PROMOTION OF BIOMASS COGENERATION WITH POWER EXPORT IN THE INDIAN SUGAR INDUSTRY

Scott M. Smouse and Gary E. Staats
United States Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, PA, USA

S.N. Rao
Burns & Roe Services Corporation
Pittsburgh, PA, USA

Richard Goldman and David Hess
United States Agency for International Development
Office of Energy, Environment & Enterprise
New Delhi, India

ABSTRACT

To meet the India's projected power demand over the next 25 years, over 300,000 MW_e of new generating capacity will need to be installed. Cogeneration, the combined generation of steam and electricity, is an efficient and cost-effective means to save energy and reduce pollution. Many studies around the world have identified sugar mill cogeneration as an attractive low-cost option to place additional generating capacity on the grid. Most studies estimate the cogeneration potential of India's sugar industry at around 3500 MW_e.

The United States Agency for International Development (USAID) has implemented a Greenhouse Gas Pollution Prevention (GEP) Project to assist in the direction and pace of India's power sector development. This seven-year, $19 million effort is funded through the United States' contribution to the pilot phase of the Global Environmental Facility (GEF). The GEF's mission is to assist developing countries in investing in environmental protection initiatives that yield global benefits in terms of reduced or avoided greenhouse gas emissions. Technical aspects of the GEP Project are being managed by the United States Department of Energy's Pittsburgh Energy Technology Center. The objective of the Advanced Bagasse Cogeneration (ABC) Component of the GEP Project is to promote year-round cogeneration in Indian sugar mills with power export. The structure of the ABC Component, which is implemented through technical assistance and investment subcomponents, and the status of various activities are reviewed. Also, sugar production and economics are reviewed from both a global and local perspective to reveal how they impact the potential for cogeneration projects in Indian sugar mills. Progress in the Indian sugar industry should pave the way for cogeneration projects in other industrial sectors, such as paper, chemicals, and textiles. Contributions from these sectors are important if India is to meet its huge power generation needs.

INTRODUCTION

India, with a total population of about 920 million, has a burgeoning middle class that is nearly as large as the total population of the United States — 250 million. This middle class is driving India's future with regard to power generation and the environment. With an annual per capita generation of only 300 kWh, India's power generation needs are very high even in comparison to other fast developing countries (such as China and Mexico, which annually generate about 550 and 1450 kWh/person, respectively) (1). If such countries develop generation capabilities approaching that of the developed countries (U.S.: 12,250 kWh/person/yr, and most European countries: 2500-8000 kWh/person/yr), the resulting impact on the global environment will likely be severe.

Electricity supplies about 14 percent of India's total energy needs (2). As of 1990, about 80% of the country was electrified (2). Thermal units, which are nearly all coal fired, represent about 70% (57,000 MW_e) of India's total generation capacity of about 82,000 MW_e (2-5). Despite significant investments by the government in all of the previous five-year plans, the gap between peak demand and supply in India for all forms of energy, including electricity, has increased and is likely to widen further in the near future. Recently, the growth in India's electrical demand has been about 10-13% per annum; however, supply has grown only between 5-10% per annum during the same period (2, 6). India's current peak generation capacity falls short of peak power demand by about 23%, which is up sharply from the shortages of 19% in 1992 and 15% in 1991 (6,7). Regional power shortages have been much higher — as high as 34% (6,7). The Central Electricity Authority forecasts that India will need a total generating capacity of about 386,000 MW_e by 2020 — an addition of over 300,000 MW_e in less than 25 years (8). The capital cost of this expansion has been estimated at $390 billion (8). However, the transmission and distribution networks required to deliver this power brings the total capital required to nearly $800 billion (8). It has been estimated that as much as 56,800 MW_e of the 142,000 MW_e of the new generation needed by 2005 will be in the private sector (3). The private sector must increase its participation in the development of all viable generating options within India because the capital requirements necessary to meet the country's power sector goals are beyond the government's capabilities. All power generation options, including biomass-based technologies, need to be fully exploited where economically and technically feasible. With its large coal reserves, India will continue to rely on conventional coal-based power generation technologies to meet most of the country's future power generation needs. However, nonconventional power sources, such as biomass, wind, and solar, are expected to provide small, but regionally important contributions, to the country's power supply.

Cogeneration — the combined generation of steam and electricity — is an efficient and cost-effective means to save energy and reduce pollution. Cogeneration, or combined heat and power (CHP), can result in primary fuel savings of 35% for a typical system as a result of the increased efficiency of a CHP system, which may be as high as 85%, compared to separate generation of steam and power. Despite the obvious advantages of cogeneration, it remains an untapped potential in most countries, including India. For example, CHP accounts for just 6% of total electricity production in the European Union; although about 30% of total electricity production in Denmark, the Netherlands, and Finland is cogenerated (9). About 7% of total electricity generated in the U.S. is cogenerated (10)

Several studies in India, and other parts of the world, point to the sugar industry as a prime candidate for supplying low-cost, nonconventional power via cogeneration. The advantages of sugar mill cogeneration include relatively low capital cost requirements and the use of a renewable, indigenous waste as a "non-polluting" fuel. Furthermore, the number and size of Indian sugar mills are sufficient to make a measurable contribution to local power supplies. India has been estimated to have a total industrial cogeneration potential of about 18,000 MW_e but only about 8000 MW_e has been developed to date (3). The sugar industry alone has been estimated to have the potential for 1500-4000 MW_e, with most estimates around 3500 MW_e (6,11-14). In a study conducted by Maharashtra's Commissioner of Sugar, the estimated capital investment to implement cogeneration with power export in the state's existing sugar mills was estimated at $567/kW; for the planned new mills, the incremental investment was estimated at only $320/kW (6). Most studies estimate the total capital cost of new sugar mill cogeneration projects at less than $900/kW (11), which is substantially lower than that for new coal-fired power generation.

WORLD AND INDIAN SUGAR INDUSTRY STATISTICS

World Sugar Industry

There are two main types of sugar-yielding plants in the world: cane and beet. Both produce the identical refined (centrifugal) sugar product when processed. Cane, which accounts for 65-70% of world sugar production, is a bamboo-like grass with a fibrous stem that is grown in semi-tropical regions. Sugar beets are grown in more temperate climates.

World sugar production and consumption for 1995-1996 are projected to reach record levels of 119.0 million metric tons (130.9 million tons) and 118.1 million metric tons (129.9 million tons), respectively (15-19). World sugar projections for 1995-1996 are about 3 percent higher than the output of the previous year and about 1 percent higher than the previous record of 116.4 million metric tons (128.0 million tons), which was set in 1991-1992 (15-16). Over the last decade, the growth in global sugar consumption has been about 1.2 percent per year, which is down from about 2 percent during the previous decade (15-16). However, world consumption is forecast to rise a robust 3.5 percent over the next year because the rapid declines in consumption associated with the economic turndowns in the countries of the former Soviet Union and Central Europe appear to have ceased and consumption has either stabilized or is starting to rise (16). The world's largest producers of centrifugal sugar are listed in Table 1 (18). About one-third of the world's centrifugal sugar production is in four countries (India, Brazil, the United States, and China); an additional one-third is grown in the next four largest producers (Thailand, Australia, France, and Mexico) (17-18). Table 2 lists the world's largest producers of sugar cane. India and Brazil are easily the world's largest cane growers at 146.0 and 125 million metric tons (160.6 and 137.5 million tons), respectively.

World sugar production is very dependent on weather and the global demand-supply balance, which dictates free market pricing. The free market for sugar is classified as a "residual market" — a market in which the freely traded product is only a residual of the world's total production (19). Because the free market for sugar is typically only 20-25% of world production (15-17, 19), a 5% change in production can represent a 25-35% change in free-market sugar supply (19), which is one of the reasons for the high historical volatility of sugar prices. During 1995-1996, world exports are expected to total about 31 million metric tons (34 million tons) (17). As shown in Table 1, only a few countries produce enough excess sugar to export large amounts of sugar (17). Half of the world's traded sugar is exported by four countries: Brazil, Thailand, Australia, and Cuba. The productivity of these countries can significantly affect world free-market sugar supply and price. This is particularly true of Brazil, the world's largest sugar exporter in 1995-1996 at an estimated 4.8 million metric tons (5.3 million tons) (17). Over half of Brazil's sugar cane is used to produce fuel alcohol for transportation uses (15-16). Shifts in production between alcohol and sugar can affect the amount of sugar that Brazil exports, which affects world free-market supply. Brazil's estimated sugar production for this year (1995-1996) is up 5 percent over last year to a total of 13.6 million metric tons (15 million tons) because less cane is being used for alcohol production (17-18).

Sugar demand has been historically price inelastic, with consumptions levels showing little response to changes in price (15,16,19). From the end of World War II until the early 1970's, world sugar prices remained generally below 22 cents/kg (10 cents/lb). In 1973, however, low sugar stocks and production levels, rising consumption, and accelerating world inflation caused sugar prices to soar. By the fall of 1974, prices had peaked at $1.45/kg (66 cents/lb). The traditional inelasticity did not hold as sugar users reacted to the high prices causing consumption levels to fall. Before long, increased production, decreased consumption, and the greater use of other sweeteners pulled prices back down to their pre-1973 levels. An imbalance between world production and consumption in 1980 sent prices skyward again — from around 33 cents/kg (15 cents/lb) at the beginning of the year to about 99 cents/kg (45 cents/lb) in the fall. By the next year, however, prices had fallen back to their previous level of about 17 cents/kg (8 cents/lb). Ample supplies and market uncertainties yielded sugar prices in the range of 4-35 cents/kg (2-16 cents/lb) over the next few years. Free-market raw sugar prices have ranged from a low of about 13 cents/kg (6 cents/lb) during 1985-1987 when world sugar stocks were built up to a high of about 31 cents/kg (14 cents/lb) in 1989-1990 and 1994-1995 (16-17) when stocks were drawn down. The last major price hike occurred in 1981-1982 when world prices averaged about 51 cents/kg (23 cents/lb). Recent raw sugar prices have been about 13 cents/kg (12 cents/lb).

After analyzing world sugar prices for the past decade, the U.S. Department of Agriculture concluded that the conditions leading to past major price spikes have largely been eliminated since 1982 (15). This conclusion was reached by considering that: (1) the bulk of import demand is no longer from high-income, price-inelastic countries but from poorer, price-elastic countries, (2) corn and high-intensity (i.e., artificial) sweeteners are now viable substitutes in many countries, which has greatly increased the price elasticity of sugar demand, and (3) policy reform has occurred in many countries, which has increased price transmission to internal markets. Previous world sugar price spikes led to expansion of global sugar capacity, which was subsequently followed by periods of relatively low prices until production and consumption regained balance and prices increased. Fluctuations in world sugar prices have historically resulted in short-term drops and spurts in sugar production around the world, including India. In the past, such fluctuations made it difficult to evaluate the viability of sugar mill operations around the world. Stabilization of world sugar prices (in a reasonable price range) clarifies the long-term economics of specific projects and thus, support the development of sugar mill cogeneration projects with power export.

Indian Sugar Industry

As shown in Tables 1 and 2, India is the largest producer of sugar cane and sugar in the world accounting for about 13% of world sugar production (6,17,18,20,21); India does not grow sugar beets commercially (18-21). About 50% of the cane produced in India goes into making refined mill (i.e., centrifugal) sugar, while most of the balance is processed into traditional crude sugar forms (gur and khandsari) (18,20,21). Including khandsari, a traditional brown centrifugal sugar, centrifugal sugar production annually consumes 55-65% of the cane grown in India (20,21). About 30% of remaining cane is used to produce gur and the balance is used for other purposes (20,21).

Sugar cane is cultivated in many of India's 25 states and 7 union territories; however, production is centered in nine states: Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Maharashtra, Punjab, Tamil Nadu, and Uttar Pradesh (6, 12-14, 20, 21). Roughly half of India's land is used for agriculture, a figure exceeded only by Bangladesh among the world's major developing countries and far higher than the world's average of 11 percent (22). Currently, 3.87 million hectares (9.56 million acres) of land are under sugar cane cultivation in India (20, 21). and, as shown in Table 3, over half of this total is in Uttar Pradesh (23). As shown in Table 3, nearly 70% of land under sugar cane cultivation in India is concentrated in only three states: Uttar Pradesh, Maharashtra, and Tamil Nadu (6, 13, 14, 21); nearly half of the total is in Uttar Pradesh. Although complete data was found only for the 1989-1990 season, the ranking and relative contribution of these states to total production is about the same today. Across India, the amount of land used to cultivate sugar cane is growing annually at about 7% per year, with Maharashtra nearly doubling the national rate at about 13% per year (14,21). This increase is often at the expense of other agricultural crops, such as grains (21).

Annual statistics on India's sugar cane cultivation and sugar production are given in Table 4 (22, 21). As shown in Table 5, the national average yield of sugar cane has remained steady in recent years at about 66 metric tons/hectare (29 tons/acre) (18, 20, 21), which is slightly higher than the world average yield of about 62 metric tons/ha (27 tons/acre) for 1995-1996. National sugar cane yields around the world range from about 25 to 110 metric tons/ha (11 to 48 tons/acre). However, regional cane yields within India vary considerably. For example, during the 1991-1992 season, Tamil Nadu exceeded the national average of 172 cane-crushing days by 32 days, while also enjoying a yield of 101 metric tons/hectare (45 tons/acre) — a yield more than 50% higher than the national average (13). Although the length of the cane crushing season varies from state to state, and from year to year, depending on weather conditions, it typically runs from October/November to May and is 170-200 days long (6, 11, 13, 14, 21). This year, the recovery of sugar from cane is expected range from about 7.5% to 13% in various countries; India's recovery rate is estimated at 11.3%, which is slightly higher than the estimated world average of 10.7% for this year (18).

Indian sugar production rose significantly during the last decade and, as shown in Table 5, production has been generally increasing in recent years to match the rise in domestic consumption of 3-5 percent per year (6, 17). In 1990-91, about 240 million metric tons (265 million tons) of sugar cane were processed in about 450 mills to produce about 12 million metric tons (13 million tons) of sugar (6, 17, 18, 20, 21). However, a drop in world sugar prices as a result of oversupply caused India's cane and sugar production to drop for the two seasons following the 1990-1991 season. A number of factors caused sugar cane and sugar production to rebound in 1994-1995. During this season, cane production hit a record of 259.4 million metric tons (285.3 million tons), which was a 13% increase over the prior year's level (17, 18, 20, 21). Centrifugal sugar production also hit a record of 16.35 million metric tons (17.98 million tons) — a 40% increase over the prior year's yield (17, 18, 20, 21) . Factors contributing to the record production include: (1) firm sugar prices enabled the mills to pay outstanding appears to cane farmers, which subsequently increased mill deliveries of cane; (2) the reduced demand for gur by consumers and the reduced demand for khandsari by the alcohol industry made more cane available for centrifugal sugar production; (3) central and state government incentives increased the amount of land under cane cultivation (about 10% higher in 1994-1995 than in 1993-1994, as shown in Table 5); (4) favorable weather conditions improved cane yields (from about 67 mt/ha in 1993-1994 to 69 mt/ha in 1994-1995, as shown in Table 5); and (5) new sugar mills, which were licensed in the late 1980's and early 1990's, came on line with improved efficiency and greater cane crushing capacity.

However, India's sugar output is forecast to drop during the 1995-1996 season to 15.15 million metric tons (16.67 metric tons), which is down 1.2 million metric tons (1.3 million tons) from the record production in 1994-1995 (17, 18, 20, 21). This drop is attributable to several factors, including: (1) mounting sugar stocks are depressing prices and causing mills to delay cane payments to farmers and (2) the near-month delay in the onset of the 1995 monsoon in many areas coupled with erratic rainfall in the important cane growing areas of Maharashtra and Karnataka is expected to hurt cane yields. Also, government policy changes, including not renewing incentives because of rising stocks, are expected to negatively impact sugar production (16, 17, 21).

After importing 1.5 millions metric tons (1.65 million tons) in 1993-1994 and 600,000 metric tons (660,000 tons) in 1994-1995, India is expected to return as a net sugar exporter in 1995-1996 (17, 18, 21). Since 1994, the Indian government has permitted duty-free sugar imports under Open General License, which means that any organization can import sugar (21). However, sugar exports, except for quota deliveries to a few countries, have been banned but the government expected to allow limited exports in the near future because of the increased availability of sugar (21). After falling to nearly zero in 1993-1994, sugar exports have rebounded to their previous levels. Exports in 1995-1996 are expected to total 700,000 metric tons (770,000 tons) (17, 18, 20, 21). Recently, Indian sugar mills have been pressuring the government to increase exports and eliminate imports because of the country's rising level of sugar reserves. In response to industry concerns of potential oversupply, the Indian government decided to cancel contracts for imported sugar at the end of 1994-1995 season. As shown in Table 5, India imported sugar during 1993-1995 when the cost of domestic production exceeded the world's free-market price for sugar. With stable world sugar prices and price supports from the central and state governments, India does not expect to import sugar this season (1995-1996) (16, 17, 21).

SUGAR MILL COGENERATION IN INDIA

As in mills around the world, the principal fuel used to raise steam in India's sugar mills is bagasse. Bagasse is the fibrous waste that remains after recovery of sugar juice via crushing and extraction. The fiber content of sugar cane varies somewhat but averages about 15% on cane, which is equivalent to approximately 30% by weight of the cane on a mill-wet basis (48-52%) (6, 13, 14). The gross heating value of mill-wet bagasse is approximately 2300 kcal/kg (4100 Btu/lb) — one ton of bagasse is equal to about two barrels of oil on an energy basis. Based on Table 5 data, sugar production in India yields 70-80 million metric tons (77-88 million tons) of waste bagasse each year.

In recent years, the use of bagasse as a raw material in the pulp and paper industry has been growing. Bagasse also has other uses, some of which are limited, including use as a wood substitute in the manufacture of particle board, as a feedstock for furfural (a solvent for nitrocellulose and for manufacturing plastics and dyes), and as an animal feed (13, 24). Depending on the technology deployed, and the corresponding efficiency, about 75-90% of the bagasse available at Indian mills is used to produce internal steam and electricity; the balance is considered surplus and is either discarded or used for other purposes (6, 13). The availability of surplus bagasse, or other fuels, is a major issue when considering year-round cogeneration with power export to the grid. Bagasse generation data for a typical Indian sugar mill with a crushing capacity of 5000 metric tons/day (5500 tons/day) is given in Table 6 (6).

Various references indicate that there are between 400-500 mills currently in operation in India (6, 11, 13, 14). Using the highest figure of nearly licensed 500 mills, nearly 300 are owned by farmer cooperatives, approximately 125 are privately owned, and approximately 60 are owned by various state governments (6). The crushing capacity of Indian sugar mills ranges from about 1000 to 8000 metric tons per day (TPD) (1100 to 8800 tons/day) of cane (6, 11, 13, 14). Most mills have a capacity of less than 2500 TPD (2750 tons/day); the average size is under 2000 TPD (2200 tons/day) (6, 11). There are over 50 mills in India with a capacity greater than about 5000 TPD (5500 tons/day) (11). Since 1987, a minimum capacity of 2500 TPD has been imposed for new mills and incentives have been created for mill expansion up to 5000 TPD (13). In terms of the standard "2500-TPD equivalent" mill, about 360 will be in operation by the 1996-1997 season (13).

Figure 1 shows the current design of a representative boiler and power generation system found in a typical Indian sugar mill (6). Prior to the mid-1970's, the steam pressure used in the majority of boilers located in Indian sugar mills was in the range of 10-15 ata, which subsequently increased to the prevailing average of 21 ata (6, 14). Most existing mills, which process less than 2500 TPD, employ 440-volt turbine-generator (TG) sets capable of producing 1.5, 2.5, or 3.5 MW_e, which meets the mill's internal needs (11). The majority of the boiler systems in Indian sugar mills operate at a pressure of 21 ata and temperature of 340°C, although some mills employ 14 ata/265°C or 32 ata/380°C steam systems (6, 13, 14). Steam consumption in Indian sugar mills is as high as 50-55% on cane (i.e., mass of steam as a percentage of the mass of cane processed) compared to as low as 40% in modern sugar mills, such as those in Hawaii, USA (6, 13). Boiler and turbine generator data for the typical Indian mill shown in Figure 1 are given in Table 7. In the mid-1980's, a few Indian mills installed higher pressure (42 ata) boilers (6, 13). The decision to install higher pressure boilers is largely dependent on two technical issues: (1) the availability of high-pressure boilers and turbine-generators in the local market and (2) the confidence of the mill's staff in operating and maintaining higher pressure systems (6). Using bagasse as their primary fuel, most mills have boilers with step-grate/horse-shoe furnaces equipped with air heaters. Bagasse drying, which increases boiler efficiency by reducing stack losses, is not practiced in India (14).

Many Indian sugar mills have recognized the potential for the profitable generation of excess power (i.e., greater than the internal needs of the mill) via cogeneration. Also, many of the State Electricity

Boards (i.e., the state-owned utilities) are looking to the sugar mills as economical power sources to meet the growing national demand. As a result, optimum utilization of bagasse and steam within the mills has taken priority. Thus, sugar mills have started looking at alternative schemes to increase power generation. Figure 1 shows typical in-season and off-season operations for an existing Indian sugar mill that produces 7.5 megawatts of power with no power export. Note that the mill does not operate in the off season. One alternative scheme to produce additional power (32 MW_e instead of the current 7.5 MW_e) for export and potential year-round operation is shown in Figure 2. By converting to systems operating at 65 ata/480°C, a mill can generate surplus power economically that can be exported. With a higher pressure system, a typical 2500-TPD mill can generate about 11 MW_e of power of which 8 MW_e is surplus to the needs of the mill and could be supplied to the grid or an nearby industrial customer (11). A few industrial plants in India currently wheel excess power through the grid; a similar approach can be pursued by the sugar mills. Larger mills of 5000 TPD capacity can be configured to produce 35-50 MW_e of which 20-35 MW_e could be exported (11).

Based on other regions of the world, such as Hawaii, USA, where sugar mill cogeneration of 60-80 kWh/metric ton of cane has been achieved, the potential for cogeneration in Indian sugar mills is significant (6). Although the larger mills offer the greatest potential for cogeneration, regionally significant additions to the power grid can be accomplished via cogeneration even in smaller mills. A recent study sponsored by the Asian Development Bank suggests that mills crushing at least 200,000 metric tons/year (220,000 tons/year, or about 1100 TPD, or 1200 tons/day, based on an annual crushing season of 180 days) of cane in at least one recent year could consider cogeneration investments (13). This study concluded that with highly efficient mill operations (i.e., at a steam/cane ratio of about 45%) and using high-pressure steam (42 or 62 ata) systems, the potential for sugar mill cogeneration in India is about 2800 MW_e in 1996-1997. At more modest conditions (i.e., at a steam/cane ratio of about 55% and using lower pressure boilers), the potential was estimated to be about 1400 MW_e in 1996-1997. In this study, 174 sugar mills located in the nine primary sugar-producing states were thought to have cogeneration potential. The majority of these mills are located in the three largest sugar-producing states: Maharashtra (55 mills), Uttar Pradesh (51 mills), and Tamil Nadu (24 mills). Other recent studies peg the cogeneration potential of Indian sugar mills at higher levels. The Government of India's Ministry of Non-Conventional Energy Sources (MNES) estimated the total cogeneration potential within the sugar industry at 3000-3500 MW_e (6, 12). A study by the U.S. Agency for International Development (USAID) estimated the total potential at 3800 MW_e (6). Many factors enter into these estimates, including estimates of current and future cane production and prices by locality, the current design and status of the mill (thus its potential for upgrading), the differing local fiber content of the cane (which determines the bagasse yield and, thus the amount of fuel available), the availability of other fuels (such as other biomasses and/or coal) to supply energy for year-round power production, and issues related to interfacing with the local grid.

The recent USAID study of Indian sugar mills evaluated the general ability of Indian industry to supply the equipment and instrumentation needed to produce surplus steam and power within the mill via cogeneration such that power can be exported to the grid (6). The study found that Indian boiler manufacturers can supply reliable steam generators that operate at pressures of 42 ata and higher. While the requisite boiler technology is available, Indian progress towards developing efficient steam turbines in the appropriate size range (1-5 MW_e) for the smaller mills, which operate with low-to-medium steam throttle pressures, has lagged that of other countries. This is not a major issue because cogeneration with power export will likely be pursued in the larger mills, which require larger turbines. Larger turbines, which are often produced in technical collaboration with foreign firms, are generally available.

The conventional turbine technology deployed in Indian sugar mills has been back-pressure systems, which are usually single or multistage axial types of local origin. These turbines have relatively poor conversion efficiencies in the range of 55 to 65%. The average steam consumption per kWh in Indian mills is 10-12 kg compared to 7-9 kg in the modern sugar mills located in Hawaii, USA. Moreover, with only a few steam turbine manufacturers in the country, the mills have to contend with long lead times for delivery, typically in excess of 18 months, and generally unsatisfactory levels of performance and service. Extraction condensing turbines are more appropriate than back- pressure turbines to maximize power production and provide performance flexibility over a wider range of operational conditions. Also, the indigenous industry is not fully ready to supply and service all of the equipment and instrumentation necessary for reliable, efficient cogeneration, such as automatic combustion control systems with load following features and high-efficiency systems that are dual- or multi-fuel (bagasse with other biomasses and/or coal) fired.

COGENERATION ISSUES IN INDIA

Industrial cogeneration has been the subject of considerable interest in India for over a decade (6). In general, cogeneration in India has been restricted to the production of electricity for self use (i.e., captive power) and has been viewed as a means to meet simultaneous on-site needs for heat and power independent of the grid. Many Indian industries, including the sugar, pulp and paper, and textile industries, have been cogenerating steam and electricity for many years. In these industries, cogeneration has been favored for several reasons: (1) these industries have significant simultaneous steam and power requirements, (2) by-products or wastes are produced in these industries that can be used as low-cost fuels, (3) many of the plants in these industries are located in areas not connected to the grid, and (4) the industries want to insulate themselves from undependable utility supplies and lower their plant operating costs.

The main arguments for cogeneration in India have centered on two compelling issues: cogeneration is a relatively inexpensive means to augment conventional power supplies and energy conservation via cogeneration can reduce costs, and possibly increase profits, while reducing or avoiding the pollution attendant with fossil fuel utilization. The need for electrical power in India clearly justifies industrial cogeneration where technically and economically feasible. The major obstacles to be overcome before cogeneration in India’s industrial sector can be effectively exploited relate primarily to issues with power purchase agreements between the cogenerators and the local utility (6). Establishment of a firm purchase power price over the project’s life is the principal issue affecting cogeneration economics. Other issues that need to be resolved between potential industrial cogenerators and the utilities include: (1) the absence of regulatory incentives for the utilities to purchase private power, (2) utility apprehensions regarding the reliability and availability of privately generated power, and (3) grid synchronization. Some of the issues facing potential cogenerators include: (1) securing the capital and financing required to implement cogeneration projects, (2) the lack of institutional resources to assess cogeneration project feasibility, (3) the lack of project development and cogeneration experience, and (4) securing adequate fuel supplies for year-round cogeneration. Although, recent policy changes by the Government of India encourage greater participation by the private sector in electricity generation through modifications of the financial, administrative, and legal framework controlling the sector (6), it will take time before biomass cogeneration with power export to the grid can be realized.

USAID GEP PROJECT

GEP Project Overview

The United States Agency for International Development (USAID) has implemented a Greenhouse Gas Pollution Prevention (GEP) Project to assist in the direction and pace of India's power sector development. This seven-year, $19 million effort is funded through the United States' contribution to the pilot phase of the Global Environmental Facility (GEF). The GEF's mission is to assist developing countries in investing in environmental protection initiatives that yield global benefits in terms of reduced or avoided greenhouse gas emissions. The GEF was established in cooperation with the United Nations Development Programme (UNDP) and the World Bank following the 1991 environmental summit held in Rio de Janeiro, Argentina. Technical aspects of the project are being managed by the United States Department of Energy's Pittsburgh Energy Technology Center (USDOE-PETC) through a Participating Agency Service Agreement (PASA) with USAID-India.

The GEP Project has two components: (1) Efficient Coal Conversion (ECC) and (2) Advanced Bagasse Cogeneration (ABC). The ECC Component will demonstrate state-of-the-art approaches to improve the thermal and environmental performance of existing coal-fired power stations through the Centre for Power Efficiency and Environmental Protection (CenPEEP), which was established recently by the National Thermal Power Corporation (NTPC), the central government utility. Eventually, CenPEEP will support all Indian utilities on a cost-recovery basis by providing services in power plant life extension, preventive maintenance, environmental monitoring and compliance, and ash management/utilization. The ABC Component of the GEP Project concentrates on the year-round (i.e., minimum of 270 days) use of biomass fuels for efficient cogeneration in the Indian sugar industry. The project will work with Indian sugar mills to promote cogeneration with year-round export of power to the grid by supplementing their traditional fuel, bagasse, with other biomass fuels, such as cane trash and rice hulls.

The ABC Component activities build upon prior work by USAID and other U.S. and Indian organizations Specifically, the USAID-India study on cogeneration in the Indian sugar industry, the MNES's National Bagasse Cogeneration Program, and the UNDP's Maharashtra Bagasse Energy Efficiency Project provided a solid foundation for ABC activities. Component activities will focus on studying, promoting, and investing in cogeneration projects that use alternative biomass fuels during the off season. This will enable Indian sugar mills to cogenerate year-round without resorting to greenhouse gas-producing fuels, such as coal.

There are two subcomponents within the implementation of the ABC Component: (1) technical assistance (TA), which is funded at about $2.8 million and (2) investment (INV), which is funded at about $8.0 million. The ABC-INV subcomponent, which is being implemented by the Industrial Development Bank of India (IDBI), will provide project financial assistance (FA) grants for sugar mill cogeneration schemes that operate year-round on bagasse and other biomass fuels. PETC's activities are associated with implementation of the TA subcomponent and technical portions of the INV subcomponent of the GEP-ABC project.

The primary objective of the ABC Component is to reduce CO_2 emissions per kilowatt hour of electricity generation from bagasse and encourage the use of alternative biomass fuels during the off season (instead of fossil fuels) in high-efficiency cogeneration plants. USAID-India will achieve this objective by increasing the awareness of the advantages of sugar mill cogeneration by making available technical and economic information on cogeneration, along with practical examples of the applicability of state-of-the-art sugar mill cogeneration technologies to utilize both bagasse and alternative biomass fuels. ABC-TA subcomponent activities include project development assistance; research and development on biomass collection, storage and handling; technical and management training; and conduct of workshops and seminars. Project outputs for the ABC-TA subcomponent include results of research and development activities on bagasse collection, handling, and storage; regional fuel supply assessments; establishment of a research consortium for cogeneration project developers; project promotion; and project analysis and technical studies.

Combustion of bagasse to generate steam and power for internal requirements has been practiced for a long time in Indian sugar mills. While mill operators are becoming increasingly aware of the benefits of generating excess electricity, greater access to technical data is required for them to commit to projects. In particular, the mills are skeptical of burning other biomass fuels during the off season. This project will seek to increase awareness of the benefits of cogeneration and promote cooperation between Indian sugar mills and the State Electricity Boards.

<u>ABC Component Plans</u>
There are four major activities in the implementation of the ABC Component of GEP Project:

- Project Development Assistance
- R&D in Biomass Collection, Storage, and Use
- Data Base and Awareness Development
- Professional Development

<u>Project Development Assistance (TA and FA)</u>: ABC Component activities include working with sugar mill project developers to assess the technical, economic, and social aspects of each project before implementation. It is expected that many project-specific issues will arise, particularly in terms of the impact on the local workforce and the availability of alternative fuels during the off season. As part of the TA subcomponent, up to twelve projects will be assisted in developing feasibility reports. Five of these projects, which are further along in their development cycles, will receive investment support up to about 10% of the total required project investment, provided that they are designed to use excess bagasse and other biomass fuels during the off season. The project reports from these studies will be widely distributed and compiled to create a handbook so that other sugar mills can benefit.

<u>R&D in Biomass Collection, Storage, and Use</u>: Many potential biomass feedstocks are unwieldy to collect and require considerably more storage space. In many instances, their storage and handling

difficulties may outweigh their fuel value. Some ABC Component activities will explore solutions to these problems through matching grants (MG) of up to $25,000 with a minimum of 50% cost share by the proposer on the total project. In addition, a consortium will be created through which sugar mill cogeneration operators can share their findings and pool resources to solve common technical problems.

<u>Data Base and Awareness Development</u>: Periodic seminars, workshops, and conferences will be held during all the phases of the GEP Project. Furthermore, most sugar mill operators in the country will be contacted during the first two years of the project to increase awareness of the ABC Project. Major operators will receive on-site presentations if requested.

<u>Professional Development</u>: Another important ABC activity is to increase the number of professionals trained in developing, financing, maintaining, and managing sugar-mill cogeneration facilities. Specialized workshops and plant site visits will be held on a regular basis to train staff in issues such as biomass fuel management; equipment selection, installation, and maintenance; negotiation of power purchase agreements with State Electricity Boards; project finance; and cogeneration project development. In addition, funds will be available for developers to participate in study tours of existing modern sugar cogeneration facilities in the United States and elsewhere. Relevant training courses will be developed and held if determined necessary.

<u>ABC Component Status</u>

Significant activity within the ABC Component started during mid-1995 and progress has been made in several activities. Over 300 sugar mills were contacted in 1995 to inform them of the project's activities, including plans for issuance of a request for proposals (RFP) for technical and financial assistance grants to sugar mill cogeneration projects with power export, and matching grants for biomass research and development activities. Several representative sugar mills were visited by project personnel to ascertain the sugar industry's needs and requirements. A RFP, which was developed by IDBI, USAID-India, and PETC, was issued at the end of November, 1995 by IDBI.

Workshops were held during December, 1995 at three strategic locations: Pune, Lucknow, and Madras. Background information on the GEP Project, including details on the active ABC Component RFP, were provided. The workshop participants, who totaled over 400, overwhelmingly expressed their interest in the ABC Component of the GEP Project. Workshop participants included representatives of several State Electricity Boards, who explained their power buy-back schemes and power wheeling mechanisms.

Over 30 proposals were received by the closing date for the RFP (February 29, 1996). Twelve of the proposals requested financial assistance, but three of these were considered as either nonresponsive or incomplete. The other nine indicated that they were well along in their feasibility studies having already identified fuel resources and developed financing requirements and project schedules. Three of these proposals were submitted by mills with ongoing projects that had expended more than 50% of the projected total project cost and had completed over 90% of their design and major equipment procurement efforts. Seven proposals were from Tamil Nadu, three from Uttar Pradesh, and two from Maharashtra. Selected proposals will receive up to 10% (which is estimated to be in the range of $1-1.5 million) of the project's total required capital investment.

Table 8 compares the existing and proposed operating conditions for the mills in the proposals requesting financial assistance against the Indian sugar mill norms identified in the USAID study (6) and the goals of the ABC RFP. The mills in the nine FA proposals discussed above have cane crushing capacities in the range of 2500-6000 TPD (2750-6600 tons/day). A typical cogeneration scheme for the mill shown in Figure 1, which is similar to those in the FA proposals, is shown in Figure 2 (6). About 32 MW_e of power is generated in the upgraded mill compared to 7.5 MW_e that is currently being generated to meet the mill's internal requirements. The proposed power generation capacity for the mills in these proposals ranged from 15 to 35 MW_e with proposed ABC investment ranging from $1.1 to 2.9 million. As shown in Table 8, the total capital investment for the various projects ranged from $371 to $886 per kW of capacity. The typical total capital cost for these mill projects was $14.1 million, which corresponds to about $440/kW. All of the proposals met the minimum bagasse capacity and boiler design conditions expressed in the RFP. However, some of the proposals either did not meet the minimum of 270 days of operation required by the RFP or the mill's operation on non-bagasse biomass fuels was unclear and clarifications have to be obtained.

Nine proposals requested technical assistance to conduct feasibility studies. Many of these mills are well established with good histories of executing similar projects. Eleven proposals requested MG to conduct biomass research and development activities. Selected TA and MG proposals will be provided with a grant up to $25,000 with the requirement that the proposer provide at least 50% of the project's total cost.

Evaluation of the proposals for the financial assistance grants are nearing completion. Selection and announcement of these proposals are scheduled for the first week of June 1996. Selection of the TA and MG proposals is planned for July 1996.

SUMMARY

India's power needs — over 300,000 MW_e in next 25 years — are well known and projects are being aggressively pursued by both local and foreign companies. Cogeneration, the combined generation of steam and electricity, is an efficient and cost-effective means to save energy and reduce pollution. Despite the advantages of cogeneration, it remains an untapped potential in most countries, including India. India is estimated to have a total industrial cogeneration potential of about 18,000 MW_e but only about 8,000 MW_e has been developed to date. Many studies around the world have identified sugar mill cogeneration as an attractive low-cost option to generate power. Most studies estimate the cogeneration potential of India's sugar industry at around 3500 MW_e.

The United States Agency for International Development (USAID) has implemented a Greenhouse Gas Pollution Prevention (GEP) Project to assist in the direction and pace of India's power sector development. This seven-year, $19 million effort is funded through the United States' contribution to the pilot phase of the Global Environmental Facility (GEF). The GEF's mission is to assist developing countries in investing in environmental protection initiatives that yield global benefits in terms of reduced or avoided greenhouse gases emissions. Technical aspects of the project are being managed by the United States Department of Energy's Pittsburgh Energy Technology Center through a Participating Agency Services Agreement with USAID-India.

The Advanced Bagasse Cogeneration (ABC) Component of the GEP Project is implemented through technical assistance and investments subcomponents. The investment subcomponent will provide financial assistance up to 10% of the total cost for sugar mill cogeneration projects that operate year-round on bagasse and other biomass fuels with power export to the grid. This is being implemented by the Industrial Development Bank of India (IDBI) and is funded at about $8 million. PETC's activities are primarily associated with the implementation of the technical assistance subcomponent, which is funded at about $2.8 million. These activities include project development assistance; support for research and development on biomass collection, storage and handling; technical and management training; and the conduct of sugar mill cogeneration workshops and seminars. Project outputs for the technical assistance component include results of research and development activities on bagasse collection, handling, and storage; regional fuel supply assessments; establishment of a research consortium for cogeneration project developers; project promotion; and project analysis and technical studies.

All project activities are progressing in accord with the project's schedule. Over 30 proposals have been received in response to a request for proposals issued by IDBI for technical and financial assistance, and matching grants for research and development activities from Indian sugar mills. The proposals are being evaluated and selections will be made soon. This USAID-India project is expected to significantly advance cogeneration in Indian sugar mills with power export to the grid. Progress in the Indian sugar industry should pave the way for cogeneration projects in other industrial sectors, such as paper, chemicals, and textiles. Contributions from these sectors are important if India is to meet its huge power generation needs.

REFERENCES

1. Global Energy Facts, Edition 2, ABS Energy and Power Market Research & Publishing, 1994.

2. Country Analysis Briefs: 1994, U.S. Energy Information Administration, DOE/A.-0595, May 1995.

3. International Private Power Quarterly, The McGraw-Hill Companies, First Quarter 1996.

4. Economic Survey 1993-1994, Government of India Ministry of Finance.

5. 1992 International Energy Data, World Energy Council, 1993.

6. Advancing Cogeneration in the Indian Sugar Industry - Three Mills in Tamil Nadu and Maharashtra, U.S. Agency for International Development, Report No. 93-02, May 1993.

7. Electric Power Generation Markets in India and Pakistan, U.S. Agency for International Development, Office of Energy and Infrastructure, Bureau for Research and Development, February, 1993.

8. “Government Planner Hard at Work,” Electricity International, December 1995/January 1996.

9. Skelton, T., “Small-Scale Cogeneration - Revised Analysis,” Centre for Analysis and Dissemination of Demonstrated Energy Technologies Newsletter, No. 1/1996.

10. Gas Research Institute, <u>1996 Policy Implications of the GRI Baseline Projection of U.S. Energy Supply and Demand to 2015</u>, 1996.

11. Eniasivam, S., “India - Utopia Amidst Political Chaos and Myopia?,” World Cogeneration, Vol. 7, No. 5, November/December 1995.

12. Indian Sugar Mills Association, Directorate of Economic and Statistical Advisor, Government of India.

13. Personal communication with the International Fund for Renewable Energy and Energy Efficiency (IFREE) and deLucia and Associates based on work done for the Asian Development Bank, April 1996.

14. Bagasse-Based Cogeneration in India: A Market Primer for U.S. Companies, Prepared by the National BioEnergy Industries Association, March 1995.

15. Sugar and Sweetener Situation and Outlook Report, Commercial Agriculture Division, Economic Research Search, U.S. Department of Agriculture, December 22, 1995.

16. Sugar and Sweetener Situation and Outlook Report, Commercial Agriculture Division, Economic Research Search, U.S. Department of Agriculture, March 25, 1996.

17. World Sugar Supply and Distribution Report, U.S. Department of Agriculture, Foreign Agricultural Service, November, 1995.

18. World Sugar Cane and Sugar Production Report, U.S. Department of Agriculture, Foreign Agricultural Service, May, 1996.

19. Coffee, Sugar & Cocoa Exchange, Inc., World Wide Web Home Page (http://www.ino.com/gen/csce), April, 1996.

20. Indian Sugar Mills Association data as reported by the American Embassy (New Delhi, India) to the U.S. Department of Agriculture (various 1994-1995 reports).

21. Sugar Reports from the American Embassy (New Delhi, India) to the U.S. Department of Agriculture (various 1994-1995 reports).

22. <u>World Resources 1994-1995 - A Guide to the Global Environment</u>, World Resources Institute, 1994.

23. Chandrashekhar, G., “Cane Output Set to Exceed Target,” The Hindu Business Line, December 2, 1995.

24. Silva, E. and Beaton, P., “Swirl Systems for the Suspension Burning of Bagasse: Evaluation of Industrial Results,” 2nd Asian-Pacific International Symposium on Combustion and Energy Utilization, Beijing, China, October 15-18, 1993.

Table 1. 1995-1996 Leading Centrifugal Sugar (Cane and Beet) Producing Countries

Country	Sugar Production (million mt)	Sugar Imports (million mt)	Sugar Exports (million mt)
India	15.15	0.00	0.60
Brazil	13.00	0.03	4.80
United States	6.90	2.18	0.36
China	6.50	2.50	0.42
Thailand	5.75	0.00	4.00
Australia	4.95	0.00	4.00
France	4.60	0.38	2.55
Mexico	4.25	0.06	0.10
Germany	4.20	0.15	1.10
Cuba	4.00	0.00	3.25
Ukraine	4.00	0.30	2.00
Pakistan	3.22	0.00	0.10
Indonesia	2.10	NA	NA
Colombia	2.07	0.00	0.10
Russia	1.90	3.00	0.02
Phillippines	1.80	0.40	0.18
South Africa	1.79	0.00	0.50
Poland	1.79	0.00	0.13
Italy	1.69	0.21	0.10
Turkey	1.60	0.50	0.05
Argentina	1.50	0.00	0.14
Guatemala	1.33	0.00	0.91
United Kingdom	1.30	1.41	0.40
Spain	1.15	0.28	0.10
Netherlands	1.10	0.05	0.30
Egypt	1.08	0.52	0.04

Table 2. 1995-1996 Leading Sugar Cane Producing Countries

Country	Area Harvested for Centrifugal Sugar Production (thousand ha)	Sugar Cane Production for Centrifugal Sugar (million mt)	Sugar Cane Yield (mt/ha)
Argentina	250	13.7	54.8
Australia	384	36.7	95.6
Brazil	1950	125.0	62.5
China	1015	63.7	62.8
Columbia	131	17.3	132.1
Cuba	1100	42.0	38.2
Dominican Republic	215	5.8	27.0
Egypt	101	8.6	85.4
Fiji	58	4.0	69.0
Guatemala	165	13.2	79.7
India	2220	146.0	65.8
Indonesia	400	30.0	75.0
Mauritius	75	5.2	69.3
Mexico	540	42.3	78.3
Pakistan	525	27.6	52.5
Peru	54	5.8	107.9
Phillippines	380	19.0	50.0
South Africa	289	16.8	58.0
Sudan	50	5.0	100.0
Swaziland	37	3.3	89.2
Taiwan	49	4.0	81.0
Thailand	960	55.5	57.8
United States	356	26.2	73.6
Venezuela	109	6.6	60.6
Zimbabwe	34	3.9	116.0

Table 2. India's Leading Sugar Cane Producing States

State	1989-1990		1995-1996	
	Production (million mt)	Percent of Total	Production (million mt)	Percent of Total
Uttar Pradesh	97.0	44.6	109.9	43.1
Maharashtra	34.0	13.5	NA	NA
Tamil Nadu	21.9	11.2	31.3	12.3

Table 3. Land under Sugar Cane Cultivation in India (1995-1996)

State	Total Cane Cultivation Area (million hectares)	Percent of Total
Uttar Pradesh	1.8	47.3
Maharashtra	0.5	13.2
Tamil Nadu	0.3	7.9
Karnataka	0.3	7.9
India Total	3.8	100

Table 4. Indian Sugar Cane and Centrifugal Sugar Statistics

Seasonal Year	Total Cane Cultivation Area (million ha)	Sugar Cane Production (million mt)	Sugar Cane Yield (mt/ha)	Sugar Production (million mt)	Sugar Exports (million mt)	Sugar Imports (million mt)
1990-1991	3.69	241.05	65.39	12.00	NA	NA
1991-1992	3.84	254.00	66.08	15.25	0.59	0.00
1992-1993	3.57	228.03	63.84	12.47	0.40	0.00
1993-1994	3.39	227.06	67.06	11.66	0.03	1.50
1994-1995	3.75	259.49	69.12	16.35	0.10	0.60
1995-1996	3.87	255.00	65.87	15.15	0.70	0.00

Notes:
1) Statistics are seasonal (October/November to May)
2) Centrifugal sugar includes refined and khandsari
3) NA - not available
4) 1995-1996 data is estimated

Table 5. Typical Sugar Mill General Data

Parameter	Value
Mill Capacity, TPD	5,000
Cane Crushed, mt/yr	707,671
Crop Duration, days/yr	205
Average Cane Crushing Rate, TPD	4234
Downtime, % of Milling Season	16.33
Fiber, % of Cane	14.62
Bagasse, % of Cane	31.8
Moisture, % of Bagasse	51.32
Bagasse Produced, mt	224,326
Bagasse Sold to Pulp Manufacturers, mt/yr	13,334

Table 6. Typical Sugar Mill Power Generation Data

	Boiler #1	Boiler #2	Boiler #3	Boiler #4	Boiler #5
Capacity, mt/hr	20	40	40	35	70
Year of Installation	1974	1975	1975	1970	1986
Pressure, ata	14	14	14	14	32
Temperature, ^{o}C	265	265	265	265	380

	TG #1	TG #2	TG #3	TG #4
Year of Installation	1976	1965	1970	1989
Capacity, kW	1000	1250	2000	3000
Speed, RPM	7500	8000	7500	9000
Steam, kg/kWh	12.5	13.0	15.0	9.0
Inlet Temperature, ^{o}C	260	260	265	380
Inlet Pressure, ata	10.5	13.0	13.0	32.0
Exhaust Pressure, ata	1	1	1	1

Table 7. Comparison of Current and Proposed Cogeneration Schemes

Parameter	Current	USAID Study Norms	RFP Requirements	Proposed
Capacity, TPD	2500-6000	2500-6000	2500	2500-7000
Pressure, ata	14-21	63	60	62-87
Temperature, ^{o}C	320-340	480	430	480-510
Operation, day/yr	180-210	300	270	270-310
Steam Consumption, % on cane	50	40	NS	NA
Power Generation, MW_e	3-8	15-50	NS	15-50
Capital Investment, $/kW	0	714	NS	371-886

Notes:
1) NS - Not Specified
2) NA - Not Available

In-Season Flow Diagram

Off-Season Flow Diagram

Figure 1. Typical Existing Sugar Mill Operations

In-Season Flow Diagram

Off-Season Flow Diagram

Figure 2. Typical Proposed Sugar Mill Operations

As in most countries, India has four main categories of electricity consumers: residential, commercial, industrial, and agricultural. The intensity of consumption in each category varies significantly in the different regions of India as a result of climatic differences, the status of industrial development, and the extent of agricultural activity. About 51 percent of the total end use of electricity is by industrial consumers, 24 percent by the agricultural sector, 23 percent by commercial and residential consumers, and 2 percent by the transportation sector (7).