can otherwise be provided to the Indian market.

### 3.4.3 Research Needs and Data Availability.

The analysis and conclusions presented in this report are based on publicly available data and other reports on the Indian refinery industry, drawing on, where possible, original Indian data. The analysis, however, could be strengthened and extended by the acquisition of additional data, including refinery costs, energy consumption intensity by processing unit by refinery, contribution of each unit to overall refinery energy consumption, and details of the unique Indian MBN calculation process. These additional data would permit analysis of India's current "efficiency gap" by technology to derive a more robust estimate of the potential for refining sector energy savings.

## 3.5 Summary and Conclusions

In terms of energy efficiency, Indian refineries have in general been able to improve their performance over the past 5 years despite the challenges of the installation of new energy intensive processing units at the same time as distillation capacity has expanded by over 75%. Further gains are possible, as indicated by the large efficiency gap between the EIL benchmark values for each processing unit and the range of actual performance found during the 1995/96 survey. In total, savings of 20% are possible in the process units at public-sector refineries, while savings of 15-43% are possible in the steam and utilities systems.

The current benchmarking approach for Indian refineries—the MBN—is currently under reevaluation based on new process unit operating conditions and values. In the face of the liberalization of the Indian refining sector and its opening to international participation, as the reevaluation of MBN continues, refiners should consider directly adopting an internationally comparable measure of performance such as the EII in order to provide them with a clear sense of their efficiency performance and improvements over time compared to their international competitors.

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# 4. Fertilizer Industry

## 4.1 Fertilizer Production Processes

Fertilizers consist of three nutrients: nitrogen (N), phosphorous (P) and potassium (K). Each of these nutrients can be a single element or in a combined form.

In order to produce the raw material ammonia (NH3), which is needed for the production of nitrogenous fertilizers, a source of nitrogen and hydrogen (H2) is required. 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 CO2. 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 feedstocks such as residual oils and coal. Heavy feedstocks and coal are first gasified and the synthesis gas is then processed as for other feedstocks. This process requires between 40 to 50% more energy (Schumacher and Sathaye, 1999) but allows more flexibility in the choice of feedstocks.

In India, the phosphate requirement is largely met through import of rock phosphate and sulfur/phosphoric acid, although low-grade rock phosphate is indigenously mined and made available to the producers of single super-phosphate (SSP). There are no domestic sources of potash ore and the entire requirement is imported.

As nitrogen is the most energy intensive fertilizer to produce[14], our analysis focuses on the potential energy savings in the manufacture of nitrogen fertilizers.

## 4.2 Fertilizer Production in India

Chemical fertilizers played a major role in the accomplishment of India’s green revolution. India’s fertilizer production increased in step with the green revolution. It achieved near self-sufficiency in its needs for nitrogen, and by 2002-03, India imported less than 1% of its nitrogen needs. It is currently the third largest producer in the world, after China and the U.S (US Geological Survey, 2003), and production has grown at an average rate of 6% annually since 1981.

### 4.2.1 Fertilizer Industry Characteristics

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

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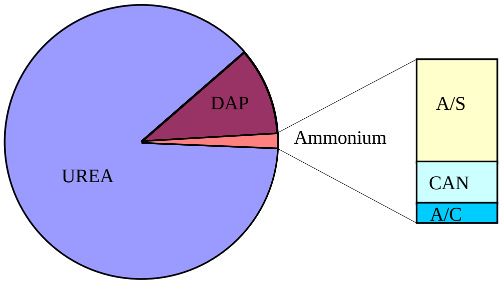
[14] average specific energy consumption of phosphorous fertilizer is approximately 10 times lower that nitrogen fertilizer (Kongshaug, 1998)

remaining share consists of the complex fertilizer di-ammonium phosphate (10%) and different types of ammonium fertilizers (2%). The output of nitrogenous fertilizers in India reached 10,590 tonnes by 2002-03. **Error! Reference source not found.** shows the share of nitrogenous fertilizers by type in that year.

**Figure 4-1. Production Shares of Nitrogenous Fertilizers by Type, 2002/03**



Source: GOI, 2004.

Note: DAP: di-ammonium phosphate, A/S: ammonium sulfate, CAN: calcium ammonium nitrate, SSP: single super phosphate

## 4.2.2 Energy Consumption

The production of fertilizers is one of the most energy-intensive processes in the Indian industry. Due to its large share, the production of nitrogenous fertilizers has the greatest impact on energy use. The major determining factors for energy efficiency in this industry are capacity utilization, feedstocks, plant age and technology.

The average fuel consumed per ton of fertilizer produced (nitrogen and phosphorous fertilizers) shown in Table 4-11 represents the energy intensity of the fertilizer industry. This indicator shows a decrease over time reflecting the progress in technology and the increasing attention paid to monitoring energy consumption.

**Table 4-1. Energy Intensity in Fertilizer Industry**

| | **93-94** | **94-95** | **95-96** | **96-97** | **97-98** | **98-99** | **99-00** | **00-01** | **01-02** |
|---|---|---|---|---|---|---|---|---|---|
| GJ/t of total Fertilizer produced | 49.06 | 44.07 | 44.44 | 44.74 | 43.06 | 41.00 | 37.15 | 35.51 | 34.20 |

### *4.2.2.1 Capacity Utilization*

Capacity utilization is a good indicator of the efficiency of energy use. Energy losses and waste heat are about the same magnitude regardless of a plant's actual output. The domestic fertilizer industry maintains a high level of capacity utilization, yet there is room for improvement (see Table 4-2). The national average capacity utilization during 2002-03 and 2003-04 was 87.2% and 88.6% respectively. The capacity utilization of the fertilizer industry is being improved through revamping, modernization of the existing plants and closure of unviable capacity of inefficient fertilizer units. Still, 23 out of 56 nitrogenous plants utilize less than 80% of their rated.

**Table 4-2. Capacity Utilization – Nitrogen Plants (2002-03)**

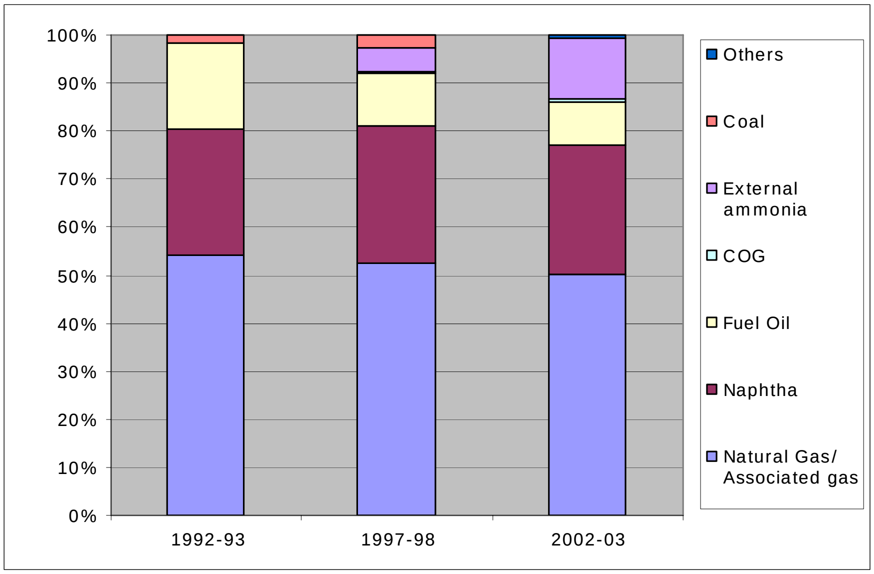
| Capacity Utilization (%) | No. of Plants |
|---|---|
| Above 100 | 10 |
| 91-100 | 17 |
| 81-90 | 6 |
| 71-80 | 9 |
| 61-70 | 4 |
| 51-60 | 1 |
| 41-50 | 1 |
| 1-40 | 4 |
| Nil | 2 |
| Total number of plants | 54 |

Source: FAI, 2004.

#### *4.2.2.2 Feedstock Utilization*

The feedstock mix used for ammonia-urea production has changed over the past few decades. From the 23 plants set up in the 1960s and 1970s, fourteen were naphtha based, six were natural gas and three were fuel oil based. In contrast, with natural gas becoming available from offshore Bombay High and South Basin in the 1980s, a number of gas-based ammonia-urea plants were set up. This altered the mix of plants towards natural gas, and as a consequence during the 1980s and 1990s, 11 plants were natural gas based, four were naphtha based, two were coal based (closed by the government in 2002) and one used fuel oil. As the usage of gas increased in the 1990s, and the available domestic supply decreased, the more recent expansion projects were designed to use dual feedstocks, both naphtha and natural gas. The feasibility of using liquefied natural gas (LNG) to meet the demand for existing fertilizer plants and/or for expansion projects, along with the possibility of utilizing newly discovered natural gas reserves is also being explored by various fertilizer companies in India. The Indian fertilizer sector is still characterized, however, by a high share of non-natural-gas-based units (see Figure 4-2**Error! Reference source not found.**). Worldwide, the share of natural gas in ammonia-urea production capacity is approximately 83% (GOI, 2003) compared to only 50% in India.

**Figure 4-2. Feedstock-Wise Share in Total Capacity of N (%)**



Source: FAI, 2004; GOI, 2004.

The shift towards the use of natural gas as feedstock is an improvement in terms of energy efficiency as its conversion into nitrogenous fertilizer is considerably less energy intensive than for other types of feedstocks. Table 4-33 shows the specific energy consumption for the production of ammonia. Natural gas plants used 40.2 GJ/t of energy for the production of ammonia in 1990-91. Naphtha plants used 24% more, and fuel-oil based plants used 57% more energy per unit of output. The intensity of energy use declined by 1997-98 for the first three feedstocks by 8%, 8%, and 12% respectively, and that for the first two feedstocks declined further by 2000-01.

**Table 4-3. Specific Energy Consumption (GJ/t $NH_3$) for the Production of Ammonia**

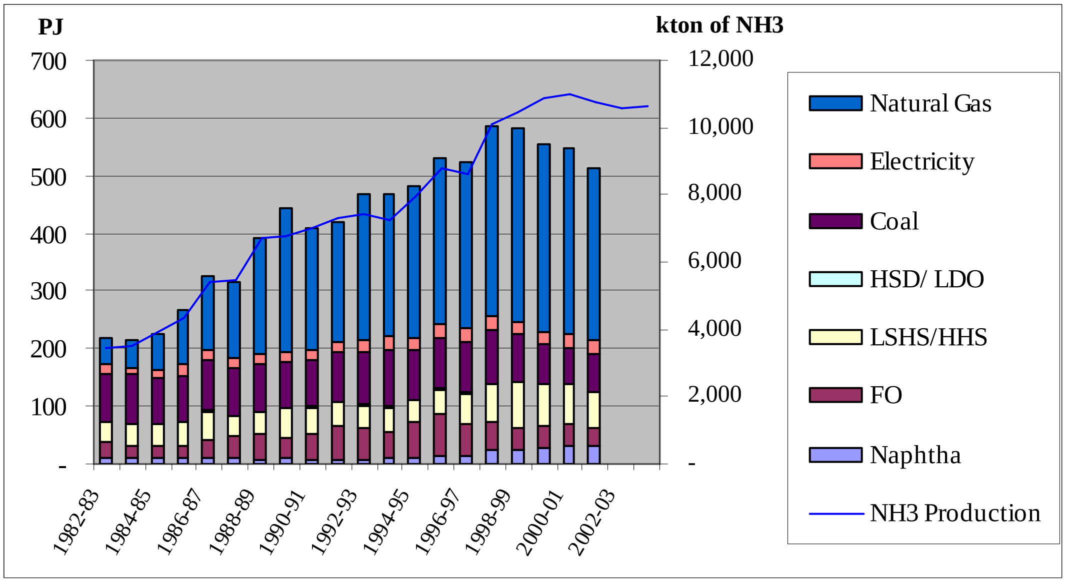
| | 1990-91 | 1997-98 | 2000-01 |
|---|---|---|---|
| Gas | 40.2 | 37.1 | 36.5 |
| Naphtha | 49.9 | 45.8 | 39.9 |
| Fuel Oil | 63.1 | 55.7 | 58.4 |
| Coal | 163.8 | 201.5 | NA |

Source: 1990-91 and 1997-98, TERI, 2003; 2000-01, Anonymous, n.d.; Ashraf, et al., 2003;

### *4.2.2.3 Energy Consumption*

Energy consumption in the fertilizer industry grew as fast as the production of fertilizer during the 1990’s and then declined continuously as the fuel mix changed and plants became more efficient.

**Figure 4-3. Energy Consumption in the Indian Fertilizer Industry and Production of Nitrogenous fertilizers.**



Source: Central Electricity Authority, 2003; India Ministry of Coal, 2003; India Ministry of Petroleum and Gas, n.d., TERI, 2004.

Note 1: FO: Furnace oil; LSHS/HHS: Low Sulfur Heavy Stock/Hot Heavy Stock; HSD/ LDO: High-Speed Diesel/ Light Diesel Oil

Note 2: these figures include energy products used for electricity production

Figure 4-3 shows the total energy consumption in the fertilizer industry over the last 10 years; it includes fuel used as feedstock as well as that used for energy purposes. The figure shows simultaneously the production of nitrogenous fertilizer on a second axis. With the limits on the domestic availability of natural gas, its total consumption has stagnated since the late 1990s, while that of naphtha has increased since the early 1990s. From the late 90s up until now, energy efficiency has improved despite the increased use of naphtha, a more energy intensive fuel. This may be explained by the focus on energy efficiency techniques encouraged by the BEE and new policies that promote higher capacity utilization and efficiency.

### *4.2.2.4 Technology Employed and Vintage of Plants*

Ammonia production technology has evolved over a long period of time. Standard plant sizes were primarily governed by the maximum available sizes of key equipment. The first generation commercial plants commissioned in the 1960s had capacities of about 300-450 tons per day (tpd) and utilized reciprocating compressors. The advent of centrifugal compressors triggered the construction of ammonia plants with capacities of 600 tpd or higher. This reduced the energy consumption of ammonia production significantly. The subsequent generation ammonia plants were again scaled up to 900-1000 tpd, which resulted in a further reduction in energy consumption. Recent generation plants are of 1350 tpd capacity with a similar added improvement in energy consumption. Thus, vintage, size, technology level and plant configuration determine the energy efficiency levels. For example, large single stream ammonia and urea plants using centrifugal compressors will have lower energy consumption than old, small size and multi-stream plants using reciprocating compressors. (GOI, 2003). Table 4-44 shows the installed nitrogenous capacity over time.

**Table 4-4. Nitrogenous Units and Capacity**

| **Year of installation** | **1960's** | **1970's** | **1980's** | **1990's** | **2000 onwards** |
|---|---|---|---|---|---|
| Number of units | 5 | 13 | 14 | 11 | 2 |
| share in Total | 11% | 29% | 31% | 24% | 4% |
| Agg. Installed capacity ('000't) | 644 | 2938 | 3275 | 3681 | 856 |
| share in total | 6% | 26% | 29% | 32% | 8% |
| Average Size | 129 | 226 | 234 | 335 | 428 |
| Feedstocks (capacity, ('000't)) | | | | | |
| Naphtha | 248 | 1812 | 254 | 1070 | |
| Gas | 98 | 394 | 2285 | 1866 | |
| FO/LSHS | 0 | 691 | 357 | 0 | 0 |
| External ammonia | 0 | 41 | 380 | 97 | 71 |
| Mixed Energy | 298 | | | 648 | 785 |

Source: Compiled from data from the GOI, 2004 and FAI, 2004
Note: capacity figures are current figures (31/03/04) of plants that were commissioned at different times.

Many old Indian fertilizer plants have been revamped and can compete with modern plants. For an older ammonia plant a typical revamp would include the following: a) capacity increase, b) energy-saving, and c) reduction in raw material and utility consumption. All of these directly or indirectly improve a plant’s energy intensity..

## 4.3 Future Development of the Fertilizer Industry

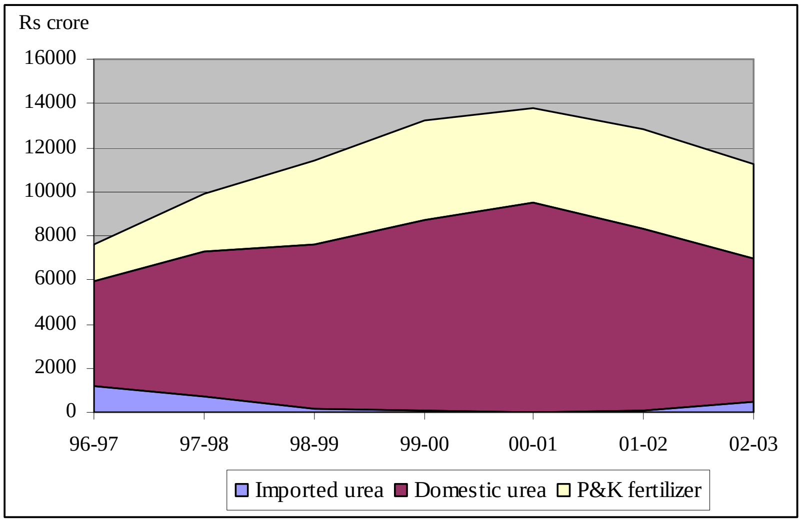
### 4.3.1 Ongoing Changes in the Fertilizer Industry

The fertilizer industry performance and profitability is highly subjective to government policies. In 1977, the government of India introduced the Retention Price Scheme (RPS) with the objective of providing fertilizers to farmers at an affordable price without harming the interests of manufacturers. This subsidy scheme has been very favorable to the domestic development of the industry. However, subsidies have continued to grow ever since, and the government is looking for means to reduce its contribution without harming domestic manufacturers and consumers.

Phosphatic and potassic fertilizers were decontrolled from the RPS in 1992, leading to sharp increases in prices, inducing farmers to shift their usage to more nitrogenous fertilizers rather than use the more expensive phosphatic and potassic fertilizers. The net effect was that the ratio of NPK consumption which was 5.9:2.4:1 in 1991–92 became heavily imbalanced at 8.5:2.5:1 during 1995–96 (far from the ideal ratio of 4:2:1 for Indian soils).

The government introduced a separate concession scheme to encourage the consumption of P and K fertilizers once again. The government approach was to fix a Maximum Retail Price (MRP) and calculate the average cost of supply; the difference forms the basis for concessions that are paid to manufacturers. As shown in Figure 4-4**Error! Reference source not found.**, the concession rates of potassic and phosphatic fertilizers have substantially increased in recent years

**Figure 4-4. Government Expenditure on Fertilizer Subsidies**



Source: India Ministry of Finance, 2002. Note: 2002-03 are estimates

Nitrogenous fertilizers are still subsidized under the RPS. The government calculated a retention price as the cost of production by urea plant ensuring a 12% net return on capital and subsidizes the difference of prices to the manufacturing units. In 2000-01, the retail price to farmers was fixed by the government at Rs. 4,600 /ton, and the average retention price was equal to Rs. 9,147/ ton; thus the subsidy per ton of urea came to around Rs. 4,547 per ton of urea on average (Ministry of Finance, 2000). Subsidies vary across plants, depending on the age of the plant, technology used and the feedstock utilized. Over the years, the total subsidies paid by the government have increased significantly (**Error! Reference source not found.**). The sharp increase from FY 1997-98 to 2000-01 is attributable to the rising cost of feedstocks due to the price decontrol of the petroleum industry, and the subsequent decrease is due to a reassessment of capacity utilization, which was understated by companies.

The RPS policy successfully achieved the development of nitrogenous fertilizer production in India while permitting an increase in its consumption by farmers owing to an affordable price. However, the policy has nurtured inefficiency and allowed high-cost naphtha and fuel oil based plants to stay competitive and to prosper. The government is aware of this bias and has announced a new policy to move toward price decontrol where domestic industry will have to compete with each other and with imports.  The new policy objective is to encourage efficiency in feedstock utilization and gradually reduce subsidies. In the initial phase, plants will be grouped in six categories with each group getting a uniform concession rate replacing the unit wise RPS. Groups are structured according to their specific energy consumption. Then, the number of groups will be reduced from six to two by 2006, and all units except those that are based on naphtha/LNG would be economically viable. For naphtha/LNG-based units, a concession of Rs. 1900 per tonne of urea will still be given. Under the new scheme, the efficient players will be allowed to retain the benefits of their efficiency improvement measures and inefficient plants will either revamp, close down operations or be acquired by more efficient ones. The goal of the policy is to gradually raise the farm gate price towards parity with international prices based on the most efficient feedstock and state of the art technology.

### 4.3.2 Potential for Energy Efficiency Improvement

As mentioned earlier, the biggest drawback of the Indian fertilizer industry is its reliance on non-natural gas-based plants. If we consider only the natural gas based plants, Indian plants compare very favorably with international practices (see Table 4-5). The figures in brackets are the improvement potentials if plants were to reach best practices available in India. The highest energy saving potential is observed with fuel oil based plants.

**Table 4-5. Specific Energy Consumption by Feedstock Type (GJ/t NH3)**

| **Feedstocks based plants** | | **India Average** | **India Best (Improvement Potential)** | | **World Average (1998)** | **World Best** | **China Average (2000)** |
|---|---|---|---|---|---|---|---|
| Gas based plants | Ammonia | 36.5 | 30.3 (17%) | TCL Babrala | 36.6 | 28 | 36.7 |
| | Urea | 26.5 | 22.5 (15%) | TCL Babrala | 25.8 | 20.9 | 26.3 |
| Naphtha based plants | Ammonia | 39.9 | 34 (15%) | CFCL Kota | | | 38.7 |
| | Urea | 29.1 | 24.3 (16%) | CFCL Kota | | | 28.3 |
| FO based plants | Ammonia | 58.4 | 47.9 (18%) | GNFC Bharuch | | | |
| | Urea | 40.5 | 31.3 (23%) | GNFC Bharuch | | | |

Source: Anonymous, n.d.; Ashraf, et al., 2003; Kongshaug G., 1998; GOI, 2003; EFMA, 2000; Worrell E., et al., 1997.
Note: The urea figures include the embedded energy in the production of ammonia.

The best practice energy intensity worldwide is 28 GJ per ton of ammonia, and is a result of auto-thermal reforming technology process. Autothermal 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).

Tata Chemicals owns and operates one of the more energy-efficient plants for the production of ammonia and urea in India with an energy intensity of 30.3 GJ/t of ammonia and 22.5 GJ/t of urea. These energy intensity values are among the lowest recorded internationally. Manufacturing facilities at Babrala comprise an ammonia plant of 1350 TPD and a urea plant of 2250 TPD capacity which were implemented and commissioned in December 1994. Even though the plant currently uses natural gas, it has been designed for full flexibility in the use of natural gas and naphtha as a feedstock and fuel.

When only natural gas-based plants are considered, India appears to maintain very competitive plants compared to the world average (see Table 4-5). However, this conceals the fact that only 50% of the plants in India uses natural gas whereas worldwide the average is close to 80% (Swaminathan B., 2004).

**Table 4-6. Average Specific Energy Consumption by Country/Regions (GJ/t of NH3)**

| **Process** | **India average (2003)** | **World (1998)** | **Europe (1997)** | **US average (1995)** |
|---|---|---|---|---|
| Ammonia | 41.8 | 36.6 | 35.5 | 37.1 |
| Urea | 28.4 | 25.8 | 24.5 | 30.4 |

Source: Kongshaug G., 1998; GOI, 2003; Worrell E. et al., 1997 and 2000.

Due to the low share of natural gas based plants, Indian national average figures of specific energy consumption shown in Table 4-66 are far from best practices abroad. In a competitive environment, with energy cost representing between 55% to 80% of total production cost depending on the type of plant (Vaidya, 2000), companies will be compelled to gradually switch over to natural gas in order to have an energy consumption per ton of output closer to world average and as a result become more competitive in the international market.

### 4.3.3 Categories of Energy Efficiency Improvement

Over the past 30 years, induced by major technological improvements and by a better energy management, the energy used to produce each ton of ammonia has declined by 30 to 50%.

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. Different methods are available to reduce losses that occur in the primary reformer: installing a pre-reformer, shifting part of the primary reformer to the secondary with installation of a purge gas recovery unit, and upgrading the catalyst to reduce the steam/carbon ratio. It is possible to reduce energy losses by 3-5 GJ/t of NH3 (de Beer, 1998).

CO2 removal phase: The removal of CO2 from the synthesis gas stream is normally based on scrubbing with a solvent. A reduction of the energy requirement for recycling and regeneration of the solvent can be achieved by using advanced solvents, pressure swing absorption or membranes. Energy savings are on the order of 1 GJ/t NH3.

Ammonia synthesis phase: A lower ammonia synthesis pressure reduces the requirement for compression power, but it also reduces production yield. Less ammonia can be cooled out using cooling water so more refrigeration power is required. The recycling power increases also, because larger gas volumes have to be handled. The overall energy demand reduction depends on the situation and varies from 0-0.5 GJ/t NH3. Another type of catalyst is required to achieve the lower synthesis pressure. Furthermore, adjustments have to be made to the power system and the recycle loop.

Additionally, energy price escalation and growing concerns regarding pollution have intensified the attention on energy conservation at all levels. Improving energy efficiency does not necessarily require investment and can result from a better balancing of energy flow along the process. 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. During the fiscal year 2001-02, Rashtriya Chemicals & Fertilizers Ltd. (RCF) achieved energy savings worth Rs. 63 million by reducing its electricity consumption by 16,292 MWh and natural gas use by 674,000 m3 without investing extra money on any of the different energy efficiency schemes, see table below. This kind of energy improvement can be accomplished by using benchmarks and careful audits to identify and analyze primary energy users in a plant. See Table 4-77 for examples of energy efficiency schemes applied by RCF.

**Table 4-7. Energy efficiency scheme in RCF Ltd., Trombay, (2001-02)**

| | Actual achievement of energy savings per year basis. | | | Investment incurred on the project |
|---|---|---|---|---|
| | Power | Gas | Total | |
| Project Description | MWh | kNM3 | Rs .Million | Rs. Million |
| Ammonia I | | | | |
| Diverting of excess air in Ammonia V PAC to Ammonia I for operating Inert Gas Plant thus shutting one air compressor | 1,980 | - | 7 | 0 |
| Cooling water line hooked up from Nitric Acid Plant cooling water header facilitating closure of cooling tower in Ammonia I | 2,659 | - | 10 | 0 |
| Connecting Grid air in Ammonia Storage thus stopping Air compressor in Storage Area. | 103 | - | 0 | 0 |
| Excess 4 data steam from synthesis section is diverted to gasification section thus decreasing the steam import from grid | - | 674 | 2 | 0 |
| Ammonia V | | | | |
| Change over of Benfield pump from Motor drive to Steam driven | 11,550 | - | 44 | 0 |
| Total | 16,292 | 674 | 63 | 0 |

Source: RCF report submitted to the BEE for National Energy Conservation Awards – 2003

Appendix 4 shows examples of energy efficiency schemes applied by three different plants in India. The table illustrates the investment, the energy saved, and the corresponding monetary savings as well as the pay back periods for each energy efficiency investment.

## 4.4 Scenarios of Future Energy Use

### 4.4.1 Future Trends in Fertilizer Production

Country's endowment of feedstock:

The major difficulty of the sector is the uncertainty surrounding the availability of raw materials in India. Although natural gas is the preferred feedstock, due to dwindling supplies, some natural gas based units have been forced to partially use naphtha instead. During FY 03-04, RCF: Trombay-V unit produced only 8.1 kton of nitrogenous fertilizer (5.3% capacity utilization) due to non-availability of natural gas. IFFCO: Kalol was originally a natural gas based plant, where it was decided to install a naphtha unit for pre-reforming to be able to operate the plant as a dual feedstock unit. Table 4-88 shows clearly the trend since 1996 of adding new ammonia/urea plants that have dual feedstock capacity.

Maintaining self-sufficiency and at the same time moving towards more efficient natural gas based plants implies that new domestic or imported sources of natural gas will need to become available. In order to overcome the constraints in domestic availability of natural gas in India, the government is looking at the possibility of developing infrastructure to import LNG. The government is also encouraging joint venture projects in countries where feedstocks and raw materials are abundant and relatively cheaper.

**Table 4-8. Capacity of Ammonia/Urea Plants**

| | 1996 | 2003 |
|---|---|---|
| Gas | 47% | 41% |
| Naphtha | 27% | 31% |
| Fuel Oil | 11% | 9% |
| Coal | 3% | 0% |
| Ext. Ammonia | 5% | 5% |
| Coke Oven Gas | 1% | 0% |
| Dual Gas/Naphtha | 6% | 15% |

Source: GOI, 2004.

Impact of increasing price of urea and decreasing subsidies:

The consequence of the new policy will probably initially be a decrease in the indigenous production of urea and a decrease in the utilization of urea by farmers. Following the GOI recommendations, the urea price would be increased from the present Rs 4,600 to Rs 6,900 per ton with the provision for a seven per cent increase per annum, and ultimate complete deregulation of price by the year 2006. It is probable that a period of adaptation may be needed by the industry. Companies with specific energy consumption above the group average will face uncovered costs. It is not clear how these companies will be able to make the necessary investment to maintain their profitability if at the same time their share of subsidies is to decline to equal their group subsidy. It is possible that this would further weaken their profitability, particularly if they are unable to make the investment to reduce their energy consumption.

### 4.4.2 Future Trends in Energy Efficiency

In terms of energy efficiency, the new policy is sending the right signal by inducing a changeover from naphtha/fuel oil based plants to LNG/natural gas, as might be expected in a more open fertilizer market. Natural gas is the most energy efficient and economical feedstock for urea. The new urea policy will induce manufacturers to revamp their plants and place energy efficiency at the top of their priorities. In order to stay or become competitive in a decontrolled market, significant efforts will be needed.

The changeover of feedstock from naphtha to LNG or dual feedstock in general requires limited changes to the existing process equipment (Christensen, 2001). For Naphtha based plants, it is recommended to install a new heater preheating the LNG in parallel with the existing heater preheating the naphtha. For FO/LSHS based plants, since they operate on partial oxidation, they can change over to natural gas feedstock through auto thermal reforming rather than conventional reforming of gas.

Furthermore, the progressive shift to an open market will sharpen competition. As energy cost represents between 55 to 80% of total production cost, it is to be expected that an increasing number of plants that want to stay competitive will try to reduce their energy intensity.

## 4.5 Summary and Conclusions

In a more competitive market, it is expected that most of the production of nitrogenous fertilizers will occur where raw materials are the cheapest and that countries with scarce natural gas resources like India will import most of their needs. However, fertilizer production has been a priority for India during its development, and it is now an important part of the local industry. The prospect of making available the infrastructure to import and use LNG will allow this industry to reduce its energy intensity and become competitive in an international market. Moreover, increased attention towards saving energy is essential for an energy intensive industry. The former RPS policy allowed inefficient processes to linger, but this opens the possibility for large energy savings today.

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## Appendix 4 Energy Efficiency Savings

### Example of Energy Savings Implemented or Proposed and Their Costs for Three Plants

| Scheme | Cost | energy saving | Monetary saving | Pay back period | Date |
|---|---|---|---|---|---|
| Units | Thousand US $ | GJ/t of NH3 | Thousand US$/year | Years | |
| Kribhco-Hazira fertilizer complex | | | | | |
| Purge gas recovery unit | 390 | 0.293 | 240 | 1.6 | Jul-89 |
| Ammonia converter retrofit | 5,546 | 1.080 | 1,220 | 4.5 | Dec 93 - Mars 95 |
| NG feed preheat coil in reformer convection | 392 | 0.147 | 283 | 1.4 | 2001-02 |
| Urea 21 stream CO2 compressor revamp | 2,030 | 0.108 | 799 | 2.5 | 2000-01 |
| Installation of pre-decomposer & pre-concentrator in all urea streams | 5,119 | 0.845 | 3,518 | 1.5 | 2001-02 |
| Atmospheric condensate storage tank V-2 pressurization in urea plants | 44 | 0.123 | 200 | 0.2 | 1998-99 |
| MV-1 HP separator off-gases modification in all urea streams | 174 | 0.051 | 87 | 2.0 | 1997-99 |
| CO2 blowers installation for seal losses recovery in urea plants | 218 | 0.051 | 85 | 2.6 | 1998-99 |
| Modification of refrigeration compressor anti surge loop in ammonia plants | 17 | 0.008 | 174 | 0.1 | 2001-02 |
| Modification for reducing the over pressure of ammonia receiver in ammonia plants | 5 | 0.017 | 126 | 0.0 | 2001-02 |
| IFFCO Aonola-I | | | | | |
| Reduction of Steam to Carbon ration from 3.3 to 3.0 | 4,430 | 0.795 | 1,464 | 3 | proposed |
| Revamping of CO2 removal system | | | | | |
| New LT Shift guard and BFW Pre-heater | | | | | |
| Closing steam balance | | | | | |
| New Make up gas chiller | 7,297 | 0.963 | 1,699 | 4.3 | proposed |
| New Motors for GV solution pumps & CW pump | | | | | |
| S-50 converter with HP boiler | | | | | |
| Retrofit of Syngas compressor turbine | | | | | |
| Energy plans and targets for NFL, Vijaipur, Guna | | | | | |
| Replacement of Condensing steam turbine of Ammonia CW Pump with motor | - | 0.061* | 387.7 | - | proposed |
| Heat recovery from PC by installing DM water pre-heater in Ammonia-I | - | 0.110* | 694.8 | - | proposed |
| Import of Process Air in Ammonia-1 from Ammonia-2 | - | 0.007* | 45.7 | - | proposed |
| Installation Of Additional Trays in Urea Reactor in all streams of Urea Plant | - | 0.042* | 263.6 | - | proposed |
| Installation of Purge gas heater in Ammonia plant | - | 0.001* | 7.4 | - | proposed |
| Replacement of Condensing steam turbine of one CW Pump in Urea II plant w/motor | - | 0.063* | 357.2 | - | proposed |
| Installation of Pre-concentrator in both streams of Line-I Plant | - | 0.049* | 1317.8 | - | proposed |
| CO2 Compressor turbine change over in one stream of Urea-I | - | 0.048* | 1278.6 | - | proposed |

Source: BEE 2003, Note: exchange of rate of 45.91 INR/USD, October 4th rate from Reserve bank of India.
*: GJ/mt of urea

# 5. Textile sector

## 5.1 Textile Production Processes

The textile industry produces a wide range of products. The production process includes four main activities: spinning, weaving and knitting, wet processing and stitching (sewing). The production from fibers to spun yarn takes place through the spinning process and constitutes the first stage. Then the yarn is weaved to make fabrics in looms. Most woven fabrics retain the natural color of the fibers from which they are made and are called “grey fabrics” at this stage. These fabrics then undergo several different processes including bleaching, printing, dyeing and finishing; these are grouped under the category of wet processing. Finally, the stage from fabrics to garments is done by stitching. The industry uses cotton, jute, wool, silk, man-made and synthetic fibers as raw material.

<u>Spinning</u>: Spinning involves opening/blending, carding, combing, drawing, drafting and spinning. It uses four types of technologies: ring spinning, rotor spinning, air jet spinning and friction spinning. Ring spinning is the most used in India with its main advantage being its wide adaptability for spinning different types of yarn. Rotor spinning technology is also widely used.

<u>Weaving</u>: It uses two main technologies: Shuttle and shuttleless. Shuttleless has higher productivity and produces better quality of output.

<u>Wet processing</u>: is the third stage. It covers all processes in a textile unit that involve some form of wet or chemical treatment. The wet processing process can be divided into three phases: preparation, coloration, and finishing. It uses different types of technologies depending on the type of yarn or fabric that are dyed. Jigger, winch, padding, mangle and jet-dyeing are some of the important dyeing machines. Similarly, there are different types of printing: direct printing, warp printing, discharge printing, resist printing, jet printing, etc..

## 5.2 Textile Production in India

### 5.2.1 Textile Industry Characteristics

The Indian textile industry contributes about 14% to the national industrial output and about 25% to the total national export earnings. The textile industry in India is a key sector in terms of employment as it is the second largest employment provider after agriculture with direct employment of about 30 million (India Planning Commission, 2002).

Cotton is the predominant fabric used in the Indian textile industry – nearly 60% of overall consumption in textiles and more than 75% in spinning mills is cotton. India is among the world's largest producers of cotton with over 9 million hectares under cultivation, and an annual crop of around 3 million tons (Carver et al., 2004).

Processes and technologies differ considerably across factories. Composite mills cover complete sets of processes, from raw material to final products, however most manufacturing units tend only to deal with a part of the process. India's textile industry is generally divided into the organized and the unorganized sector. The organized sector includes spinning mills and composite units. The unorganized sector comprises power looms, handlooms and garment sectors.

#### *5.2.1.1 Yarn Production*

Yarn spinning in India is dominated by the organized sector, with smaller scale industries having only about 7% of the capacity. It consists of 1,588 spinning mills and 278 composite mills (ADB, 1998). Currently India has the second largest capacity in the world after China. The spindleage capacity increased from 21 million in 1980 to 36 million in 2002. The production of total spurn yard has been growing at an annual growth of about 4% during the last twelve years (Table 5-1). The growth has been more significant for blended and 100% non-cotton yarn with an annual average growth of 9% each compared to cotton yarn which grew at an annual average of 3%.

**Table 5-1. Production of Spun Yarn (Million kg)**

| **Year** | **1990–91** | **1995–96** | **2000-01** | **2001-02** | **2002-03** |
|---|---|---|---|---|---|
| Cotton | 1510 | 1788 | 2267 | 2212 | 2193 |
| Blended/Mixed | 207 | 395 | 646 | 609 | 588 |
| 100% Non-cotton | 107 | 196 | 247 | 280 | 307 |
| **Total** | 1824 | 2379 | 3160 | 3101 | 3088 |

Source: India Ministry of Textiles, 2003.

#### *5.2.1.2 Fabric Production*

The total production of cloth by all sectors (mills, powerlooms, handloom and khadi, wool and silk) has increased at an annual growth rate of 5% during the last 12 years (see Table 5-2). However, this progression has been very uneven across sectors. The organized sector, composed of the mill sector for the weaving process, has experienced a considerable decrease in its production, with an average fall of 4% annually. The other sectors have increased their production, the highest average annual growth was the hosiery sector (9%) followed by the powerloom (6%) and the handloom sector (3%). As a result, the relative shares of the sectors have experienced significant changes over the last two decades with a significant decrease of the share of the organized sector.

During fiscal year 2002-03, total production of fabrics in both sectors combined was 42.3 billion square meters, with 63% of the total fabric production produced by the power loom sector, 18% by the hosiery sector, 14% by the handloom sector, and only 4% by the organized mill sector In 1980-81, powerlooms represented 39% of the total fabric produced, handlooms 25% and mills 36% (ADB). The production of cloth in the organized mill sector and in the handloom sector has been decreasing and has been supplanted by increasing power loom and hosiery production. The increase of power looms has resulted from a government policy that supports the unorganized sector in the form of reservation of product categories, export quotas, and pricing interventions, such as subsidized electricity (Carver et al., 2004).

**Table 5-2. Production of Fabrics in Different Sectors (in million square meters)**

| **Type of fabric** | **1990–91** | **1995–96** | **2000-01** | **2001-02** | **2002-03** |
|---|---|---|---|---|---|
| **Mill Sector:** | | | | | |
| Cotton | 1859 | 1159 | 1106 | 1036 | 1032 |
| Blended | 689 | 602 | 332 | 296 | 288 |
| 100% Non-cotton | 41 | 258 | 232 | 214 | 213 |
| **TOTAL** | **2589** | **2019** | **1670** | **1546** | **1533** |
| **Handloom Sector:** | | | | | |
| Cotton | 4237 | 6239 | 6577 | 6698 | 5196 |
| Blended | 11 | 18 | 111 | 95 | 122 |
| 100% Non-cotton | 47 | 945 | 818 | 792 | 663 |
| **TOTAL** | **4295** | **7202** | **7506** | **7585** | **5981** |
| **Decentralized Powerloom sector:** | | | | | |
| Cotton | 6887 | 7014 | 6584 | 6473 | 7512 |
| Blended | 1562 | 3137 | 5071 | 5025 | 4646 |
| 100% Non-cotton | 4899 | 7050 | 12148 | 13694 | 14333 |
| **TOTAL** | **13,348** | **17,201** | **23803** | **25192** | **26491** |
| **Decentralized Hosiery sector:** | | | | | |
| Cotton | 2448 | 4488 | 5451 | 5562 | 6295 |
| Blended | 109 | 268 | 837 | 871 | 811 |
| 100% Non-cotton | 139 | 282 | 408 | 634 | 560 |
| **TOTAL** | **2696** | **5038** | **6696** | **7067** | **7666** |
| **All Sector** | | | | | |
| Cotton | 15,431 | 18,900 | 19718 | 19769 | 20035 |
| Blended | 2371 | 4025 | 6351 | 6287 | 5868 |
| 100% Non-cotton | 5126 | 8535 | 13606 | 15334 | 15768 |
| **TOTAL** | **22,928** | **31,460** | **39675** | **41390** | **41671** |
| Khadi, Silk and Wool | 402 | 431* | 581 | 644 | 643 |
| **GRAND TOTAL** | **23,330** | **31,891** | **40256** | **42034** | **42314** |

Source: India Ministry of Textiles, 2003.

### *5.2.1.3 Wet processing*

Units which start with grey fabrics to produce dyed/printed fabrics as finished goods are known as process units/process houses. The wet processing includes scouring, de-sizing, washing, mercerizing, bleaching, dyeing, printing and finishing of yarns and fabrics. These units are spread over the different states of India, the majority located in about 20 centers. There were about 1,542 units processing cotton, wool, polyester, acrylic, blended fabrics, etc. in the late 1990s (ADB, 1998).

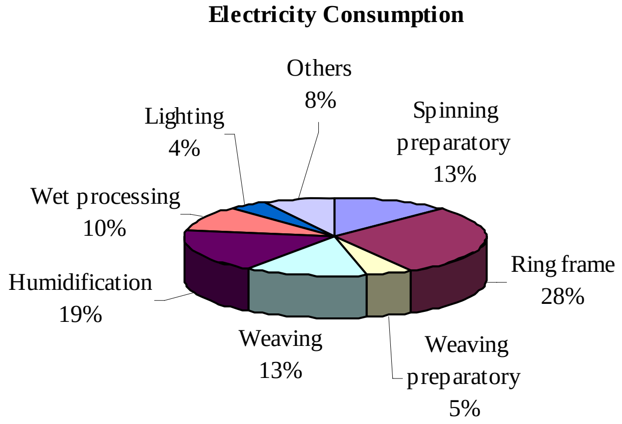
### *5.2.1.4 Garment Manufacturing:*

The apparel industry is the largest foreign exchange earner, accounting for 12% of India’s exports. Small-scale fabricators dominate the garment manufacturing sector. Most of the manufacturing units are at a medium technology level.

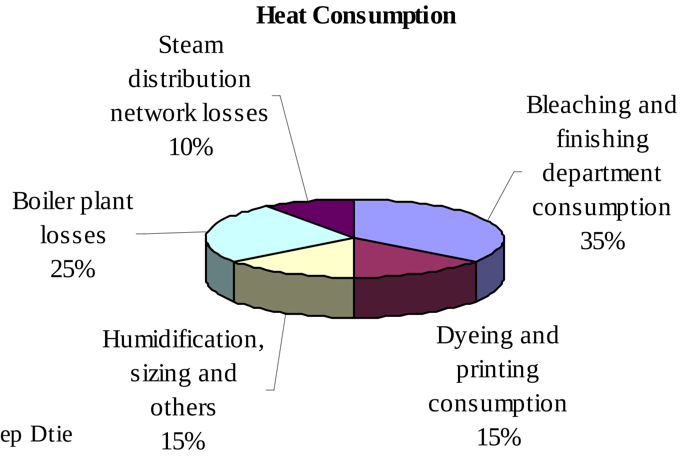
### 5.2.2 Energy Consumption

Energy consumption in the textile industry has augmented with increased mechanization. Energy consumption per unit of output is higher in modern textile units due to technological development, which tends to replace manual labor by electric power. However technological development also offers better productivity and quality that can overcome the efficiency measure. Energy costs vary from 5 to 17% of total manufacturing costs according to the type of process involved (ADB, 1998). Wet processes require high amounts of thermal energy, inducing a higher share of energy costs.

**Figure 5-1. Distribution of Power and Heat Requirement in a Composite Textile Mill**



Source: Teri, 2001



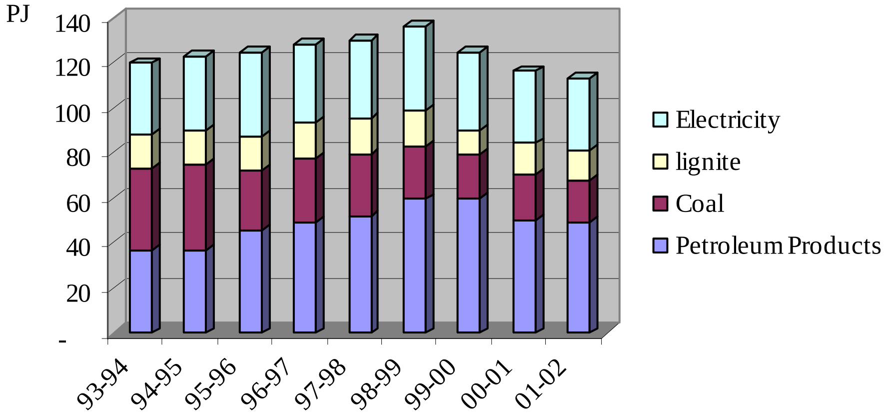
Source: Unep Dtie

The textile industry requires both thermal and electrical energy for its operation. About 80% of the energy requirement is met in the form of heat. Figure 5-1**Error! Reference**

**source not found.** shows the amount of consumption of electrical and thermal energy in different stages of production in a composite mill.

In 2001-02, total energy consumption in the textile sector was about 113 PJ which represents about 3% of industrial consumption. Petroleum products supply about 43% of the energy, coal/lignite and electricity represents 28% each of the remaining energy supplied (See Figure 5-2).

**Figure 5-2. Final Energy Consumption in the Indian Textile Industry**



Source: CEA, 2001; India Ministry of Coal, 2003; India Ministry of Petroleum & Natural Gas, n.d.; Teri, 2001
Note: these figures include energy products used for on site electricity production for plant capacity of 1 MW and above.

Energy consumption in the textile industry increased during the 1990s to reach a peak during the fiscal year 1998-99, and then decreased during the next four years. Production of yarn and fabrics slowed in 1998-99, after a sharp expansion during the five previous years. From 1993-94 to 1997-98, production of yarn and fabrics grew at rates of 10% and 8%, respectively, and then from 97-98 to 2001-02, they both grew at the slower paces of 1% and 3%.

## 5.3 Future Development of the textile Industry

### 5.3.1 Ongoing Changes in the Textile Industry

The textile sector has often been seen as a catalyst of a country's development by creating employment for excess labor. This belief has been the basis of policies followed by the government of India in the textile sector from independence until the late 1980s to slow the displacement of labor-intensive manufacturing by mechanization. The government provided favorable and protective taxes and other regulations to the unorganized sector, thus explaining the growth in that sector compared to the organized sector. Large-scale production was curtailed by restrictions on total capacity and mechanization of mills. However, in pursuing this goal, the government of India underestimated its impacts on productivity and competitiveness.

Since 1990, the policy has been changed as the government came to realize that efficiency and competitiveness were suffering under numerous regulatory burdens. This led to the relaxation of many of the constraints previously imposed on the textile sector. Licensing requirements were removed in the early 1990s by the Statement of Industrial Policy and the Textile Development and Regulation Order. In 1995, India signed the General Agreement of Tariffs and Trade (GATT) bringing its liberalization policies to an international level. The Agreement on Textiles and Clothing abolished all quota restrictions on trade in textiles and clothing in January 2005. Dismantling the quota regime represents both an opportunity for developing countries to expand exports, and a threat, because quotas will no longer guarantee markets and even the domestic market will be open to competition. In this context, the textile industry in India is going to face increasing competition, mostly coming from China.

### 5.3.2 Potential for Energy Efficiency Improvement

The textile industry is one of the longest industrial chains in manufacturing industry and is characterized by production of diverse outputs. This fragmentation and heterogeneity make it difficult to classify industrial practices and to compare Indian practices with international norms. Products are numerous and depend on the type of fibers used, the density and quality of the thread, the colors and the process being operated.

#### *5.3.2.1 Spinning*

Existing textile spinning units in India can be segregated into three types, i.e. conventional, modern and semi-modern. Conventional units have conventional machines where the production rate is low and the fluff or dust liberation from the process is within tolerable limits. Modern units have high speed machines and higher production rates with increased fluff and dust generation. Semi-modern units are units which fall between modern and conventional (ADB, 1998).

#### *5.3.2.2 Weaving*

Powerlooms produce nearly 60% of the fabric output. Less than 1% of all powerlooms are shuttleless, and, in the organized mill sector, less than 6% are shuttleless looms. These levels are much lower than those of several developed and developing countries, which have seen a high replacement rate of old looms with modern shuttleless looms; more than 80% of looms in Taiwan, Korea and the U.S. are shuttleless. Even in Pakistan, 62% of looms are shuttleless, indicating how important that country regards modernization of its weaving sector (Carver, 2004).

#### *5.3.2.3 Wet processing*

The processing industry is decentralized and is marked by hand processing units, independent units and the composite mill sector. Indian processing industry has deployed low-end technology with few technology upgrade initiatives.

The Asian Regional Research Program in Energy, Environment and Climate (ARRPEEC) has been working at assessing the energy saving potential in the Indian textile industry. They assessed average energy use in the textile industry and found that energy consumption varies from 3 to 3.5 kWh of electricity per kilogram of yarn in a modernized spinning mill. In the case of weaving, it varies from 2.9 to 3.1 kWh per meter of fabric. For knitting units, the energy consumption stands at 0.09 to 0.2 kWh per kg of fabric. In the case of dyeing it is 0.04 to 0.15 kWh per kg of fabric. Steam consumption in a fabric dyeing unit may vary from 4 to 9 kg of steam per kg of fabric[15] (Swaminathan and Rudramoorthy, 2004).

Measures for improvement in energy efficiency have been adopted by some large-scale mills. However, Small and Medium Industries (SMI), which form the backbone of the Indian economy, continue to use older technologies. The awareness level of energy conservation remains poor among the SMIs. ARRPEEC estimated that SMIs have a potential to save 15 to 20% of their energy consumption.

### 5.3.3 Categories of Energy Efficiency Improvement

The three major factors for energy conservation in the textile industry are high capacity utilization, fine tuning of equipment and technology upgradation

Energy-efficiency Improvement Options Identified (ADB, 1998; ARRPEEC, 2003):

Spinning Unit
- Installation of automatic power factor correction system with capacitors
- Replacement of old energy-inefficient transformers with energy-efficient ones
- Replacement of energy-inefficient motors with energy-efficient ones (for ring frames and open end spinning machines)
- Installation of photocells for speed frames;
- Installation of synthetic flat belts for spinning ring frames;
- Installation of energy-efficient lighting system (in place of conventional lighting)
- Installation of energy-efficient fans for humidification plants
- AC variable frequency drive for fans of humidification plants
- Diesel engine operated captive power plant

Weaving Unit
- Conversion of V-belt drives to flat belt drives;
- Replacement of standard motors with energy-efficient ones
- Installation of energy-efficient lighting system (in place of conventional lighting)
- Installation of energy-efficient fans for humidification plants
- Use of electronic ballast in place of conventional electromagnetic chokes.

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[15] The factory which consumes less steam is employing a soft flow dyeing machine, a relatively new technology.

Wet Processing Unit

- Replace conventional rapid jet dyeing machine with low liquor ratio jet dyeing machine
- Replace steam dryer with RF dryer for dyeing yarn
- Replace inefficient boilers with coal-fired water tube boiler with bag-filter
- Replace ordinary submersible pump with an energy-efficient one
- Additional fourth effect caustic recovery plant
- Naphtha-based gas turbine with waste heat recovery boiler (cogeneration)
- Monitoring for heat recovery potentials
- Recovery and reuse of waste water in fabric dyeing

A summary of the economic analysis of energy-efficiency improvement options identified by a study done by the Asian Bank for Development for a typical spinning unit and a typical composite mill are given in Table 5-3.

## Table 5-3. Economic Analysis of Energy Efficiency Improvement Options

| Energy Efficiency Improvement Options | Investment in '000 US $ | Energy Savings | | pay back period in years |
|---|---|---|---|---|
| | | GWh/year | in '000 US $ | |
| **Spinning Unit** | | | | |
| Replacement of old energy-inefficient transformers with energy-efficient ones (two 1250 kVA, two 1000 kVA transformers) | 42 | 0.39 | 28 | 1.5 |
| Replacement of energy-inefficient motors with energy-efficient ones for ring frames and open end spinning machines<br>Ring frame: 18.5 kW—10 motors<br>Open end spinning machine: 22 kW—11 motors;<br>15 kW—11 motors | 25 | 0.34 | 24 | 1.1 |
| Installation of energy-efficient lighting system—replacement of conventional copper ballast and tube lights with electronic ballast and energy-efficient tube lights. Replacement of 1172 tube lights and chokes with 880 energy-efficient tube lights and 440 chokes | 11 | 0.15 | 10 | 1.1 |
| Installation of energy-efficient fans for humidification plants (along with energy-efficient motors of appropriate capacity). Replacement of 28 fans (265 kW motors); present fan efficiency—45%; improved fan efficiency—68% | 67 | 0.48 | 34 | 2.0 |
| AC variable frequency drive for fans of humidification plants—total 28 drives | 31 | 0.15 | 10 | 3.0 |
| ***Investment for long term measure*** | | | | |
| Diesel engine operated captive power plant) | 2,182 | – | 522 | 4.2 |
| **TOTAL** | **2,383** | **1.50** | **643** | **3.7** |
| **Composite Mills** | | | | |
| Replacement of energy-inefficient motors with energy-efficient ones for humidification plants Total number=48; Rating=15 MW | 35 | 0.38 | 27 | 1.3 |
| Installation of energy-efficient lighting system—replacement of conventional copper ballast chokes and tube lights with electronic ballast chokes and energy-efficient tube lights. Replacement of 3000 conventional tube lights and chokes with 1130 energy-efficient tube lights and 565 electronic chokes | 14 | 0.71 | 51 | - |
| Installation of energy-efficient fans for humidification plants (along with energy-efficient motors of appropriate capacity). Total 48 fans with 340.5 kW power consumption; present fan efficiency—45%; improved fan efficiency—68% | 2 | 0.82 | 58 | - |
| Low liquor ratio jet dyeing machine | 17 | 0.16 | 21 | - |
| Energy-efficient RF dryer | 120 | 1.35 | 166 | - |
| Fourth effect caustic recovery plant | 22 | – | 38 | - |
| Energy-efficient submersible pump | 10 | 0.05 | 4 | 2.6 |
| ***Investment for long term measure*** | | | - | |
| Energy-efficient coal-fired water tube boiler with bag-filter | 611 | – | 98 | 6.3 |
| Naphtha-fired gas turbine with waste heat recovery boiler | 26,184 | – | 4,077 | 6.4 |
| **TOTAL** | **27,016** | **3.5** | **4,539** | **6.0** |

Source: ADB, 1998 and ARRPEEC, 2003. Note: kVA: kilo Volt Amps

## 5.4 Scenarios of Future Energy Use

### 5.4.1 Future Trends in Textile Production

At the end of 2004, the Agreement on Textiles and Clothing (ATC) will expire and quotas on textiles and clothing will no longer be used to govern international trade. The main drawback of the Indian textile industry is its excess capacity, lower productivity of labor and machines, lack of modernization and technological upgradation, increase of input, particularly the key raw materials, and lack of adequate working capital (ADB, 1998).

There is a shift toward the use of more capital intensive rather than labor intensive technology. Power costs are rising with more automation and higher running speeds for machines. Additionally, the production is getting more segmented, as the number of composite mills is declining in favor of separate units that are specialized in their domain. Many state of the art technology weaving units have come up in the past 5 years, based on air jet technology. These units are export oriented.

The total textile exports increased from $8.53 billion during 1995-96 to $12.10 billion during 2000-01, far from the target of $20.17 billion of the Ninth Plan (Planning Commission, 2002). The GOI considers that large investments in weaving, knitting, processing and apparel are necessary to successfully compete on cost and quality parameters in the international market. The Government of India created a Technology Upgradation Fund (TUF) in 1999 for a 5-year subsidy with interest to phase out outdated technologies and replace them with scaled up alternatives to meet the modernization needs of ailing textile units. This involves modernization assistance at advantageous interest rates. As of 31 March 2003, the Technology Upgradation Fund received 2,092 applications with projected costs of US $3,448 million and a loan requirement of US $1,978 million. More than 87% of these projects have been sanctioned with a loan accounting for a total of US $1,305 million[16]. Upgradation of the process of spinning and composite mills received the highest share, 29% and 28% respectively (Power Loom Development and Export Promotion Council, 2003).[17]

### 5.4.2 Future Trends in Energy Efficiency

Energy consumption patterns vary for different types of units and different types of products. One of the most important steps towards energy savings is to establish machine-wise and unit-wise energy consumption norms referred to as "energy labels". They display optimal and achievable level of thermal and electrical energy use per unit of product and help companies assess energy consumption before making a buying decision. Textile Research Associations (TRAs) have been set up by the Textile Ministry to carry out research and render consultancy services (quality management services - ISO-9001) to industry on various aspects of textile technology with emphasis on reducing cost,

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[16] Exchange rate as of 8th October 2004 from reserve bank of India (45.83 INR/USD)

[17] The processing of fibers received 16%, followed by weaving & knitting with 14%, and the garment sector a little less than 4% (the remaining 9% were accorded to other categories)

improving quality and durability, reducing pollution, conserving energy, utilizing waste, adopting new technology, improving technology, etc. ATIRA, BTRA, SITRA, and NITRA[18] are four main TRAs which have collaborated to produce benchmarks and standards for energy efficiency that local industry can consult. They have published several reports on improvement possibilities. They also regularly conduct energy audits in textile mills and have created databases condensing the information related to specific energy consumption (SITRA).

### 5.4.3 Summary and Conclusions

The textile industry is very fragmented and energy consumption can appear to be a minor factor at the plant level, however, the total consumption of the sector is considerable (3% of total industry). 80% of the textile sector is composed of small and medium industries making the implementation of energy conservation measures more challenging to be diffused. Initiatives have been undertaken to inform industries on energy saving measures through the development of norms, reports and audit. Theses initiatives should be furthermore fostered and diffused to contractors. The textile sector in India faces new challenges. The expiration of the ATC will intensify the competition leading to a shift towards more capital-intensive machinery. Electric energy consumption is expected to continue to rise over time due to increasing automation and higher running speeds for machines. However, the gain in productivity due to increasing mechanization will certainly overhaul the increase of electrical energy requirement. A smaller increase of energy will be required compared to the large amount of output that will be produced per unit of energy consummed. New developments also augment opportunities to spur energy conservation at the plant level. The textile sector being such a diverse industry, data collection is a challenging task. A more in-depth study to collect information on energy consumption by process and by different types of plants and a comparison with developed countries and developing counties like China would be an instructive future study. Futhermore, since the Technology Upgradation Fund has been implemented and with the expiration of the ATC, it would be useful to assess the changes in the progress of the sector.

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[18] ATIRA - Ahmedabad Textile Industry Research Association. BTRA - Bombay Textile Research Association, SITRA - South Indian Textile Research Association., NITRA - Northern India Textile Research Association.

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# 6. Chlor-Alkali

The chlor-alkali industry consists of the production of three inorganic chemicals: caustic soda (NaOH), chlorine ($Cl_2$) and soda ash ($Na_2CO_3$). Caustic soda and chlorine are produced simultaneously while soda ash is produced during a different process. Hence, this chapter on chlor-alkali is divided in two parts; the first part discusses potential energy savings in the production of caustic soda and chlorine, and the second part focuses on potential energy savings in the production of soda ash.

## 6.1 Caustic Soda and Chlorine

### 6.1.1 Caustic Soda and Chlorine Production Processes

The production process consists of applying a direct electric current to a solution called brine made of common salt dissolved in water. Chlorine is produced and collected at the negative electrode, called the cathode, and sodium hydroxide solution, also called caustic soda, and hydrogen are produced and collected at the anode, the positively charged electrode.

The inputs are primarily salt and water; acids and chemical precipitants used to remove impurities in the input brine or output chlorine/caustic soda; and cooling agents for liquefying and purifying the chlorine gas produced. The process requires a large amount of electricity for the electrolysis of brine.

Three processes are currently used to produce these products worldwide: diaphragm cell, mercury cell and membrane cell electrolysis. The oldest process is the diaphragm process. Diaphragms made of asbestos and fibrous fluorocarbon polymer separate the two parts of an electrolytic cell. The diaphragm process was superseded by the mercury cell method. In the mercury process, flowing mercury acts as cathode. In a membrane cell, the anode and the cathode are separated by an ion conducting membrane. The membrane cell process is a more recent technology; it has inherent ecological advantages over the two older processes as it does not use mercury or asbestos, and it is the most energy efficient process.

Caustic soda, chlorine and hydrochloric acid are basic chemicals and are used by many industries. Caustic soda finds application in various fields like manufacture of viscose yarn, pulp and paper, newsprint, staple fiber, aluminum, cotton, textiles, soaps, detergent, dyestuffs, drugs and pharmaceuticals, petroleum refining, etc. Chlorine is used as a disinfectant, in water treatment, pharmaceuticals, in PVC and vinyl production, etc.

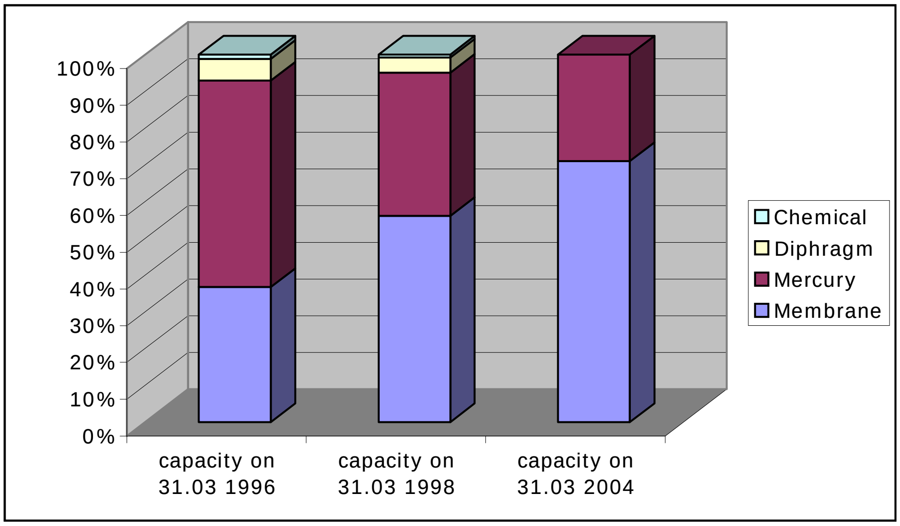
### 6.1.2 Caustic Soda and Chlorine Production in India

#### *6.1.2.1 Caustic Soda and Chlorine Industry Characteristics*

The caustic soda industry in India is approximately 65 years old. There are 40 major caustic soda plants with an average plant size of 150 tons per day (TPD), which is relatively small compared to sizes found in developed countries (500 TPD). Five large-scale caustic soda units have been commissioned since 1997. During the last 8 years, caustic soda has increased at an average annual growth of 4%. The production of Caustic Soda during the year 2003-2004 was 1,741 thousands of metric tons.

The production of caustic soda is associated with chlorine. This inevitable co-production has been an issue for the chlor-alkali industry. Both products are used for very different end uses with differing market dynamics and it is only by rare chance that demand for the two coincides. The synthesis of PVC, which uses chlorine as an input, is a major driver of chlor-alkali production in most European countries and in the US. Contrary to this tendency in industrialized countries, the Indian chlor-alkali industry is driven by the demand for caustic soda, and chlorine is considered a by-product.

**Figure 6-1. Process-wise share of installed capacity of caustic soda**



Source: AMAI, website 2004.

Over the last 8 years, India has undergone a major change in its process to produce caustic soda and chlorine. In 1996, the majority of the installed capacity used the mercury process (56%). Today India produces 71% of its caustic soda through the membrane process, and 29% through the mercury process. However, unlike most developed countries where mercury cells have been given a specified period to close down, no such timeframe has been stipulated by the Indian government (CSE, 2002). **Error! Reference source not found.** shows the distribution of installed capacity for different processes in India over the last 8 years.

### *6.1.2.2 Energy Consumption*

The raw material necessary in the production of caustic soda consisting of salt and water is abundant and inexpensive. Conversely, the electrical energy required to process salt into caustic soda and chlorine is expensive and occasionally unreliable. Energy costs represent 50 to 65% of the total cost of production (Pramanik, 2002).

Table 6-1 shows the final energy consumption in GJ per tonne of caustic soda during different production phases. The electrolysis phase is the most energy intensive. The process necessitates large quantities of direct current (DC) electric power that is usually obtained from a high voltage source of alternative current through a rectifier and involves energy losses. The mercury cell has a higher decomposition voltage and therefore requires more power than the diaphragm and membrane cells. However, the thermal energy requirement is null in the mercury process as the caustic soda solution formed is highly concentrated (50%). The diaphragm process results in a caustic soda solution with a much lower concentration of around 10%, and thermal energy is needed to evaporate and concentrate the solution to 50%. The membrane cells produce a solution of about 30-35%, requiring less thermal energy. However, the additional thermal energy requirement is not always necessary as highly concentrated caustic soda need not always be produced.

**Table 6-1. Specific Energy Consumption for Manufacturing Caustic Soda Lye***

| | **Diaphragm (1994)** | **Mercury (1999)** | **Membrane (1999)** |
|---|---|---|---|
| **Power Consumption (**kWh/t of NaOH) | | | |
| DC Power | 2561 | 2833 | 2342 |
| AC/DC losses | 107 | 160 | 104 |
| Auxiliary | 457 | 307 | 254 |
| **Thermal energy for evaporation** | 942 | | 148 |
| Total | 4067 | 3300 | 2848 |
| ***total in GJ/t* of NaOH** | ***14.64*** | ***11.88*** | ***10.25*** |

Source: TERI.

*sodium hydroxide in aqueous solution with a concentration of 48,5%

**Table** 6-42 shows the specific final energy consumption in GJ per ton of caustic soda produced over the last 20 years. As can be observed, major progress in energy consumption per unit of caustic soda product has been achieved over this period. This has been the result of various technological improvements within each type of technology and other factors such as larger sized units.

**Table 6-2. Caustic Soda Specific Energy Consumption *(in GJ/t of NaOH)***

| | **1982** | **1992** | **1994** | **1999** |
|---|---|---|---|---|
| ***Diaphragm*** | | | | |
| Final energy | 21.25 | 14.04 | 14.64 | - |
| Primary energy | 53.92 | 35.62 | 37.14 | |
| ***Mercury*** | | | | |
| Final energy | 13.16 | 15.55 | 12.36 | 11.88 |
| Primary energy | 39.48 | 46.66 | 37.07 | 35.64 |
| ***Membrane*** | | | | |
| Final energy | - | 11.65 | 10.64 | 10.25 |
| Primary energy | | | 30.85 | 29.69 |

Source: TERI

Note: Primary electricity calculated using an electricity conversion efficiency of 33%.

During the last 10 years, production has shifted to membrane cell technology. This shift, combined with technology improvements in mercury and membrane cell processes and energy conservation programs intended to reduce auxiliary and rectifiers' energy consumption, has resulted in an estimated overall energy savings of more than 10% (Table 6-3).

**Table 6-3. Evolution of Indian Average Specific Energy Consumption**

| Average consumption | 1990-91 | 1994-95 | 1999-00 |
|---|---|---|---|
| kWh/t | 3,351 | 3,130 | 2,977 |
| GJ/t | 12.06 | 11.27 | 10.74 |

Source: GOI, Ministry of Environment and forests and Teri.

This compares favorably with US specific energy consumption of about 16.8 GJ/t (Worrell et al., 2000)

Since electricity is the most important form of energy required in the process of caustic soda production, we have also indicated the specific primary energy requirement. The primary energy includes the energy necessary to produce electricity. Almost all of the energy requirement for the mercury process is electricity, which worsens its specific primary energy consumption compared to the other processes.

### 6.1.3 Future Development of the Caustic Soda and Chlorine Industry

#### *6.1.3.1 Ongoing Changes in the Caustic Soda and Chlorine Industry*

As mentioned earlier, the Indian domestic market is driven by the demand for caustic soda rather than the demand for chlorine. Because of the inevitable co-production of both products, European and North American markets are characterized by caustic soda surpluses. As India needs and imports this product, it is argued that excess production from abroad is dumped in India. In contrast, chlorine is a very hazardous product which is very dangerous to transport, meaning that export of chlorine from India to the rest of the world is difficult.

This report focuses on analysis of energy consumption in the chlor-alkali industry. However, it is worth noting that this sector is plagued with serious environmental issues. The mercury cell technology, besides consuming excessive power also causes mercury pollution. Some mercury is lost from the process to air and water and shows up in products and wastes.

#### *6.1.3.2 Potential for Energy Efficiency Improvement*

The type of process used in the production of caustic soda has a significant impact on the quantity of energy used. In that regard, India performs favorably compared to most of the industrialized countries. The geographic distribution of caustic soda processes differs noticeably worldwide. In Western Europe, the mercury cell process is still largely used, representing 55% of installed capacity, diaphragm cell process represents 22% and membrane cell process only 20%. In the US, diaphragm cell process predominates with 75%, and in Japan, it is the membrane cell process that covers 90% of installed capacity (IPPC, 2001). India went from 37% of membrane cell capacity installed in 1996 to 71% in 2004 and as a consequence has significantly lower specific energy consumption. As seen earlier, the average specific energy consumption per tonne of caustic soda in India using mercury cells is about 11.88 GJ/t and about 10.25 GJ/t when using the membrane cells (**Table** 6-4).

**Table 6-4. Comparison of Specific Energy Consumption across Technology (GJ/t NaOH)**

| | India (1999) | Best Practice New Plant India (2002-03) | Best Practice New Plant EU (2000) |
|---|---|---|---|
| Mercury cell | 11.88 | - | 11.21 |
| Membrane cell | 10.25 | 8.91* | 8.1 |

Source: TERI; IPPC, 2001, Indian Rayon Ltd.

Note: Including energy used for the evaporation process to concentrate caustic soda solution to 50%.

* We estimated the evaporation energy requirement for a 50% solution according to TERI's average data for membrane cell technology, conf Table 6-1.

In 2003, Indian Rayon Industries Ltd (IRIL) received the chlor-alkali National Energy Conservation Award from the Bureau of Energy Efficiency for its energy conservation performance. The plant commissioned in 1997 has a very low specific energy consumption of 8.91 GJ/t. The technology and principal items are supplied by the German company Krupp Uhde with engineering from Uhde India Ltd. Energy consumption represents 60% of its production cost. During the 2002-03 fiscal year, the plant invested Rs 9.5 million, which resulted in an annual savings of Rs 9.3 million in the first year. The world best practice for new plants is a plant sold by Uhde and installed in Germany; it has an electricity consumption of 2,250 kWh/t or 8.1 GJ/t of NaOH.

#### *6.1.3.3 Categories of Energy Efficiency Improvement*

Energy is used both as electricity and as heat. About half of the energy expended is converted into the enthalpy of the products. The rest is converted into heat transferred to the air in the building and the products, which have to be cooled (IPCC, 2001). Energy savings are possible by redistributing the excess heat where it is necessary. Insulation of the cells and salt dissolvers reduce the need for ventilation of the cell room and increase the amount of heat transferable.

**Adoption of membrane technology**: energy savings by adopting membrane cell plants compared to mercury are about 1.3 GJ per ton of NaOH produced. Plus, the additional thermal energy requirement for the membrane process is not constantly necessary, as concentration of caustic soda is not always needed.

**Installation of Advanced Cell Controls:** Advanced instrumentation systems such as short circuit elimination, anode control and protection devices help to operate the cells at minimum gap, thereby reducing power requirements. The range of power savings obtained by these means is above 75 kWh/t. The cost of installating such control systems depends upon the intended version (i.e. automatic, semi-automatic) and age of the plant (i.e. in the case of older cells, with fixed covers and a large number of anodes, cost of modification is very high). Realizing its importance as a potential energy saver, a few plants in the country have installed such advanced instrumentation systems and many others are intending to adopt them.

**Conversion From Rubber Lined To Bare Bottom Configuration:** Even today, many of the plants are still equipped with rubber lined cells, and hence there is scope for energy savings through their conversion to bare bottom orientation which will reduce millivolt drops and bus losses. This will reduce the cathodic mV drop to the tune of 40%.

**Revamping Of Electrical Systems:** Rectifier equipment is an important element on which power consumption depends. An old generation mercury-arc rectifier, if it exists, could be replaced with a newer generation silicon rectifier, which offers much better AC-DC conversion efficiency. Installation of correct capacity rectifiers is essential, as under-utilization of its capacity reduces transformer losses.

**Effective Utilization Of Hydrogen As Fuel:** Hydrogen gas is produced as a by-product of caustic soda; it can be captured and used as a fuel in on-site power co-generation. The heat can be used for the evaporation of caustic soda and for the preparation of the brine. Moreover hydrogen is clean fuel. The use of by-product hydrogen gas can substitute up to 35% of the total fuel requirement in a caustic fusion plant.

**Adoption Of Energy Efficient Chlorine Handling Systems**: Considerable energy savings can be achieved by revamping chlorine compressors, refrigeration systems and avoiding inefficient capacity control practices such as hot gas bypass.

**Other Alternatives:** Alternatives other than those discussed above for energy savings in the chlor-alkali industry are wide ranging, and other methods that can be used effectively are listed below:

- Brine recycling up to 40% for retention of thermal energy.
- Direct hot lye pumping to concentrator plant for heat saving.
- Minimization of exposed surface area of clarifiers and lagging of the same for surface loss reduction.
- Modifications in brine pumping system to reduce the pumping power.
- Application of modern flat belts in place of conventional V-belts to reduce transmission losses.
- Application of energy savers in drives with varying duty and machine side capacity controls.
- Application of variables speed drives for energy efficient capacity control in varying duty fans and pumps.
- Effective insulation of pipelines carrying hot cell liquor at $85^0$C from the cells to the evaporators to save about 0.3 tonne of steam per tonne of caustic soda.
- Controlling the water addition in the filters to save steam.

### 6.1.4 Scenarios of Future Energy Use

#### *6.1.4.1 Future Trends In Caustic Soda And Chlorine Production*

The change of technology to membrane cells in India is expected to continue. Table 6-3 shows the projected new development of caustic soda capacity for 2005. Two companies are expected to switch a total of 105 kt of their current mercury cell capacity to membrane cell technology. This exchange, plus new capacity will increase membrane cell technology capacity by 258 kt, reaching a new share of 78%.

**Table 6-3. New Caustic Soda Capacity Production Development for 2005 (Mt per year)**

| | **Mercury** | **Membrane** |
|---|---:|---:|
| **Current Capacity** | **628,913** | **1,545,380** |
| Bihar Caustic & Chemicals Ltd | -54,750 | 82,125 |
| DCM Shriram Consolidated Ltd | -50,735 | 73,000 |
| Kanoria Chemicals & Industries Ltd | 0 | 40,150 |
| The Andhra Sugars Ltd | 0 | 54,750 |
| The Travancore Cochin Chemicals Ltd | 0 | 8,250 |
| **Estimation of 2005 capacity** | **523,428** | **1,803,655** |
| *Share* | *22%* | *78%* |

Source: Amai 2004.

However, the sector is characterized by a low capacity utilization (68% in 2002-03), resulting from cheap imports. The domestic industry has to face high electricity prices. Current electricity tariffs in India are close to 8-9 cents per kWh, compared to power tariff levels of 5 cents per kWh, in the US for example (US EIA, 2004). As energy consumption represents 50-65% of total cost of production, the government protects the domestic industry with duties of 30% on imported caustic soda.

Technology improvement is dependent on imports, as the country is not equipped to produce the membrane technology indigenously. To support cleaner and energy efficient technologies, the government has recently brought down the customs duty on components of membrane cell technology used in the caustic soda industry from 15% to 5%**.** These factors should encourage further changeover of technology to the membrane process.

In the past few years, chlorine has become important as a principal intermediate material in the manufacture of PVC. About 11 per cent of the chlorine production is consumed by the PVC sector. In recent years India has also started to export a substantial quantity of chlorine based products, which will help improve the industry’s profitability.

### 6.1.5 Future Trends In Energy Efficiency

New developments in the production of caustic soda are expected to emerge on the market in the near future. The current technology based on cell membrane process is a mature technology, from which no significant energy savings can result from further development without a change in the fundamental approach to chlor-alkali electrolysis. A new technology called Oxygen Depolarized Cathodes (ODC) is currently developed with substantial potential energy savings of around 440-530 kWh per ton of caustic soda (1.5 to 2 GJ final energy/t NaOH) (IPPC, 2000). The new approach consists in diffusing oxygen gas through the cathode and avoids the production of hydrogen. When the hydrogen-evolving cathode is replaced by an oxygen-consuming cathode, the voltage of the cell could be reduced, in principle, by about 0.9 V (IPPC, 2000). The standard chemical reaction and the new ODC reaction are represented under the following equation:

Standard chemical reaction: $2H_20 + 2NaCl \rightarrow 2NaOH + H_2 + Cl_2$

ODC chemical reaction: $O_2 + 2H_2O + 4NaCl \rightarrow 4NaOH + 2Cl_2$

In the second equation, as no hydrogen is formed, the cell voltage is lower and so is the power consumption. Energy savings of nearly 30% are expected.

In Europe, a new plant using the ODC technology has been built in Germany at Brunsbüttel through a program of cooperation between Bayer AG, UHDENORA, a joint venture between UHDE, Dortmund, Germany, and De Nora, Milan, Italy, and De Nora North America. However this plant is using hydrochloric acid (HCl) as input instead of salt (NaCl) which results in the production of chlorine only. In the US, collaboration between Dow Chemical and Los Alamos National Laboratory with financial help from the Office of Industrial Technologies (OIT) is working on the possibility of the ODC technology transfer to industries with co-production of caustic soda and chlorine with considerable energy savings.

## 6.2 Soda Ash

### 6.2.1 Soda Ash Production Processes

Sodium carbonate or soda ash can either be obtained through a process by reacting trona (the principal ore from which soda ash is made) with water, or it can be produced by the Solvay process referred to as the synthetic process. Soda ash is then produced by reacting an ammoniacal brine with carbon dioxide to produce bicarbonate, which is then calcinated to produce sodium carbonate. About 25% of the world's production is produced from natural sodium and 75 % through the synthetic process (IPPC, 2000).

Soda ash is mostly used in the production of glass, chemical, soaps and detergents, paper and paper pulp production, and water treatment.

## 6.2.2 Soda Ash Production in India

### *6.2.2.1 Soda Ash Industry Characteristics*

The Indian soda ash industry is highly concentrated with three players accounting for nearly 80% of the total installed capacity. Plants are mostly located in Gujarat to take advantage of the availability of inputs like salt, limestone, coke, water, chemical compounds and power. Soda ash in India is not obtained as a naturally occurring product as is the case in the US for example, but is produced through a synthetic manufacturing process. Soda ash is produced by a total of 6 units with an average size of 1000 TPD. Out of the six plants, three are based on the standard Solvay process, one unit uses the *modified Solvay process* or *dual process* and the two other units use the *Akzo dry lime* process. The dual process produces soda ash in co-production with ammonium chloride, which is used as a fertilizer. The dry lime process uses dry lime instead of lime milk for ammonia recovery. This last process is considered as the state of the art technology.

In India, around 40%of the soda ash produced is consumed by the detergents industry, 20% by glass, 16% by sodium silicate, and the remainder is consumed by the chemical industry (Financial Express, 1999).

### *6.2.2.2 Energy Consumption*

The energy needs for the production of soda ash take on different forms: electrical, thermal and mechanical energy and feedstocks. Coke is used as a source of carbon dioxide in the soda ash production during the limestone calcination.

Two types of soda ash are produced: “light soda ash” with a specific weight of about 500 kg/m$^3$ and “dense soda ash” of about 1000 kg/m$^3$ (IPPC, 2004). Light soda is directly used in the detergent sector and certain chemical intermediates. The remainder is transformed by crystallization after drying to produce dense soda mainly used in the glass industry. This extra step requires further energy. Table 6-4 shows the energy requirements at different stages in the production of soda ash for the standard Solvay process and the dual process. Unfortunately, this level of detail is not available for the dry lime process. However, the basic advantage of the use of dry lime instead of milk lime is a better steam balance and the reduction in the raw material inputs, resulting in energy savings. The consumption of steam and lime is much lower as compared to other processes (India Infoline, 2002).

**Table 6-4. Specific Final Energy Consumption in Different Sections in a Soda Ash Plant (1994)**

| **(GJ/t)** | **Solvay Process** | | | **Dual Process** | | |
|---|---|---|---|---|---|---|
| Manufacturing | Thermal | Electrical | **Total** | Thermal | Electrical | **Total** |
| Limestone Calcination | 4.2 | 0.1 | **4.3** | - | - | **-** |
| Salt purification | 0.4 | 0 | **0.5** | 0.4 | 0 | **0.5** |
| Calcination of sodium bicarbonate | 4.2 | 0.1 | **4.3** | 4.2 | 0.1 | **4.3** |
| Crystallization, drying and purification | 4.2 | 0.1 | **4.3** | 4.2 | 0.1 | **4.3** |
| Ammonia recovery | 2.5 | 0 | **2.5** | - | - | **-** |
| Manufacture of ammonia chloride | - | - | **-** | - | 0.7 | **-** |
| Utilities and general requirements | 0.4 | 0.7 | **1.1** | 0.4 | 1.2 | **1.6** |
| **Total** | **15.9** | **1.1** | **17.0** | **9.2** | **2.2** | **11.4** |

Source: TERI, 1999.

## 6.2.3 Future Development of the Soda Ash Industry

### *6.2.3.1 Ongoing Changes in the Soda Ash Industry*

Demand for soda ash is mainly affected by the demand from glass industry. Demand has decreased due to the fall in demand for container glass. Bottles made of container glass are being replaced with PET (Polyethylene Terephthalate) bottles; this has affected the demand for soda ash and driven up the demand for chlorine.

One of the main specific problems of the soda ash industry in India is that most of the units are located in the western region, which has the advantage of being in close proximity to the raw material source but far from consumers. Since soda ash is a high volume low cost commodity, costs of transportation are very high. This leaves other markets like the eastern and the northern regions vulnerable to imports. Further, being a high-power consuming product, Indian producers are always at a disadvantage compared to their foreign counterparts.

### *6.2.3.2 Potential for Energy Efficiency Improvement*

Table 6-5 shows the detail of the soda ash industry plants in India. 34% of the total production capacity consists of the state of the art dry lime process, 4% the dual process and 62% the standard Solvay process.

**Table 6-5. India Soda Ash Plants Characteristics**

| Company | Location | Year | Process | Capacity | |
|---|---|---|---|---|---|
| | | | | '000 t/y | % |
| Tata Chemicals | Gujarat | 1948 | Standard Solvay | 875 | 33% |
| Saurashtra Chemicals Ltd. | Gujarat | 1960 | Standard Solvay | 650 | 25% |
| GHCL | Gujarat | 1988 | Dry lime | 525 | 20% |
| Nirma Ltd | Gujarat | 1998 | Dry lime | 365 | 14% |
| Tuticorin Alkalis | Tamil Nadu | 1982 | Dual/ Modified | 115 | 4% |
| Dcw Limited | Gujarat | 1939 | Standard Solvay | 96 | 4% |

India’s average specific energy consumption is about 13.6 GJ/t (Pramanik, 2002) (Table 6-6). The EU best available technology has a specific energy consumption of about 10.8 GJ/t according to the recent study from EU IPPC. The US specific energy consumption is very low since most of its industry uses the natural process, which is much less energy intensive.

**Table 6-6. Specific energy Consumption of Soda Ash, GJ/ton**

| | **US*** | **EU best practice** | **India** | **India Best Practice Nirma Ltd** |
|---|---|---|---|---|
| **Energy use** | 8.5 | 10.8 | 13.6 | 11.3 |

Source: Energetics , EU IPPC, Teri and Nirma Ltd.
* Energy use in Manaufacture of Soda Ash from Trona Ore (1997)

Potentials for energy savings in the soda ash industry in India are about 17%. Even though India possesses some of the best technology available, potential savings remain large and would require revamping the oldest plants. Nirma Ltd represents the best technology available in India, its specific energy consumption comes close to the EU best practice.

#### *6.2.3.3 Categories of Energy Efficiency Improvement*

Energy needs for the production of soda ash take on different forms: electrical, thermal and mechanical energies.

**Cogeneration:** (IPPC, 2004).The Solvay process requires a large amount of steam, a big part of which is used as low pressure steam, injected directly into the process for the recovery of ammonia (steam stripping). Energy savings can be realized by reducing steam pressure in a set of turbo-generators while generating electricity. This electricity is produced with a "cogeneration" of steam, with an excellent efficiency (about 90%) because all the steam leaving the turbines is used in the process. In comparison, the same quantity of energy will be generated, in a classical power station, with a much lower efficiency (about 30%) because of the lost released steam. Comparison of the primary energy needs of a co-generation unit (based on gas) - for a soda ash plant - with that required for the separate production of steam and electricity (by a classical power station for electricity and boilers for steam), shows that it is possible to achieve 30% savings with co-generation.

**Heat Recovery:** (IPPC, 2004). The recovery of heat has been gradually improved throughout the history of the process by optimizing energy fluxes of different thermal levels contained in gas and liquids flowing through the process. Low-grade heat is used to preheat different streams such as:

- raw brine entering the brine purification step to improve purification efficiency
- raw water used for milk of lime production
- boiler feed water
- mother liquor from the filtration to the recovery of ammonia by the distillation off gas.

Vacuum flashing of distillation liquor may be used for producing low pressure steam available for distillation and any evaporation units like salt production.

**Energy minimization**: (IPPC, 2004). The following techniques may be considered:

- careful control of the burning of limestone and a good choice of the raw materials allow a reduction of the primary energy necessary for the operation
- improvement of process control by the installation of distributed control systems (DCS) - reduction of water content of the crude bicarbonate by centrifugation before calcination to minimize energy need for its decomposition
- back-pressure evaporation (e.g. calcium chloride liquors)
- energy management of stand-by machinery
- equipment lagging, steam trap control and elimination of energy losses

### 6.2.4 Scenarios of Future Energy Use

#### *6.2.4.1 Future trends in Soda Ash production*

No additional capacity of soda ash is expected in the near future. In 2001-02, customs duty on soda ash was drastically reduced from 35% to 20%. This steep reduction in customs duty has adversely affected indigenous manufacturers. Recently, the GOI increased the customs duty back to 25% in order to protect domestic industry.

#### *6.2.4.2 Future trends in energy efficiency*

Potential energy savings in the soda ash industry are large, estimated at about 17%. The sector is very concentrated; only six companies produce soda ash in India, which makes the scope of the possible plants retrofit more focalized. However, the soda ash industry is rarely perceived to be an energy intensive one, and hence inadequate attention is given to its potential energy savings.

## 6.3 Summary and Conclusions

The chlor-alkali sector is a very energy intensive sector where energy represents approximately 60% of total production cost. In a country like India, where the cost of industrial electricity is high, industries using large quantities of electricity such as the caustic soda industry have been focusing more attention on reducing energy consumption. Hence some caustic soda companies are closely monitoring their energy consumption, resulting in overall moderate specific energy consumption. Internationally, India compares positively with a substantial share of membrane cell technology. Both caustic soda and soda ash production have energy saving potentials of around 17%. The main weakness in this sector seems to be its lack of indigenous technology equipment production. For example, membrane cell equipment which needs to be changed every three years must be imported. There is no indigenous producer. The potential development of the caustic soda production through the new ODC technology is gradually emerging in the market. India needs to take part in this future advancement.

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# 7. Summary and Next Steps

This report reviewed energy consumption and energy efficiency trends in five energy-intensive industrial sectors in India -- fertilizers, textiles, chlor-alkali, cement, and petroleum refining.

In each study sector, Indian industry has made strides towards reducing its energy intensity. This has happened through the use of modern best available technologies in new plants, upgradation and modernization of existing plants, and shift towards less energy intensive processes. This improvement has come about due to stricter environmental regulations as in the case of chlor-alkali production,[19] driven by economic consideration as in the use of dry cement plants, and/or being caused by government macro policy that is shifting fertilizer production towards increased use of natural gas. As a consequence of these types of changes during the last decade, Indian industry has acquired some of the best production technology, the Reliance refinery is a case in point. Its energy intensity measured by the international EII index is one of the lowest worldwide. While there is room for improving the best available technology being installed in India when compared to Europe, the marginal improvement to be made in new plants is small.

At the same time, however, these industries continue to own older plants that operate sub-par technologies with high specific energy consumption. In the case of each industry, there appears to be a potential for improvement that ranges from 15% to 35%. Tapping this potential will require the installation of new equipment, better management practices, and an integrated systemic approach to the evaluation of energy use in a plant. In the earlier chapters, we note the many industry-specific improvements that are being made worldwide, which have the potential for reducing specific energy consumption in the study sectors in India.

In industrialized countries, a recent assessment found that many policies, programs and measures are being pursued in order to improve energy efficiency in industry (Table 7-1) (Galitsky et al., 2004). The assessment found that all countries provide information through a combination of audit or assessment reports, benchmarking, case studies, fact sheets, reports and guidebooks, and tools and software on energy efficiency. Energy management assistance is provided through the use of standardized energy management systems, provision of energy awareness promotion materials, industry experts, training programs and provision of some form of verification and validation assistance for companies to help them to track and report energy use or GHG emissions reductions. Financial assistance for energy-efficient technologies or through assessments is available to industry in each of the countries examined. Target-setting, where companies or industrial sectors determine a goal for energy-efficiency improvement is done through a process of establishing visions and roadmaps as well as with negotiated agreements, which provide the framework for reporting and undertaking actions to increase energy efficiency. Awards and recognition provide positive publicity related to energy efficiency

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[19] Stricter environmental controls can also work the other way; the installation of hydrodesulfirizers to produce low sulfur fuel increases the energy consumption of refineries.

or GHG emission reduction achievements and can consist of logos, awards or articles in the newspapers or newsletters. Energy efficiency standards, such as motor efficiency standards, are used to specify mandatory minimum energy consumption levels for specific types of equipment.

A key tool for achieving improved energy efficiency is to build capacity, train, encourage, and/or mandate the *benchmarking of energy consumption* at the plant level. Benchmarking will help plant owners to realize the level of their own specific energy consumption relative to similar plants elsewhere in India and the world. A continual reminder of the cost of energy consumption will serve a means to compel plant owners and operators to take action, including adoption of energy management systems. Benchmarking is not a new idea. It has been practiced in industry for some time now. Its specific use for monitoring energy use at all levels, however, will strengthen its intent of cost reduction, and provide environmental benefits.

The Indian government enacted the Energy Conservation Act, October 2001 which became effective in March 2002. It set up the Bureau of Energy Efficiency. The Act calls for the setting up of industry-specific task forces on energy conservation. In some sectors, the BEE and others are already implementing benchmarking programs. The Bureau of Energy Efficiency is currently leading the Indian Industry Programme for Energy Conservation. The activities of this project related to the cement industry include formation of a Cement Task Force, energy audits, identification of best practices, and development of energy consumption norms (BEE, 2004). BEE has set up Task Groups for textiles, cement, pulp and paper, fertilizer, chlor-alkali and aluminum sectors. Industry members participate in this project to share information about best practices, declare their voluntary targets and adopt benchmarks for their processes. A benchmarking tool being developed through the Indo-German Energy Efficiency & Environment Project will provide cement manufacturers with information regarding their relative energy consumption level compared to their peers and to industry average (IGEEP, n.d.).

Once a facility has participated in a benchmarking exercise, it requires more detailed information about the energy savings and costs of specific energy-efficiency improvement measures that can be adopted. Information from the Indian case studies and best practice examples, combined with international information on energy-efficiency technology energy savings and costs, could be provided to Indian manufacturers in the form of an energy management guide (similar to those produced by the U.S. Environmental Protection Agency’s Energy Star Industry program) or could be integrated into a benchmarking tool in order to provide projected savings for an individual plant given the adoption of a chosen set of energy-efficient technologies and practices.

Similarly, various other activities identified in Table 7-1 could be implemented in order to accelerate the improvement in industrial energy efficiency in the country.

### Table 7-1. Industrial Energy Efficiency Policies, Programs, and Measures (Partial List) in Selected Industrialized Countries and Selected Industrial Sectors in India

| Country | Australia | Canada | Denmark | European Union | France | Germany | Japan | Netherlands | Norway | Sweden | Switzerland | United Kingdom | United States |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **INFORMATION** | | | | | | | | | | | | | |
| **Audit or Assessment Reports** | | | | | | | X | X | | X | | X | X |
| **Benchmarking** | | | X | | | X | | X | X | | | X | |
| **Case Studies** | X | X | | X | | | X | X | X | X | | X | X |
| **Fact Sheets** | X | | | X | | | | | | X | X | X | X |
| **Reports and Guidebooks** | X | X | | X | | X | X | X | X | X | X | X | X |
| **Tools and Software** | X | X | X | X | | X | | X | X | | | X | X |
| **Websites** | X | X | X | X | X | X | X | X | X | X | X | X | X |
| **Working Groups** | | X | | X | | | X | X | X | | X | | X |
| **Conferences and Trade Shows** | X | X | | X | X | X | X | X | X | | | X | X |
| **Demonstration: Commercial Technologies** | | | X | | X | X | X | X | | | X | X | |
| **Demonstration: Emerging Technologies** | | X | | X | X | | | X | | X | | | X |
| **ENERGY MANAGEMENT** | | | | | | | | | | | | | |
| **Energy Management Systems** | | | | | | | | | | | | | X |
| **Energy Awareness Promotion Materials** | X | X | X | | X | | X | | X | X | X | X | |
| **Industry Experts** | X | X | X | X | | | X | | X | | | X | X |
| **Training** | X | X | | X | X | X | X | X | X | X | X | X | X |
| **Verification and Validation** | X | X | | X | X | X | | X | X | | | | X |
| **FINANCIAL ASSISTANCE** | | | | | | | | | | | | | |
| **Financial and other assistance** | X | X | X | X | X | X | X | X | X | X | X | X | X |
| **Subsidized Assessments** | X | X | X | X | X | X | X | X | X | X | | X | X |
| **Tax Abatement for EE Technologies** | | X | X | | | X | X | X | X | X | X | X | X |
| **TARGET-SETTING** | | | | | | | | | | | | | |
| **Visions and Roadmaps** | X | X | | | | | X | X | | X | | | X |
| **Negotiated Agreements** | X | | X | | X | X | X | X | X | | X | X | |
| **AWARDS AND RECOGNITION** | | | | | | | | | | | | | |
| **Public Recognition** | X | X | | X | X | X | X | | | X | | | X |
| **ENERGY EFFICIENCY STANDARDS** | | | | | | | | | | | | | |
| **Motor Efficiency Standards** | | | | | | | | | | | | | X |

## 7.1 References

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