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INVESTIGATING THE CHALLENGES OF BAGASSE COGENERATION IN THE KENYAN SUGAR INDUSTRY

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ABSTRACT

The overall objective of this research was to determine the factors hindering cogeneration in the Kenyan sugar industry and the way out. The technical, financial and policy issues hindering cogeneration were investigated. The study targeted sugar factories, the Ministry of Energy, the Kenya Sugar Board, Kenya Power and Lighting Company Ltd and Kenya Electricity Generating Company Ltd (KenGen). The capacity of operating Kenyan sugar factories was determined. Data was collected through observation, questionnaires, interviews and document analysis and review. In this research, of great concern was the capacity to use sugarcane bagasse as a fuel for export-based cogeneration in the sugar industry in Kenya. Whereas cogeneration in sugar production has been around for long, export-based cogeneration is a new concept that is yet to be adopted in many countries, Kenya included. The research showed that at current capacity and efficiency, the seven operating sugar factories have export capacity of 586 GWhrs. This capacity improves to 972 GWhrs at factory overall efficiency of 90% for the current production capacity. The potential is 1,803 GWhrs based on planned factory capacities as per strategic plans of operating factories at efficiency of 90% and high steam pressure of 82 bars. However, to realize this potential, the current legal and regulatory challenges, technical limitations and financial challenges need to be addressed. To facilitate export-based cogeneration, investing in high-pressure steam generation facilities, process improvements to reduce process steam demand and electricity consumption while availing more steam for power generation, deliberate government policy to encourage export bagasse cogeneration through fiscal and regulatory measures to spur up investments in bagasse cogeneration, were recommended.

Key Words: Bagasse, Cogeneration, sugar industry, Electricity generation; Sugar processing; steam boilers; biomass to energy.

1. INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Electricity is at the center of global economies and has a rising share of energy demand and supply. The electricity demand continues to grow further as a result of increasing household incomes, electrification of transport, process and domestic heating applications, and growing demand for digital applications and air conditioning (IEA, 2019). The global power production in the year 2000 was 13 TW of primary power from all resources with the US consuming a quarter of this. With projected growth in electricity demand, about 5000GW of new electricity generation capacity should be developed between the year 2000 and 2030 with almost half of these in developing countries lone (IEA, 2002). The production is projected to be 28 TW by 2050. To stabilize at 550 PPM of carbon dioxide (CO_2) we would require 20 TW of carbon free power and 10 TW of carbon free power for 750-ppm concentration. (Lewis, 2000).This calls for a friendly macroeconomic environment with facilitating legal, and regulatory environment to attract needed massive foreign capital investment (IEA, 2002).

Biomass energy constitute an important component of the energy transition globally and 185 TWh of electricity is produced from biomass in Europe alone, which means that biomass provides 18.4 % of renewable electricity generation (Then, 2019). With the energy crises in 1974 and 1979 and the gulf war in early 1990s coupled with uncertainty of oil supply and price, sugar-producing countries, particularly those with no local fossil fuel resources, have been showing increasing interest in improving energy efficiency in cane processing with a view to export power to the public grid. The emphasis is therefore to generate maximum power from bagasse by efficient use of latent heat of steam and to minimize heat losses in the flue gases leaving the boilers. To supply to the grid, necessary legal and policy framework must be put in place (Kassiap, 2000).

In Kenya, energy demand is expected to increase in future as Kenya has the ambition to be a middle-income country by the year 2030 as stated in Vision 2030. As a result, Kenya has put in place strategies to achieve this goal. They include, among others, rural industrialization and rural electrification programs. The net result of this effort is increased demand for conventional energy. It is projected that electric power demand in Kenya will reach 2400 MW by 2016. For the country to meet this increasing demand, there is need for heavy investment in energy sector and exploitation of non-conventional energy resources. (GOK, 2004)

The coming to force of the Kyoto Protocol of which Kenya is a signatory has generated momentum for investment in power generation from renewable energy resources. This will limit greenhouse gas emission and enhance the concept of sustainable development. With liberalization of the power sector through the Electricity Power Act in 1997, the private sector and independent power producers (IPPs) can produce /generate, distribute and transmit power. With this opportunity, sugar factories can use their bagasse resources to produce steam and power for supply of electricity to the national grid. Enhancing bagasse cogeneration will generate extra power to the grid and hence stabilize the grid and avail more power for the growing demand, minimize greenhouse gas emission by avoiding methane formation from normal bagasse decomposition since methane is about 29 times more potent than carbon dioxide (Kassiap, 2000).

1.2 STATEMENT OF THE PROBLEM

The world sugar production in 2018/2019 was estimated at 178.93. Million metric tons (Statistica, 2019). This is an increase compared to 2002 when world sugar production is estimated at 130 million tons of which 30 million is sold on the world market while the remainder is consumed at local markets of sugar producing countries. At any one time about 13 million tons of sugar is floating in high seas on transit to export markets at low prices. This represents surplus inventory that can be secured at $ 180 to $ 200 a ton compared to Kenya's local sugar production cost of about $ 450 a ton. This means that it is very difficult for Kenyan sugar to compete with imported sugar in a free market encounter. Therefore, there is need to make the sugar industry in Kenya competitive and sustainable. One solution to the looming danger is diversification into export cogeneration as a product. (Kabeyi, 2003).The world sugar production was expected to decline by about 6 million metric tons in 2019 to about 174 tons due to reduced production and yield from India and other factors (USDA, 2019).

As in 2007, Kenya had seven operating sugar factories producing mill white and brown sugar. They are Mumias, Nzoia, Chemelil, Muhoroni, West Kenya, Soin and South Nyanza. Two factories, namely, Miwani and Ramisi are not operating. The sugar factories use bagasse to generate process steam and electrical power for their internal use (Kenya Sugar Board, 2007).

With reforms in the Kenyan power sector leading formation of Electricity Regulatory Commission for regulatory purposes, it is now possible for sugar factories to produce and export power to the national grid and earn extra income and profits. However, this opportunity remains untapped with only Mumias exporting 2 MW electric power to the national grid but with complaints over the price at which the power is exported, i.e. 4 US cents per kWhr, which is claimed to be too low. This compares quite unfavorably with the case of Mauritius where about 40% of the country's installed generation capacity is supplied by sugar factories at an average price of 6 US cents per kWh and US 8 cents per kWh in India (WADE, 2003).

1.3 Objectives of the Research

The objective of this study was to identify problems hindering cogeneration in the sugar industry in Kenya and establish the cogeneration potential of the sugar industry in Kenya.

1.5 Significance of the Study

1.5.1 General importance of cogeneration

Oil prices and other fossil fuels continue to be expensive and uneconomical while their supplies are non-renewable. Known energy sources in Kenya like from hydropower continue to be limited. Bagasse is a reliable renewable energy source and supply is guaranteed by demand for sugar, which is unlimited and continues to grow.

Now, sugar industries are free to supply power to the grid and hence this is an opportunity the sugar factories cannot afford to let go. However, this opportunity continues to be elusive to many sugar companies in Kenya except Mumias to some extent. This research was aimed at enhancing the capacity of sugar industries to generate power from bagasse and maximize the use of bagasse as an alternative energy source for export power production in Kenya.

Cogeneration is a very efficient method of making use of all available energy expended during any process generating electricity or shaft power and then utilizing the waste heat or steam. Standard design practices make use of at best, up to 30% of available energy from raw fuel source. Of the remaining 70% of available energy 30% of the heat is rejected to the atmosphere, through a condenser or similar process, an additional 30% through the stack, and finally approximately 7% to 10% is radiated to the atmosphere because of high relative temperature of the process system (Thurman, 1984).

With heat recovery however, potential useful application of available energy more than doubles, although in a low-quality form. The entire condenser related heat might be used and 40% of the stack heat may be recovered. Thus, it may be seen that effective use of all available energy may more than double. System efficiency can be increased from 30% to 75% (Turner and William, 1984).Cogeneration therefore offers energy, environmental, and economic benefits, including, saving money or fuel cost, improving power reliability, reduced environmental pollution and conserving fossil fuel.

1.5.2 Rationale for Bagasse Cogeneration

From financial point, bagasse cogeneration is a classic win-win for the sugar industry, as it boasts of numerous advantages over traditional generation. Cogeneration of energy from bagasse is attractive as it combines low cost, efficiency and social benefits with the provision of clean renewable energy. Bagasse cogeneration especially in high temperature and pressure configurations could play an important role in encouraging much more efficient use of resources and ensuring widespread access to electricity services. Unfortunately, an insufficient incentive to supply electricity to the grid because of low or inexistent buyback rates has meant that until recently, around two thirds of harvested bagasse was wasted. This situation is now set to improve, with the introduction of more effective biomass feed-in tariffs in countries such as Brazil and India (Synergy, 2005).

i.) Conserving limited resources of fossil fuel

The average efficiency of the fossil-fueled power plants in the U.S. is around 30-33% and has remained virtually unchanged since the 1930's. This means that two-thirds of the energy in the fuel is lost as heat. Cogeneration systems recycle this waste heat and convert it to useful energy and achieve effective electrical efficiencies of 50% to 70%. This improvement reduces emissions of sulfur dioxide, nitrous oxide, mercury, particulate matter, and carbon dioxide, which is the leading greenhouse gas, associated with climate change. In addition to reducing air pollution, cogeneration conserves our limited fossil fuel resources, thereby increasing our nation's energy self-sufficiency.

Cogeneration of energy from bagasse is attractive as it combines low cost, efficiency and social benefits with the provision of clean, renewable energy (WADE, 2003).

ii.) Economic benefits

Economic benefits and advantages of bagasse cogeneration include

a. Increasing the viability of the sugar mills
b. Near zero fuel costs, paid in local currency and valuation of bagasse as a waste product
c. Increased fuel efficiency
d. Location at the point of energy demand, leading to minimal transmission and distribution (T&D) costs and losses.

iii.) Social Benefits

The social benefits of onsite bagasse-fired cogeneration are:

a.) Greater employment for local populations.
b.) More widespread availability of electricity.
c.) More secure and reliable supply of electricity for existing consumers.

iv.) Environmental Benefits

Bagasse combustion is environmentally friendly because it boasts low particulate and CO_2 emissions. This is especially true where bagasse cogeneration replaces carbon-intensive fossil fuel generation. For instance, in India and China, bagasse could displace coal, which amongst other problems has very high levels of ash (Wade, 2004).

2. SUGAR CANE COGENERATION

Sugarcane is an important crop globally cultivated in more than 100 countries around the world although 10 countries account for 80% of the world production led by Brazil and India (Schlindwein, Correa &Vasconcelos, 2017). The largest transformation of biomass after charcoal production in the world is in the electricity sector. A typical sugar mill has an electricity demand of about 20 to 30 kwh/ton of cane. One ton of cane can produce 150 kg of sugar and 90 kg of bagasse (Dry mass). The thermal requirements of the sugar mill are met by bagasse combustion. Low efficient mills generate 60 to 70 kWh/tc while more efficient mills generating at 88 bars steam have capability to produce of 130 kWh/tc. (WEC, 2007). The analysis of bagasse use by sugar factories shows that e production of exportable electricity from sugarcane factories in can be increased from between 10 and 20 kWh to around 60 kWh per ton cane crushed. If the bagasse is dried and pelletized, and Cane Tops and Leaves (CT & L) together used, electricity generation can increase to around 100–110 kWh per ton of cane crushed. An economic analysis of the process shows that the cost of electricity generated within the sugar industry is competitive with that of electricity from fossil fuel (Baguant, 1984). In addition, it is shown that almost twice the current annual electricity consumption, or the postulated annual electricity consumption for the year 2000, of the island can be provided by the Mauritian Sugar Industry.

The Word Alliance for Decentralized Energy (WADE) has estimated that 11 leading countries had a 3.9 GW of installed bagasse based generating capacity with Brazil contributing 1.7 GW due to PROFINA, a programme guaranteeing power sales to the grid. Mauritius with 40 % of all electricity generated from bagasse has demonstrated through 20 years, the restructuring needed in the sugar industry to access enough bagasse and capital for bagasse to be a major efficient contributor (Bell, 2005). Bagasse cogeneration potential is determined using available transformation technologies. The technology is dependent on the mode of operation of the power plant. There are Intermittent Power plants and Firm Power plants. Intermittent power plants operate only partially during the milling season using bagasse while Firm Power plants operate throughout the year, using bagasse during the crop and alternative fuel during the inter-crop. The predominant technology today for generating of electricity from bagasse remains use of steam Rankine Cycle- steam turbines that are designed either as ‘back pressure’ or as condensing systems. The Biomass Integrated gasifier or Gas Turbine Combined cycle (BIG/GTCC) technology is of considerable interest since in approximate terms, it will make electricity generation two or more times as efficient as conventional steam cycle.

Cogeneration, also known as combined heat and power (CHP), and total energy, is an efficient, clean, and reliable approach to generating power and thermal energy from a single fuel source. That is, cogeneration uses heat that is otherwise discarded from conventional power generation to produce thermal energy. This energy is used to provide cooling or heating for industrial facilities, district energy systems, and commercial buildings. By recycling this waste heat, cogeneration systems achieve typical effective -efficiencies of 50% to 70% — a dramatic improvement over the average of 33% efficiency of conventional fossil-fueled power plants. Cogenerations' higher efficiencies reduce air emissions of Nitrous oxides, Sulphur Dioxide, mercury, particulate matter, and Carbon Dioxide, the leading greenhouse gas associated with climate change.

In the United States, the first commercial power plant was a cogeneration plant designed and built by Thomas Edison in 1882 in New York. Primary fuels commonly used in cogeneration include natural gas, oil, diesel fuel, propane, coal, wood, wood-waste and biomass. These are both renewable and non-renewable energy sources. Cogeneration offers the promise of cheap electricity, with electricity price under the control of the plant owner rather than of a utility company. However, this promise may well be an illusion unless five conditions are met (Thumann, 1984).

2.1. The Conditions for Successful Cogeneration

For cogeneration to be successful, the following conditions are necessary

i.) The need for heat must coincide with the need for electricity.

ii.) Unless economics are overwhelming, retrofitting should not be considered. Bottoming cycle equipment is usually very heavy and can require substantial renovating of building foundations. To define this and other installations it is a good idea to get a detailed feasibility study. It is also obvious but notable that a facility designed to produce electricity in addition to process heat now being provided or vice versa will necessarily be larger than present facility. This increase in scale is usually expensive.

iii.) Any sale of electricity planned into economics must be based on legally binding documents, and the conditions under which electricity can be sold. An electric utility is under no obligation to buy electricity in any way that would result in net loss. An electric company is not obligated to pay premium rates for electricity delivered when the company has surplus, and the company is not obligated to deal with an electric source having a phase difference or frequency difference that can harm the electrical system.
iv.) The source of fuel for the prime mover should be considered carefully. When electricity is to be sold to the utility, the price is based in part on the reliability of the cogenerating source, and this places greater burdens on the cogeneration investor.
v.) The co-generator must be prepared to purchase or provide backup heat and/or electricity for occasions when the cogeneration unit is out of service. This is an important economic consideration (Thurmann, 1984).

2.2 Energy Situation in Kenya

2.2.1 Supply and Demand of Electricity in Kenya

The Kenya Power and Lighting Company Ltd (KPLC) has more than 980,000 customers who consumed over 5,000 Gigawatt hours of electricity in the financial year 2006/7. During the year, effective generation capacity was 1041 Megawatts. The peak demand is projected to grow to 1153 MW in 2007/2008 against an effective generation capacity of 1185 MW, leaving a reserve capacity of 3 % (KPLC, 2007). As in most sub-Saharan countries, biomass fuels used mainly in households constitute an estimated two-thirds of Kenya's energy mix. Petroleum and grid electricity constitute the remaining third of the total energy used in industrial, commercial and household sectors. Access to grid electricity for households currently stands at a low 15.3% nationally and less than 2% in rural areas. Total installed grid-connected generation capacity is 1230 MW dominated by hydropower at 56%, while thermal and geothermal contribute 32% and 10% respectively. Consumption of electrical energy is dominated by the industrial sector at 63%, followed by domestic and small-scale industrial at 33%, while consumption by rural electrification customers comprises only 4% of the total demand (KPLC, 2007). Investment in the power sector has lagged growth in demand, with the effect of this situation being felt throughout the Kenyan economy, largely in the form of lost production due to inadequate power supplies. The principal challenges facing the power sector are to:

i.) ensure provision of reliable, efficient, and cost-effective power supplies
ii.) increase the population's access to electricity as a means for stimulating income and employment growth
iii.) improve the efficiency of power distribution and supply through reductions in technical and non-technical losses and collection of revenues
iv.) strengthen the regulatory framework
v.) Enhance green power contribution to the grid in line with the Kyoto Protocol

Over the last decade, the intensity of commercial energy use has been on the decrease, indicating a decline in economic growth. While the cost of, and accessibility to, energy for industry has been cited as the reason for poor economic performance leading to a low demand for power (786 MW), it is believed that demand is suppressed by the prevailing poor economic conditions, which is a cyclic situation. Historical average demand growth rate over the past five years has been a low 1.4% (KPLC, 2006).

Table 2.1: Installed Generation Capacities

SOURCE	**INSTALLED MW**	**EFFECTIVE (MW)**	**ENERGY 2005 (MWHrs)**
KenGen Hydro	677	660	2869
KenGen Thermal	214.2	143.4	491
KenGen Geothermal	115.0	115.0	920
Kengen Wind	0.4	0.4	0.4
KenGen Total	1006.6	918.8	4280.4
REP Stations	5.1	4.6	11.0
Iberafrica	56	56	330
Tsavo Power	74	74	508
IPP Thermal	130	130	842
Orpower	13	13	115
UETCL	0	0	99
Total	**1154.7**	**1066.4**	**5343.4**

SOURCE: KPLC 2006

2.2.2 Enhanced Generation Capacity in Kenya

Generation capacity will be enhanced when the ongoing committed generation projects with a combined capacity of 556 MW are commissioned between 2008 and 2010. Some of the projects include the 60 MW Sondu Miriu hydropower plant, and additional 52.2 MW from Iberafrica Power Ltd. and 25 MW from Mumias Sugar Company Ltd. (KPLC, 2006).

Projected committed additions between 2007 and 2010

The electricity projects planned for Kenya up to the year 2010 are as tabulated below:

Table 2.2: Planned Electricity projects for Kenya between 2007 and 2010

YEAR	PROJECT	MW	COST in US$ x10^6
2007/08	Sondu Miriu	60.0	153.36
2007/2008	Sondu Miriu additional	20.6	53.8
2007/08	Kiambere Rehabilitation	20.0	5.87
2007/08	Kindaruma 3rd Unit	20.0	10.0
Total Hydro		**120.6**	**223.03**
2007/08	Orpower – IV phase 2	36	IPP
2007/08	Ol karia II 3rd unit	33.6	58.0
2007/08	Ol Karia IV	67.2	147.5
Total Geothermal		**136.8**	**205.5**
2007/08	Rabai Medium Speed Diesel	80.0	67.2
2007/08	Lanet Medium speed Diesel	80.0	67.2
2007/08	Eldoret Medium Speed Diesel	80.0	67.2
	Upgrade of Kipevu from GT to CCCycle	60.0	40.0
	Total thermal	300	241.6
	Total Additions to 2010	**457.4**	**670.13**

Source: Ministry of Energy 2007

Transmission and Distribution

KPLC is responsible for ensuring that there is adequate line capacity to maintain supply and quality of electricity across the country. The interconnected network of transmission and distribution lines covers about 30,404 kilometers (KPLC, 2006).

National grid

The national grid is operated as an integral network, linked by a 220 kV and 132 kV transmission network. There is a limited length of 66 kV transmission lines. The national grid affects the future growth of the energy sector because any new generation capacity must take into consideration the existing network and its capacity to handle new loads. (KPLC, 2006).

Expansion

KPLC reinforces the power transmission and distribution network by constructing additional lines and substations across the whole country. Currently, KPLC has a commitment to connect150, 000 Consumers annually (KPLC, 2006).

Efficiency

Efficiency of the transmission and distribution network continues to be enhanced in both technical and non-technical aspects. Technical improvements include re-conducting of lines, installation of capacitors, and construction of additional feeders and substations. Non-technical improvements include introduction of electronic meters, improvement of meter reading accuracy, fraud control and resolution of billing anomalies. All these omissions have led to huge power and revenue losses to the country’s power grid (KPLC, 2006).

2.3 Overview of Global Sugarcane Processing Industry

Sugarcane is currently grown under a wide range of conditions, in tropical and sub-tropical regions between 35°N in Spain to 35°S in South Africa. As water requirements for the crop are, 1,200-1,600 mm/year, good distribution of rainfall is required if there is no irrigation. Sugarcane harvesting generally occurs every 9-24 months, depending on crop variety. The three largest sugarcane growers in terms of production are Brazil, India and China (Kabeyi, 2003). World sugar production in 2007/08 (October/September) is estimated by FAO to reach 169 million tonnes (raw sugar equivalent), 2.7 percent more than in the previous year, and about 12 million tonnes higher than the projected world sugar consumption of 157 million tonnes. Virtually all the growth in output would stem from developing countries, which are forecast to produce 128.5 million tonnes, up from 124.3 million tonnes in 2006/07, led by a record harvest in India. Total production in developed countries is forecast at 40.5 million tonnes, 0.7 percent more than in the previous year, reflecting increases in Australia and the United States. While a strong growth is anticipated in South Africa, production may fall in Kenya and Mauritius (FAO, 2007).

2.4 Sugar Making Process

2.4.1 History of sugar

It is thought that sugar was first used by man in Polynesia from where it spread to India. In 510 BC the emperor Darius of Persia invaded India when he found sugarcane but that was kept a secret. When Arabs invaded Persia in 642 AD, they learnt how sugar was made and spread these to other areas including North Africa and Spain where they conquered. Western Europeans only discovered sugar because of crusades in the 11th century AD. The first sugar was recorded in England in 1099. Sugar was available in London at ten shillings a pound in 1319 AD i.e. about US$100 per kilogram at today's prices so it was very much a luxury (Hugot, 1963).

In 15th Century AD, European sugar was refined in Venice while in the same century Columbus sailed to the Americas, the "New World". In 1493, he took sugarcane plants to grow in Caribbean. By 1750, there were 120 sugar refineries operating in Britain with combined outputs of 30,000 tons per annum. Sugar beet was first identified as a source of sugar in 1747. However, stakes in cane sugar plantations made sure that it stayed as no more than a curiosity until the Napoleonic wars at the start of the 19th Century when Britain blockaded sugar imports to continental Europe. Those same stakes probably delayed the introduction of beet sugar to England until the First World War when Britain's sugar imports were threatened (Hugot, 1963). Today's modern sugar industry is still beset with the government interference at many levels and throughout the world. The European Union Brazil and India are the top three producers and together account for some 40% of annual production. However, most sugar is consumed locally within the country of production and only approximately 25% is traded internationally (Hugot, 1963).

2.4.2 Sugarcane in Kenya

The story of the sugar industry in Kenya has not been sweet. Poor pay, delayed payments, mismanagement and corruption has characterized the industry. With a new sugar strategy in place for 2004-09, however, the sector has started showing signs of recovery. British settlers established the first sugar mill in 1922 but the industry has recorded minimal growth for the past half century due to political interference and dilapidated infrastructure in sugarcane growing areas (Kenya Sugar Board, 2007). Many farmers have abandoned the crop and cane production in South East of the country, near coast, when Ramisi Sugar Company Ltd. collapsed in 1980s. Today sugarcane is grown mainly in four districts in Kenya: Nyanza, South Nyanza, Mumias and Busia. The area under cane is currently 120,000 hectares, annually producing between 400,000-500,000 tonnes. Almost half of this is produced on smallholdings while the remainder comes from large plantations. Domestic demand for sugar is about 600,000 tonnes, which leaves a deficit of about_200000 tonnes that is met by imports from regional producers. (Kenya Sugar Board, 2007)

2.4.3 How Sugar is made

According to Hugot (1963) Sugar is made by some plants to store energy that they do not need straight away, rather as animals make fat. People like sugar for its sweetness and its energy so some of the plants mainly sugar cane and beets are grown commercially to extract sugar. Sugar is produced in 121 countries and global production now exceeds 120 million tonnes a year. Approximate 70% is produced from sugar cane and 30% is produced from sugar beet.

2.4.4 Sugarcane processing

Sugarcane processing is focused on the production of cane sugar (sucrose) from sugarcane. Other products of the processing include bagasse, molasses and filter cake. Bagasse is used for several purposes, e.g., fuels for boilers and limekilns, production of paperboard and panel boards, agricultural mulch and raw materials for production of chemicals. Bagasse and bagasse residue are primarily used as a fuel source for boilers in generation of process stream. Dried filter cake is used as animal feed supplement, fertilizer and source of sugarcane wax. Molasses is produced in two forms: inedible for humans (black strap) or as edible syrup. Black strap molasses is used primarily as an animal feed additive but also is used to produce ethanol, compressed yeast, citric acid and rum. Edible molasses and syrups are often blending with maple syrup, invert sugar or corn syrup (Hugot, 1963)

2.4.5 Process description

i.) Cane sugar production

Hand cutting is the most common harvesting method throughout the world but some locations like Florida, Louisiana and Hawaii in U.S.A have used mechanical harvesters for many years. After cutting the cane is loaded by hand, Mechanical grab loaders or continuous loaders. Cane is transported to mills using trailers, trucks rail cars or burgers, depending upon relative location of cane fields and processing without excessive deterioration of sucrose content.

i.) Process description

The cane is received at the mill and prepared for extraction of juice. At the mill, the cane is mechanically unloaded, placed in a large pile and prior to milling, cane is cleaned. The milling process occurs in four steps: breaking the hard structure of cane and grinding cane. Breaking the cane uses revolving knives, shredders, crushers or a combination of these processes. For grinding or milling the crushed cane, multiple sets of three roller mills is used but some mills have four, five or six rollers in a tandem of four, five, six or even more. Conveyors transport the crushed cane from one mill to the next. Imbibition is the process in which water or juice is applied to crushed cane to enhance extraction of juice at the next mill. In imbibition water or juice from other processing areas is introduced into the last mill and transferred from mill to mill toward first mill while crushed cane is conveyed from the first to the last mill. The crushed cane exiting the last mill is called bagasse. The juice from the mills is strained to remove large particles and clarified in juice clarifiers. In raw sugar production, clarification is done almost exclusively with heat and lime (as milk of lime or lime saccharate) Small quantities of soluble phosphate also may be added. The lime is added to neutralize the organic acids and temperature of juice raised to about 95°C (250 degrees F). A heavy precipitate form, which is separated from the juice in the clarifier. The insoluble particulate mass, called mud is separated from the limed juice by gravity centrifuge. Clarified juice goes to evaporators without additional treatment. The mud filtered and filter cake is washed with water to further remove sugar before disposal.

ii.) Evaporation

Evaporation is performed in two stages: Initially in an evaporation station to condensate the juice and then in vacuum pan to crystallize the sugar. The clarified juice is passed through heat exchangers to preheat the juice and then to the evaporation stations. Evaporation stations consist of a series of evaporators termed multiple effect evaporators: typically, a series of five evaporators. Steam from large boilers is used to heat first evaporation; and steam from the water evaporated in first evaporation is used to heat the second evaporator.

This heat transfer process continues through the five evaporators and as temperature decreases (due to heat loss) from evaporator to evaporator, the pressure side inside each evaporator decreases which allows the juice to boil at the lower temperature in subsequent evaporation. Some steam is released from first three evaporators and this steam is used in various process heaters in the plant. The evaporator station in cane sugar manufacture typically produces syrup with about 65% solids and 35% water. Following evaporation, the syrup is clarified by adding lime phosphoric acid and polymer flocculants, aerated and filtered in the clarifier. From clarifier, the syrup goes to vacuum pans for crystallization.

iii.) Crystallization

Crystallization of sugar starts in vacuum pans; whose function is to produce sugar crystals from the syrup. In the pan boiling process, the syrup is evaporated until it reaches the super saturation stage. At that point, seeding or shocking the solution initiates the crystallization process. When the volume of the mixture of liquor and crystals known as massecuite reaches the capacity of the pan, evaporation can proceed until the final massecuite is formed.

At that point, the contents of the vacuum pans are discharged to the crystallizer, whose function is to maximize the sugar crystal removal from massecuite. Some mills seed the vacuum pans with the isopropyl alcohol and ground sugar (or other similar seeding agent.) rather than with crystals from the process. From crystallizer, the massecuite (A massecuite) is transferred to high speed centrifugal, in which the mother liquor (termed molasses) is centrifuged to outer shell and crystals remain in inner centrifugal buckets.

iv.) Centrifuging and molasses

The liquor (A molasses) from the first centrifugal is returned to vacuum pans and are boiled to yield a second massecuite (B massecuite), that in turn yields a second batch of crystals. The B massecuite is transferred to the crystallizer and then to the centrifugal and the raw sugar is separated from molasses. This raw sugar is combined with the first crop of crystals.

The molasses from the second boiling (B molasses) is much lower in purity than first molasses. It is reboiled to form a low-grade massecuite (C massecuite) which goes to crystallizer and then centrifugal. Thus, low-grade cane sugar is mingled with syrup and is sometimes used to in vacuum pans as seeding solution. The final molasses from third stage (blackstrap molasses) is a heavy, viscous material used primarily as supplement in cattle feed. The cane sugar from combined A and B massecuite is dried in fluidized bed or spouted bed driers and cooled. After cooling, the cane sugar is transferred to packing bins and sent to bulk storage. In Kenya, the current trend is to package sugar in small packs of ½ kg, 1 kg, 2 kg and 5 kg.

v.) Refined Sugar

Cane sugar is refined either at the same location where it is produced as part of an integrated facility or as separate raw sugar refineries. The initial step in cane sugar refining is washing the sugar, called affination with warm, almost saturated syrup to loosen the molasses film. This is followed by separation of the crystals from the syrup in a centrifugal and washing of the separated crystals with hot water or a high purity_Sweetwater. If the refinery is part of cane sugar production facility the cane sugar may be washed more heavily in previous steps and the affixation step omitted. The washed raw sugar is sent to a premelter and then to a Melter where it is mixed with high purity sweet water from other refinery steps and is steam heated. The resultant syrup is passed through screen to remove any particulate in syrup and send to the clarification step. The syrup from crystal washing called affination syrup is transferred to remelt processing station or reused in raw sugar washing step.

In the remelt station, the syrup volume is reduced to form the massecuite and the sugar crystals are separated from the syrup. The separated liquor is blackstrap molasses. The sugar crystals are sent to a melter and then to clarification step. Two clarification methods commonly used are pressure filtration and chemical treatment. The two most common adsorbents are granular activated carbon and borne char, manufactured from degreased cattle bones. The decolorized sugar liquor is sent to heaters (at some refineries) followed by multiple effects evaporators and then to vacuum pans same as in cane sugar manufacture. In refined sugar production, the most common boiling system is the four-strike system. From the process description, the process of sugar manufacture involves cutting, squeezing, filtration, centrifuging, washing, pumping and heating. All this requires a lot of energy in various forms namely heat, electrical and mechanical energy (Hugot, 1963).

Figure 2.1. Shows the sugar making process

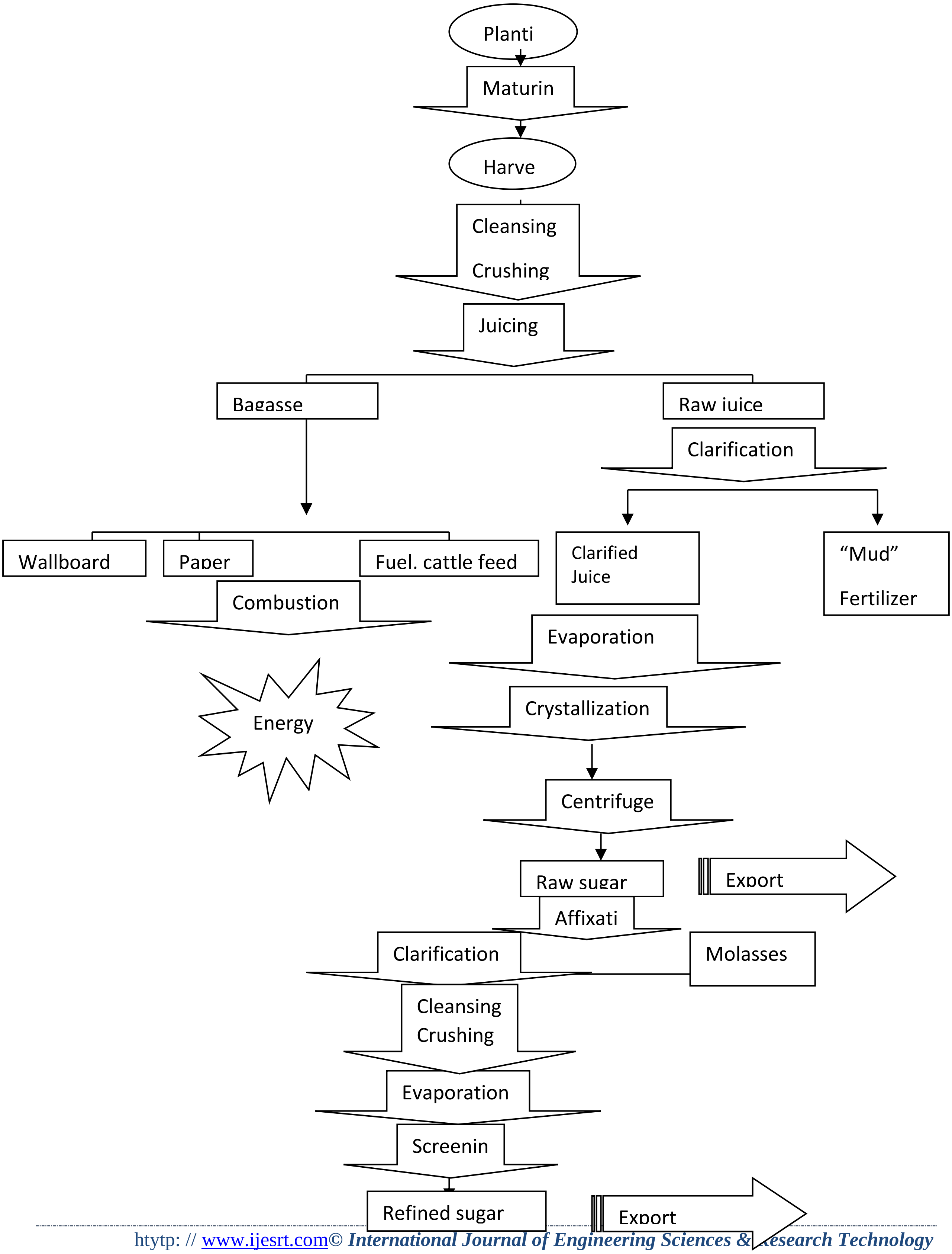
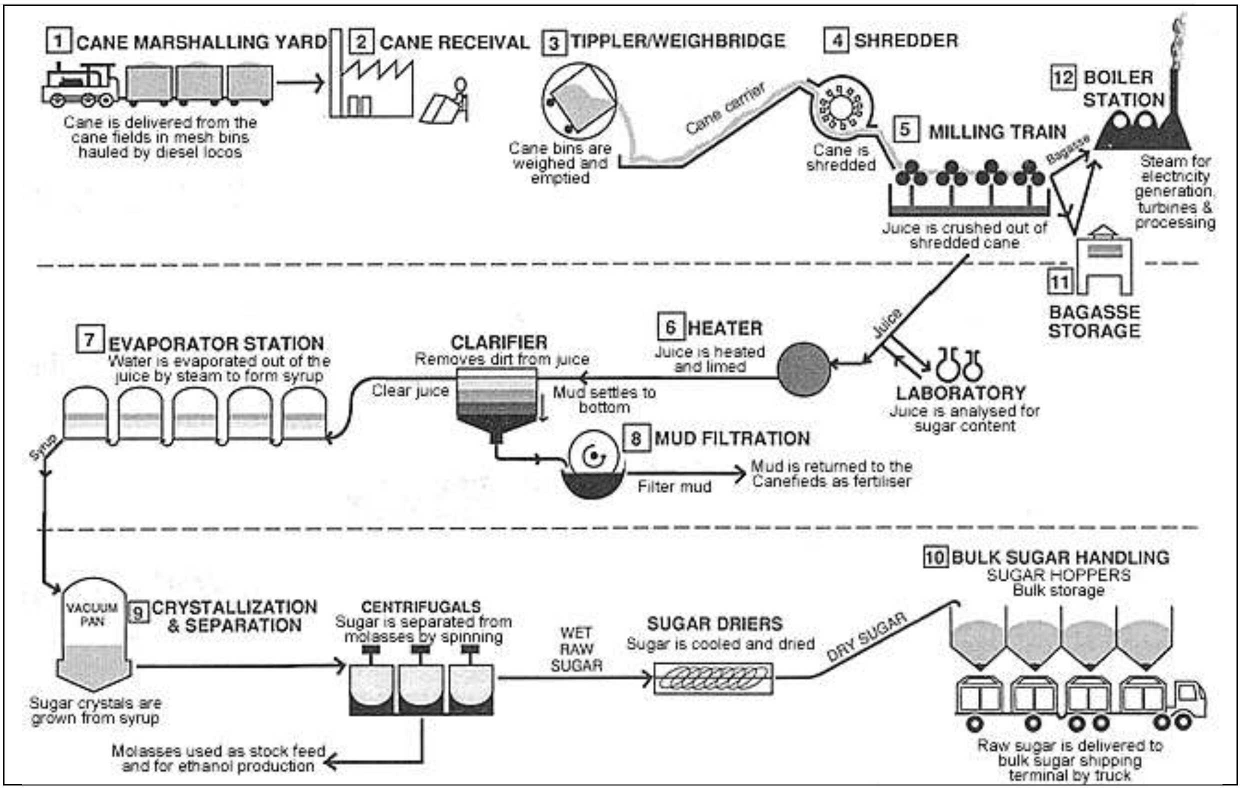


Figure 2.1: Sugar processing flowchart



Source: Hugot (1963)

Figure 2.2: Simplified Diagrammatical Explanation of the Process for producing raw sugar

2.5 The Sugar Industry in Kenya

Sugar is a political as well as a strategic commodity in Kenya. The sugar subsector is a source of livelihood to over one million people in Kenya. It offers employment and helps in rural infrastructure development. It is a commodity that faces competition from imported sugar under the COMESA protocol or from residual world market. (Kegode etl, 2003).The development of the sugar industry in Kenya started with private investments at Miwani in 1922, followed by Ramisi Sugar Company in 1927. After independence, six additional companies were established namely: Muhoroni (1966), Chemelil (1968), Mumias (1973), Nzoia (1978), South Nyanza (1979) and West Kenya-Sugar (1981). The establishment of the parastatals was driven by a national desire to:

1. Accelerate social-economic development;
2. Address regional economic imbalances;
3. Increase Kenyan citizen’s participation in the economy;
4. Promote indigenous entrepreneurship; and
5. Promote foreign investments through joint ventures.

Despite these investments, self-sufficiency in sugar has remained elusive over the years as consumption continues to outstrip supply. Total sugar production grew from 368,970 tons in 1981 to 517,000 tonnes in 2004. This is the highest production realized since the inception of the industry. Domestic sugar consumption increased even faster, rising from 324,054 tonnes to 669,914 tones over the same period. Consequently, Kenya has remained a net importer of sugar with imports rising from 4,000 tonnes in 1984 to an all-time high of 249,336 tons in 2001. The country on average imports 200,000 tonnes of sugar per annum to bridge the deficit between domestic production and consumption. (Kenya Sugar Board, 2007) Sugar cane is still one of the most important crops in Kenya alongside tea, coffee, maize and horticultural crops. It directly supports over 250,000 small-scale farmers who supply over 80% of the cane milled by the sugar companies. An estimated 6 million Kenyans derive their livelihood directly or indirectly from the sugar industry. Domestic production of sugar saves the country in excess of US$ 250 million (Kshs. 20 billion) in foreign exchange annually.

Price and market liberalization under the World Trade Organization (WTO) and other trading arrangements under East African Community (EAC), Common Markets for East and Southern Africa (COMESA), and African Caribbean and Pacific–European Union (ACP-EU) have precipitated stiff competition to the domestic sugar industry (Kenya Sugar Board, 2007)

2.5. Kenyan Sugar Factories

Kenya has the following sugar factories:

2.5.1. Chemelil Sugar Company

Chemelil Sugar Company situated in the Nyando Sugar Belt was incorporated on 5th July 1965 as a Limited Company. The sugar cane milling factory is in Nyando District, 50 Km from Kisumu town. Its initial milling capacity was 95 Tonnes of Cane per Hour (TCH), which has been expanded to 135 TCH over the years. Chemelil Sugar Company boasts a pilot cane irrigation project, which was facilitated by the Sugar Development Fund. This project has enabled the factory to irrigate 400 out of its 2030 hectares nucleus estate cane, improving yields and lowering cane maturity period. Plans are underway to expand the acreage under irrigation. Factory receives 85% of its cane supply from out -grower farms and 15% from Company's Nucleus Estate

2.5.2: Muhoroni Sugar Company

Muhoroni Sugar Company (MUSCO) is Kenya's first post-independence sugar factory, established in 1966 with a cane crushing capacity of 800 TCD. Through three stages of expansion, the factory's crushing capacity was increased to 1,200 then 1,800 TCD and subsequently to the current capacity of 2,200 TCD. The factory, which is operational, is currently under receivership. Agrochemicals Food Company Ltd. gets its molasses supply from the neighboring Muhoroni Sugar Company. Molasses is a raw material for the manufacture of yeast, spirits etc.

2.5.3 Nzoia Sugar Company

Nzoia Sugar Company Nzoia Sugar Company (NSC), located between Webuye and Bungoma Towns of Western Province was commissioned in 1978 with an initial rated capacity of 2,000 TCD, which was later expanded to 3,000 TCD. Out grower companies supply 80% of the cane it crushes while it harvests 10%from its nucleus estate.

2.5.4 Mumias Sugar Company Ltd

Mumias Sugar Company Ltd. was established in 1973. The factory had an initial crushing capacity of 1,250 TCD but was gradually expanded to 7,000 TCD. The Company has installed a diffuser, which has enabled the factory to expand its capacity to 8,400 TCD. The diffuser technology has an added advantage of being efficient in the extraction of sucrose from sugar cane. The factory accounts for over 60% of the total sugar produced in the country. Due to its financial stability, Mumias Sugar Company has managed to transform Mumias Township and its environs into hubs of economic activities that evolve around sugar production.

2.5.5 Soin Sugar Company

Soin Sugar Company situated in Kericho District Soin Division is a privately-owned company established in 1999. Soin factory with an open pan system, started full operations in July 2006 has a capacity of 300 TCD expandable to 500 TCD. The factory has been commissioned and the first batch of brown sugar has been produced by one milling tandem, which has been completed. Work on the second milling tandem will soon be completed. The full operation of this factory will decongest the operations at the neighbouring Muhoroni Sugar Company.

2.5.6 South Nyanza Sugar Company (SONY)

South Nyanza Sugar Company is situated in Sare Awendo, South Nyanza.It was built in 1979 with an initial crushing capacity of 2,200 TCD, which has since been expanded, to 3,000 TCD.

2.5.7 West Kenya Sugar Company

This is a privately-owned sugar company established in 1981 with an initial crushing capacity of 100 TCD, which has been expanded over time to the current was later expanded to 2500 TCD. The company is undergoing expansion to 6000 TCD after acquiring an old mill from Mumias Sugar Company Ltd.

2.5.8. Miwani Sugar Company Ltd

Miwani Sugar Factory (MCS) was the first sugar mill to be built in Kenya. The factory, situated in the Nyando Sugar Belt in Nyanza Province was incorporated as Miwani Sugar Mills (MSM), a limited liability company, in 1922. The factory had an initial crushing capacity of 800 metric tonnes of cane-crushed daily (TCD), eventually expanded to 2,400 TCD. The factory is currently under receivership.

2.6 The Status of Sugar Industry; July 2006 - June 2007

a) Sugar production

Total sugar production in 2006/07 was 474,955 tonnes compared to 504,584 tonnes in 2005/06, giving a production decrease of 5.9%. The decrease was attributed to low production at Mumias, Nzoia and South Nyanza sugar Companies. The highest decrease in sugar production was observed from Mumias Sugar Co. with 218,680 tonnes down from 265,911 tonnes in 2005/06, which is 18% lower, blamed on shortage of cane supply. Nzoia sugar factory came Second in-terms of decreased production with 64,574 tonnes against 65,369 tonnes in 2005/06, a decrease of 14%, mainly attributed to closure for OOC in September- October 2006. For more details refer to Table A (i).

b) Sugar sales and closing stocks

Total sugar sales in 2006/07 were 469,557 tonnes compared to 498,658 tonnes in the previous financial year, representing a decrease of 6%. Sugar closing stocks started period under review at 7,029 tonnes and maintained a decreasing trend to finish June 2007 at 2,135 tonnes compared to 1,052 tonnes at the end June 2006. The decrease in sugar stocks is attributed to lower sugar production in this year, against the growing sugar demand.

c) Foreign trade

Total sugar imports for 2006/07 were 238,826 tonnes compared to 166,354 tonnes in 2005/06, giving an increase of 44%. The composition of sugar imports for the period was 48% brown / mill white and 52% refined white sugar. Overall, a total of 126,919 tonnes (53%) were imported from COMESA FTA countries in 2006/07 against 71,977 tonnes (43%) in 2005/06, with the main supplier in both cases being Egypt at 105,669 tonnes and 60,947 tonnes respectively.

CIF Mombasa landed price for imported sugar started the year 2006/07 at a monthly average of Kshs. 29,488 per ton up from Kshs. 22,845 in July 2005. The CIF values maintained a gradual increase to attain a high of kshs.35, 077 in March 2007 and then embarked on a downward trend to end the review period (July 2006 - June 2007) at had an overall average of Kshs.31, 296 per ton.

2.6.1 Management of Kenyan Sugar Industry

The Government of Kenya through the Kenya Sugar Board manages the policy and administrative issues of the Kenyan sugar industry (KSB, 2006)

Roles of the Sugar Board

i.) Provide advisory services to growers and millers;
ii.) Facilitate an equitable mechanism for the pricing of sugarcane and appropriation of proceeds from the disposal of the byproducts of sugar production between growers and millers;
iii.) Represent the industry in other organizations that are relevant to the promotion of the industry;
iv.) Oversee the formulation of standard provisions governing the mutual rights and obligations of growers and millers;
v.) Collect, collate and analyze industry statistics and maintain a database for the industry; and
vi.) Promote the efficiency and development of the industry through the establishment of appropriate institutional linkages
vii.) Coordinate the activities of individuals and organizations within the industry.
viii.) Facilitate the equitable access to the benefits and resources of the industry by all interested parties.
ix.) Formulate and implement overall policies and plans for the development of the industry;
x.) Act as an intermediary between the Government and the industry;
xi.) Facilitate the flow of research findings to interested parties;
xii.) Monitor the domestic market in order to identify and advice on any distortions in the sugar market;
xiii.) Facilitate the arbitration of disputes among interested parties;

xiv.) Facilitate the export of Local sugar;
xv.) Promote and encourage the use of environment friendly technologies in the industry

2.7 Cogeneration in Kenyan Sugar Industry

Potential for cogeneration exists in the sugar industry where steam is raised from bagasse, a waste product of the cane milling process, for power generation and process heat. Unlike other industries that only consume energy; the sugar industry can generate surplus power over and above its internal requirements by burning bagasse to generate process steam and power. However, due to statutory requirements and other limitations on the sale of electricity, sugar factories in Kenya have been unable to exploit energy in bagasse. Excess bagasse is currently treated as waste and incinerated, largely as a process of disposal. Process steam and power are in this case unfortunately treated as a by process of the disposal exercise.

The current Kenyan government, voted in on a platform of accelerated economic development and infrastructure rehabilitation, has committed itself to, among other initiatives, the rehabilitation of the sugar industry. Power generation through cogeneration is seen as opening new avenues for revenue creation in the sector. Accordingly, the Ministry of Energy recently permitted sugar companies to generate power for sale to the national grid and to the public in general. Furthermore, various fiscal incentives for investments in regular and non-conventional renewable energy projects have been suggested for inclusion in the national energy policy document. Meanwhile, local utilities are looking at strengthening the transmission grid, which, coincidentally, will allow the sugar companies to feed in their power. Consequently, it has become a viable proposition for sugar companies to raise high-pressure steam in modern, high-efficiency boilers using bagasse to generate heat and power economically to provide surplus power for export to the grid.

Like other sectors in the Kenyan economy, the sugar industry has undergone continuous decline over the past decade. Statistics provided by the Kenya Sugar Board indicate that the best performance in the last decade (1992-2002) was recorded in 1996 when the industry had 131,100 hectares under cane yielding a healthy 90.9 tonnes of cane per hectare and supporting 23,900 plantation jobs in direct wage employment. In contrast, 2002 figures show that the acreage had dropped to 126,800 hectares, while the yield was down to 0.7 tonnes per hectare with the number of plantation jobs down by 2630.

While some of the job losses can be credited to increased mechanization in the farms, the bulk of the reductions are attributable to poor economic performance of the sugar factories and increased competition from cheap imports. The resulting poor sales of sugar from local factories influence negatively on payment to farmers, hence the downward spiral. Additional revenues from power generation, and the improved efficiency accompanying new investment, should help to revamp the industry.

2.7.1 Bagasse Cogeneration Experience

Experience from Réunion, Mauritius, India, Brazil and Cuba confirm the practical potential for cogeneration in Kenya, where it has hitherto been limited by the technology employed, financial and technical resources availability, and legal and regulatory frameworks. In the case of the success story countries, the development of cogeneration evolved along the well-established stages of own generation, intermittent power, continuous power and firm generation. In Kenya, one sugar factory has the capacity for intermittent power supply but has been constrained by regulatory barriers. During the electricity crisis of 2000, this factory was able to sell power, but was limited by the capacity of interconnecting transformers linking it to the grid.

It would seem natural for Kenya to avoid the intermediate steps and 'leapfrog' from own generation to firm power supplies by learning from the experiences of Réunion, Mauritius and Brazil. Kenya has the advantage that the crop season lasts an estimated 300 days a year, while the out-of-cane season is usually during the wet season, coinciding with the duration of maximum hydro availability and making firm generation attractive. Annual maintenance could be carried out during this period.

The power and process steam requirements in a sugar plant can be met in one of two ways: Conventional cogeneration deploys a bagasse-fired boiler in conjunction with an extraction condensing and/or backpressure steam turbine coupled to an electrical generator, or a double extraction-condensing turbine coupled to an electrical generator. This is the predominant method currently used in Kenya with pressures of 20-25 bars and with resultant efficiencies of less than 10%. System efficiencies of up to 25% can be achieved for steam pressures of 45-66 bars, permitting electricity exports of up to 100 kWh per ton of cane crushed. Plant performances of 110 kWh (82 bar) per ton of cane crushed are operational in Reunion, Mauritius, India and Brazil. This means that the process of generating more power from sugar factories for export to the grid is essentially an efficiency upgrade exercise accompanied by a modernization and capacity improvement of sugar mills. Integrated gasification cogeneration with combined cycle (IGCC) *uses an external* gasifier to produce combustible gases from the bagasse, which are then fired in a modified gas turbine. Hot exhaust gases are passed through a waste heat recovery boiler for generating steam; some of the exhaust gas is used for drying bagasse. Efficiencies achieved in the conversion of biomass to electrical energy can be as high as 37%. The IGCC system is still largely in a stage of commercial infancy, with a few installations in Brazil.

2.7.2 Opportunities for Cogeneration in Kenya

The current total installed cogeneration capacity in the Kenyan sugar industry is 36.5 MW, used exclusively within the industry. Sugar industry statistics show that in 2002 alone Kenya produced an estimated 1.8 million tonnes of bagasse with a gross calorific value of 16,800 TJ, equivalent to 323,000 tonnes of oil worth approximately US$194 million. In conditions such as have been established in Mauritius, this bagasse could produce 360-600 GWhrs per year of excess electricity for sale, depending on the technology used. At this rate, cogeneration from bagasse could easily provide 10% of the national electrical energy demand.

To achieve the 10% target economically, sugar factories will need to invest in firm generation through equipment upgrade, with efficiencies high enough to generate economic quantities of power for sale to the national grid. Issues that need to be addressed include:

- modular capacity, high-efficiency boilers to be installed in phases
- ample storage capacity for bagasse to cover autonomy
- factory efficiency optimization
- improved scheduled maintenance
- harvest cane trash as a possible extra boiler fuel (potential additional fuel capacity of up to 20%), which will require substantial investment

To sell their power to the national grid, sugar factories will, in addition, require investments in appropriate upgrade of grid interconnections consisting of power transformers, electrical switchgear and power lines. With appropriate investment, the bagasse could be used to generate an effective capacity of 135 MWe and 90 MWe at pressures of 82 bars and 60 bars respectively, to power the sugar factories and export up to 550 GWh of electricity to the national grid annually in addition to process steam. This could displace energy currently produced from fossil fuels. At an average consumption of 0.22 tonnes of oil per MWhr for thermal plants, bagasse-based cogeneration would save some $90 million of foreign exchange annually. Additionally, cogeneration would promote the use of indigenous energy source, build local capacity for independent power production, encourage private sector participation in the power sector and create an import of financial benefits to cane farmers.

2.7.3 Cost Implications

For cogeneration plants, the investment costs vary with net export capacity, from $1.4 million/MW at the lower pressures, through $1.8 million/MW mid-range to $3.1 million/MW at the top end. This compares with $1.1 million/MW for heavy fuel plants, $2.25 million/MW for geothermal and $2.5 million/MW for hydro power plants. Thermal power plants have significant fuel costs that are passed directly to the consumers under current tariffs. Except for disparities arising from management performance, three out of the existing six factories in Kenya have identical capacities of 125 tonnes of cane per hour (TCH), while a fourth with similar capacity currently operates at 70% of the rated capacity. These four factories are in the league of 3000 tonnes of cane per day (TCD) and have a planned expansion to 5000 TCD. A fifth factory operates at its full rated capacity of 350 TCH, producing more than half of the country's sugar. The sixth, with a similar capacity as the other four, is currently under receivership with little signs of being re-opened. Consequent analysis hereinafter - see Table 2.3 - is therefore based on 5000 TCD capacity and can be adjusted for other volumes. Current operational performance and the installed capacities will be limiting factors to cogeneration, as the cane crushing process is the source of fuel.

Table 2.3: Estimates of plant capital costs

Component	Possible plant options		
Boiler pressure (bar)	45	60	82
Recommended plant capacity (tonnes of cane per day)	5000	5000	5000
Boiler capacity (tonnes of steam per hour)	140	140	140
Bagasse feed rate (tonnes per hour)	58	62	70
Turbine capacity (MW)	25	30	50
Daily power generation, gross (MWh)	420	550	820
Equivalent capacity (MW)	18	24	40
Daily export power, net (MWh)	260	330	550
Equivalent export capacity (MW)	12.5	14	24
Total capital investment ($ million)	18	25	75
Estimated local component ($ million)	4	5	12
Estimated annual revenue from electricity ($ million)	4	5	8.3
Simple payback period (years)	4.5	5	8.8

Source: Osawa and Yuko (2004)

This means that a 10% bagasse cogeneration contribution to the grid can be achieved by investing in efficiency upgrades at the five operational sugar factories in Kenya. The total investment costs will vary according to boiler pressures and efficiencies selected, and the power plant configurations at different factories. These costs would typically range between $120 million at 60 bar and $230 million at 80 bar, delivering an estimated 480 GWh with simple payback periods of 6-7 years and 8-9 years respectively. The cost figures compare reasonably with recent investment performances for geothermal and hydro plants. Corresponding estimated annual revenues from sale of electricity is $20-36 million in addition to savings from current net electricity imports into the sugar factories.

Higher operating pressures offer better efficiencies, and therefore better resource utilization. However, they also entail higher capital costs and more sophisticated levels of technology. Given the relatively long-term operation for which power projects are designed, typically 25-30 years, the more efficient units are attractive over these periods. Like other renewable energy technologies, biomass cogeneration lends itself to modular implementation, allowing large projects to be broken down into smaller units that can be implemented in phases. Apart from being easier to finance, these modules reduce the impact of additional capacities on the grid system, enabling power sector planners to match demand with supply.

Of the total capital costs of putting up sugar factories, on the order of 60% is attributable to the cost of the cogeneration power plant. Given that several the factories are planning capacity expansions, with most in need of a large degree of reinvestment to replace obsolete plant, cogeneration provides an ideal platform for the upgrade. In this case, the power plants should be designed to take expanded capacity in future. At present, all the factories are net importers of power, either due to inadequate capacity or, in the case of one factory, inadequate arrangements for generation when the factory is under maintenance. In the cogeneration scenario, the factories consume an estimated 30% of the power generated by the plant in exchange for bagasse fuel, effectively saving on their energy bill.

2.7.4 Impacts of Cogeneration

With an optimistic job creation target of 500,000 jobs annually set by the current government, development of cogeneration in the sugar industry could provide numerous opportunities. Industry statistics show that efficient cogeneration plants create on average 3.5-5.2 jobs per GWhr directly. Thus, for a total capacity of 500 GWhr, some 2000 jobs could be created directly from the sugar industry alone through cogeneration. Most of these jobs would, however, be created upstream in sugar plantations. Current annual turnover of the industry is estimated at

$160 million, of which $100 million is due to independent sugar farmers, otherwise referred to as 'out growers'. Historically, only half of this amount is normally paid while the rest has always been carried over as arrears due to cash flow concerns within the factories. Investment in cogeneration would bring the desperately needed benefit of additional revenues to pay off the farmers for their cane. Improved plant efficiency, coupled with planned production expansion to meet international competition, would increase industry turnover by 20-40%. Secondary benefits and corresponding impacts would spread to other sectors, but the biggest beneficiary would be the small-scale out grower, thus directly addressing wealth creation targets. Sugar farmers currently frustrated by poor prices and late payments could be motivated to put more land under cane with improved factory efficiencies and healthier performance arising from better cash flows and more reliable steam and power, higher cane output from the farmers is anticipated. Ultimately, cogeneration capacity would be limited by land available for cane, and by efficient agricultural production, account being taken of the need to balance food production against commercial sugar cane plantation.

Apart from substituting fossil fuels, cogeneration provides an opportunity for the reduction of greenhouse gas emissions, while strengthening the infrastructure base in relation to electricity supply. With carbon financing currently at $5-8 per ton of carbon dioxide, additional revenues can be accessed to finance the development of the sector, once clear baselines have been established. This would substantially reduce borrowing to finance the development of these projects, with a resultant decrease on the national external debt.

2.7.5 Looking Forward

Cogeneration provides a clear potential for diversification of the sugar industry into energy-related activities such as power generation and ethanol production and should be accorded high priority. Sugar factories in Kenya have been unable to meet the national demand for sugar at competitive prices at a time when other Common Market for East and Southern Africa (COMESA) countries are desperate to sell cheaper sugar to the local market. By giving requisite attention and support to cogeneration, the sugar industry can bridge the production gap, thus making sugar farming more attractive. Furthermore, given more than 100,000 small-scale cane growers currently producing about 88% of Kenya's sugar cane, the implications for rural livelihood enhancement of this diversification could be very significant. While cogeneration matches other power generation options in terms of investment costs, it provides an indigenous source of electrical energy for the nation saves on foreign exchange, is a tool for employment and wealth creation and an agent for abatement of environmental degradation. Left on its own, the sugar industry does not have the resources and capacity to realize the full potential of cogeneration. Clearly, the biggest hurdles are policy barriers and attitudes on the part of developers and financiers. A combination of players is required make a 10% contribution by cogeneration a reality.

2.8 Bagasse as a fuel

2.8.1 Physical Composition of Bagasse

Final bagasse or simply bagasse is the solid fibrous material, which leaves the delivery opening of the last mill. Despite the diversity of milling plants and machines employed, the physical composition of bagasse varies between rather narrow limits depending on variety, age or maturity of sugarcane and harvesting method. The most important component of bagasse in view of combustion and steam production is moisture. Combustible bagasse moisture will generally range between 45-52%. It is still difficult even in a modern mill to obtain figures as low as 44% moisture contents. Each ton of sugarcane cane yield 250 kg of wet bagasse. (Synergy, 2005)
In addition to water, bagasse contains:

(1) Insoluble materials consisting mainly of cellulose
(2) Insoluble inorganic material mainly sand brought along with cane
(3) Substances in solution in water originating in juice and imbibition consisting of sugar and of impurities.

Dissolved substances are present in small quantities from 2 to 6%.
This is summarized below

Table 2.4: Composition of bagasse

COMPONENT	*COMPOSITION*
Water	*45 –52%*
Fibre	*43 – 52%*
Soluble solids	*2 - 6%*
Average Density	*150 Kg/M^3*

Source: Synergy (2005)

2.8.2 Quantity of Bagasse

The extreme value of the mean fibers content of cane is close to 10% and 17% but it generally lies in the region of 12-15%. It will be seen that the quantity of the bagasse varies between 24 and 30% by weight of cane or approximately one quarter.

2.8.3 Handling and Storage of Bagasse

The bulk density of bagasse makes it a very bulky material and storage of excess bagasse from the factory presents difficult problem. Except for dry localities, bagasse cannot be left out in the open since it ferments, decays and loses a large proportion of its value as a fuel. It is generally of advantage to store bagasse under roof. Stored bagasse should be compressed to reduce volume. In the open, bagasse should be stored in form of a conical or pyramidal stack. The principal types of bagasse press are used namely; baling press and briquette press.

2.8.4 Chemical Composition of Bagasse (Dry Analysis)

Chemical composition of bagasse varies slightly but the mean standard composition is as tabulated below

Table 2.5: Chemical composition of bagasse

ITEM	COMPONENT	PERCENTAGE
1	Carbon	47
2	Hydrogen	6.5
3	Oxygen	44
4	Ash	2.5

Source: Hugot E.A. (1963)

2.8.5 Calorific Value of Bagasse

2.8.5.1 Gross Calorific Value of Dry Bagasse

In spite of considerable difference in appearance between different varieties of cane, gross calorific value of dry bagasse is remarkably constant in all countries and for all varieties of cane. The estimated Gross calorific values for bagasse from different countries/states are as follows:

Table 2.6: GCV of bagasse by state/Country

COUNTRY	GCV OF DRY BAGASSE (Kj/kg)
Australia	19,076
South Africa	19,257
Hawaii	19,412
Cuba	19,702
Puerto Rica	19,295
AVERAGE	**19,488**

Source: Hugot E.A. (1963)

Since it will scarcely involve an error of more than 2%, the universal value for G.C.V of dry bagasse is taken as:

GCV = 19,320 kJ/kg

Table 2.7: Composition and calorific value of bagasse constituents

ITEM	CONSTITUENT	CALORIFIC VALUE (kJ/kg)
1	Fibre	19,320
2	Sugar	16,611
3	Impurities	17,220
4	Water	0

KJ/kg= Kilojoules per kilogram

Source: Hugot E.A. (1963)

2.8.5.2 Net Calorific Value of Dry Bagasse

Since dry bagasse contains 6-7% hence an average of 6.5% moisture

N.C.V = 17,850kj/kg

2.8.5.3 Caloric value of wet Bagasse

This is based on percentage composition of wet bagasse
G.C.V = 4,600 – 12s – 46w
N.C.V = 4,250 – 12s – 48.5 w
Where s= Sucrose % bagasse and w = Moisture % bagasse

2.8.6 Availability of bagasse and power potential

These factories, however, produce large quantities of bagasse and trash that could be major electricity exporters. Low-pressure boilers i.e. about 20 bars feed the backpressure steam turbines that were designed to be inefficient, so that they could consume all available bagasse while generating just the amount of electricity and steam needed to operate mills.

Changing to higher-pressure boilers of pressure 40 to 82 bars and condensing extraction steam turbines would enable the factories meet their process and heat requirements and also generate surplus electricity that can be exported from factories to the grid. System optimization and upgrading to reduce process steam demand would result in a further surplus for export.

The table 2.8 shows the quantity of bagasse produced in Kenya over a period of 11 years beginning in 1996.

Table 2.8: Bagasse production by various factories in metric tonnes

COMPANY	CHEMELIL	MUHORONI	MUMIAS	NZOIA	SOUTH NYANZA	WEST KENYA
1992	183,068	91,446	668,599	182,216	194,811	58,226
1993	228,747	108,316	725,469	128,927	198,848	95,588
1994	160,164	43,244	628,270	132,128	177,027	-
1995	210.747	128,060	744,220	175,053	207,610	83,191
1996	260,879	134,405	667,925	121,925	250,075	68,236
1997	260,637	101,416	696758	214,847	234,430	95,542
1998	-	127,782	894,068	-	-	85,569
1999	218,125	157,334	879,962	211,799	257,415	68,583
2000	256,956	67,295	725,116	160,289	185,297	57,803
2001	196,068	-	729,625	122,850	179,945	-
2002	270,674	180,477	799,166	234,046	205,546	85,099

(-) Data not available

Source: Kenya Sugar Board 2002

2.8.7 Electric Power from Bagasse

Electricity generation potential can be estimated based on the quantity of bagasse available or cane crushed. In the context of cogeneration experience in Mauritius, Baguant (1992) makes the following observations with production of exportable electricity.

2.8.7.1 Intermittent power

10 KWh of electricity per ton of cane can be produced as long as the power plant conforms to the following:
i) Crushing rate of 10 tonnes of cane per hour (TCH)
ii) Total boiler capacity of above 40 tonnes per hour producing steam at 20 to 25 bars
iii) Steam to bagasse ratio of 1.8: 2.2
iv) Specific steam consumption of 500 to 600 kg of steam per ton of cane crushed.
v) Self consumption of electricity not exceeding 20 Kilowatt-hour/tone of cane (kwh/tc)
vi). Equipped with an additional turbo alternator of 0.5 to 1.5 MW.

2.8.7.2 Continuous Power Plants

These power plants can produce up to 60 KWh/Ton of cane provided:

I) The minimum size of the power plant is 15 MW allowing a total production of around 40 GWhrs at 90% load factor (10 GWhrs for self-consumption and 30 GWhrs) for exportation.
II) Annual cane supply is above 400,000 tonnes and crushing rate 150 TCH for 3000 hours.
III) Steam bagasse ratio is at least 2.5

- IV) Specific steam consumption is brought down to at least 400 kg of steam per ton of cane through modification of juice heating, evaporation and sugar boiling systems.
- V) Total boiler capacity is 120 tonnes per hour and pressure 30 to 40 bars.
- VI) A condensing turbine, which is more efficient than the backpressure turbine, is used.

2.8.7.3 Firm power plants

110-kwh/tc electricity would be available if the following conditions are satisfied by the factory:

- I) The power plant is operational all year round, which means 300 days (7200 hours) with 65 or 66 days allowed for maintenance. In Kenya, the crop season is close to eleven months. Bagasse is available for most of the year and can be supplemented by fuel oil, cane trash or wood, whenever need arises.
- II) Total supply of cane is above 700,000 tonnes
- III) Steam to bagasse ratio is at least 2.5.
- IV) Specific steam consumption is below 400 kg per ton of cane.
- V) Total boiler capacity is 140 to 150 tonnes per hour, at pressure 82 bars.
- VI) A condensing turbine is used.

2.9 Options For Energy Production From Bagasse

2.9.1 The Backpressure Stream Turbine (BPST)

This system is characterized by air and steam cycle. Air is introduced to the air inlet using the blower, pre-heated, and fed to the boiler at an appropriate air to fuel ratio with bagasse. Ignition of the fuel results in thermos-electrical reaction that produces heat, which is subsequently used for raising steam (Banda, 2002).

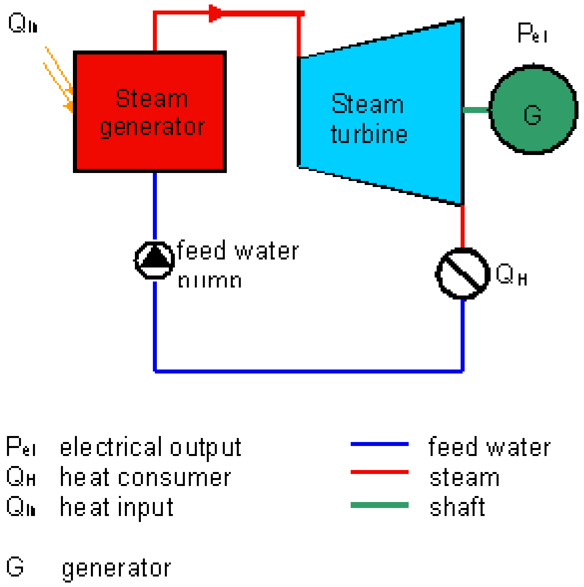


Figure 2.3: Steam cycle with backpressure turbine (Hugot, 1974).

The steam is then expanded through the backpressure turbine to the pressure required for downstream factory processes. The turbine acts as a reducing valve, generating useful electrical and mechanical power. Exhaust steam comes to contact with cold surface of the water tubes of condenser giving condensate, which is then pre heated before being returned to the boiler. Operating pressures range is 15-25 bars.

2.9.2. The Condensing Extraction Steam Turbine (CEST)

The addition of straight condensing turbine/generators to the backpressure turbine will fluctuate stable electric energy heat rate. The trend worldwide has been to consider using the condensing extraction steam turbine cogeneration system with the objective of large-scale electricity export to the grid. It follows that the higher the primary steam pressure and temperature, the lower the steam pressures for motive purposes.

The CEST system is fueled with bagasse as it comes from the mill at 50% moisture content during the milling season. In off-season, CEST system can be operated in condensing mode-producing power only using stored bagasse, trash or other alternative fuels. The exhaust steam of the backpressure turbine drives provides steam for all process steam demand. Steam is sometimes tapped off at two points, the high pressure and low-pressure lines to process area. The CEST system operates at 40-85 bars (Banda, 2002).

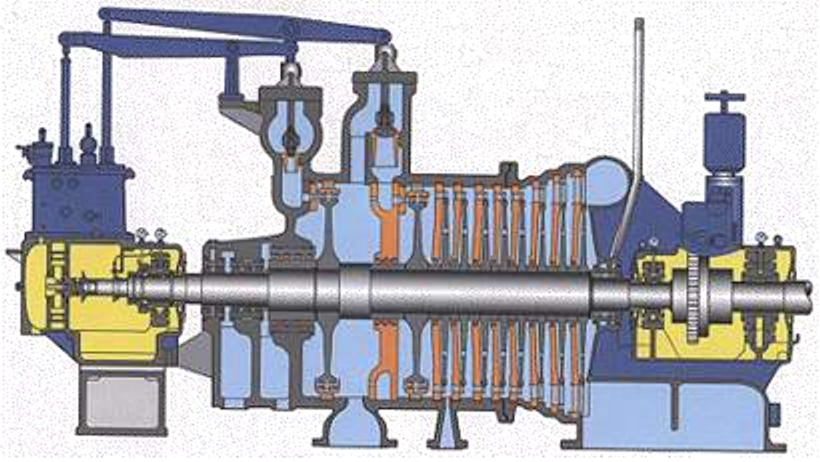


Figure: 2.4: Extraction Condensing Steam Turbine (Banda, 2002).

2.9.3 Biomass/Integrated Gasifier/Gas Turbine Combined Cycle.

This novel technology involves the partial oxidation of biomass at temperature of the order of 800°C to 1200°C to produce combustible fuel gases. Energy generation is achieved by integrating existing Brayton, gas turbine power generating or cogeneration cycle, which have already been developed for natural gas, to closely coupled biomass gasifiers. Gasification was first identified more than ten years ago as an advanced technology with the potential of being cost competitive with conventional CEST technology using biomass byproducts of sugar processing as fuel, while dramatically increasing the electricity generated per unit of sugarcane processed. Substantial efforts have since been undertaken worldwide to develop BIG/GTCC systems and carry out demonstration and commercial projects (Larson, 2001; GEF 2002).

Biomass bagasse/trash is passed through a dryer ideally fueled by waste heat before being converted into combustible fuel gas in the gasifier. This gas must be cleaned before entering the gas turbine generators. A heat recovery steam generator (HRSG) is then used to raise steam from the hot exhaust of the gas turbine and a steam turbine generator used to produce additional electricity.

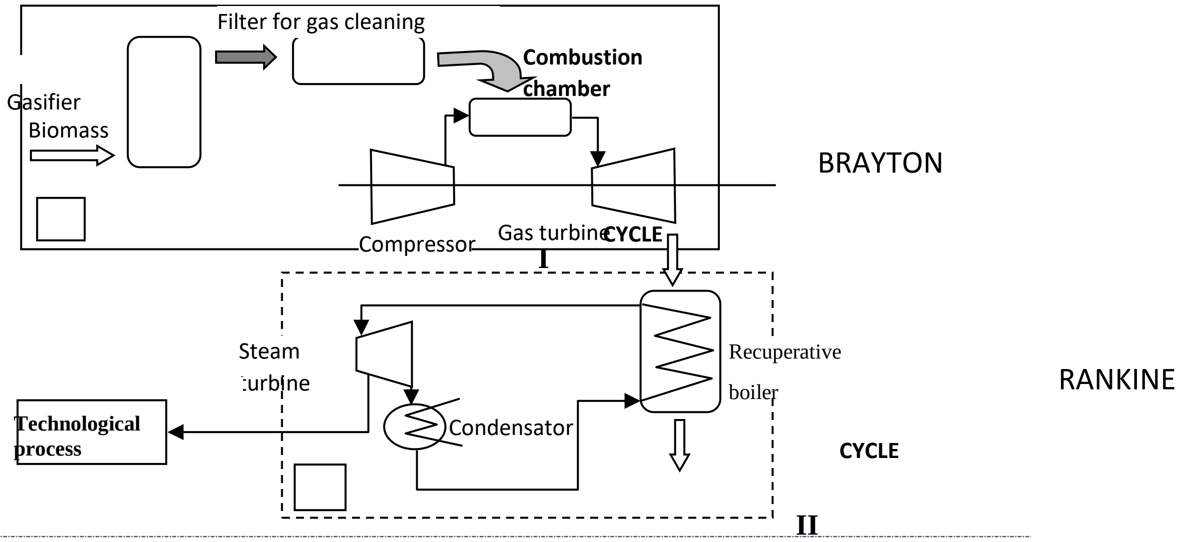


Figure 2.5: Biomass/Integrated Gasifier/Gas Turbine Combined Cycle.

Using advanced technologies with a high efficiency of conversion can generate a considerable amount of electricity. In this sense the implementation of the integrated technology of gasification and gas turbines (BIG/GT) is very attractive for sugar mills with low steam consumption. The BIG/GT were tested in several demonstration projects in the USA and Europe.

There are currently (2007) only two IGCC plants generating power in the U.S; however, several new IGCC plants are expected to come online in the U.S. in the 2012-2020 periods. The DOE Clean Coal Demonstration Project helped construct 3 IGCC plants: Wabash River Power Station in West Terre Haute, Indiana, Polk Power Station in Tampa, Florida (online 1996), and Pinon Pine in Reno, Nevada. In the Reno demonstration project, researchers found that then-current IGCC technology would not work more than 300 feet (100m) above sea level. The plant failed. The first generation of IGCC plants polluted less than contemporary coal-based technology, but also polluted water: For example, the Wabash River Plant was out of compliance with its water permit during 1998–2001. Because it emitted arsenic, selenium and cyanide. The Wabash River Generating Station is now wholly owned and operated by the Wabash River Power Association and currently operates as one of the cleanest solid fuel power plants in the world IGCC is now touted as "capture ready" and could potentially capture and store carbon dioxide. (Avant-Garge, 2006). Figure 2.8.3 shows a simplified scheme of a BIG/GT system. This system includes a bagasse gasifier, equipment that transforms the bagasse into a low calorific value gas through high temperature conversion processes. This fuel gas contains particulates, tar, alkaline metals and other compounds that could affect the gas turbine operation. Thus, before introducing the fuel gas into the turbine combustion chamber, it needs to pass through a cleaning filter. The gas turbine exhaust gases have a temperature of approximately 500 °C and they still can constitute a source of heat for steam generation in a recuperative boiler, and that could be used in a cycle with steam turbines. Therefore, in the gas/steam combined cycle there is: a topping section with a gas turbine Brayton cycle (I), and a bottoming section, that uses the heat rejected by the Brayton cycle as its source, constituted by a Rankine cycle with a steam turbine (II). This “in cascade” use (conversion) of the heat makes the efficiency of this combined cycle higher than the one of steam conventional cycles. When process steam is needed, an extraction from the steam turbine is enough. Therefore, there would be a BIG/GT system with cogeneration.

During gasification, the main goal is the conversion of the biomass into fuel gas through its partial oxidation at high temperatures. This gas, known as poor gas or *producer gas,* is an intermediate energetic, and it will be able to be further employed on another conversion process in order to generate heat or mechanical power, fitting itself to systems where the solid biomass cannot be used. The average content of the combustible components in the gas resulting from biomass is: CO between 10 and 15%, H_2 between 15 and 20% and CH_4 between 3 and 5%.

The fluidized bed gasifiers are more convenient for high capacity application in BIG/GT systems because of their high flexibility regarding the fuel (the utilization of low-density fuels with fine granulometry is allowed. This is the case of most agro-industrial residues, and due to the facility in using the data obtained in pilot plants for the designing of equipment on an industrial scale. The pressurized systems allow the disposition of more compact installations, even though the biomass feeding system is more complex.

The BIG/GT technology has not been implemented in sugar mills yet. Several simulations have been carried out by different authors, and in Australia and in Brazil, the construction of a 3-5 MWe pilot power plant was cogitated in order to help this technology to reach its commercial stage. An interesting progress was the accomplishment of bagasse gasification tests carried out by TPS as part of the project "BRA/96/G31 Biomass power generation: sugarcane bagasse and trash" that was carried out by the Centro de Tecnologia COPERSUCAR.

Hobson and Dixon (1998) carried out a study on the possibility of implementing BIG/GT systems under Australian conditions. The main conclusions of this modeling were:

- For a steam specific consumption of 520 kg/tc (52 % of steam on sugar cane) the turbine exhaust gas energy is not enough to generate the process steam. For this level of steam consumption, 70 % of the bagasse must be by-passed from the gasifier and fed directly to the steam generators; a steam consumption reduction from 520 kg/tc to 400 kg/tc increases the BIG/GT system available power from 88 to 148 MW.

- An extra steam consumption reduction down to 320 kg/tc leads to a little power increase: 153 MW. For the same conditions, a conventional steam system increases the available power from 37 to 43 MW. The annual generation efficiency using BIG/GT technology with the utilization of sugar cane trash (37 %) is almost 4 times higher than when the best technology available today is used.

2.9.4 Other Cogeneration Technologies

A typical cogeneration system consists of an engine, steam turbine, or combustion turbine that drives an electrical generator. A waste heat exchanger recovers waste heat from the engine and/or exhaust gas to produce hot water or steam. Cogeneration produces a given amount of electric power and process heat with 10% to 30% less fuel than it takes to

Produce the electricity and process heat separately. There are two main types of cogeneration techniques: "Topping Cycle" plants, and "Bottoming Cycle" plants. A topping cycle plant generates electricity or mechanical power first. Facilities that generate electrical power may produce the electricity for their own use, and then sell any excess power to a utility. There are four types of topping cycle cogeneration systems. The first type burns fuel in a gas turbine or diesel engine to produce electrical or mechanical power. The exhaust provides process heat or goes to a heat recovery boiler to create steam to drive a secondary steam turbine. This is a combined-cycle topping system. The second type of system burns fuel (any type) to produce high-pressure steam that then passes through a steam turbine to produce power. The exhaust provides low-pressure process steam. This is a steam-turbine topping system.

A third type burns a fuel such as natural gas, diesel, wood, gasified coal, or landfill gas. The hot water from the engine jacket cooling system flows to a heat recovery boiler, where it is converted to process steam and hot water for space heating. The fourth type is a gas-turbine topping system. A natural gas turbine drives a generator. The exhaust gas goes to a heat recovery boiler that makes process steam and process heat. A topping cycle cogeneration plant always uses some additional fuel, beyond what is needed for manufacturing, so there is an operating cost associated with the power production. Bottoming cycle plants are much less common than topping cycle plants. These plants exist in heavy industries such as glass or metals manufacturing where very high temperature furnaces are used. A waste heat recovery boiler recaptures waste heat from a manufacturing heating process. This waste heat is then used to produce steam that drives a steam turbine to produce electricity. Since fuel is burnt first in the production process, no extra fuel is required to produce electricity.

2.9.5 CRITICAL REVIEW

From literature, research on bagasse cogeneration has been centered on establishing the theoretical capacity with direct comparison on the success cases in Mauritius, India and Brazil. Little reference to the technical and practical limitations in the sugar process plant has been undertaken. From the literature review, it is evident that bagasse export cogeneration is theoretically feasible in Kenya. Crushing capacities have been main reference point with no regard to the fact that the crop season in Kenya is actually eleven months compared to six months in Mauritius giving Kenya a higher potential. In Mauritius, coal continues to be considered in cogeneration due to the short crop season unlike in Kenya where through the year availability of bagasse is guaranteed. The socioeconomic situation in Kenya is different from the successful countries like Mauritius hence need for Kenya specific study of the policy, legal and financial environment limiting exploitation of bagasse-based cogeneration potential. Based on these, a more practical capacity determination is necessary with specific reference to practical technical situation in the Kenyan sugar factories. Whereas theoretical capacity could be high or low based on bagasse availability, technical set up in terms of prime mover design, machine drives in use and steam consumption could greatly limit electricity generation and export capacity making even factories with same crushing capacity to have different capacities hence the need to optimize factory steam and power consumption. This research aimed at addressing these dimensions in bagasse-based export cogeneration.

3. MATERIALS AND METHODS

3.1 RESEARCH DESIGN

In this research, a survey of the Kenyan sugar and energy industry was carried out. Respondents were selected from the sugar industry and the energy sub sector in Kenya and included both staff and directors of organizations in the Kenyan energy and sugar industry.

In this research sampling procedure was used with purposive non-probability sampling to get information on the capacity of the sugar factories to generate power. Engineers and technicians in boilers and powerhouse sections were selected to provide information that is specific and reliable on the equipment type, state, capacity and problems afflicting the sugar industry.

Stratified probability sampling was used to select respondents based on the industry and factory. Questions on policy and regulation targeted respondents from Kenya Power and Lighting, Electricity Regulation Board and Kenya Sugar Board, while questions relating to power generation, distribution and price targeted Kenya Electricity Generating Company (KenGen), the power utility i.e. Kenya Power and Lighting Company Ltd and Energy Regulation Commission. Information specific to the sugar factories and the sugar industry targeted the sugar companies and the Kenya Sugar Board.

In the Sugar factories, targeted for data collection were specifically the electrical and mechanical engineering and finance sections for reliable technical and financial data and information. From engineering, the technical information on current equipment and machines was collected through observations, operations and maintenance manuals, questionnaires and interview. These include design, capacity, operation mode and characteristics, available options, plant capacity and efficiency of operation. This information was be used for determination of cogeneration capacities of the Kenyan sugar factories.

3.2 DATA COLLECTION INSTRUMENTS

The study made use of both primary and secondary sources of data. The primary data was collected from employees by using both structured (close ended) and unstructured (open ended) questionnaires. The secondary sources involved review of a variety of documents in order to gain more insight into the subject at hand. This included review of articles and journals, archival documents, reports and other published materials. Such documents were used to gain a deeper understanding of bagasse cogeneration. The study used questionnaires, interviews, observations, literature/manuals review, and study in the data collection.

3.2.1 Questionnaire

In this research, structured questionnaires were used with both open ended and closed questions i.e. dichotomous and multiple-choice questions. Open-ended questions were used to elicit opinions, personal suggestions and observations without limiting the respondents while closed questions were used to guide or assist respondents in understanding the questions and scope while making analysis simple and focused. The questions used were general and simple and were sent to respondents in the sugar and energy sectors in Kenya. The questions sought data and information on issues of policy and governance in the energy and sugar sub sectors including their capacity and challenges. Questionnaires used are in appendix A, B, C, D, E, F and G

3.2.2 Interviews

Interviews were used to collect data for this research. Personal interviews were held with company officers of Sugar Companies, the Kenya Sugar Board, Kenya Power and Lighting Company, Electricity Regulation Board or their representatives. Other officers interviewed included Factory Managers, Project Engineers, Electrical Engineers and Mechanical Engineers. Structured interviews were held with senior company officials while both structured and unstructured interviews were held with other officers.

The objective of using interviews was to capture as much information as possible on the budget preparation, implementation and control system. Open-ended questions were used as an interview guide that allowed for further probing of the respondents on any issues relevant to the study. Where person-to-person interviews failed, telephone interviews were held to collect data from targeted interviewees or their representatives. Telephone interviews were also used to seek clarification on issues raised in the course of interview and schedules undertaken as well as response to questionnaires that were not very clear and needed clarification.

3.2.3 Schedule Method

Data for this research was also be collected using schedules in which proforma containing set of questions was prepared and was filled in by the researcher and research assistants on the behalf of respondents. To facilitate adequate and accurate data and information, the schedules were sent to respondents in advance except where it was not possible.

3.2.4 Observation Method

The observation method was used to collect technical data concerning the facilities or cogeneration machineries in the sugar factories. Observations undertaken were both structured and unstructured and were generally non participant and uncontrolled since it was not possible to join in the actual doing of the jobs due to the technical and practical nature of operations in the sugar industries, power companies and regulatory bodies in the energy and sugar sub sectors targeted in this study. Structured observations were used to collect information on makes or models of plant machines & equipment, capacity and operation of cogeneration equipment or facilities i.e. boilers, steam turbines and turbo generators/alternators while unstructured observations were used to confirm data given out in interview, questionnaires and schedules as a means of testing reliability of the data collected.

3.3 DATA COLLECTION PROCEDURE

Questionnaires were administered personally and through research assistants and also by postage while interviews were carried out for specific officials in the energy and sugar industry and were administered personally. Observations of operations and facilities for power generation in various factories were done personally and through research assistants to establish the capacity and nature of power generating equipment so as to establish in general the capacity of individual companies in terms of equipment and operational stability and consistency. Machine/equipment operation and maintenance manuals were used for confirming/verification of the accuracy of information and also to collect any other relevant data not captured through other data collection methods. The researcher and three research assistants did the data collection exercise.

3.4 DATA ANALYSIS PROCEDURE

The data collected was analyzed, tabulated, presented and interpreted. Computations were done to establish availability of bagasse by each sugar factory and theoretical capacity of each of the factories under study through design calculations based on successful cogeneration plants in Mauritius, Brazil and India. From the data analysis, conclusions and suggestions were made on the challenges facing bagasse-based export cogeneration by sugar factories in Kenya and way forward.

Based on experience from countries with experience in export and high-steam pressure bagasse cogeneration, correlations were developed with design computations to establish the theoretical and practical capacity of Kenyan sugar factories based on sugar produced, cane milled hence bagasse availability and operational characteristics of the factories under consideration in this research. Technical data collected through observations, questionnaires, interview and document as well as literature reference and analysis were used to determine the technical capacity of sugar factories in quantitative and qualitative terms. This gave directions on the current state of bagasse cogeneration and what should be done to exploit bagasse cogeneration opportunities by the Kenyan sugar factories.

4. DATA ANALYSIS

4.1 RESEARCH DATA ANALYSIS

This research targeted the operating sugar companies in Kenya namely, Mumias, Muhoroni, Chemelil, Nzoia, Soin, West Kenya, Kenya Sugar Board and KenGen and KPLC staff. Others are Ramisi, and Miwani. Data was collected, analyzed and presented in this chapter as follows:

4.1 MUMIAS SUGAR COMPANY LIMITED

Mumias Sugar Company has a cogeneration power plant consisting of seven steam boilers generating steam at average pressure of 21 bars and 380° C, five backpressure turbo alternators producing 13.6 MW power for factory use, residential use and export to the grid.

4.1.1 Boilers at Mumias Sugar Company

The research findings showed the following boiler capacity for Mumias Sugar Company Ltd as tabulated below:

Table 4.1 Boilers at Mumias Sugar Company Ltd

Steam Capacity (Tons/hr)	Number of Units	Pressure in Bars	Steam Temperature °C	Boiler Age (Years)
110	1	21	380	10
55	2	21	380	27
22	4	21	283	33
308	**7**			

Then boilers 10 – 15 years, most of these boilers at Mumias have the age between 10 and 33 years.
All the existing turbo generators are bagasse fired steam boilers and are summarized in table 4.2 below.

Table 4.2: Installed Steam Turbines Generators

Configuration (MW)	Number of Units	Total Capacity (MW)	Age (Years)
7	1	7	10
2.5	2	5	15
1.25	1	1.25	22
1.75	1	1.75	22
Total	**5**	**15**	

The 7 MW backpressure turbine generators is the only reliable generator at Mumias Sugar currently. The effective capacity is 13.6 MW due to the inefficiency of existing old turbines

Table 4.3: Proposed boilers at Mumias Sugar Company Ltd

The two boilers will be in place after the new boiler is installed

Steam Capacity (Tons/hr)	Number of Units	Steam pressure (Barg)	Steam temperature (ºC)	Age (Years)
110	1	21	380	10
170	1	87	525	-

(-) New boiler (Not yet installed and time of research)

With planned capacity improvement, the 110 Tons/hr boilers will be retained. A new boiler of 170 Tons/hr capacities is to be constructed while six other boilers will be discarded or will no longer be used by the factory for steam generation.

Table 4.4 Proposed generators at Mumias Sugar Ltd

These are the units that will be in place after the expansion

Proposed Configuration	Number of Units	Total Capacity (MW)	Age (Years)
7 MW	1	7	10
2.5 MW	2	5	15
25 MW	1	25	-
Total	**4**	**37**	

(-) New turbo generator (Not yet installed at time of research)

The two 2.5 MW capacity turbo-alternator units will be retained. The 7 MW turbo-alternators will be retained while a 25 MW capacity new unit is planned for installation. Effective capacity is taken as 35 MW because of age and current performance of 2.5 MW turbines whose effective capacity is taken as 3 MW instead of 5MW.

Table 4.5: Power Generation and Consumption trends in Mumias (MWhrs)

Year	2003	2004	2005	Total
Turbo alternators	56,505.70	62,702.37	65,172.77	184,380.84
Diesel alternators	142.47	68.14	421.81	632.42
KPLC import	2922.36	1,579.40	1,758.70	6,260.46
KPLC Export			4591.54	
Total				191,273.72
Yearly average consumption				63,757.91
Yearly average power (MW) over 300 days (7200 hrs)				8.8

Table 4.6 Sugarcane and bagasse production and utilization trends (in tonnes)

Year	Sugar cane crushed	Bagasse produced	Bagasse Utilized	Bagasse Dumped
2003/4	2,290,427	857,994	602,039	255,955
2004/5	2,339,954	881,695	626,640	255,055
2005/6	2,443,299	938,227	693,898	244,329
Total	7,073,680	267,7916	192,2577	755,339
3 year Average	2,357,893	892,638	640,859	251,780

From the above table, the following information is generated

- Bagasse yield is 37%
- For each ton of sugarcane crushed, 0.27 tonnes of bagasse is used to produce process energy (Steam and electricity). Therefore, 3.7 tonnes of cane require one ton of bagasse for energy for steam and electricity production at Mumias Sugar Company Ltd.

4.1.2 Cogeneration investment plan for Mumias Sugar Company Ltd.

Mumias is currently working on a 35 MW bagasse-based cogeneration project whose objective is to satisfy the ever-increasing demand for electricity in Kenya. The project is in phase I and involves:

- The interim installation of 5MVA transformer on the power export line to KPLC to facilitate 24 hr a day transportation of power.
- Installation of 170-tonnes/hr high-pressure 87-Barg steam boiler.
- Installation of 25 MW double condensing extraction turbine alternators.
- Decommissioning of the 22 tonnes/hr and two 55-tonnes/hr bagasse fired steam boilers.
- With implementation of the project, the powerhouse will consist of 2 boilers and 4 turbo alternators. The new 25 MW turbine and existing 7 MW will always be run while the two 2.5 MW turbines will be running only on need basis as determined by internal power demand to ensure the 25 MW export to the national grid.
- The 1.25 MW and 1.75 MW turbines will be decommissioned during phase II of the project immediately after commissioning of the project, Mumias Sugar will start a second project phase involving energy efficiency improvement where all current steam turbines drives will be replaced by electric motor drives.

The old 110-tonnes/hr boiler will be refurbished and economizers fitted. This will result in 20 MW more in export power to the power grid. The sugar factory operates for 300 days (11 months and 1 week) with 2 days of maintenance shutdown each month.

The company bases the internal consumption on historical internal power consumption. The average lies between 8 MW and 9 MW and a conservative figure of 10 MW is used. The internal consumption is measured using energy meters and calculated based on the generation data. Currently, capacity exists to export 2 MW, which cannot be exported continuously on 24-hour basis due to limitations of existing transformer. The transformer will be replaced by a bigger transformer that can take 25 MW export. The cost of installing the new transformer is to be borne by Mumias Sugar Company Ltd.

4.1.3 Measures to exploit cogeneration potential

(a) Expansion of cane growing and factory capacity to avail more bagasse.
(b) Modernization of factory to reduce on steam demand and avail more steam for power generation.
(c) Invest in high-pressure steam boilers and condensing steam turbines.
(d) Train staff in design, operation and maintenance of an export bagasse power plant
(e) Identify an effective financing mix for expansion and investment in the sugar processing and power plant infrastructure.

4.1.4 Benefits of Cogeneration for Mumias Sugar Company Ltd.

The benefits for cogeneration include:
(a) More payment to farmers as bagasse power earns more revenue for the sugar company.
(b) Methane abatement through avoidance of dumping of bagasse and instead using generated electricity, which is expected to achieve GHG emission reductions
(c) Reduced energy bill as the company generates and uses what it would otherwise import from the national grid.
(d) Competitive advantage for the company as the revenue per ton of cane processed increase as a result of export cogeneration leading to increased viability of cane processing and production for the company.
(e)

Observations on Mumias

Mumias sugar has plans to export more power to the grid by generating 25 MW more after replacement of all but one low pressure boiler. The company may need to consider replacing the low 110 tons/hr boiler with a high-pressure boiler and a new high pressure turbo- generator to use the steam from the additional boiler hence realize the full potential of high pressure bagasse cogeneration and power export from the factory.

4.2 MUHORONI SUGAR COMPANY LTD

4.2.1 Introduction

Data for Muhoroni Sugar Company was collected, analyzed and presented as follows:

4.2.2 Boilers at Muhoroni sugar Company

Muhoroni Sugar Company Ltd has 4 boilers as tabulated below

Table 4.7: Boilers at Muhoroni Sugar Company Ltd

Steam Capacity (Tons/hr)	Number of Units	Pressure (Barg)	Steam Temperature (^0C)	Age (Years)	Economizer
20	1	27	350-400	43	Yes
20	1	27	350-400	43	Yes
40	1	27	350-400	30	No
40	1	27	350-400	30	No
120	**4**				

From the table above,

i.) Muhoroni has two boilers without economizers and two with economizers for flue gas heat recovery.
ii.) The age of boilers at Muhoroni varies from 30 to 43 years

4.2.3 Turbine Generators at Muhoroni Sugar Company Ltd.

Muhoroni Sugar Company has three turbine generators with total capacity of 3 MW as shown in table 4.8 below.

Table 4.8: Turbine generators for Muhoroni Sugar Company Ltd.

Installed Capacity (MW)	Number of Units	Age (Years)
1.5	1	30
0.75	1	40
0.75	1	40
3	**3**	

The turbine generators have age between 30 and 40 years.

4.2.4 Proposed Boilers

Muhoroni Sugar Company Ltd has a modernization plan that will see installation of a new 40 tonnes / hr at 27 barg steam pressure as an addition to the three existing boilers as tabulated in 4.9

Table 4.9: Proposed Boilers for Muhoroni Sugar Company Ltd

Steam Capacity (Tons/hr)	Number of Units	Pressure (Barg)	Temperature (^0C)	Economizer	Age (Years)
20	1	27	300-400	Yes	43
20	1	27	300-400	Yes	43
40	1	27	300-400	No	30
40	1	27	300-400	Yes	New
120	**4**				

The existing boiler of capacity 40 tons/hr is to be rehabilitated to generate 65 Barg install a new 3 MW turbo alternator. This will be as an addition to the three-existing turbo generators at 350-400 ^{o} C.

4.2.5 Proposed turbine generators

In the planned expansion and modernization plan, Muhoroni Sugar Company Ltd. will install a new 3 MW turbo alternator. This will be as an addition to the three existing turbo alternators. This is presented in table 4.10.

Table 4.10: Proposed generators for Muhoroni Sugar Company Ltd

Installed Capacity (MW)	Number of Units	Age (years)
1.5	1	30
0.75	1	40
0.75	1	40
3	1	New
6	4	
Standby diesel Generator	1 MVA	
KPLC Connection	1 MVA	

i.) Standby generator and KPLC connection will only be used in cases of serious emergencies
ii.) About 3.5 MW of generated power will be used for internal use and 2.5 MW excess power will be exported

4.2.6 Power Generation and Consumption trends in Muhoroni (MWh)

From company records, Muhoroni Sugar Company Ltd generates 89% of own power from the turbo-alternators and a diesel generator and imports 11% of the electricity demand. The power generation and consumption data for the company is presented in table 4.11

Table 4.11: Power data for Muhoroni Sugar Company Ltd.

Year	**2004**	**2005**	**2006**	**Total energy Generated**	**Proportion of Total energy (%)**
Turbo alternators	21600	21600	21600	64800	89
Diesel alternator	22	24	45	92	0
KPLC Import	2742	2637.8	2576.9	7956.8	11
Total	**24364**	**24262**	**24222**		**100**
Year Average over 300 days (7200 hrs)					

The plant is expected to work for a minimum of 300 days per year. Each month 1.5 days will be set aside for maintenance with 11 months of annual maintenance shutdown.
Muhoroni has crushing capacity of 2200 tonnes per day.

4.1.2.7 Sugarcane and bagasse production and utilization trends (Tonnes)

Records show that Muhoroni Sugar Company has a sugarcane production average of 364,539, bagasse yield of 40.62 and 148,173 tonnes of bagasse based on date for financial years 2003/4 to 2005/6 as shown in table 4.12

Table 4.12: Sugarcane and bagasse data for Muhoroni Sugar Company Ltd.

	Cane Crushed (Tonnes)	**Average % of Bagasse from Cane**	**Bagasse produced**	**Bagasse used**	**Bagasse Dumped**
2003/4	383,894	40.33	154,824	116,118	38,706
2004/5	337,126	40.33	135,963	101,972	33,991
2005/6	372,596	41.26	153,733	115,300	38,433
Total	1,093,616	121.92	444,520	333,390	111,130
Average	**364,539**	**40.62**	**148,173**	**111,130**	**37,043**

i.) Average Bagasse yield average for Muhoroni is 40.62%.
ii.) Average cane crushed/production is 364,539 tons
iii.) Average annual bagasse production is 148,173 tons

4.2.8 Challenges of Bagasse Cogeneration at Muhoroni Sugar Company Ltd

From the data collected, the following challenges affecting cogeneration in the factory are;

i.) There is need for rehabilitation, retubing and installation of economizer to one of the 40-tonnes/hr steam boiler No. 4, which is currently not in use.
ii.) Installation of 3 MW backpressure water-cooled turbo generator at Muhoroni Sugar Company Limited whose procurement plan is complete.

iii.) Muhoroni Sugar Company is currently under receivership and funding is difficult since it is not attractive to potential financiers.

iv.) Currently, Muhoroni staff has experience in operation and maintenance of 27 barg pressure boilers but will need additional training on operation and maintenance of new boiler at 65-barg and turbo generator

v.) Muhoroni sugar generates 3 MW of electricity from its installed power generation system against high peak demand of more than 3.5 MW

4.1.3 SOUTH NYANZA SUGAR COMPANY LIMITED (SONY SUGAR CO. LTD)

South Nyanza Sugar Company currently has two boilers with total capacity of 76 tonnes/hr at 21 Bars. Table 4.13 below shows the boiler capacity for SONY sugar Company Ltd.

Table 4.13: Boilers at Sony Sugar Company Ltd

Boiler No.	Capacity (Tonnes)	Steam Pressure (Barg)	STATUS
1	38	21	OLD
2	38	21	OLD
Total	**76**		

4.3.2 Proposed boiler capacity and bagasse availability

Sony Sugar currently operates two low-pressure boilers at 21 bars with combined capacity of 76 TPH

Based on 500kg of steam per ton of cane and 140 TCH, total factory steam requirement for prime movers and processing is 70 TPH. Therefore, at present level, the company continues to accumulate surplus bagasse. This bagasse has a potential to produce 28.6 TPH of steam at steam to bagasse ratio of 2.2. However, this would require putting up an additional 30 TPH boiler.

4.3.3 Electricity Capacity

The current installed generation capacity for Sony is 7.2 MW and average generation is 4 MW to satisfy internal power demand. The nearest substation is Awendo substation 400 M from the factory. Rated at 7.5 MVA 33/11 KV. This power station supplies Awendo town, Kamagambo, Dede Market and Renen Market and its environs. By expanding to 6500 TCD, a new boiler, additional milling plant and process house is needed, and company will export 26 MW of electricity to national grid and 9MW for internal use. In phase II, at crushing capacity of 8,000 TCD, 36 MW will be exported to national grid,

4.3.4. Proposed boilers for South Nyanza Sugar Company Limited.

Based on future capacity expansion plan, the following is a summary of boilers proposed

Table 4.14: Proposed boilers for SONY Sugar Company Ltd.

Boiler No.	Boiler Capacity Tons/hr)	Steam Pressure (barg)	STATUS
1	36	21	NEW
1	36	21	NEW
1	30	27	NEW
1	120	66	NEW
4	**232**		

SONY will have 4 boilers of the following capacity, 21 bars, 27 bars and 66 bars

Table 4.15: Factory performance parameters for Sony Sugar 1997-2005

YEAR	RATED CAPACITY (Tonnes/hour)	TCH (Tonnes/hour)	CAPACITY UTILIZATION	BAGASSE PRODUCTION (Tonnes)
1997	120	118	87.10	234,430
1998	125	127	84.10	278,218
1999	135	127	73	257,415
2000	120	120.1	52.1	185,297
2001	125	122	55.81	179,945

2002	125	124	67.66	205,546
2003	100	123	61.19	196,321
2004	135	135	70.38	256,318
2005	135	133	71.31	268,533
Average	**125**	**126**	**69.18**	**229,113**

TCH: Tonnes of Cane Crushed per Hour

The highest quantity was realized in 1998 followed by 2005. The quantity is set to more than double at an average of 667,000 tonnes on completion of phase 1 of expansion plan.

4.3.8 Challenges and recommendations for SONY Sugar Ltd

As at 30th June 2005, the Company's total liabilities stood at US$ 30.48 million against US$ 46.76 Million in total assets hence poor liability asset ratio.

Training and exposure to high-pressure steam boiler and turbines operation and maintenance is needed for mill engineers, technicians and operators. Training in operation and maintenance of export based electrical and instrumentation installation is needed for electrical and instrument crew.

From these findings, it is recommended that South Nyanza Sugar Company continue to utilize the BPST technology and consider investing in CEST technology for commercial power export to the national grid.

At internal rate of return of 10%, the company would not be able to get a reasonable return on investment. But at a tariff of US cents 6/ kWhr and unit generation cost of US cents 4.2/ kWhr/

Table 4.17: Investment Cost estimates for Sony Sugar Company Ltd.

	Works Description	Estimated Cost in US$	Data Source
1	Installation of 30 TPH, 27 bar and 120 TPH, 66 bar boilers	8	J.P.M & A, strategic plan
2	Installation of 25 MW turbo alternator and auxiliaries	12	J.P.M & A, A.J.J (Pty) ltd, strategic plan
3	Civil works, powerhouse, bagasse shed, access roads	2.0	J.P.M & A
4	Detailed feasibility study	0.5	J.P.M & A
5	Development costs (1-2%) of capital cost	0.7	Estimates
6	Engineering costs (5 –8%) of capital cost	1.3	Estimates
7	Contingency (10 –15%) of capital cost)	4.5	Estimates
	Total	**29**	

4.3.10 Operation and maintenance

To keep the plant operational, the following expenditures are anticipated;

i.) Annual bagasse costs (procurement and handling=US$ 4.4 Million or US# 2.2/ton of bagasse at 50% moisture content (US $ 4.5/ton of dry bagasse, fiber content of cane of 17 to 18%, cost of cane (US$ 25/ton) and annual cane crushing capacity of 2 million after factory expansion.

ii.) Spares, consumables and maintenance outsourcing at US$ 0.2 Million

iii.) Major overhaul every 5th year at 2% of capital cost or US$ 0.8 Million, administration costs and overheads at 15% of total annual cost+ US$ 0.9 Million

iv.) Annual insurance at 2% total cost or US$ 0.8 Million

4.1.4 NZOIA SUGAR COMPANY LIMITED

Nzoia Sugar Company Ltd. (NSC) currently has three boilers and two turbo generators. Steam turbine prime movers are used for driving its five mills and cane knife.

4.4.1 Boilers at Nzoia Sugar Company Ltd.

Table 4.19: Table showing Boilers at Nzoia sugar Company Ltd

Boiler No.	Make	Pressure (Bars)	Steam temperature (^{0}C)	Capacity Tons/hr	Age (years)
1	FCB	25	330	27	30
2	FCB	25	330	27	30
3	Alpha	25	330	54	13
Total	**3**			**108**	

Source: Research Data

FCB: Five Cail Babcock
The two FCB boilers have operated for between 30 years while Alpha Boiler has operated for 13 years
Whereas installed capacity for the three boilers is 108 tonnes/hr, on average 75 tons of steam per hour is produced at average temperature of 330° C. However, operations are interrupted by frequent machine breakdowns, mill chokes and boiler house congestions all affecting throughput.

Table 4.20: Installed steam turbine generators

Installed Capacity (MW)	Make	Number of Units	Type/design
3	Dresser Rand (DR)	1	Back pressure
1.5	Five Cail Babcock FCB)	1	Back pressure
4.5		**2**	

Source: Research Data

The 1.5 MW backpressure turbo-alternator is used during factory start up to provide electricity to power cane knife motors and injection motors. These units consume a lot of electricity and the factory avoids using import power for their running and is immediately offloaded once the 3-MW Dresser Rand turbo alternator is loaded. Since it is not needed

Table 4.21: Proposed Boilers for Nzoia Sugar Company Ltd.

Boiler Configuration	Make	Capacity (Tons/hr)	Age Years	Steam Temp	Pressure
1	FCB	27	30	330	25
2	FCB	27	30	330	25
3	Alpha	54	13	330	25
4	Alpha	54	New	330	25
Total	**4**	**162**			

Source: Primary Research Data collected

The two FCB boilers were installed in 1978 while the Alpha boiler was installed in 1995 during phase one expansion that raised capacity from 2000 TCD to 3000 TCD.
The fourth boiler is part of pending phase III expansion, but there are plans to install the boiler in 2008/9 financial year. Poor planning on the side of the company has led to stagnated capacity improvements as new equipment like turbines, boilers, turbo- generators lie idle in the yard while the factory continues to face milling bottlenecks due to poor through put and poor steam generation.

Table 4.22: Proposed Turbine Generators for Nzoia Sugar Company Ltd

Turbine make	**Capacity (MW)**	**Normal Status**	**Age (Years)**	**Type/Make**
FCB	1.5	Standby	30	Back pressure
Dresser Rand	3	Operational	13	Back pressure
Dresser Rand	3	Proposed	-	Back pressure
Dresser rand	3	Proposed	-	Back pressure
Total	**10.5**			

Source: Primary Research Data

(-) Not yet installed

From the table

i.) Two turbo generators are operational with combined capacity of 4.5 MW while two with a combined capacity of 6 MW are still lying in the yard awaiting installation. The installed capacity will increase to 10.5 MW once all turbo generators are installed.

ii.) The two Dr turbine generators proposed for installation were purchased as part of the phase III expansion, which is currently still pending since 1995.

iii.) Once installed the capacity will be raised to 10.5 MW

4.4.5. Factors inhibiting cogeneration at Nzoia Sugar Company Ltd:

i.) Lack of access to finance needed to construct an effective cogeneration power plant with efficient boilers and turbo alternators.

ii.) Lack of enough technical capacity needed to make technical spear headers and proposals for funding and investment in bagasse cogeneration.

iii.) Limited factory capacity hence low quality and quantity bagasse and capacity to generate and export power to the national grid.

iv.) Low time efficiency hence potential to have high power plant unavailability due to milling stoppages and interruptions due to various factory operation bottlenecks.

v.) Lack of clear policy from government on export cogeneration hence limited awareness and incentive with the government being the main shareholder in the sugar company.

vi.) Boilers especially the FCB types are old and have low steam generation efficiency. This limits the overall steam production in quantity and quality.

vii.) The backpressure turbo alternators in use are less efficient and limit power generation capacity. Both the Dresser Rand (DR) and Five Cail Babcock (FCB) turbo alternators exhaust steam as at design pressure of 1.5 bars for process use.

Viii.) A lot of steam is used to run the factory's 3 mill turbines and cane knife 1 instead of being used to generate electricity by running turbo-alternators

4.5 CHEMILIL SUGAR COMPANY LIMITED

4.5.1 Boilers at Chemilil Sugar Company Ltd.

Chemelil Sugar Company Ltd. has 4 boilers of capacity 20 tones/hr each generating steam at 21 bars and 300 ° C.

Table 4.23: Boilers at Chemilil Sugar Company Ltd.

Steam Capacity (Tons/hr)	**Boiler No.**	**Steam Pressure (Bars)**	**Steam temperature (^{O}c)**
20	1	21	300
20	1	21	300
20	1	21	300
20	1	21	300
80	**4**		

Source: Research Data

From table 4.23 the factory has 4 boilers with capacity of 20 tons/hr each hence total steam generation capacity is 80 ton/hr. The steam is generated at 21 bars

4.5.2 Steam Turbine Generators

Chemelil Sugar Company Ltd. has Allen make turbine generators with a capacity of 3.5 MW but they generate an average of 2.8 MW against a demand of 4 MW. The balance is imported from the grid making the factory a net importer of electricity. Plans are underway for a 15 MW power plant, which will export 11 MW power to the grid.

4.5.3 Factors inhibiting co-generation at Chemelil sugar factory

i.) Low capacity of boilers
ii.) Low capacity steam turbo alternator
iii.) Limited access to funding hence inability to invest in capacity improvement
iv.) Low cane production/availability

4.5.4 Way forward for Chemelil sugar

i.) Identify sources for funding
ii.) Increase cane production and crashing capacity
iii.) Increase factory efficiency to reduce steam wastage
iv.) Need for thorough feasibility study and development of investment strategy for export power cogeneration.
v.) Restructuring to improve financial position of the company, which is currently highly indebted.

4.5.5 Measures put in place:

Chemeilil Sugar Company has put in place the following measures to utilize bagasse cogeneration potential.

i.) Currently high-level talks are going on with KenGen and a committee has been formed already to facilitate investment in export power cogeneration that will cost ksh 4 billion.
ii.) The company's strategic plan has captured export cogeneration.

4.6 WEST KENYA SUGAR COMPANY LTD

4.6.1Introduction

This is a privately-owned sugar company established in 1981 with an initial crushing capacity of 100 TCD, which has been expanded over time 2500 TCD. The company is undergoing expansion to 6000 TCD after acquiring an old mill from Mumias Sugar Company Ltd.

4.6.2 Challenges of bagasse cogeneration

Challenges facing cogeneration at West Kenya are

i.) The factory has no nucleus estate and hence it entirely relies on out growers who are smallholder farmers with low capacity.
ii.) The factory faces unstable or unreliable supply of cane due to frequent strikes by farmers and transporters.
iii.) The factory operates below capacity due to low cane supply hence interruptions in milling and bagasse supply. The situation is bound to worsen with increase in capacity to 6,000 TCD
iv.) The factory has no expert on export cogeneration making development and focus on cogeneration a remote issue.
v.) Financing limitation due to other competing investments like priority to capacity expansion at the expense of investment in export cogeneration

4.7 MIWANI SUGAR COMPANY LTD

4.7.1 Introduction

Miwani Sugar Factory was the first sugar mill to be built in Kenya. The factory, situated in the Nyando Sugar Belt in Nyanza Province was incorporated as Miwani Sugar Mills (MSM), a limited liability company in 1922. The factory had an initial crushing capacity of 800 metric tonnes of cane-crushed daily (TCD), eventually expanded to 2,400 TCD. The factory is currently under receivership.

4.8. SOIN SUGAR COMPANY

Soin Sugar Company situated in Kericho District Soin Division is a privately-owned company established in 1999. Soin factory with an open pan system, started full operations in July 2006 and has a capacity of 300 TCD expandable to 500 TCD. The factory has been commissioned and the first batch of brown sugar has been produced by one milling tandem, which has been completed. Work on the second milling tandem will soon be completed. The full operation of this factory will decongest the operations at the neighboring Muhoroni Sugar Company.

4.9 RAMISI SUGAR COMPANY

Ramisi Sugar Company Ltd at the coast also collapsed and currently no sugar production and cogeneration are going on. The factory however could be soon operational after the government sold it to a private investor. Investment in these factories requires huge financial and technical resources and reviving sugar production may be the immediate objective. It is however encouraging that export cogeneration is a real agenda in reviving these factories going by proposals in the companies' strategic plan.

5. RESULTS AND DISCUSSONS

In this chapter, the results are presented and discussed

5.2 Technical Challenges to Bagasse Cogeneration

The research revealed that the seven operating sugar mills still rely on inefficient technology, such as 21 to 25 bars pressure boilers. All the seven sugar factories covered in this study were designed to consume as much bagasse as possible to minimize bagasse disposal costs. High steam pressure cogeneration technology, which is also more expensive, was therefore not required, as this would significantly improve the bagasse utilization efficiency. However, with CDM (Clean Development Mechanism) funds, and despite the perceived associated risks, bagasse cogeneration is commercially attractive, and the more costly high-pressure cogeneration technology is more affordable.

High steam pressure export cogeneration is a new technology in local sugar industry and therefore initially there would be inadequate trained manpower to operate power plants, so sugar companies will invest in manpower training and development. It would be difficult to find repair and maintenance services for the machines and even spare parts would have to be sourced from abroad at least for first years of operations. All sugar industries in Kenya except for Soin were built in sixties and seventies. Since then the trend has been the same, any sugar company being proposed does not incorporate export cogeneration, and only sugar production is considered.
Because of these trends, the practice in the sugar industry has remained the same and this is considered a barrier to implementation of bagasse cogeneration projects in the Kenyan sugar industry.

Local utilities are looking at strengthening the transmission grid, which coincidentally will allow the sugar companies to feed in the power. It is now viable for sugar companies to raise high-pressure steam in modern, high efficiency boilers using bagasse to generate heat and power economically to provide surplus power for export to the grid. This is from experience in other leading sugar producing countries like Mauritius, Brazil and India. Experience from Re union, Mauritius, India, Brazil and Cuba confirms the practical potential of export cogeneration. In case of success story countries, the development of cogeneration evolved along the well-established stages of own generation, intermittent power, continuous power and firm power generation.

It would seem natural for Kenya to avoid intermediate step and leapfrog from own generation to firm power supplies by learning from experiences of Re union, Mauritius and Brazil. Kenya has advantage that the crop season lasts an estimated 300 days a year, while out of crop season is usually during the wet season coinciding with the duration of maximum hydro availability and making firm generation attractive. Annual plants maintenance could be carried out during this period. The power and process steam requirements in a sugar plant can be met in one of the two ways explained below.

i) Conventional Cogeneration Technology

A bagasse-fired boiler in conjunction with a backpressure steam turbine coupled to an electrical generator is the predominant method currently used in Kenya with pressure of 20-25 bars and with pressure resultant efficiencies of less than 10%. System efficiencies of up to 25% can be achieved for steam pressure of 45 to 66 bars. The process of generating more power from sugar factories for export to the grid is essentially an efficiency upgrade exercise accompanied by a modernization and capacity improvement of sugar mills.

ii) Integrated Gasification Cogeneration with Combined Cycle (I G CC)

This uses an external gasifier to produce combustible gases from the bagasse which are then fired in a gas turbine. Hot exhaust gases from the gas turbine are passed through a waste heat recovering boiler for generating steam, some of the exhaust gas is used for drying bagasse. Efficiency achieved in the conversion of biomass to electrical energy can be as high as 37%. The gasification process can produce syngas from high-Sulphur coal, heavy petroleum residues and biomass. The plant is called "integrated" because its syngas is produced in a gasification unit in the plant, which has been optimized for the plant's combined cycle. The gasification process produces heat, and this is reclaimed by steam "waste heat boilers". Steam turbines use this steam to run generators for electricity production.

5.2.1 The Current Total Installed Cogeneration

The current generating capacity industry is 36.5 MW at the time of this study. This power is used exclusively within the industry. Sugar Industry statistics show that in 2002 Kenya produced an estimated 1.8 million tonnes of bagasse. With a gross calorific value of 16800 TJ, equivalent to 323,000 tonnes of oil worth approximately US$194 million. In conditions such as have been established in Mauritius, this bagasse could produce 360-600 GWhr per year of excess electricity for sale, depending on the technology used. At this rate, cogeneration from bagasse could easily provide 10% of the national electrical energy demand. To achieve 10% target economically, sugar factories will need to invest in firm generation through equipment upgrade, with efficiencies high enough to generate economic quantities of power for sale to the national grid. In areas that need to be addressed are:

i.) Modular capacity, highly efficient boilers to be install in phases.
ii.) Ample storage and handling for bagasse to cover autonomy.
iii.) Factory efficiency optimization.
iv.) Harvest cane trash as a possible extra boiler fuel (potential additional fuel capacity of 20%), which require substantial investment.

To sell their power to the grid, sugar factories will in addition require investment in appropriate upgrade of grid interconnections consisting of power transformers, electrical switchgears and transmission power lines.

The sugar industry has been cogenerating for many decades and is now moving towards substantially improved power stations so that it can export surplus energy when price is right. However too many engineers in the industry do not understand key aspect of co-generation and find it difficult to specify, let alone design, an export power station (Inkson, 2005)

A typical boiler may be 85% efficient when fossils fuel fired but only say 67% when firing a fibrous fuel like bagasse because boilers efficiency depends largely on fuel moisture. About a third of bagasse energy is lost, mainly up the stack due to moisture in bagasse. The turbine is relatively efficient in converting energy in the steam to mechanical energy and is usually about 85% efficient for machines used in the sugar industry. Considering small gearbox and generation losses overall efficiency of turbo generator set, as a unit is about 80%.

Without cogeneration, what appears to be a somewhat efficient cycle (67% to 80%) is only about 22% efficient since the latent heat is not used. The extent to which a station uses latent heat is called utilization factor and is about 33% in the sugar industry h and overall station efficiency is 53.3% to 50% in practice. In a cogeneration cycle most of the losses are from the boiler and about 90% of those losses are stack losses in a bagasse fired boilers and hence proportional to the gas exit temperature. So, the challenge is to reduce these losses and optimize on energy recovery to improve on electricity output at the end.

5.2.2 Practicalities of steam and pressure setting

A conventional sugar factory has an exhaust condition of 120°C saturation temperature compared to a condensing steam turbine with final temperature of about 40°C hence more work in condensing arrangement. Exhaust steam should ideally be slightly superheated to allow for line losses so that it is just on saturation at first effect and any other exhaust users like evaporators, sugar pans and dryers. In Kenya, the evaporators receive steam at a temperature of 120 to 125^o C at the first effect. In most pass out turbines, which are the best if power export is required beyond the end of crop, it is necessary to keep the backend cool by passing some steam through to the condenser. A typical figure will be 15% to 20% of the full flow steam rate. In practical designs, dryness fraction of 0.95 and 0.9 is used.

The other practical limit is at the HP/HT end of the cycle. Not only does higher pressure mean thicker materials of construction but the higher temperatures means that the strength of materials deteriorates, forcing selection of more exotic (and therefore expensive) materials. There are two cases to consider namely saturation condition, which affects the entire pressure part system, and superheated condition, which only affects the super heater, steam pipe work and turbine.

5.2.2.1 Temperature/pressure relationship of saturated steam

As the pressure rises, the temperature becomes more asymptotic so that it takes substantial pressure increases to make relatively modest gain in temperature. In the end though, the issue is only a matter of economics: can the extra mass and /or more expensive materials of construction of pressure parts be justified in the light of extra work gained from the cycle. It is not possible to play with saturation curve on T/S diagram. Therefore, it is only the evaporation and condensation temperature plus the amount of superheat, which must be decided upon when developing a cogeneration scheme

5.2.2.2 Exhaust steam temperature

One of the first requirements of export cogeneration is to have an efficient factory, they are likely to be few other users of exhaust. The key in optimization is the approach to the operating temperature of first effect normally 120 to 125°C. As the condensing temperature is reduced to improve work output from the cycle, the cost of evaporation goes up as more heat transfer surface is required for the same duty. With a typical cycle having 6,000 KPa HP condition, reducing the condensing temperature from 124 °C to122°C increases the work output to 1%.

Once the condensing temperature has been agreed upon, the preferred exhaust point can be determined. The actual exhaust point will depend on the turbine selected. A typical amount of superheat for the exhaust point might be 5°C so the exhaust point is 5°C above selected condensing temperature, along the constant pressure curve to the right of the vapour saturation curve. Working backwards from the exhaust point the inlet condition can be derived if the barrel efficiency of turbine is known. As a first approximation, assume an efficiency of 85% and establish the expansion line. It is then possible to consider the high end of the cycle.

5.2.2.3 HP/HT Steam condition

For whatever selected boiler-operating pressure there is a unique curve of evaporation and superheating. There is no theoretical limit to the amount of superheating if the boiler can create it.

However, there is optimal amount of superheat for any boiler operating pressure. For conditions selected for 125°C exhaust steam saturation temperature, 2°C superheated and 85%-barrel efficiency, optimal HP/HT steam conditions is as tabulated below;

Table 5.1: Optimal High pressure versus high temperature

Steam pressure (KPa)	3100	4100	6100	8100	10100
Steam temperature (°C)	388	423	475	513	545

Source: Inkson 1995

Any lower steam temperature for the pressure selected above either means a lower efficiency turbine to achieve the same exhaust point or less superheated –more probably a dryness fraction of less than 1.0 in the exhaust steam. Any higher HP/HT steam temperature from pressure-selected means either a higher efficiency if available or more superheated in exhaust steam. The optimum conditions are quite dependent on barrel efficiency of the turbine.

Table 5.2: Table for steam pressure and temperature

Steam pressure (kpa)	3100	4100	6100	8100	10100
Steam temp (°C) (80%)	370	402	450	486	515
Steam temp (°C) (85%)	388	423	475	513	545
Steam temp (°C) (90%)	407	445	502	545	579

Source: Inkson 1995

All the above assumes that the inlet does not affect turbine efficiency steam conditions but that is not true. One of the main influence or barrel efficiency (as distinct from the losses and other turbine efficiency), is the volume flow rate of the steam and hence their specific volumes of the inlet steam. That is because lower volume flows mean shorter blades and blade end effects (boil the root effect and tip effects) become more significant.

In theory having selected the exhaust points and the HP/HT steam conductions, it is now possible to approach potential turbine suppliers. From Mollier diagrams it seen that as pressure rises for any one temperature, the total enthalpy falls. So higher steam pressure required less bagasse. It therefore pays to fine-tune the cycle with increasing pressure taken than with reducing temperature.

Taking base HT/HT steam condition at 62 bars and 480°C and assuming 12°C of superheat in exhaust, amount of superheat reduces by increasing pressure then bagasse requirement falls while power output increases so specific bagasse consumption falls. But if reducing steam temperature reduces amount of superheat, the bagasse requirement falls but power output falls marginally faster and specific bagasse consumption actually increases slightly.

***Table 5.3**: All at 480°C*

Steam Pressure (bars)	**Baggasse kg/hr**	**Power KW**	**SUPERHEAT (°C)**	**Ratio kg/kw**
62	49297	16234	12	3.037
63	49296	16286	11	3.026
64	49254	16337	10	3.015
65	49233	16387	8	3.004
66	49211	16435	7	2.994
67	49190	16483	5	2.984
68	49168	16529	4	2975
69	49147	16575	3	2967

Souce:Inkson, 1995

Table 5.4: All at 62 bars

Steam Temp. (°C)	**Bagasse kg/hr**	**Power (Kw)**	**SUPERHEAT (°C)**	**Ratio Kg/Kw**
480	49297	16234	12	3.037
478	49216	16185	11	3.041
476	49135	16135	10	3.045
474	49054	16086	8	3.050
472	48972	16036	7	3.054
470	48891	15987	6	3.058
468	48810	15938	4	3.063
460	48728	15889	3	3.067

Source: Inkson, 1995

For boiler tubes exposed to furnaces radiation, this is the order of 50°C higher than saturated temperature at higher steam drum safety valve setting. For drums and manifolds, which are heated by hot gases, including the convention bank tubes, the design temperature may be +25°C higher than the saturated temperature at designed pressure. For superheated tubing the design temperature is even higher taking into account the following-:

i.) Lower internal heat transfer coefficients.
ii.) Variations in steam flow due to floor flow distribution.
iii.) Variation in steam flow during sudden load changes.
iv.) Variations in heat fluxes resulting from uneven gas flow in the boiler.

The selection of materials for boiler parts with the exception of super heaters is permanently based upon the selected operating pressure. The materials selected for super heaters and its components are more complicated and are influenced by factors such as creep and high temperature corrosion resistance.

Following these principles and ignoring any potential corrosion issues from fuel the following materials requirements become evident:

Table 5.5: Boiler and super heater material

Steam conditions		**Boiler components**	**Super heater**
3100kpa	400°C	C or C- Mn steel class 300	C and low alloy class 600.
4100kpa	440°C	C or C-Mn steel glass 600	Low alloy steel glass 600.
6100kpa	480°C	C-Mn steel glass 600	Low alloy steel class 600.
8100kpa	520°C	C-Mn and alloy steel class 900	High chrome alloy class 1500.

10100kpa	550°C	C-Mn and low alloy steel class1500	Stainless steel and chrome alloys class1500 to class2500.

Source: Inkson 1995

From table 4.31,
C: Carbon
C-Mn: Carbon Manganese
Low alloy: Carbon molybdenum, chrome molybdenum, manganese- chrome – molybdenum-vanadium.
High chrome alloy: 2¼ chrome, chrome and 12 chrome alloys.

The other challenge for HP/HT conditions is the quality feed water, boiler water and steam. Above 60 bars the water quality requirements become far more stringent and demineralization and volatile treatments become a necessity. The control of boiler water quality becomes critical to minimize steam impurities and prevent deposits forming in super heaters, control devices and turbine blades.

5.2.2.4 Implications for turbine

Turbine inlet conditions are slightly below the boiler outlet conditions. These limitations are a function of materials selection as well as thickness in the inlet sections and they vary from manufacturer to manufacturer. For some manufacturers, the first temperature break point is around 480°C, whereas for others it is around 510°C. Overall, the material limitation on inlets section follows the same engineering issues as for steam piping. Temperature limitations of a given material quality of a specific thickness are basically a function of the operating pressure. In addition to pressure/temperature limitation on the material's creep life and softening point, additional limitations may be set by the physical design of inlet valves and distribution pipes and wheel chamber design limitations come into play.

Above certain pressure and low temperatures, a manufacturers design may require as inner casing to protect the outer casing from excessive stresses. Higher temperatures may require a change in rotor material and, temperature above 524 or 530°C may require advanced alloys to maintain the integrity of the equipment (Inkson, 19995).

5.2.2.5 Condenser Temperature

Many cogeneration stations must operate as conventional condensing station out of crop. One option is to have exhaust turbine for cogeneration and condensing turbines for generation, but the usual approach is to have a pass out machine.

5.2.2.6 Overall optimization

From thermodynamic point of view, the barrel efficiency has to be the starting point. It may be of benefit to pay more for the turbine if more work is obtained. Higher barrel efficiency will allow lower steam inlet pressure, which might bring down the cost of the boiler.

The starting point for designing a cogeneration cycle is the selection of the exhaust point. The lower the exhaust temperature the more efficient the system. It quickly becomes apparent that the boiler engineer and turbine supplier need to work closely together will sugar factory management if a cogeneration project is to be fully optimized and unless it is to optimize it will not be efficient.

5.2.2.7 Interruption

Complete interruption of output from a sugar mill should be accomplished in one or two ways. If there is enough time available, the mill may be requested to voluntarily interrupt its output via verbal request from NCC (National Control Center) to the mill operations. However, in other circumstances where there is immediate danger to the system equipment or personnel, the utility may disconnect the mill from the utility via interconnection breakers operated by the NCC, which can be remotely done. However, provision is made for the mill to later change such an interruption if it believes that the utility acted without proper justification.

5.2.8 Conclusion

The maximization of power generation from bagasse-based cogeneration plant is the thrust factor in implementation of cogeneration plants in sugar industries. The basic design of the plant consists of the selection of power cycle parameters, the number of units and capacities of the boiler and turbo generators. The techno-economic viability depends on the correct selection of the technology and adopting higher power cycle parameters. The issues relating to the selection of the size, the number of units and the design of various other systems such as bagasse handling system, the water system etc., needs careful attention and a more in-depth study of the feedbacks and operating experience worldwide. There is no technological constraint in adopting high-pressure cycles for the sugar plant cogeneration systems. Adoption of high-pressure boilers and turbines of condensing and extraction type is necessary while staff must be trained in operation and maintenance of high-pressure boilers and the condensing and extraction turbines.

5.3 Policy Challenges for Bagasse Cogeneration

The research shows that the government of Kenya does not have a specific policy on bagasse cogeneration. No specific incentives have been put in place to encourage investment in export cogeneration and specifically bagasse cogeneration by the struggling sugar industry. However, on it's on initiative and to show case the potential of bagasse export cogeneration, Mumias Sugar Company is currently exporting 2 MW.

The price of exported power from bagasse cogeneration remains low at 4 US cents per kWhr paid to Mumias for the 2 MW power it exports. This does not provide enough financial motivation for sugar companies to invest in bagasse cogeneration. This compares quite unfavorably with the Indian case where a price of 8 US cents per kWhr and 6 US cents for the case of Mauritius was established as a favorable price for export power from bagasse cogeneration in India.

Financing of energy projects of the nature contemplated in bagasse cogeneration involves levelized payments to the tender for 8 years to 10 years term. Capacity payments are made by the utility only for on peak-kWhr, delivered by the mill for sale to the utility. This payment, strictly for performance nature of contract alienates the need for extensive contractual provisions covering the potential failure of the mill to perform (WADE, 2004).

As a standard practice, a contract is structured so that the mill is obligated to pay all of costs for necessary interconnection facilities. This is because interconnected facilities would not be required were it not for the desire for the mill to sell to the utility. The utility, i.e., KPLC in this case has the right to establish the design specifications for interconnection facilities to ensure that the operational interface is compatible with the balance of the utility system. Both sugar factories and KPLC are responsible for the determining that design incorporates those features necessary to protect their own facilities in events of a problem with other party's facilities.

From the sugar mill point of view, the great majority of sugar mills do not consider investment in cogeneration for export of electricity as a priority. The sector even in the new political context does not seem to be motivated to invest in a process that is seen with mistrust and no guarantee that the produce will have a safe market in the future. Moreover, the sugar mills are essentially managed by the government, which handles the association with external financial agents that would allow the sector to be more competitive and diversifying its investment. From the points of the view of economic agents, the excessive level of guarantees required to finance the projects is a common barrier to achieving a financial feasibility stage for bagasse cogeneration projects.

Other barriers have more to do with the lack of adequate commercial contractual agreement from energy buyer, KPLC (i.e. bankable long-term agreements or contracts and payment guarantee mechanism for noncredit worthy local public sector and private customer) making it much more difficult to obtain long-term financing from commercial banks. Some other financing barriers occur simply due to prohibitively high transaction costs, which include the bureaucracy to secure the environmental license and electricity generation license. At the same time, the government has had to liberalize power generation partially due to pressure from the World Bank. This has resulted in changing the legal framework to facilitate cogeneration.

Due to nature of business in sugar industry, the marketing approach is variously focused on commodity type of transaction. Therefore, the electricity transaction based on long-term contract (power purchase Agreement) represents a significant breakthrough in their business model. In this case, the electricity transaction must represent a safe investment opportunity from both economic and social environmental perspective for convincing the sugar mills to invest. In sugar, factories/companies have therefore had to overcome several huddles during the negotiation or the power purchase agreement. The national policy on energy as stated in, sessional paper number 4 of 2004 recognizes success of socio economic and environmental transformation strategies pursued by government at present and future is to a large extent dependent on the performance of energy sector as an economic infrastructure. The paper encourages the use of environmentally friendly and efficient technology for generation of electricity from renewable energy sources through a wider adoption and use of renewable technologies and thereby enhance their role on the country's energy supply matrix. This enhancement will reduce the country's dependence on oil based thermal generation (GOK, 2004)

5.3.1.1 Permits for Cogeneration Projects

The sugar mill is responsible for obtaining all permits necessary for the project. Provision should be made in the contract for the reimbursement of any cost, which KPCL may incur, in voluntary assisting with the permitting process to the miller. This would encourage supportive cooperation and collaboration between millers and utility company.

5.3.1.2 Terms in Contracts

In keeping with standard practice followed in U.S.A for contracts of this nature, the initial term sets a three-year advance notice for termination of the contract. The three-year notice period is designed to provide KPLC enough lead-time to obtain replacement capacity for that provided by the mill. Since this practice has been successful in the U.S.A, it can be adopted in Kenya between the national utility company, KPLC and sugar mills.

5.3.1.3 Default

The contract should be unique in its limitations on the reason for which either party can declare the other in default. The standard provision for the failure to meet materials contractual obligation are included but a unique provision must include preventing a default by the KPLC for failure to make payments due to the mill. The provision of a mechanism for direct bank payment at the request of the mill is very unusual. This is a novel way to stimulate private power development given concern of the mill about financial capability of the utility to pay for power supplied by sugar mills.

5.3.1.4 Indemnification and Force Majeure

In contract between KPLC and sugar mills it is observed that parties should agree that neither party would be adversely affected by actions taken by the other party. A key element of the force majeure provision is that if either of the party is prohibited from performing in accordance with the contract by an event of force majeure, the second party will not be obligated to pay for service not rendered. A contractual obligation must be established for moving any disputes to a higher level in attempt to have disputes resolved without having to resort to arbitration (Winrock Internationals 1993).

While regulatory environment for bagasse cogeneration appear to be improving there remain key issues that should be addressed if the full potential is achieved. This are-:

i.) Detailed rules for interconnection apply only to central power, whilst interconnection arrangements for one-site systems in general remain to be clearly defined in our power regulations.
ii.) Requirement for connection protection and measurements are still strictly, causing difficulties and added expenses that affects small IPPs.
iii.) Utilities often apply old system rules that do not permit inside the fence generation to run in parallel with the grid. This will likely affect the smaller sugar mills that have less weight than larger players like KenGen and IPPS.

Other policy issues to enhance bagasse cogeneration that are not in place include arrangements for third party sale and limited wheeling, escalated feed in tariffs, payments of guarantees by the national power utility company KPLC.

Wade, 2004, says that despite huge potential and focused promotional efforts, achievements in the field of bagasse cogeneration have so far been minimal, primarily due to complete social-economic policy issues creating barriers as well as reluctance to invest in what can seem a risky venture. In such a climate, CDM could prove effective tools to mobilize resources internationally.

The research findings show that except for Mumias, West Kenya and Soin Sugar Company all other factories under study are government parastatals. Therefore, any effort to develop cogeneration in Kenya will have to begin with a look at the performance of the sugar Industry and electricity sector in totality. In a situation where all the sugar factories are largely owned by the government, it would be essential to develop policies that facilitate the accelerated development of these sectors through the involvement of private sector.

5.3.4 Key issues that policy needs to address include;

i.) Clear bagasse development policy, recognizing bagasse as resource and facilitating development of bagasse projects.
ii.) Stimulating of investment by offering tax breaks and other incentives for investment in firm generation plant and efficiency improvement initiatives; incentives should lower from end barriers to project development.

iii.) Restructuring the Kenya Sugar Board to enhance management and investment in the sugar sector and to promote cogeneration and efficiency improvement like what similar organizations do.
iv.) Enactment of clear fiscal incentives for cogeneration to encourage investment.
v.) Creating suitable and attractive regimes for independent power producer involvements involving pricing and grid feed in laws for cogent electricity.
vi.) Provision of support to indigenous private sector participation in energy sector to ensure sustainability.
vii.) The setting of realistic but challenging targets for increased cogeneration contribution to electrical energy supply mix.
viii.) Development of a national pool of multi-disciplinary competence to develop design and oversee local implementation of cogeneration projects.
ix.) Involvement of local and international financing groups to provide finance for investment in the sugar sector, especially for cogeneration project
x.) Development and implementing coherent and consistent policies that cover these areas will ensure comprehensive and efficient development of cogeneration and the sugar sector and facilitates the implementation of projects through private sector involvement.
xi.) Bagasse as an energy source has broad commercial, community and environmental benefits but before further investment takes place the business project has to be commercially viable.
xii.) In most countries, bagasse and other renewable sources have to compete in an established energy market dominated by fossil fuel generation, which until recently has been run and supported by the public sector.
xiii.) Limitations on access to electricity market can last until there is urgent need for new generation capacity arising from increased demand and replacement of time expired plant. Some markets may be constrained for up to 10 years after de-regulation of the market, so deployment of bagasse renewable energy will still be slow.
xiv.) Without this constraint, biomass, which is effectively a zero-cost fuel, is already competitive with the fully bordered cost of new diesel. So, deployment is commercially possible where countries are dependent on diesel generation, where there is substantial growth in demand for electricity and particularly in rural areas where substantial quantities of bagasse is available.
xv.) There is also physical constrain to selling electricity especially in isolated areas with Poor infrastructure.

5.3.4.1 Questions that need to be answered are:

Is the plant to be captured or grid corrected?
Are the grids national or isolated?
How far are the transmission lines?
Is there enough long-term full supply and can power be sold?
Sugar cane mills are typically isolated and located far from urban areas without significant infrastructure connection traditionally. Even with substantial and rapid expansion of grids, many mills will still be distant from transmission lines. So, interconnection will be prohibitively expensive. If a sugar mill cannot connect to the grid and cannot sell surplus energy, there will be no reason to improve energy conversion efficiencies and deployment will not be possible. Alternatively, in such condition it will be probably be uneconomical to transport the bagasse to a location where connection is possible. In many situations, there is a concentration of one type of agro-industry at one geographical area. If all the bagasse were converted efficiently to steam and electricity, in some cases the surplus electricity would exceed the demand of local consumer's particularly when existing generating capacity is considered.

There is a tendency to want to make bagasse project as big as possible in order to maximize the benefits of scale. This leads to an aggressive approach to the collection and acquisition of bagasse, some time putting undue stress on the bagasse resource and its availability. The result is either failure to financially close and complete the project or excess pressure on bagasse resources.

5.3.5 Observations on Policy Issues of Bagasse Cogeneration

Any efforts to develop cogeneration in Kenya will have to begin with a look at the performance of the sugar industry and electricity sector in totality. In a situation where all the sugar factories are largely owned by the government, it will be essential to develop policies that facilitate the accelerated development of these sectors through the involvement of the private sector. Key issues that policy needs to address include:

i.) Clear bagasse development policy, recognizing bagasse as a resource and facilitating development of bagasse-based projects
ii.) Stimulation of investment by offering tax breaks and other incentives for investment in firm generation plant and efficiency improvement initiatives; incentives should lower front-end barriers to project development
iii.) Restructuring the national sugar authority to enhance management, development and investment into the sugar sector and to promote cogeneration and efficiency. The Kenya Sugar board should take leadership role in promoting bagasse cogeneration since this is Key to sustainable sugar industry for Kenya
iv.) Enactment of clear fiscal incentives for cogeneration to encourage investment
v.) Creating suitable and attractive regimes for independent power producer involvement, including pricing and grid feed-in laws for cogenerated electricity
vi.) Provision of support to indigenous local private sector participation in the energy sector to ensure sustainability.
vii.) The setting of realistic but challenging targets for increased cogeneration contribution to the electrical energy supply mix
viii.) Development of a national pool of multi-disciplinary competence to develop, design and oversee local implementation of cogeneration projects
ix.) Involvement of local and international financing groups to provide finance for investment in the sugar sector, especially for cogeneration projects

Developing and implementing coherent and consistent policies that cover these areas will ensure comprehensive and efficient development of cogeneration and the sugar sector and facilitate the implementation of projects through private sector involvement.

5.4 Financial and Investment Challenges

Cogeneration is to be implemented in an industry that is still to a large extent being controlled by the government and therefore perceived as inefficient in terms of management. In addition, most of the companies have been making losses successively over the years and only started making some profits in 2003 after a new-political dispensation (Kenya Sugar Board Report 2005). Viewed against this background, most investors or financiers would be reluctant invest or extent credit facilities to such projects because of the perceived higher risk associated with the weather uncertainty as well as anticipated political interference. The Clean Development Mechanism (CDM) funds would make it more attractive for the investors and financiers, if utilized by sugar companies in Kenya.

Furthermore, most of the local investors and financial institutions do not have any experience in financing this kind of projects. In Kenya banks do not have all the tools and information to critically analyze the reliability of such a project to warrant them extend loan facility to the cogeneration projects. If cogeneration were to be considered for funding in any case, getting guarantors would be very difficult because of the perceived risk and huge capital outlay required. Equally, interest rate charged would be higher than the prevailing interest rates to perceived risk element, but with CDM funds, the revenue realized would help make the project financially attractive despite the high interest rates charged. There is also a barrier arising from the fact that still the government does not have a comprehensive policy on price that KPLC is to pay on power from bagasse cogeneration source and this has made it difficult to have strict and precise projection on sales revenue and profits, these facts can also deter investors and financiers. The pricing aspects has made cogeneration projects unattractive to sugar companies in the country as KPLC tends to offer a lower price for cogeneration power than from fossil fuel sources on the assumption that production costs are low.

In Kenya, the government plays a very active role in the management and regulation of the sugar and energy sectors. As far as political interference is concerned, the Government through the ministry of Energy ordered Kenya Electricity Generating Company limited (KenGen) not to charge KPLC the earlier agreed rates as it was felt that it would destabilize KPLC commercial recovery .This scared the potential investors and financiers and introduced the political risk dimension in financing of power projects in Kenya. The CDM fund would be used to improve the return on investment and make the project worth implementation despite the perceived risks.

5.4.1 Cost Implications of Cogeneration Projects

For cogeneration plants, the investment costs vary with net export capacity, from $1.4 million /MW at lower pressure, $1.8 million / MW mid-range to 3.1 million /MW at top end. This compares with $1.1 million /MW for heavy fuel oil plants, $ 2.25 million /MW for geothermal and $2.5 million /MW for hydro power plants. Thermal power plants have significant fuel costs that are passed directly to the consumers under current electrical tariff structure hence making it expensive. (IRSEAD, 2005)

Higher operating pressures offer better efficiencies and therefore better resource utilization. However, they also entail higher capital costs and more sophisticated levels of technology. The relatively long-term operations for which power projects are designed, typically 25-30 years; the more efficient units are attractive over this period. Like other renewable energy technologies, biomass cogeneration lends itself to modular implementation, allowing large projects to be broken down into smaller units that can be implemented in phases. (Wade, 2004)

Table 5.6: Estimates of plant capital cost

Component	**Possible plants options**		
Boiler pressure (Bars)	45	60	82
Recommended plant capacity (TCD)	5000	5000	5000
Boiler capacity (Tons of steam/hrs)	140	140	140
Bagasse feed rate (Tonnes/hr)	58	62	70
Turbine capacity (MW)	25	30	50
Daily power generation gross (MWh)	420	550	820
Equivalent capacity (Mw)	18	24	40
Daily export power net (MWh)	260	330	550
Equivalent export capacity (Mw)	12.5	14	24
Total capital Investment ($ million)	18	25	75
Estimated local component ($ million)	4	5	12
Estimated annual revenue ($million)	4	5	8.3
Simple payback period (year)	4.5	5	8.8

Source: Osawa etl, 2004

From the table, the cost of a cogeneration plant depends on selected operating pressures with 82 bar plant having the highest cost. This is followed by a 60-bar power plant and then a 45-bar power plant.

Of the total capital costs of putting up sugar factories, about 60% is attributable to the cost of the cogeneration power plants. At present, all factories are net importers of power, either due to inadequate capacity or, in the case of one factory namely Mumias, inadequate arrangements for generation when the factory is under maintenance. In the cogeneration scenarios, the factories consume an estimated 30% of power generated by the plant in exchange for bagasse fuel, effectively saving on their energy bill.

5.4.2. Revenue projections from bagasse cogeneration

The purpose of cogeneration investment for Sony is twofold, to reduce or eliminate electricity imports from the grid by generating own power for internal use and export excess power to the grid and generate additional revenue to the company. For proposed investment

Avoided cost (9000 KW x 0.1 US $ /kWh **270 days** x 24 hrs= US$ 5.8 Million
The plant would generate a total of 134.8 million kWh/ yr (For calculation based on 26 MW x LF x operating hrs/year.

At current IPP energy prices for continuous power (Mumias rate of 4 US cents per kWhr) this would translate to annual revenue of
134.8 million KWhrs x US 0.04= US$ 5.4 Million
Based on US cents 6 per KWhr
134.8 million KWhrs x 0.06= US$ 8.1 Million

5.4.2.2 Financial Analysis

The following assumption will be made
Plant lifetime is estimated to be 20 years
A real discount rate of 12% is used in LCPDP and many studies in Kenya
Capital costs, operation & maintenance and revenue based on market rates for similar capacities
Electricity export will be at prices similar to those in the LCPDP (ksh 5/kWhr - ksh 8/kWhr)
Factoring in avoided electricity import costs
NPV=US$ 3.8 million and IRR= 10% at tariff rate of US cts4/kWhr. At 6 US cents/kWhr,
NPV=US$ 14.2 Million at IRR 18%
Without factoring in avoided investment purely in power generation outside existing sugar factory, such investment would only start being viable with tariffs > 8 US cents/kWhr
NPV= +2.9/20.7 Million USD at 8/10 us cents/ kWh
Total annual operation and maintenance costs+ US$ 6.3 Million starting year (Year 1) after project commencement (Year zero) except year 5, year 10 and year 15 when major overhauls are undertaken, and annual cost are US$ 7.1.

5.4.3 Financing options for CDM project

As CDM projects, bagasse cogeneration projects have the following funding options

i.) Annex I investor co-finances part of the project in return for shared financial return and CER.
ii.) Local investor's co-finance the projects in host country may wish to share CERs so that they have opportunity to sell the credits later.
iii.) Annex I investor provide loan or lease financing at concessional rates in return to CERS
iv.) Annex I investor agrees to buy CERS as they are produced by the project (Emission Reductions Purchase Agreement)

Investors can co-establish a local company, through which they shall invest in a foreign-capital- enterprise. Preferably, this investment should be made in the form of upfront payment, on premise of future delivery of CER. The rest of the project funds can be obtained by use of co- financing of public and private financing institutions (Synergy, 2005).

5.5 Cogeneration Capacity of Kenyan Sugar Factories

Sugar cane trash could be recovered in suitable quantities and quality for use as supplemental fuel to bagasse for power generation. Research shows that biomass gasifier/ Gas turbine BIG/GT technology with trash supplementing bagasse could increase the production of electricity by sugarcane mill by 500%. (Wade, 2004). Electricity production could be increased from 50 to 60 KWh/ton of cane processed with conventional high-pressure steam turbine technology firing only bagasse to 250 to 300 kWh/ tonne of cane processed with BIG/GT system using both bagasse and trash. It is estimated that use of BIG/GT technology with sugar cane residues as fuel has potential to achieve reductions in CO_2 emissions in the range of 26 to 40 million tonnes of CO_2 equivalent/year, depending on degree of technology penetration assumed if the world's I billion tonne sugar cane industry converted its bagasse and field waste into power, use of nearly 250 million tons of oil could be avoided every year. (WADE, 2004).

On average, Kenya produces 4.5 to 5 million tons of sugar cane annually, producing 1.8 Million tons of bagasse with net calorific value equivalent to 300,000 tons of oil. Conversion efficiency currently stands at around 50-110 kWh per ton of cane. This would allow 10 –20 kWh export per ton of cane milled

Karekezi and Kithyoma, 2005, states that the Mauritius experience is as follows:
i) For 21 -31 bars pressure, efficiency is 50kWh/ ton of cane. This is the base scenario.
ii) 44 bars pressure efficiency is 80 kWh/ton of cane. This is the middle scenario.
iii) 82 bar pressure at 110 kWh/ ton of cane. This is the high case scenario.

Table 5.7: Current and planned Sugar factory capacity

	Factory	**Current Capacity**		**Planned Capacity**		**10-year Average Production**	**2005 Production**	**2006 Production**
		TCH	TCD	TCH	TCD			
1	Mumias	380	8,450	450	12,000	2,129,750	260,224	228,379
2	Sony	125	3,000	330	8,000	625,072	72,557	59,445
3	Chemilil	125	3,000	250	6,000	594,192	38,189	52,722
4	Nzoia	125	3,000	292	7,000	517,959	62,587	59,050
5	Muhoroni	94	2,200	250	6,000	293,944	28,369	32,145
6	West Kenya	105	2,500	250	6,000	201,802	27,071	43,400
7	Soin	50	1,250	70	1,600	_	0	513
Total		1,004	24,400	1,892	46,600	4,362,719	488,997	475,654

Source: Kenya Sugar Board 2007

The initial design capacity for Mumias Sugar was 8,450 TCD before installation of a diffuser, which improved throughput to 10,000 TCD. Soin Sugar Company Ltd. Started operations in 2006 with no production in 2005 so it is not used in computing the 10-year average cane production by the Kenyan sugar industry.
From the table above, the planned capacity for the seven factories is 46,600 TCD with Mumias leading at 12,000 TCD.

Table 5.8: Sugar Industry Potential at Current Capacity

FACTORY NAME	**Average Cane Crushed**	**Potential export GWh (21 bars)**	**Potential Export GWh (31-40 Bars)**	**Potential Export GWh Firm Power (82 bars)**
Chemilil	594,172	5.94	35.7	65.3
Muhoroni	293,944	3.0	17.6	32.3
Mumias	2,129,750	21.3	128	234.3
Nzoia	517,959	5.18	31.1	57.0
South Nyanza	625,072	6.25	35.7	68.8
West Kenya	201,802	2.02	12.1	22.1
Total(10-year average)	4,362,699	43.69	145	479.8
Based on 2005	4,845,384	48.5	161.0	533

Table 4.34 shows potential export from the sugar factories based on actual production statistics. It shows that:

- actual export potential at 82 bars was 533 GWhr,
- At 21 bars, the actual potential was 48.5 GWhrs.
- While at pressure of31 to 40 bars, actual potential was 161.0 GWhrs

Soin Sugar Company Ltd is not included in this data because it started operations in 2006 and therefore there is no data on production in the table.
Conversion ratios used are
i) 100,000 tonnes of cane =1 GWh for 21 bar boiler plant
ii) 16,708 tonnes of cane =1 GWh for 31-40 Bar boiler plant
iii) 9,080 tonnes of cane =1 GWh for 82 Bar boiler plant

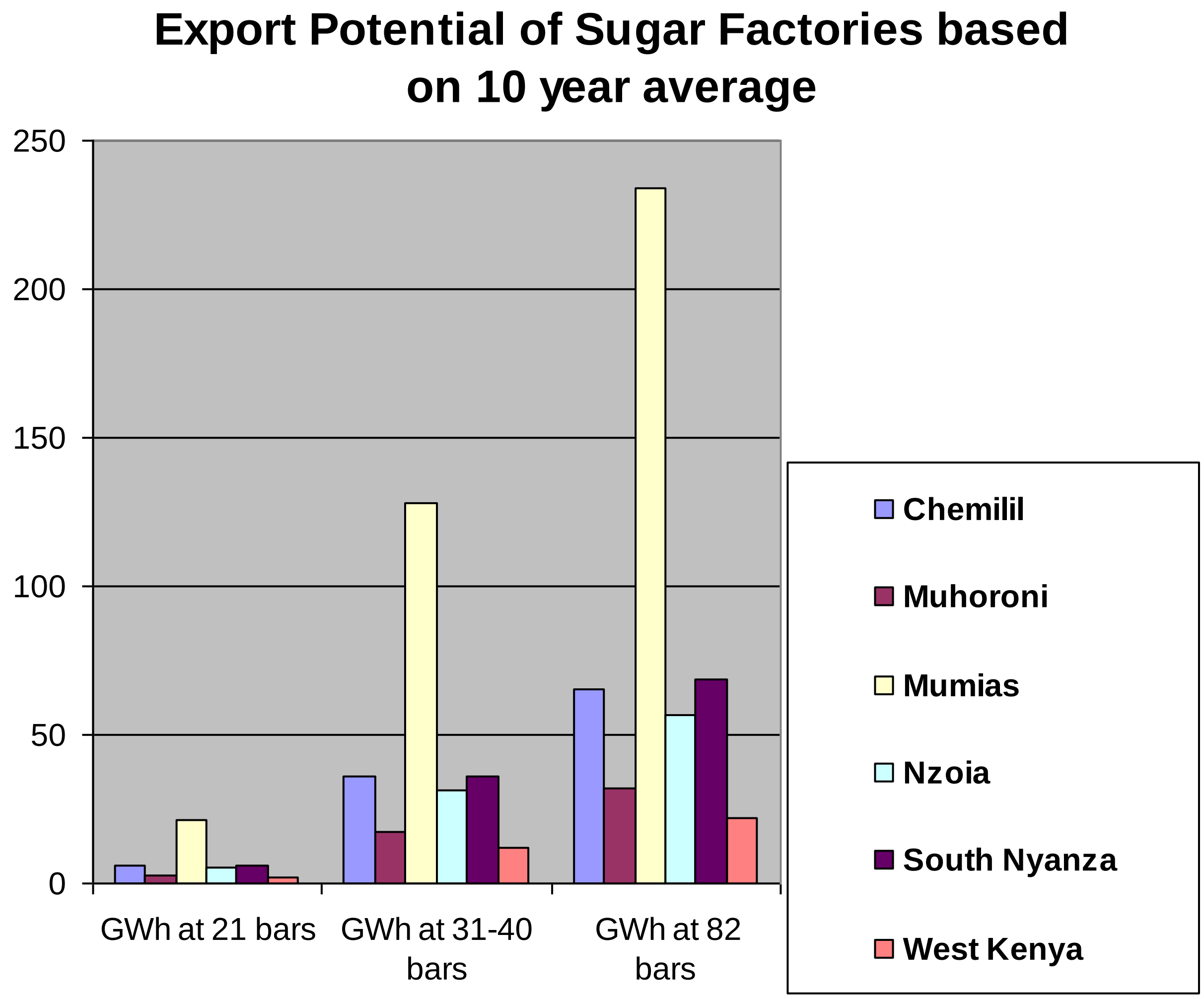


Fig 5.1: Export potential in GWhrs of Kenyan Sugar factories based on their 10 year average capacity

From the table Mumias has the highest potential, followed by SONY, Nzoia West Kenya and Muhoroni Sugar Company Ltd.

Table 5.9: Potential and planned generation Capacities

Company	**Current Capacity TCH**	**Planned Capacity TCH**	**Ave. Steam Production (Tonne/Hr)**	**Peak Demand (Tonnes/Hr)**	**Ave.Power Output (Mw)**	**Peak Demand (Mw)**
Chemilil	135	250	60	70	2.5	3.0
Muhoroni	120	150	45	60	2.25	3.0
Mumias	380	500	200	210	9.0	9.0
Nzoia	125	300	60	65	3.0	4.5
Sony	125	330	60	70	3.0	4.0
West. Kenya	105	100	28	33	2.0	2.5
Soin	50	70	-	-	-	-
Total	1,040	1,700	455	508	21.75	26

(-) Data not available
Source: Kenya Sugar Board, 2007

From the table 4.35, it is realized that:

- Mumias has the largest factory capacity both planned and current.
- The current total TCH is 1,040 while the
- Total planned TCH is 1,700.

The combined steam generation capacity is 455 tonnes per hour and combined peak demand for steam is 508 tonnes per hour. This shows that the industry generates less steam than it requires. The total power output for the industry is 21.75 MW against demand of 26 MW. This shows that the sugar industry in general is a net importer of power.

Table 5.10: Cost Implication

Cost Item	**100 TPH 45 BAR**	**100TPH 60 BAR**	**100TPH 82 BAR**	**200 TPH 45 BAR**	**200 TPH 60 BAR**	**200 TPH 82 BAR**
Boiler price in US $ Millions	9.71	12.1	25.04	15.03	17.62	36.28
Turbo alternator prices US$ Millions	2.30	4.25	7.25	7.50	8.26	12.50
Cost of auxiliaries in US$ millions	8.58	14.89	16.28	18.30	32.60	46.60
Total price for package US$ millions	20.59	31.24	48.57	40.83	58.48	95.38
Gross output MW	12.80	17.85	25.06	25.60	35.80	50.20
Cost per MW US$ Millions	1.61	1.75	1.93	1.59	1.63	1.90

Source: Institute for Research in Sustainable Energy and Development (IRSEAD), 2006

Observations

From table 4.36,

- a power plant at 82 bar steam pressure will cost about 95.38 Million Dollars compared to a 45 bar steam pressure plant which costs about 20.59 million Dollars.
- Therefore a sugar factory will invest more money for cogeneration at higher steam pressure.

Table 5.11: Comparison of plant Cost for Renewable Energy Project Options

Plant Type	**Capital Costs**	**Estimated O& M Costs (US$)**	**Unit Energy Cost**
Unit Cost	$/KW	$/MW	$/MWh
Hydro (Sondu Miriu I&II	2550	7	60
Geothermal (Olkaria)	2000	6	48
Bagasse cogeneration at 40 bars	1600	21	80
Bagasse Cogeneration at 60 Bars	1710	28	59
Bagasse cogeneration at 82 Bars	2000	40	42

Source: Institute for Research in Sustainable Energy and Development (IRSEAD), 2006
Observations and table interpretation

From table 5.11:

i.) Hydropower plants have largest capital costs followed by geothermal power plants.
Geothermal power plants have lowest operation and maintenance costs followed by hydropower plants.
ii.) High-pressure bagasse power plants have highest cost of operation and maintenance.
iii.) Low steam pressure cogeneration has highest unit cost per MWh followed by hydropower.
iv.) High-pressure bagasse cogeneration at 82 bars has lowest energy costs compared with hydropower, geothermal, low and middle pressure bagasse cogeneration.

Table 5.12: Comparing Costs of projects identified in LCPD against Bagasse Cogeneration

Source: IRSEED, 2006

Plant Type/ Fuel	**Capacity MW**	**Capital Costs (US$)**	**Cost per MWhr (US$)**	**Fuel Rate/KWh**	**Variable Costs US$/MWh**
Coal/Steam	100	196	1.96	11.07	99.0
Oil Fired Steam/LRFO	60	80	1.33	11.9	81.7
Gas Turbine/IDO	30	23.2	0.77	13.0	80.6
Combined Cycle/IDO	90 (3x30)	85.9	0.95	11.5	77.8
Low Speed Diesel/LRFO	60 (2x30)	89.3	1.49	9.0	85
Low Speed Diesel/LRFO	50	80	1.6	8.3	85
Medium Speed Diesel/LRFO	20	20.3	1.02	8.3	80.0
Medium Speed Diesel/LRFO	60 (3x20)	52.3	0.87	8.8	80.0
200 TPH Bagasse cogen, 40 bars	25	40	1.6	29.7	24.9
200 TPH bagasse Cogen, 60 Bars	35	60	1.71	21.3	17.9
200 TPH bagasse Cogen, 82 Bars	50	100	2.0	15.2	12.8

Observations

- i.) Gas turbine/IDO gives the lowest cost per MWh followed by combined cycle/IDO.
- ii.) Bagasse cogeneration at 82 bars steam pressure gives the highest cost per MWh power cost.
- iii.) A coal steam plant has the highest cost variable costs.
- iv.) Bagasse plants have the lowest variable cost hence cheapest to operate.
- v.) A coal steam plant has the highest capital cost while gas turbine/IDO has lowest capital cost.
- vi.) A medium speed diesel power plant has lowest capital cost.

Table 5.13: Identified Targets and Investment Costs for all Sugar Factories

Source: Source: Institute for Research in Sustainable Energy and Development (IRSEAD), 2006

Factory	**Estimated Generation Capacity. (MW)**	**Export Capacity (MW)**	**Estimated Costs US$ Millions/Unit Cost**	**Energy Export GWh**
Mumias	70	55	120/1.7	300
SONY	25	15	40/1.6	90
Chemelil	25	15	40/1.6	60
Nzoia	25	15	40/1.6	66
Muhoroni	18	12	30/1.6	40
West Kenya	10	6	18/1.6	30
Total	**173**	**118**	**305/1.76**	**586**

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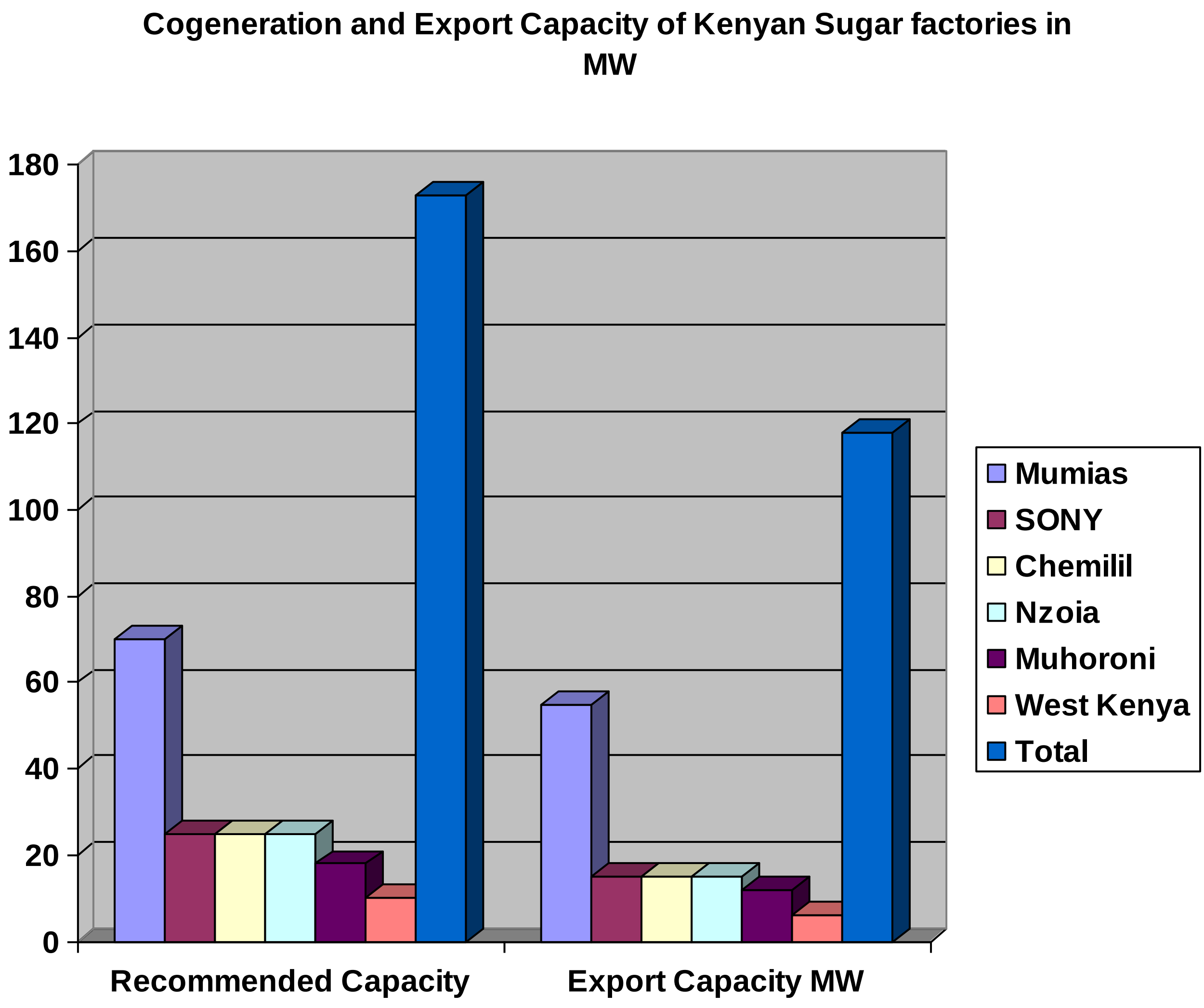

Figure 5.2: Generation and export potential in MW based on current capacity

Source of Data: Source: Institute for Research in Sustainable Energy and Development (IRSEAD), 2006
The above estimates are based on the current level of production capacity, which is not optimum since most of the sugar factories in Kenya have low efficiency levels and need to invest in process improvements. SOIN is a company not included since it started operations in 2006 and reliable statistics are not available except for projections and estimates.
From the table and graph,

- Mumias has the highest generation and export capacity while West Kenya has the lowest.
- The current industry generation capacity is 173 MW
- The current export potential is 118 MW
- Export potential is 586 GWhrs at current capacity of the factories

5.5.9 Capacity Based on Optimum Process Efficiency for Firm Power Plant

In this case, an overall efficiency of 90% will be assumed and export capacity of 20kwh/ton of cane will be used in computation. A crushing period of 300 days per year will be used.

FACTORY NAME	TCD	OPTIMUM PRODUCTION (Ton of cane)	GENERATION CAPACITY (GWhrs)	EXPORT POTENTIAL (GWhrs)
MUMIAS	10,000	27,000,000	2,138	389
SONY	3,000	810,000	642	117
CHEMILIL	3,000	810,000	642	117
NZOIA	3,000	810,000	642	117
MUHORONI	2,200	594,000	471	86
WEST KENYA	2,500	675,000	535	97
SOIN	1,250	337,500	267	49
TOTAL	**24,950**	**6,736,500**	**5,337**	**972**

Table 5.14: Generation and Export Capacity of sugar factories

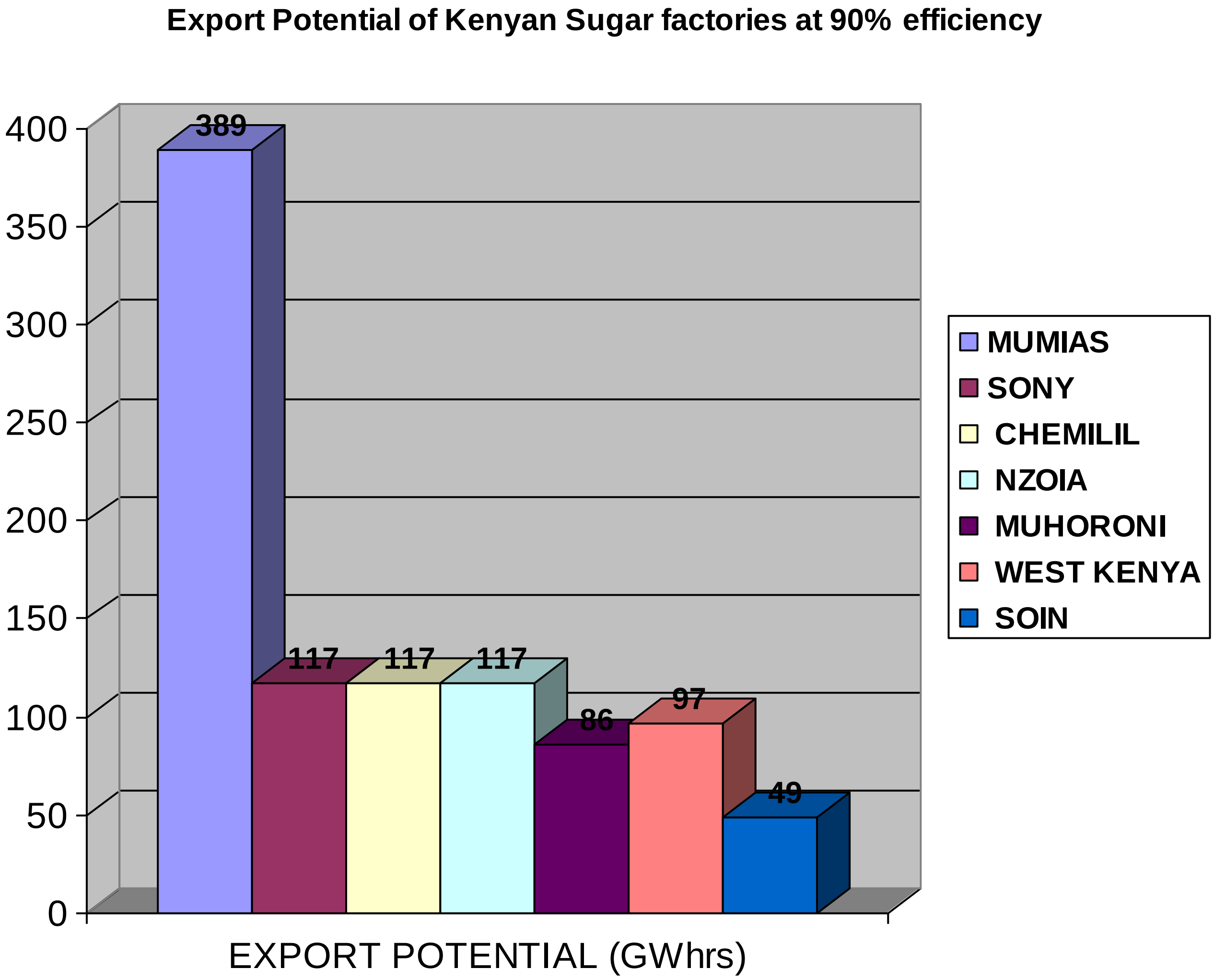

Figure 5.3: Export capacity of Kenyan Sugar factories at 90% Efficiency

NOTES

- Optimum production is based on 90% efficiency realized in countries like Mauritius, Reunion and Brazil, which will establish cane milling and cogeneration sugar factories.
- Crop period of 300 days is used.
- Export potential of 20 kwhr/ton of cane is used
- Generation capacity is based on firm power plant conversion of 110 kWhr/ton
- This is current generation capacity of the seven operating sugar factories based on current installed crushing capacity.
- Firm Power Plant installation is assumed in all cases.
- With process efficiency improvements, more power will be available for export.
- Generation capacity refers to total energy potential
- Export potential refers to electricity export potential

Table 5.15: Generation Capacity based on planned milling Capacity

FACTORY	**Capacity in TCD**	**Optimum Annual Milling**	**Generation capacity (GWhrs)**			**Export Capacity**
	(Cane crushed)	Tonne of cane	21-30 bars	42 bars	82 bars	GWhr
Mumias	12,000	3,240,000	1,166	1,866	2,566	467
Sony	8,000	2,160,000	778	1,244	1,710	311
Chemilil	6,000	1,620,000	583	933	1,283	233
Nzoia	7,000	1,890,000	680	1088	1,497	272
Muhoroni	5,000	1,620,000	583	933	1,283	233
West Kenya	6,000	1,620,000	583	933	1,283	233
Soin	1,750	372,500	134	215	295	54
TOTAL	**46,750**	**12,522,000**	**4,507**	**7,212**	**9,917**	**1,803**

Notes

Generation capacity is computed based on milling capacity for use in 7 sugar factories at 90% efficiency.

Conversion efficiency is as follows:

- 50kwh for 25 -31 bars.
- 80 kwh/ton for 44 bars.
- 110 kWh/ ton of cane for 82 bars.
- Firm power export capacity is 20kwh/ton of cane.
- Export capacity is based on 82 Bars steam pressure

1. Research Findings

The research led to the following findings;

i.) There is no government policy specific on bagasse or export cogeneration for sugar factories.

ii.) There is no power purchase agreement specific to the sugar industry hence no special treatment or preferential treatment is offered for investors in bagasse cogeneration.

iii.) Kenyan sugar factories are designed in such a way they that generates just enough electricity for their internal use and they supplement by buying from the grid. Mumias however exports 2 MW excess power.

iv.) The bulk purchase fee for cogenerated power is low and not encouraging sugar Companies to incur the huge financial investment needed for Bagasse export cogeneration.

v.) The technical efficiency for current cogeneration and extraction technology is lower than expected for effective export cogeneration.

vi.) All the sugar factories use the backpressure steam turbines, which are less efficient in terms of electricity generation.

vii.) Biomass gasifier/gas turbine (BIG/GT) technology with trash supplementing bagasse could increase the production of electricity by a sugarcane mill by 500%. Electricity production could be increased from 50 to 60 kWh/ton of cane processed with BIG/GT system using both bagasse and trash (UNDP, 2007)

viii.) Seasonality of milling with some two days or weekly maintenance and 8 weeks of out of crops maintenance causing generation interruption due to unavailability of bagasse.

ix.) Bagasse cogeneration faces other competition for use of excess bagasse. This include production of paper and pulp, furniture and board, charcoal bracketing

x.) Low bulk density and high moisture content for Bagasse causes handling, storage and safety problems, hence a challenge in its use as a fuel for bagasse based cogeneration.

xi.) The development of power plant requires high initial capital needed to design, purchase and install boilers, turbo generators and process improvements

xii.) All the Kenya sugar factories are struggling to remain financially afloat in a competitive sugar market with COMESA concession that were meant to end in 2008 but have been extended courtesy of Kenyan ailing sugar industry that will remove import limitation and access of sugar from cheap producers with the COMESA trading block. This makes the factories to undergo capital-intensive investment in form of power plant development.

xiii.) The Kenyan government has other priorities other than providing financial incentives and subsidies to sugar companies to invest in export cogeneration hence placing a challenge on provision of financial incentives.

6. CONCLUSSION AND RECOMMENDATIONS

6.1. CONCLUSIONS

Bagasse cogeneration provides a clear potential for diversification of sugar industry into export power generation and should be accorded priority. Except for Mumias and other privately managed companies, the other companies are loss making which makes it attractive but difficult . By selling power to the grid; the factories will get extra income putting them in healthier financial positions. This will enable them to pay farmers promptly and reduce the unit cost of sugar which is currently above world prices. This will make the Kenyan sugar industry to be globally competitive.

While cogeneration provides an indigenous source of electrical energy for the nation, saves on foreign exchange on avoided fossil fuel importation, acts as a tool for employment and wealth creation and an agent for abatement of environmental degradation in line with the Kyoto Protocol on greenhouse gas emissions of which Kenya is a signatory.

The Kenyan Sugar industry does not have the resources and capacity to realize full potential of bagasse cogeneration. A combination of players is required to make 10% contribution by cogeneration a reality in Kenya as stipulated in the Sessional paper no. 4 of 2004 by the government.

For bagasse cogeneration to grow within the Kenyan energy market, it has to overcome barriers like competition from fossil fuel fired generation, cheap hydropower and smooth geothermal energy generation, policy restrictions caused by public sector/government biases, physical constraint and lack of confidence within the financial sector towards financing bagasse cogeneration projects. All these factors restrict the commercial deployment of bagasse cogeneration to a greater or lesser extent. However, bagasse cogeneration will continue to grow, as benefits of cogeneration are more than the value of negative cost fuel, which can compete with fully burdened cost of diesel and heavy fuel oil.

Internationally, there is a commitment to generate the increasing demand for electricity from clean, renewable fuels. This support will create a rapid increase in biomass projects coming onto the energy market. Bagasse will give Kenyan energy market positive social- economic and environmental attributes, which are missing from the current energy mix.

Environmental benefits of bagasse include low Sulphur content and relatively clean combustion by products. Newer biomass technologies offer an alternative to older industrial boilers and uncontrolled open-air combustion of agricultural wastes, which may emit organic substances and carcinogens. In addition, energy uses for bagasse may promote better forestry management, and cultivation of certain high-energy content species may prove beneficial in preventing soil erosion.

Bagasse energy is a mature technology relative to most other sources of renewable energy. Prospects for further developments of this energy source depend on economics, including the cost for alternatives to waste disposal. While technological advancements in combustion may improve bagasse economics in future, capacity constraints based on substantial land requirements will continue to prevent bagasse from significantly displacing any of Kenya’s traditional sources of energy namely hydropower, thermal and geothermal energy sources.

As far as fuel supply is concerned, if bagasse energy is to play a larger role in energy mix, bagasse power plants will require a steady supply of bagasse year-round. If bagasse power plants must supply power around the year, there must be enough biomass available throughout the year to meet their obligations. Furthermore, bagasse energy operators must compete with other industries for biomass for example charcoal bricketing, production of paper and board, animal feed and manure.

Professionally, in the sugar industry, most engineers are not familiar with modern bagasse energy conversion technologies and export power plant design while farmers lack the experience and knowledge of growing, storing and transporting or handling of cogeneration crops. With bagasse competing with other established and competitive energy options, this lack of knowledge and experience is enough to discourage quick adoption of bagasse cogeneration technology. These calls for further investment in training and development in bagasse energy technology particularly export cogeneration design, operation and maintenance.

As far as technology is concerned, there are still several technical challenges to bagasse cogeneration commercialization. This includes development of multi fuel usage power plants and reducing cost of power plants per unit output. But with legislative support and research into bagasse power technologies and commercialization of bagasse, export cogeneration will be a reality.

The research showed that bagasse as a fuel for export cogeneration in the sugar industry in Kenya, is feasible if necessary measures are put in place and the operating sugar factories can generate as much as **9,917 GWhrs** with a potential to export **1,803 GWhrs** of electrical energy based on the planned capacities as stated in the strategic plans of the operating sugar companies. Based on the current capacity, **5,337 GWhrs** of energy can be generated with a potential to export **972 GWhrs** of electricity to the grid. These estimates assume improved overall factory efficiency of 90%, which is yet to be realized by the industry until process improvements with massive capital investment, is made to improve throughput in the factories.

Cogeneration provides a clear potential for diversification of the sugar industry into energy-related activities such as power generation and ethanol production and should be accorded high priority. The discussion and conclusion in this research show that export bagasse cogeneration in Kenya is feasible but requires policy incentives, investment in technology and capital and requisite training and experience in high steam pressure bagasse cogeneration technology for it to realize the full potential.

6.2. RECOMMENDATIONS.

i.) There is need to separate power generation, transmission and distribution is to enhance easy access to use national power grid. This will ensure that planning and regulatory paths are cleared for development of enhanced cogeneration facilities. This includes ensuring fair and easy access to the grid for both large and small generators as well as guaranteeing that the incumbent generators and utilities do not hinder this process. This process started with the formation of (Kenya Electricity Transmission Company) KETRACO but KPLC continues to own and operate the existing grid and therefore has a monopoly on power transmission, distribution and determining whom to license to generate power which it has to buy.

ii.) A Power Purchase Agreement (PPA) should be developed and be specifically tailored towards bagasse cogeneration. The PPA should provide for the challenges of bagasse cogeneration and fix a price that will motivate sugar processors to invest in cogeneration and enhance sustainability with both the sugar and energy sub-sectors of the economy. The PPA for Mumias Sugar Company does not capture the cost of fiber provisions for the same yet this may be an issue soon or latter as the cane farmer may lay claim on the power revenue.

iii.) Financial and tax incentives in line with other incentives for renewable energy be provided to boost the initial development of cogeneration facilities in sugar mills. This will motivate sugar companies to invest in necessary equipment and infrastructure to maximize their electricity output whilst making the effective use of heat and electricity generated onsite. Financial incentives include the provision, where possible of renewable energy feed-in tariffs that reflect the benefits of onsite production and biomass combustion. Where financial incentives are currently unavailable, the CDM should be promoted and developed. The CDM could provide the incentives required for the upgrade or installation of cogeneration equipment in mills in a cost-effective manner whilst facilitating the meeting of Kyoto Protocol commitments by Annex 1 parties.

iv.) The government should come up with subsidies and tax incentives to attract both foreign and local investment i.e.

v.) Tax rebates or tax holidays and an investor is given sufficient time to recoup his investment before taxation is initiated by the Kenya Revenue Authority.

- vi.) No custom duty on equipment and imported raw materials needed by bagasse power plants e.g. coal, water treatment chemicals
- vii.) Exemption from income tax of foreign expertise called in to initiate the bagasse cogeneration plants
    - a. Government participation in infrastructure development namely (water, roads, telecommunication, power transmission infrastructure)
    - b. Land conversion tax where one is taxed more for converting from cane cultivation to something else or leaving fallow land in cane growing areas e.g. in Mauritius. This will lead to sustained production of sugarcane thus sustainable bagasse production
    - c. The Government can provide free feasibility studies through the ministry of energy or the Sugar Board.
- viii.) Sugar factories should embark on the process improvements that will lead to reduced process steam consumption and electricity consumption. This will ensure more steam and electricity is available for use in export cogeneration. Such changes include:
- ix.) Conversion of steam turbine drives to electric motor driver drives like for mill drives and cane knife drives. This will avail more steam for turbo-generator
- x.) Cane knives to be driven by electric motors instead of steam turbines as it is currently done in most sugar factories
- xi.) High-pressure boilers should be developed to generate steam pressure of above 60 bars as compared to the current installations of boilers of pressures between 20 to 25 bars.
- xii.) Backpressure turbines should be replaced with condensing steam turbines to ensure maximum pressure drop in steam turbines and conversion of thermal to electrical energy.
- xiii.) Extraction turbines can be used to generate process steam at 1.5 bars for sugar production or alternatively small capacity backpressure turbines can be used to supply low pressure steam for process use
- xiv.) Process improvements need to be done so that factory energy requirements are reduced and hence avail more energy in form of electricity for export to the national grid.
- xv.) The factory cane carrier elevators with electric motors and turbine drives should be replaced with VFD drive to reduce power consumption at cane carriers.
- xvi.) Strained juice and weighed juice pumps are commonly run on electric motors with pumps operated manually with a recirculation of up to 20% provision. Introduction of variable frequency drives with auto control valves will save up to 25% power in strained juice pump. This will save energy for export.
- xvii.) Installation of a mass flow meter for juice measurement will avoid the use of electrically driven juice pumps hence reduced electricity demand.
- xviii.) Sulphited juice pumps should be right sized and the drives should be changed to the required size with variable frequency drive provision depending on individual plant size and design. Sulphited juice pumps are always running to supply the pans with juice if process house is running and have many starts and stops leading to high loads at start up.
- xix.) The fibrisers and mills provide with turbine drives should be changed electric drives for fibrisers and DC drives for mills. These will avail more steam to drive turbo alternators to produce more electricity for used and export.

xx.) During the cane crushing season, the plant receives the bagasse directly from the mill, and the surplus bagasse is taken to the bagasse storage yard. The bagasse thus saved could be used for the off-season operation of the plant or could be used to run the plant on the cleaning days or when the mill is not running due to some other reasons. Under such occasions, back feeding of the bagasse from the yard to the boiler is required. As the unit size becomes larger the quantum of bagasse to be back fed is so high. The feeding becomes non-uniform, resulting in the overloading of the conveyors if the feeding is done improperly with bulldozers or pushers. To overcome the back-feeding difficulties stacker reclaimers have been designed.

- xxi.) The bagasse from the mill contains 50% moisture. This moisture is evaporated in the furnace and is let out from the boiler at a temperature of about 160 ^{0} C without any useful contribution. This moisture restricts the efficiency of the boiler to around 70%. If this moisture is removed from the bagasse before it is fed into the boiler, the boiler size can be designed to be much smaller in dimensions for the same output or the capacity of the boiler can be increased in an already existing boiler. For every 5% reduction in moisture the boiler efficiency will go up by about 1%.

xxii.) Any efforts to develop cogeneration in Kenya will have to begin with a look at the performance of the sugar industry and electricity sector in totality. In a situation where all the sugar factories are largely owned by the government, it will be essential to develop policies that facilitate the accelerated development of these sectors through the involvement of the private sector. Key issues that policy needs to address include:

xxiii.) Clear bagasse development policy, recognizing bagasse as a resource and facilitating development of bagasse-based projects

xxiv.) Restructuring the national sugar authority to enhance management, development and investment into the sugar sector and to promote cogeneration and efficiency

xxv.) Provision of support to indigenous local private sector participation in the energy sector to ensure sustainability

xxvi.) The setting of realistic but challenging targets for increased cogeneration contribution to the electrical energy supply mix

xxvii.) Development of a national pool of multi-disciplinary competent engineers to develop, design and oversee local implementation of cogeneration projects

xxviii.) Involvement of local and international financing groups to provide finance for investment in the sugar sector, especially for cogeneration projects

xxix.) Developing and implementing coherent and consistent policies that cover these areas will ensure comprehensive and efficient development of cogeneration and the sugar sector and facilitate the implementation of projects through private sector involvement.

6.3. Recommendations for Further Research

Based on findings of this research, further research is recommended on the cogeneration capacity of sugar factories if selectively collected trash is used in cogeneration and its impact on the environment particularly with the biomass integrated gasifier and gas turbine combined cycle technology.

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REFERENCES

[1] Avante-Garde Engineers and Consultants Ltd, (2006): Modern Trends in Technology and Relevant issues in Cogeneration Plants of Sugar Industry http://cdm.unfccc.int/Projects/DB/SGS

[2] Barquant, J. (1984). Electricity production from the biomass of the sugarcane industry in Mauritius.*Biomasss*, *5*(4), 283-294. https://doi.org/10.1016/0144-4565(84)90074-X

[3] Bell, J (2005): Sweetening the power sector: Current experience and future potential for Bagasse CHP around the world, International sugar journal

[4] FAO (2007): Food Outlook, Global Analysis. Http://www.fao.org/docrep/ah876e00.HTM

[5] GOK (2004): Sessional Paper No.4 of 2004 on Energy, Government Printer, Nairobi

[6] Harman C and Shepard M, (2000): Introduction to Energy Technology, Ann Arbor Science Publishers Inc, Michigan

[7] Hugot, E. A (1963): Handbook of Cane Sugar Engineering, 2nd Edition Elsevier Publishing Company, Amsterdam

[8] IEA (2002). World energy outlook 2020 and global electricity investment challenges. *International Energy Agency*. https://www.oecd-nea.org/ndd/investment/session1/Birol.pdf

[9] IEA (2019). World Energy Outlook 2019. International Energy Agency https://www.iea.org/reports/world-energy-outlook-2019/electricity

[10] IRSEAD (2006): *Bagasse Cogeneration*, IRSEAD, Nairobi

[11] Kabeyi M (2003): An investigation into financial policies and Practices in Sugar Industries in Kenya, Case Study of Nzoia Sugar Company, KIM, Eldoret.

[12] Karekezi S, (2000): AFREPEN Occasional Paper No 1, AFREPEN regional Seminar on Renewables-

Focus: Cogeneration, AFREPEN, Nairobi
[13] Kassiap, 2000: Sugarcane Bagasse cogeneration- Lessons from Mauritius, Mauritius Sugar Authority, Mauritius
[14] Kegode, O. & Ochola (2003): The Challenges and Way Forward for Sugar Sub-Sector in Kenya, Friedrich Ebert Steiftung (FES), Nairobi
[15] Kenya Sugar Board (2007): Sugar Production in Kenya. http://www.kenyasugar.co.ke/About%20us.html
[16] Larson and William, (2000): Princeton University, Princeton, U.S.A http://www.princeton.edu/~energy/publications/pdf/2001/Larson-01
[17] Lewis N. (2000): Chemical challenges in Renewable Energy, California Institute of Technology, California. http://undp.org/seed/eap/activities/wea
[18] Mike Inkson (1995): Cogeneration Thermodynamics revisited http://www.sucrose.com/bsst/2006agm1.pdf.
[19] Miller A and Martinot E: The Global Environment Facility (2001): Financing and Regulatory Support for Clean Energy, GEF, Washington. D.C
[20] Moreia, J.R (2000). Sugarcane for energy, recent results and progress in Brazil.
[21] Morgan.R and Murray B: (1982): Energy Resources, 2nd Edition Edward Arnold, London
[22] Muhoroni Sugar Company Ltd (2007): 6 MW Bagasse Based Cogeneration Project, Muhoroni Sugar Company Ltd, Muhoroni. http://www.pioneercarbon.com/documents.
[23] Mumias Sugar Company.Ltd. (2005): Annual Report and Financial Statements for the Year ended 30th June 2005, Mumias
[24] Mumias, 2007: 35 MW Bagasse Cogeneration project, Mumias Sugar Company Ltd,Mumias. http://cdm.unfccc.int/UserManagement/FileStorage
[25] Osawa B. and Yuko D. (2004): Bagasse fuelled cogeneration in Kenya, Earthscan, London. http://www.cospp.com/articles/print_screen.cfm
[26] Rabah, .V. (2000.): Application of Sugarcane Residue as biofuel for generation of Electricity. \`akafy proceedings/icibs.ic-mfa/rabahpaper.html.
[27] Rabah V. Kefa, 2000: Renewables: The Energy for the 21ss Century, World Renewable Energy Congress VI 1-7 July 2000, Brighton, UK 2000, pages 1340-1343
[28] Statica (2019). Sugar production worldwide from 2009/2010 to 2018/2019 (in million metric tons). Retrieved from https://www.statista.com/statistics/249679/total-production-of-sugar-worldwide/
[29] Then, O. (2019, January). Electricity generation 2019|2020.*VGB PowerTech e.V.* https://www.vgb.org/daten_stromerzeugung.rss?dfid=98051
[30] Turner C. & William K. (1984): Energy Management, Prentice Hall international, London
[31] Thumann. A (1984): Fundamentals of Energy, Fairmont press, Inc, Atlanta.
[32] UNDP, (2007): Biomass Power Generation: Sugar Cane and Trash http://www.undp.org/gef/05/documents/writeups_doc/cc/Brazil_biomass.doc
[33] USDA (2019, November). Sugar: World Markets and Trade. United States Department of Agriculture.
[34] Schlindwein, M.M., Correa, A., &Vasconcelos, P.S. (2017). Electricity Cogeneration from Sugarcane Bagasse in Mato Grosso Do Sul, Brazil. *International Journal Advances in Social Science and Humanities, 5 (3),* 11-26. Retrieved from https://apps.fas.usda.gov/psdonline/circulars/sugar.pdf
[35] Synergy, (2005): D11 Annex 4 – Pre-Feasibility study of a Bagasse Cogeneration Project: Case Study for Mozambique http://www.rgesd-sustcomm.org/CDM_Africa/
[36] WEC, (2007): 2007 Survey of Energy Resources, WEC http://www.wec.org
[37] Winrock International, 1993: Advancing Cogeneration in Indian Sugar Industry, Winrock International, Arlington, US
[38] WADE, 2004: Bagasse Cogeneration, Global Review and Potential, WADE, London.