ornl

ORNL/TM-13095

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Preliminary Assessment of Off-Season Fuels for Electricity Generation at Indian Sugar Mills

Robert D. Perlack
J. Warren Ranney

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM-13095

PRELIMINARY ASSESSMENT OF OFF-SEASON FUELS FOR ELECTRICITY GENERATION AT INDIAN SUGAR MILLS

Robert D. Perlack
Oak Ridge National Laboratory

and

J. Warren Ranney
Joint Institute for Energy and Environment

Date Printed: November 7, 1995

Published by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6205
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract DE-AC05-84OR21400

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This report on off-season fuels is part of a preliminary feasibility assessment to retrofit Indian sugar mills to cogenerate heat and power with sales of excess electricity to the local grid. To justify the high capital costs of retrofitting existing facilities, sugar mill operators must attempt to maximize the amount of power they sell to the local grid. This fact means that sugar mills must operate and sell power well-beyond the milling season, which typically lasts about 200 days. The purpose of this report is to assess and determine whether low cost and reliable sources of off-season fuels can be secured for two sugar mills (Simbhaoli and Daurala) within their respective sugar growing districts, located in western Uttar Pradesh. Off-season fuels under consideration include excess bagasse that is stored for off-season use, agricultural field residues (e.g., wheat straw), forest residues (e.g., bark and small limbs), and dedicated energy crops (short-rotation woody crops and herbaceous energy crops). Results of the pre-feasibility indicate that bagasse and some agricultural residues are available in sufficient quantity and may be available at reasonable cost.

ACKNOWLEDGMENT

This work was sponsored by the U.S. Department of Energy; Office of Solar Energy Conversion; Solar Thermal and Biomass Power Division.

1. INTRODUCTION

1.1 BACKGROUND

Shortages, inefficient transmission and distribution, and low quality service are endemic to India's power system. These problems are also exacerbated by an inefficient tariff structure that encourages waste, subsidizes certain users, and does not generate sufficient revenues for maintenance and expansion. Like many other countries faced with high demand growth, India is looking toward private sector power generation as a possible and inexpensive way to add capacity and deal with power shortages. Many industries are also finding that selling excess power to the grid can be a profitable addition to operations (Bell, 1991). In India, there exists a very large untapped cogeneration potential in the sugar industry. India's cane electricity generation potential has been estimated at about 25 million MWh or 20% of current generation (USAID, 1987). Efforts are underway to determine how best to exploit this potential.

To justify the high capital costs of retrofitting existing facilities with high-pressure boilers, condensing-extraction steam turbines, and other equipment, sugar mill operators must attempt to maximize the amount of power they sell and export to the local grid subject to meeting process steam and power needs. This fact means that sugar mills must operate and sell power well-beyond the milling season. The milling season lasts about 200 days in western Uttar Pradesh and off-season fuels would be required to operate another 100 to 130 days. A preliminary screening of potential sources of off-season fuels indicated that there were five to consider:[1]

- bagasse that is generated during the milling but goes unused,
- excess bagasse from other mills,
- agricultural field residues,
- forest residues (e.g., bark and small limbs), and
- energy crops (primarily short-rotation woody crops).

[1] In the Indian states of Tamil Nadu and Maharashtra, lignite was considered as the prime off-season fuel for sugar mill cogeneration (Winrock, 1993). For mills located in Uttar Pradesh, lignite is not a feasible alternative for the following reasons. First, lignite supplies are distant and their cost would be high. Second, the quality of the lignite is poor (high ash content) and is difficult to combust. Third, the supplies would be unreliable because priority is given to large power plants, railways and large industrial consumers. Sugar mills would be considered small purchasers and would have little leverage in securing reliable and affordable supplies (Tapriya, 1995).

The purpose of this report is to assess and determine whether low-cost and reliable sources of off-season fuels can be secured for the Simbhaoli and Duarala sugarcane processing mills. The authors of this report visited India to collect information and to coordinate with other project participants. Data were collected at the Tata Energy Research Institute (TERI), the Simbhaoli Sugar Mill, the Simbhaoli cane collection centers, the Forestry Ministry, USAID, and private companies. Agricultural data were made available through Marketing and Business Associates (MBA).

1.2 ORGANIZATION

The remainder of the report is organized into four sections. The second section provides background information on existing sugar mill operations, cane procurement, and bagasse generation and handling. The third section discusses the availability of off-season fuels. The fourth section provides the integration of biomass supply and its relationship with conversion. The final section provides findings and recommendations.

2. EXISTING SUGARCANE OPERATIONS AND BIOMASS SUPPLIES

2.1 SUGARCANE PROCUREMENT AND OPERATIONS

In Uttar Pradesh, the milling season typically runs about 200 days each year (October-April). The sugar mills at Simbhaoli and Daurala (east of New Delhi) are large. Plant operators get their sugarcane from a government-defined district, in which they contract with many small farmers. The Simbhaoli mill processes about 6500 green tonnes of cleaned sugarcane stalks each day and the Daurala mill processes about 4000 green tonnes.[2] The stalks are cleaned in the field, hand tied in manageable bunches for handling, and delivered to a nearby collection center. Average farm size in these districts is small and fragmented (Table 1). About 80% of the farms are less that 10 acres with nearly half of them less than 5 acres (MBA, March 1995). The small size of land holdings is directly attributable to government land use policies.

Table 1. Distribution of land holdings in sugarcane growing districts

Land holding size (acres)	Sugar growing district (%)		Average holdings (%)
	Meerut	Bulandshahar	
<5	40	47	44
5 - <10	34	39	36
10 - <20	24	13	19
20>	2	1	1

Source: Marketing and Business Associates, March 1995.

Because of the small size of farms, sugar mills have contracts with literally thousands of individual farmers. For example, the Simbhaoli mill contracts with about 20,000 farmers for cane. The logistics of dealing with thousands of individual farmers are handled with a government system of cane collection centers. These collection centers are more or less evenly distributed within the growing district and are staffed by sugar mill employees. The Simbhaoli mill staffs 70 cane collection centers within their district. The Daurala mill has 80 cane collection centers.

---

[2]The Simbhaoli mill expects to expand daily crushing capacity to 8000 tonnes in the near future.

Mills are typically supplied within a radius of about 50 km. Cane is harvested by hand and separated into stalks (for the sugar mill, about 60% of the cut plant), tops (valued as fodder for draft animals, about 15% of the cut plant), and leaves (used as mulch and various household applications, about 25% of cut plant). Cane leaves and tops are treated as agricultural waste in further discussions. Sugarcane stalks are delivered to collection centers or directly to the mill by bullock carts (oxen-drawn carts) or farm tractor-drawn wagons from a distance of up to 8-10 km. The bullock carts and tractor-drawn wagons carry about 1.5-2.0 and 3.0-5.0 tonnes of sugarcane stalks in each load, respectively. Farmers take their cane to an assigned collection center at an assigned time. At the collection center the cane is weighed, unloaded by hand into piles by variety, and then reloaded by hand onto trucks. Collection centers typically handle about 50 tonnes of cane each day and there are no facilities at the collection center to store large quantities of cane. The sugar mills are anxious to process the cane as fast as possible usually within 24 hours of delivery to maximize sugar content. The sugar mills also encourage immediate delivery of cane from the field for the same reason. This is tempered by the farmers' interest to harvest over several days to provide fresh fodder for their animals.

Cane collection center labor wages are 50 rupees (Rs)/day.[3] This is higher than unskilled farm labor wages of 40 Rs/day. The cane trucks, which are owned and operated by the mill, can haul about 10-12 tonnes of cane on each trip from the collection centers to the main receiving yard at the sugar mill. This translates to about 5 trips/day from each collection center or about 350 truck loads a day to the mill. Cane is purchased for about 1100 Rs/tonne. However, this price varies somewhat with season and variety and sugar content of the cane. Within the cane collection area 4 to 5 varieties are grown, with the early season varieties tending to have less sugar content than the later season varieties. Farmers who take their cane directly to the mill get a premium of 20 Rs/tonne. The different varieties are used to meter out maturity, harvest, and delivery of cane over the growing season for sugarmill efficiency/capacity.

Mill officials provide information, extension services (e.g., dissemination of new and improved varieties, plant disease control, nutrition monitoring, fertilizer applications) and contracts for the farmers to operate. Farmers know within a 3-day window when their shipment of cane should be delivered, and as that window approaches are issued tickets for the day the cane is to be delivered to the mill or collection center. Upon delivery to the mill, the cane is dumped directly into a conveyor that carries it into the mill for crushing and processing. A movable overhead grapple is located at the live hopper site to help unload cane to unclog pile-ups of cane in the hopper, and to coarsely meter the cane flow into the mill. This last action involves some temporary small inventory storage beside the grapple to fill in gaps in conveyor cane flow and to compensate for daily delivery lulls. All this is directly dependent on the grapple and its operator. At the mill, the larger delivery trucks may wait for up to an hour for unloading while bullock carts and tractor-wagons may have to wait several hours in massive queues for unloading. At collection centers, carts are weighed and unloaded

[3]Currency conversion is about 31 Rs = $1US.

promptly (≈ 30 minutes). The larger trucks may be loaded in 20 minutes, if enough cane of one variety is ready to load. Otherwise trucks may have to wait for sufficient inventories to arrive. To ensure that sufficient cane is available to the mill operating at full capacity throughout the milling season, mill operators contract for about 30% more than they can actually use to account for losses and non-delivered cane.

2.2 ON-SITE BAGASSE GENERATION AND HANDLING

The amount of bagasse produced from the milling process ranges between 28 and 35% of the stalks depending on the specific variety of cane. Early season varieties tend to have higher fiber and lower sugar content than later varieties. Overall bagasse is about 30% of the cane stalks at 50% moisture content after the juice has been extracted. The stalks are crushed and washed several times leaving a sawdust-like low-density material, which is bagasse.

Bagasse is used as a boiler fuel to produce process steam and to generate power. Most of the larger mills start accumulating excess bagasse after about two months of operation. This excess bagasse is either stored for the next season as a start-up fuel or is sold to other sugar mills or to paper mills as pulp furnish. At the Simbhaoli mill the amount of excess bagasse currently produced is about 25,000 tonnes per year (Ranney and Perlack, 1995) and about 20,000 tonnes at the Duarala mill (MBA, 1995). The excess bagasse at the Simbhaoli Mill is baled and stored or sold. Selling prices range from as low as Rs 200 to Rs 300/tonne when there are plentiful supplies to as much as Rs 500/tonne early in the milling season when there is little excess available.[4]

The Simbhaoli mill recently installed a bagasse drier heated by flue gases. Moisture content of the bagasse is reduced from an initial 46 to 53% to about 36%. This raises the useful heating value of the bagasse by more than one-third. This is equivalent to a one-third reduction in fuel cost. The retrofit of the combustion system for congeneration may make more heat available to reduce further the bagasse moisture content and effectively extend bagasse supplies.

At the Simbhaoli mill and many others, the limiting activity is the capacity to crush the cane stalks. It is not the procurement of sugarcane, the handling and receiving of cane stalks, the refinement of sugar, but the stalk milling capacity of the facility. If mills are already operating at or near milling capacity, then the introduction of higher fiber, lower sugar content varieties (for energy benefit) necessarily means lower sugar output. This means that the mill operator is faced with a tradeoff between sugar and power production. Unless the power purchase agreements are very favorable, it is unlikely that this tradeoff will be made. The reason for considering this situation is that high fiber -

[4]MBA (1995) reports much higher prices ranging from Rs 110 to Rs 130/quintal (1 quintal=0.1 tonnes).

low sugar varieties of cane can produce considerably more fiber, leaves, and tops (more energy) per unit of land than from high sugar, low fiber varieties that are currently grown.

3. AVAILABILITY OF OFF-SEASON FUELS

3.1 BAGASSE

The most obvious off-season fuel available to mill operators is excess bagasse. The amount of excess bagasse produced from the milling process depends on a number of factors as well as the specific cogeneration system size and design chosen. Any measures to save steam have the effect of reducing bagasse consumption and decreasing the amount of bagasse fuel required during both the on- and off-season. It is expected that mill process efficiency improvements will reduce bagasse needs during the crushing season and about 25% of the bagasse can be saved and stored for off-season use. As noted previously, bagasse can also be saved by using waste heat to reduce moisture content. Table 2 summarizes the approximate excess bagasse that can be saved and used during the off-season as fuel. These numbers assume increased milling capacities at both facilities.

Table 2. Summary of the approximate availability of bagasse at the Simbhaoli and Duarala sugar mills

Mill	Capacity (tonnes day^{-1})	Bagasse produced (tonnes)	Excess bagasse (tonnes)
Simbhaoli	8000	436,400	109,100
Duarala	6500	354,500	88,600

Notes: The cane season is about 200 days in length. The mill is assumed to operate 4000 hours each year exclusive of mill downtime, which is about 15%. On average the mill processes 22 hours each day. Bagasse is 30% of incoming cane. It is assumed that 25% of bagasse is excess and can be used as an off-season fuel. Bagasse is 50% moisture.

The most desirable addition to on-site excess bagasse is shipment of bagasse from other sugar mills. It is essentially the same fuel to handle and combust. Within the Meerut Mandel Division there are 25 sugar mills with a total installed daily capacity of 83,500 tonnes.[5] During the 1993-94 season these mills crushed 11.3 million tonnes of cane. MBA (1995) estimates a bagasse surplus of about 212,000 tonnes. To keep costs low (Rs 200 to 300), bagasse would have to be purchased during the processing season, shipped, and stored on-site.

[5]The Meerut Mandel Division includes the following sugar districts: Hardwar, Saharanpur, Muzaffarnagar, Gaziabad, as well as Meerut and Bulandshahar.

The Simbhaoli mill already densifies bagasse into bales for sale and transport. In this condition, the cost of bagasse rises by Rs 100 to 200/tonne depending on the market and season.

3.2 AGRICULTURAL RESIDUES

The region in which the Simbhaoli and Duarala mills are located is principally agricultural with no natural forests. Dominant crops are sugar cane, wheat, potatoes, and rice (Table 3). Three crops may be grown in a year and may or may not include a fallow (wet) season. Land holdings are small-sized with rich, productive soils. Cattle are plentiful and very important to the agricultural economy. They are used as draft animals, and are a source of milk. These animals also provide dung which when dried is used for household energy.

Demand for cattle fodder and residues is high. Residues and fodder crops are intensively collected and used. Any residues left in the field are usually there for the purpose of nutrient recycling and sustaining agriculture. Because residues are already heavily utilized and are an integral part of the agricultural system, collecting large quantities of residues as an off-season fuel supply at reasonable costs may be problematic for sugar mill operators.

Cane tops and leaves. Sugar cane is the major agricultural crop grown in the area.[6] The tops and leaves are separated from the cane stalk in the field and are used on the farm for fuel, fodder, and fertilizer. This practice differs from other sugar growing regions where tops and leaves are often separated at the mill before crushing or are milled as a whole plant.

Results of a survey conducted by MBA (1995) indicated that farmers on average had about 5 tonnes each of cane tops and leaves and that there was little surplus for sale (about 2% of these residues are reported as sold). Based on these survey results and discussions with village leaders, MBA (1995) concluded that cane tops and leaves would be essentially unavailable as an off-season fuel.

Wheat Straw. As summarized in the MBA (1995) survey results (Table 3), the largest non-cane residue source is wheat straw. Surplus wheat straw residues are often sold by farmers to small-scale dealers. These dealers act primarily as brokers arranging contacts with dairy farmers needing additional sources of fodder. Individual dealers typically arrange for the sale of about 100 tonnes of wheat straw each month from April through July. The dealers never take physical possession of the residues. During periods of high availability, farmers receive about 80 Rs/quintal and may get up

[6]Cane is usually grown in rotation with wheat. The rotation consists of a cane harvest from an establishment planting, two cane harvests from ratoons (regrowth), and a planting of wheat. The cane tops and leaves (or trash) account for about 40% (green weight basis) of the sugarcane plant.

Table 3. Summary of the availability agricultural residues

Crops	District			
	Meerut		Bulandshahar	
	Residues (10^6 tonnes)	Availability (%)	Residues (10^6 tonnes)	Availability (%)
Sugarcane	4161500	0	1040580	0
Rabi crops				
Wheat	707931	17	946525	17
Barley	--	--	--	--
Pulses	15871	0	61047	0
Mustard	--	--	--	--
Potatoes	25151	0	16265	0
Kharif crops				
Rice	21976	50	9715	50
Maize	8207	3	64238	3
Bajra	2175	0	14990	0
Jowar	189	0	5495	0
Pulses	338	0	1202	0

Notes: Rabi and Kharif denotes dry and wet season crops. Cane residues (tops and leaves) are computed as 40% of production. MBA (1995) assumes tops are 10% of cane plant. Crop data and residue availability percentages based on farmer surveys conducted by MBA (1995).

to 140 Rs/quintal during periods of low availability (MBA, 1995).[7] Most farmers have some facilities for storing wheat straw and can store it for up to a year.

Results of surveys with farmers and village leaders indicate that about 17% of the total wheat straw residue supply may be available as an off-season fuel (MBA, 1995). This could approximate 120,000 tonnes for the two growing districts surveyed. Within the Meerut Mandel division, which includes cane growing districts of Meerut and Bulandshahar and the districts for the Simbhaoli and Duarala mills, surplus residues are estimated to be 582,000 tonnes (MBA, 1995).

[7] A quintal is the typical selling unit among farmers. One quintal is equal to 100 kg or 0.1 tonnes.

Rice husk. Rice is grown by only about 10% of the farmers surveyed by MBA (1995). However, results of surveys suggest that 50% of the rice husk residues are sold and most farmers are willing to sell these residues. These residues are available primarily in the months of October and November. Using rice husk presents some problems for mill operators. First, availability does not coincide with mill needs for off-season fuel (mills are at the beginning of their cane crushing season and there is bagasse). Second, rice husk would have to be stored for a number of months. Third, the quantity available is small and diffuse.

Other crop residues. The MBA (1995) survey also showed that farmers were willing to sell sticks from mustard and residues from maize (stalk and cob). The sticks are used for fuel and most farmers indicated that they have some surplus for sale. Although sticks can be easily stored for many months and are available at the end of the cane crushing season, MBA (1995) concluded that the amount available was too small and too diffuse. The stalks from maize are used by farmers for fodder and the cobs are used for fuel. These residues are available during August and September. Although farmers expressed a willingness to sell some of their surplus maize residue, the quantity available may be too small to be of interest to mill operators (MBA, 1995).

3.3 FOREST WASTES AND RESIDUES

Within the vicinity of the Simbhaoli and Duarala mills, eucalyptus is being grown on private farmlands for pulp, fuel, and wood products. These trees are usually planted in single and multiple rows along field boundaries in rotations that are somewhat longer than one would use for energy crops. Stumpage prices for eucalyptus vary seasonally and by size of the material. Logs may command a stumpage price of 650-700 Rs/green tonne, poles 550-600 Rs/green tonne, and tops, limbs, and branches 450-500 Rs/green tonne. Pulp mills will pay up to 1200-1400 Rs/green tonne for delivered pulpwood. The difference between the stumpage price and what the pulp mill pays covers harvest and transport of the material to the pulp mill. There is also some hybrid poplar being grown for high-value wood products (plywood and boards). This wood commands high prices (2400 Rs/m^3 or 6000 Rs/green tonne) at the point of end-use. Results of a survey in western Uttar Pradesh indicates that there is little waste material (i.e., limbs and tops) from hybrid poplar (Chaturvedi, 1995).

The harvesting, processing, handling, transport, and marketing of wood from private farmlands is usually done by independent contractors, although some farmers do these tasks themselves. The wood is sold according to size. Nearly all of the wood (80%) is harvested during the months of August through February. No wood is harvested during the monsoon months. The amount of wood that might be available from private farmers could not be determined from the survey conducted by Chaturvedi (1995). However, the amount of land under tree cover on private farms is small (~10%) and the quantity of residue available is likely to be too small to be of any consequence.

The major source of wood in Uttar Pradesh comes from reserved forests, protected forest areas, and forest department plantations (Chaturvedi, 1995).[8] Harvesting, processing, and sale of wood is the responsibility of the Uttar Pradesh Forest Corporation (UPFC). The UPFC handles the wood through a system of collection centers or depots. Wood that is collected at the depots is either allotted under contract to large users (pulp mills) or sold through auction. Pulp mills meet about half of their needs from this supply, the other half comes from private farmlands.

Pulp mills are designed to use wood fiber with the bark removed. For the UPFC wood, bark is removed in the field just after felling. This bark is left for nutrient recycling purposes and cannot be removed by law. Wood that is supplied to pulp mills from private producers may come delivered with or without bark. The availability of bark from private farmers may be too dispersed and too small in quantity to be considered as a potential off-season fuel. The bark that is removed at the mill site is sold to operators of brick and tile kilns for about 200 Rs/tonne. However, the amount of bark available at each of the two pulp mills is estimated to be only about 3000-4000 tonnes each year.

The smaller pieces of depot wood that are inappropriate for pulp are allotted for special users (e.g., crematories). Once these needs are met, the remaining stocks are auctioned and sold to wood merchants who distribute and sell to small industries (e.g., brick kilns), commercial establishments, and households. Auction prices currently range from about 660 to 710 Rs/green tonne (Chaturvedi, 1995).[9] These prices are at the depot. Sugar mills would have to add the costs of loading, transport, and unloading. The amount of wood that is auctioned is relatively small in quantity. For the 13 depots surveyed in western Uttar Pradesh the total quantity of firewood auctioned between April 1994 and March 1995 was 8000 tonnes (slightly more than 20,000 stacked m^3). It is doubtful that large quantities of wood could be purchased without greatly affecting price and disrupting a well-functioning fuelwood market.

The cost of forest residues is well above the cost of purchasing excess (Rs 450 to 850/green tonne) bagasse and wheat straw. High moisture content, the need for additional handling and processing equipment, such as chippers, and the small quantities available are other reasons that work against forest residues as an off-season fuel.

3.4 ENERGY CROPS

The growing conditions for energy crops around the Duarala and Simbhaoli mills are superb. Warm climate, good rainfall, and excellent soils all contribute to very high growth rates.[10] However,

---

[8]There also some community or social plantations. However, the area covered by these plantations is small and no harvesting is currently being carried out.
[9]Prices are quoted in stacked cubic meters and vary from 230-250 Rs/m^3 for eucalyptus. A stacked m^3 contains 350-400 kg of wood.
[10]These growing conditions would actually favor tropical grasses (e.g., energy cane) rather than woody crops.

growing conditions that are favorable for energy crops are also favorable for food and fodder crops. With Uttar Pradesh's high population density and demand for food, land is not available to grow relatively low-value energy crops.[11] Moreover, local acceptance of a new crop into farming system where nearly all by-products and residues of existing crops have important uses on which local populations depend for their livelihood and subsistence would also be difficult.

Chaturvedi (1995) notes that there has been a downward trend in new plantings of eucalyptus. This is because of the recent increase in agricultural crop support prices and a perceived negative impact of eucalyptus on site quality on the part of farmers. Given this background, it was concluded that short rotation woody crops (eucalyptus and hybrid poplars) and even herbaceous energy crops (tropical thick-stemmed grasses (e.g., energy or high fiber cane, sorghum) are not feasible as dedicated energy crops.

In the longer term, there is some potential to grow tree crops spatially with high-value food crops (agroforestry). Already there has been some experimentation of growing sugarcane and hybrid poplar trees, although not in the region of this study. The trees provide shade during the height of the summer and they shed leaves during the winter season so as not to inhibit cane growth. Increases in yield of the primary crop have often been demonstrated when food crops are grown in association with trees.

There may be some opportunity to grow energy crops on land that has been severely degraded from overuse and poor management. This land tends to be eroded and dry or highly saline. Eroded and saline lands currently support little vegetation and have little current use value. Chaturvedi (1985) has investigated restoring these eroded and saline lands. Restoration of this land with energy crops would require considerable site preparation and would not produce very high biomass growth; however, these lands would be available at low cost (Chaturvedi, 1985).

Table 4 summarizes the costs of establishing trees on degraded lands (eroded and saline). The costs are much higher on the saline lands due to the need to build mounds to control water logging. However, productivity is also somewhat higher. Figure 1 shows estimated levelized costs (stumpage) as a function of alternative discount rates. If sufficient degraded land could be located, production costs for woody crops (10 year rotation), costs would fall in the range of about 400 to 600 Rs/green tonne before harvest and transport and assuming some reasonable discount rate (~12%). There would also be environmental benefits from land restoration. However, waiting ten years for this supply to develop may not be feasible.

---

[11]Land that is used to grow these crops rents for about 60,000 Rs/acre within reasonable transport distances of the Simbhaoli and Duarala mills (Chaturvedi, 1995).

Table 4. Cost of establishing woody crops on degraded lands

Operation	Saline lands Rs/ha	Eroded lands Rs/ha
Saline lands		
Establishment	14000	8900
Irrigation	4000	0
Protection	2000	1100
Total	20000	10000
Expected yield at harvest (10 years)	70 tonnes	50 tonnes

Source: Chaturvedi (1985) and updated in 1995.

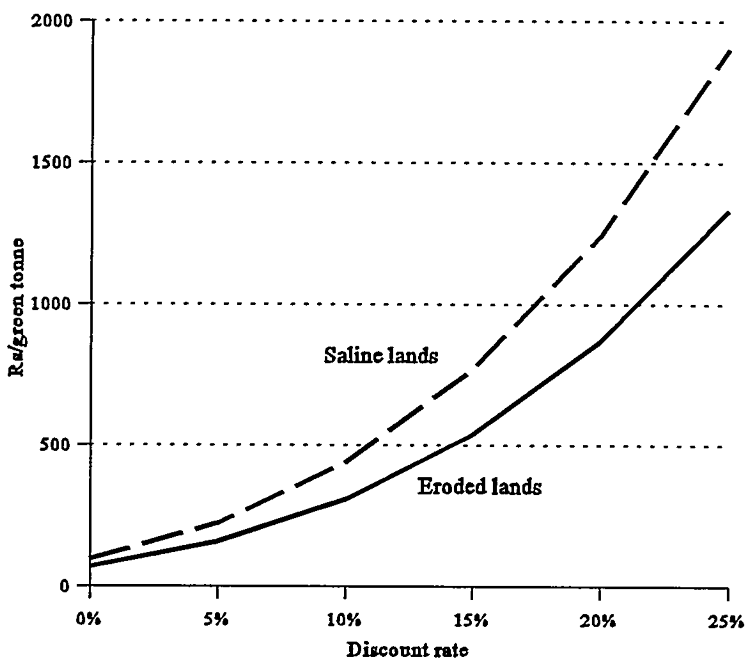

Fig. 1. Levelized cost of growing short-rotation trees on eroded and saline lands.

4. INTEGRATION OF SUPPLY WITH EXISTING OPERATIONS

There are three potentially feasible sources of off-season fuel. These sources are:

- excess bagasse that is carried over into the off-season,
- purchased bagasse from other sugar mills, and
- wheat straw that would be purchased through the existing cane procurement system.

The most reasonable source of biomass is on-site bagasse, part of which would be stored during the processing season for off-season use and the rest used to generate exported power during the processing season (and to help minimize storage of biomass on site). The second most desirable fuel is purchased bagasse because of the potential quantity available (212,000 tonnes), its low-cost (Rs 200 to 500), its compatibility with fuel handling systems and the simplicity of procurement and transport. It may be possible to double the supply of biomass for fuel at both sugar mills provided costs are acceptable and storage requirements can be met. If only half of this residue is available the contribution to power production would be significant.

The third most desirable source of fuel is wheat straw. It may be able to increase off-season fuel availability by perhaps 50% more tonnes of biomass than on-site excess biomass alone. This supply may cost over Rs 1000 and would be purchased during the dry (non-processing season for cane) season. This is advantageous because the material would be dry and of high energy value, it would be easy to store because of low moisture content. Also, it would require minimum pretreatment, and could be combusted directly without processing.

A major drawback to wheat straw besides price, is the effort required to procure it from small dispersed sources. The quantities could be handled by the sugarcane collection centers during the off-season, but the entire cost of operating the centers and transport would be placed on the wheat straw. The low bulk density of wheat straw would also mean that transport and handling costs would be relatively high.

Moisture content of biomass is a serious consideration. Usable energy of biomass is inversely related to moisture content. Reducing moisture content increases usable energy for power generation. At a moisture content of about 36% (dried bagasse), usable energy is about half way between wheat straw and raw bagasse. Paying Rs 400/tonne for raw bagasse is nearly equivalent in energy terms to paying Rs 800 for wheat straw. Although the handling requirements for wheat straw may be slightly different, its comminution to the consistency of bagasse is relatively easy. The comminuted material can also be mixed with bagasse (requiring extra equipment) to provide a homogenized fuel to the combustion chamber through the off-season.

Other agricultural residues are available in quantities too small to bother with and are also too dispersed. The most obvious exception is rice hulls. However, the quantity available is less than 10% of wheat straw and the burning/ash stream characteristics are much different. At low moisture content and mixed in small amounts with bagasse and wheatstraw, there may be some reason to consider its collection. However, the availability of rice hulls during the processing season will work against its use.

The most plausible near term strategy that emerges has sugar mills burning a mixture of raw and dried bagasse during the processing season (to minimize storage requirements leading into the dry or off-season) and burning wheat straw and dried bagasse during the off-season. Figure 2 is a flowchart of the off-season fuel supply.

A summary of the availability of off-season fuel is provided in Table 5. Excess bagasse would be available immediately after the crushing season. This fuel would be stored on-site. Purchased bagasse is available from other mills during the cane crushing season except for the initial two months (October and November) when there tends to be little excess available for sale. Wheat straw residues are available during the March to May period; however, the bulk of the wheat straw (75%) is available during April. Mills might be able to negotiate favorable prices given the quantities purchased and reliable agreements that they are likely to offer.

MBA (1995) interviewed a number of collection center managers as well as village heads (influencers) to determine whether centers could be used in the off-season for residue collection. They concluded that collection centers could be used to facilitate residue collection provided sufficient quantities of residues were available in the vicinity of the center and "good" prices were paid to farmers at time of delivery.[12] However, storage space at the collection centers is very limited. The lack of storage space means that collection centers could only serve as transhipment points and actual long-term storage would have to remain with the farmer. It is unlikely that mills will have sufficient storage space given the necessity of providing areas for storing excess and purchased bagasse.

There are obviously no transport costs for the excess bagasse that is saved for the off-season. For bagasse that is purchased it is assumed that cost of truck transport is Rs 100 tonne^{-1}. For wheat straw it is assumed that the cane collection system is used. In this system, all wheat straw would be transported to the mill from collection centers. The low bulk density of wheat straw would

[12]The use of collection centers to acquire fuel for power generation has been investigated in detail by researchers at Punjab Agricultural University (Winrock, 1990). According to a summary provided by Winrock, loose straw would be collected by farmers and transported by cart to collection centers. The loose straw would be baled and stored at the collection centers. Each collection center would have three balers (12.5 tonnes/hr) and would operate 10 hours each day over a 6 month season. Baled straw would then be trucked to the power plant as needed. The specifics of this study were not available to the authors of this report.

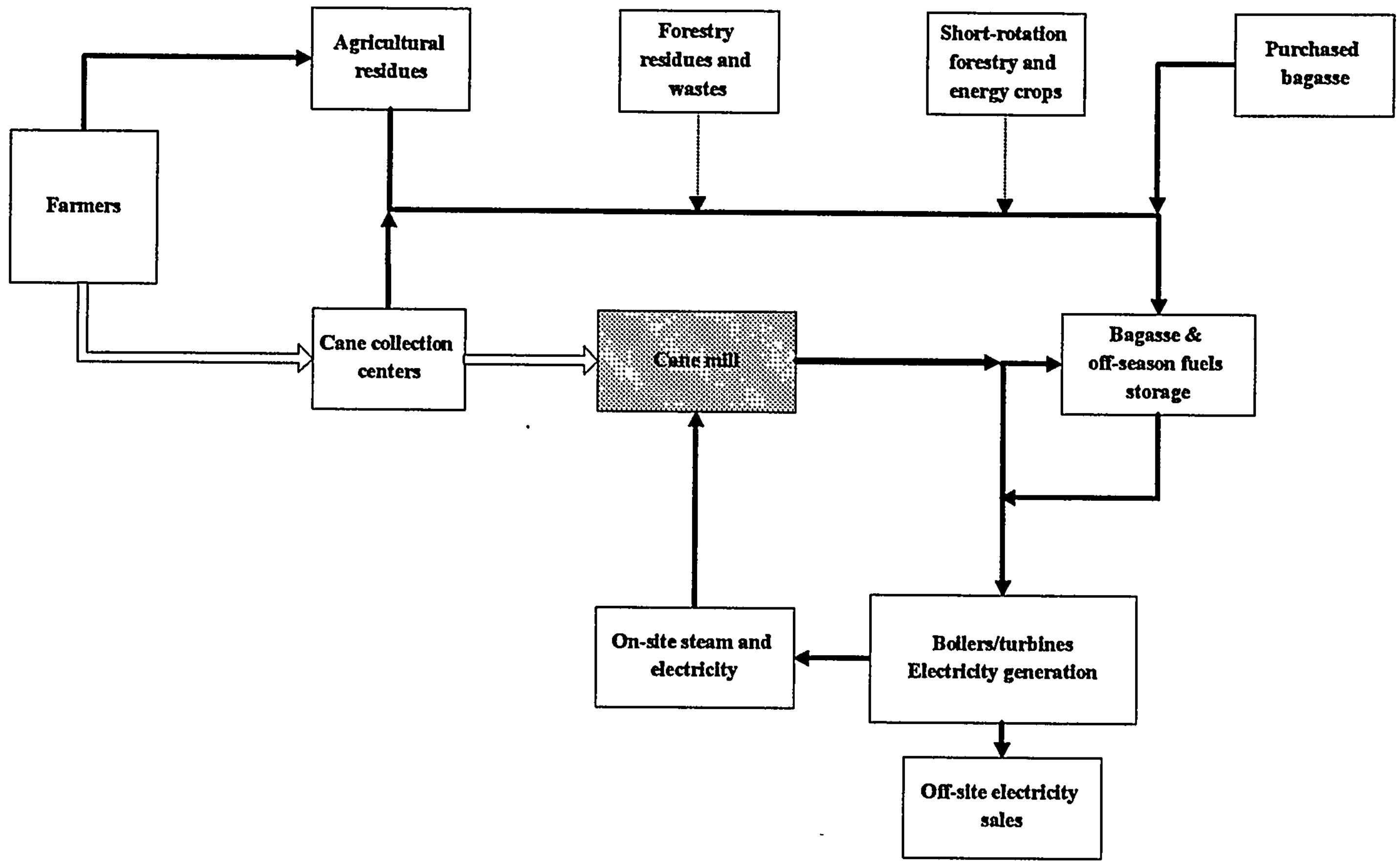

Figure 2. Flow of off-season fuels to the proposed mill sites.

Table 5. Availability and cost of off-season fuels

Off-season fuel	Peak availability	Cost (Rs tonne^{-1})
Bagasse		
Excess/carryover	April - onward	--
Purchases	December-April	300-500 to 1100-1300[a]
Wheat straw	March-May	800
	Off-peak	1400

[a]Lower range in selling price is from Ranney and Perlack (1995). Higher range is from MBA (1995). MBA (1995) reports selling prices of 110 to 130 Rs quintal^{-1}.

effectively preclude individual farmer delivery. The cost of transporting wheat straw was estimated by MBA (1995) to be about Rs 300/tonne (Rs 0.30/kg) for an average haul distance of 10-15 km. The high cost of transporting wheat straw is due in part to its low bulk density.

A supply curve for off-season fuels for both the Simbhaoli and Duarala sugar mills is shown in Figure 3. This curve is based on three sources of off-season fuel -- excess bagasse, purchased bagasse, and wheat straw residues. Supply costs include bagasse or wheat straw purchases and transportation. The costs of farmer storage is included in the purchase price. The cost of storage at the sugar mill is assumed to be part of the cogeneration retrofit capital costs. Handling and decomposition losses are accounted for by increasing the quantity of off-season fuel requirements to offset losses.

The existing bagasse handling systems could be used for additional biomass deliveries (say 20-30% of carryover bagasse) provided several issues are recognized. Additional storage and handling equipment is installed at the mill; the mill does not expand its demand for cane much more in the future; and the additional biomass is similar in handling characteristics to cane. Some additional transport trucks may also be needed. Given the prefeasibility nature of this assessment, it was impossible to determine whether the purchase of wheat straw can be justified relative to the additional amount of electricity that can be generated during the off-season. The high cost of wheat straw and its low bulk density all work against the purchase of these residues. Moreover, additional material handling equipment and facilities will be required.

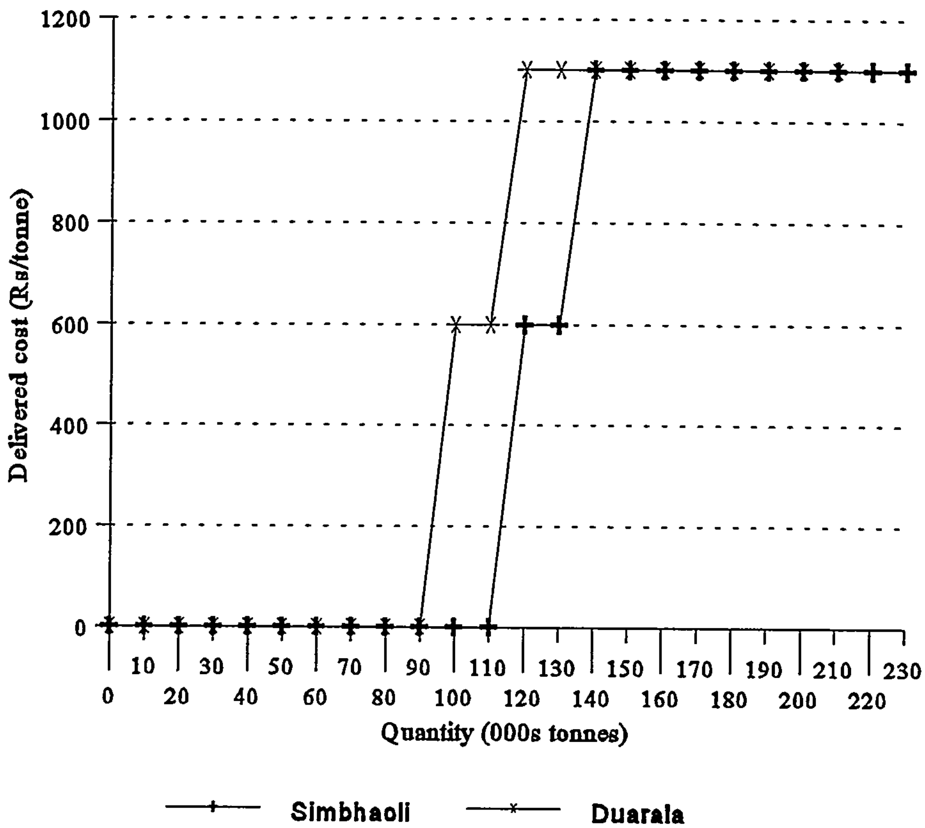

Fig. 3. Supply of off-season fuels to sugar mills at Simbhaoli and Duarala.

5. SUMMARY FINDINGS AND CONCLUSIONS

There are major constraints to finding low-cost and reliable sources of off-season fuel in the cane growing districts surrounding the Simbhaoli and Duarala mills. These constraints are:

- widespread use of all agricultural wastes as fodder, fuel, and fertilizer;
- high opportunity costs for land that precludes growing energy crops; and
- competition with pulp mills and other industrial users for forest residues and competition with farmers and commercial enterprises for fuelwood.

Although not specifically addressed in this preliminary feasibility report, there also exists some concern that transport vehicles and labor may be fully utilized and may not be available for off-season fuel collection and delivery (at least at the prices mill operators would be willing to pay for off-season fuels). During the height of the monsoon season the condition of roads could also be problematic. This latter concern suggests that mill operators will want to maintain relatively high levels of fuels in storage.

In the immediate term, there are three sources of off-season fuel. The most important source is excess bagasse. With process efficiency improvements there will be carryover savings of at least 25% of the bagasse generated. This bagasse can be stored and used to fuel the mill well into the off-season. This excess bagasse can be supplemented with purchases of excess bagasse from other sugar mills. Although there are 25 mills within the general area of Simbhaoli and Duarala, it is only the larger mills that have excess bagasse for sale. Wheat straw is the most important agricultural residue available in sufficient quantity. Because wheat is grown in rotation with cane, most farmers have some supplies of wheat straw residues available for sale. It is believed that the existing cane procurement system can be used to collect these residues. Wheat straw tends to be available at the end of the cane crushing season and extended storage of these residues would not be required. However, there is little storage space available at the collection centers and arrangements would have to be made with farmers to provide on-site storage. A distinct disadvantage of wheat straw is that it has a high bulk-density ratio which increases transportation and handling costs.

In sum, the situation for generating electricity using biomass at retrofitted sugarcane processing facilities is complex. One cannot easily assume feasibility because biomass wastes and residues are already being nearly fully utilized and are an integral component of the existing tightly integrated agricultural economy. Opportunities that look most favorable are the better utilization of on-site bagasse through more efficient combustion systems including drying of bagasse using waste heat and purchases of bagasse from other mills. Existing cane procurement systems appear suitable for collecting additional residues. More specific and detailed investigations are required to confirm these results and whether the cost of purchasing off-season fuels are financially feasible.

REFERENCES

Bell, R. H., "Biomass Power in Developing Countries: Growing Opportunities for U.S. Firms," *Biologue*, December 1991.

Chaturvedi, A. N., *Off-Season Forestry and Forestry Based Industrial Waste Fuel Supply in Western Uttar Pradesh,* Tata Energy Research Institute, New Delhi, May 1995.

Chaturvedi, A. N., "Personal Communication and Update of Chaturvedi (1983 and 1985) Reports, Delhi, February 1995.

Chaturvedi, A. N., *Firewood Farming on Degraded Lands,* Uttar Pradesh Forest Bulletin No. 50, Lucknow, Uttar Pradesh, India, 1985.

Chaturvedi, A. N., *Eucalyptus for Farming,* Uttar Pradesh Forest Bulletin No. 48, Lucknow, Uttar Pradesh, India, 1983.

Marketing and Business Associates (MBA), *Identification of Alternative Biomass Fuels*, Prepared for the Tata Energy Research Institute, New Delhi, March 1995.

Ranney J. and R. Perlack, "Site Visit to the Simbhaoli Sugar Mill," Discussion with S. Tapriya, S. Grewal, and S. Mishra, February 1995.

Tapriya, S., Personal communication, Company Secretary, Simbhaoli Sugar Mills Ltd., February 24, 1995.

U.S. Agency for International Development, Cane Energy utilization Symposium: A Report for the 2nd Pacific Basin Biofuels Workshop, Bureau for Science and Technologys, Office of Energy, Report No. 88-03, Washington, April 1987.

Winrock International, *Advancing Cogeneration in the Indian Sugar Industry*, Prepared by Winrock International and International Development and Energy Associates for the Office of Energy and Infrastructure, U.S. Agency for International Development, Report No. 93-02, Arlington, Virginia, 1993.

Winrock International, *Energy from Rice Residues*, Bioenergy Systems Report, Prepared for the U.S. Agency for International Development by Dean B. Mahin, Arlington, Virginia, March 1990.

INTERNAL DISTRIBUTION

1-5. K. R. Ballew
6. M. A. Brown
7. G. E. Courville
8. T. R. Curlee
9. J. H. Cushman
10. S. Das
11. M. E. Downing
12. R. L. Graham
13. S. G. Hildebrand
14-63. R. D. Perlack
64. C. I. Moser
65. D. E. Reichle
66. J. Sheffield
67. R. B. Shelton
68. V. R. Tolbert
69. A. W. Trivelpiece
70. G. A. Tuskan
71. M. E. Walsh
72. T. J. Wilbanks
73. L. L. Wright
74. ORNL Patent Office
75. Central Research Library
76. Document Reference Section
77-79. Laboratory Records
80. Laboratory Records-RC

EXTERNAL DISTRIBUTION

81. Mr. G. D. Burch, Director, Solar Thermal & Biomass Division (EE-132), DOE, Washington, DC 20585

82. J. E. Ferrell, Acting Director, Biofuels System Division (EE-331), DOE, Washington, DC 20585

83. Thomas E. Drabek, Professor, Department of Sociology, University of Denver, Denver, Colorado 80208-0209

84. W. Fulkerson, JIEE, 600 Henley Street, Suite 314, Knoxville, TN 37996-4138

85-94. J. W. Ranney, JIEE, 600 Henley Street, Suite 314, Knoxville, TN 37996-4138

95. Frederick Renner, Econergy International Association, 1101 30th Street N.W., Washington, D.C. 20007

EXTERNAL DISTRIBUTION -- continued

96. George F. Sowers, P.E., Senior Vice President, Law Companies Group, Inc., 114 Townpark Drive, Suite 250, Kennesaw, Georgia 30144-5599

97. C. Michael Walton, Ernest H. Cockrell Centennial Chair in Engineering and Chairman, Department of Civil Engineering, University of Texas at Austin, Austin, Texas 78712-1076

98. Office of Assistant Manager for Energy Research and Development, DOE-ORO, P.O. Box 2001, Oak Ridge, TN 38831-8600

99-100. OSTI, U.S. Department of Energy, P.O. Box 62, Oak Ridge, TN 37831