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ELECTRICITY PRODUCTION FROM SUGAR INDUSTRIES IN AFRICA: A CASE OF SOUTH AFRICA

AZEL BANDA

UNIVERSITY OF CAPE TOWN, ENERGY DEVELOPMENT RESEARCH CENTRE
2001-2002, CAPE TOWN, SOUTH AFRICA.

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AZEL BANDA
UNIVERSITY OF CAPE TOWN
ENERGY DEVELOPMENT RESEARCH CENTRE
CAPE TOWN –SOUTH AFRICA

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TO MY DARLING AND LIFE MATE
DOROTHY
AND OUR DAUGHTER,
DORAZE.

GENESIS 1 VERSE 11 (THE ORIGIN OF BIOMASS ENERGY)

Then God said, "Let the earth bring forth grass, the herb that yields seed, and the fruit tree that yields fruit according to its kind, whose seed is in itself, on the earth"; and it was so (NKJ Bible, 1982).

DECLARATION

This is to certify that the dissertation entitled 'Electricity Production From Sugar Industries In Africa: A Case Of South Africa' submitted in partial fulfilment of the requirements of the degree of Master of Science in Engineering of the University of Cape Town is a record of bonafide research work. The subject matter embodied in this report has not been submitted at any other university.

Name; Azel Banda

Signature; . Signed by candidate

Signed this.21....day of December 2002.

ACKNOWLEDGEMENT

First and foremost I would like to record my thanks to my wife Dorothy and our daughter Doraze for allowing me, for two years, to be a ‘tele’ husband and father who could be contacted mainly through telephone.

Commendation also needs to go to my classmates, Mula, Shirima and Maxwell for demonstrating the virtue of selflessness.

Like an eagle teaching its eaglet to fly, the Director of Energy Development Research Centre, Professor Ogunlade R. Davidson, had the unenviable responsibility of providing guidance while avoiding the danger of spoon-feeding me in carrying out the research.

The rest of the staff at Energy Development Research Centre for timely chipping in when need arose and having the wisdom to know when silence was golden.

Serendipity, otherwise known as God’s Providence, has been the hallmark of this work which can only be attributed to God’s sovereignty. To Him be glory both now and forevermore.

ABSTRACT

Low access to electricity is a problem in Africa. Apart from South Africa and Mauritius access to electricity generally falls below 30% of the population. The situation is even worse in the rural areas which housed about 70%or more of the population and whose access to modern energy services in these areas is between 5%-10%. Hence, this work aims at providing means of increasing access to electricity for the larger portion of the continent.

This work looked at the potential of using bagasse, a waste from sugar production, to produce electricity beyond the sugar factory to the national grid. It shows that bagasse generated electricity can contribute to increasing this access in Africa as a whole by as much as 9.4 TWh, using Condensing Extraction Steam Turbines. However, this increase varies among countries with the highest being Swaziland, 67%, and the lowest South Africa, 1.5%, due to the current capacity. The actualization of this technical potential, however, can only come about with proper application of relevant policies and measures that need to be in place for Africa in general and South Africa in particular as more detailed work was done on the latter.

Due to limitation in scope, this work did not cover the social, financial and agronomic aspects and neither was optimization of sugar considered in evaluating electricity from bagasse.

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ABBREVIATIONS AND ACRONYMS

CO_2	Carbon dioxide
GHGs	Greenhouse gases
Gasohol	A mixture of gasoline and alcohol used as a motor vehicle fuel. For fractions of up to 20% alcohol (ethanol) in gasoline there is no need for vehicle modification but higher fractions need modification of carburettor and other components.
IPPs	Independent Power Producers
PPA	Power Purchase Agreement
KWh/tc	Kilowatt hour per tonne cane
CEST	Condensing extraction steam turbine
NO_x	Nitrogen oxides
SO_2	Sulphur dioxide
CH_4	Methane
CHP	Combined Heat and Power
PM	Particulate Material
SADC	Southern African Development Community
TWh	Terawatt hour
BIG/CC	Biomass Integrated Gasifier Combined Cycle
BIG/STIG	Biomass Integrated Gasifier Steam Injected Gas Turbine

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CHAPTER 1

INTRODUCTION

1.1 Background Information

Modern biomass is defined as biomass used in new ways for transforming into solid, gaseous and/or liquid fuels which may be used for generating electricity (WEC,1992). While many biomass materials can be used, this project will be restricted to only the use of bagasse, the fibrous residue of sugarcane crushing during the production of sugar. Further, the study will be limited to Africa in scope and will concentrate on South Africa for a more detailed study. It should be noted that electricity is being produced in most sugar plants in Africa and is used only for in-house consumption but this project concerns the production of electricity beyond the sugar plant. However, when used for in-house purposes, electricity is produced to 'get rid' of the bagasse, and therefore improved efficiency has not been a priority, and as a result, electricity produced using the conventional backpressure turbines has very low efficiency. The term backpressure is used to describe turbines whose steam exit pressure is above atmospheric (Coates, 2002).

The average world production of sugar is about 128 million tonnes per year (Illovo Sugar Limited, 2002). Of this 8.3 million tonnes or 6.5%, is produced in Africa, with SADC countries contributing an average of about 3.8 million tonnes or 3% of the world total (Deepchand, 2000; Illovo Sugar Limited, 2002). South Africa alone produces about 2.8 million tonnes of sugar (Illovo Sugar Limited, 2002). Power generation from cane sugar using the Condensing Extraction Steam Turbine (CEST) is estimated at about 100-110 kWh per tonne (Deepchand, 2000). The total estimated contribution to electricity from bagasse in Africa varies depending on the source. One estimate gives it as high as 30,000 GWh (BUN,1989), while others estimate it at 8,300 GWh (Deepchand, 2000). The discrepancy seems to be that the estimate of the BUN is the bagasse potential without taking into consideration any transformation technology while Deepchand's estimate assumes transformation using Condensing Extraction Steam Turbines at 100 kWh per tonne cane. The estimate provided by BUN is in agreement with that provided by Deepchand when a Rankine Cycle of efficiency of about 30% is used and realising that exportable power refers to excess of factory demands. Then the BUN estimate comes to be less than 9,000 GWh which is very near that given by Deepchand. Using Deepchand's transformation rate of 100 kWh and CEST technology the SADC and South Africa figures given by Deepchand and Illovo Sugar Limited result in a potential of 3,800 GWh and 2,800 GWh respectively, which clearly shows the dominance of South Africa in the SADC region. These estimates also show that bagasse can contribute significantly to generation of electricity in Africa with improved analysis, and will contribute significantly to diversification of power production, as well as environmental amelioration and increased energy security.

A conceptual framework of utilising bagasse for power production is given below to provide an improved understanding of the electricity produced.

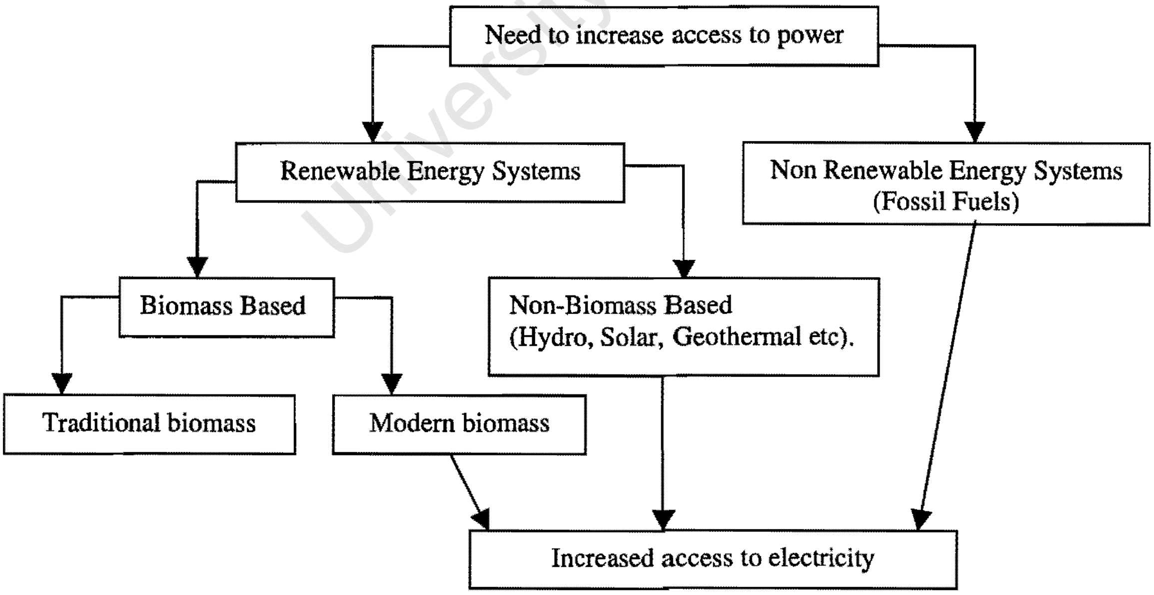

Figure 1.1 Schematic illustration of power production from fossil and renewable energy resources.

Figure 1.1 shows that access to electricity can be increased by using either non-renewable energy systems or renewable resources. Non renewable energy systems are those whose rate of exploitation is greater than the rate of replenishment while renewable energy resources are those whose rate of utilisation is lower than their rate of production.

In Africa, generally non-renewable energy systems have not penetrated deeply into rural areas where the majority of the people live because of many constraints including cost and supporting infrastructure. Renewable energy systems, mainly power generation from such systems, have been used on a small scale for meeting in-house electricity requirements. Traditional biomass defines a category that includes mainly small-scale uses, which are frequently, but not always beyond the market place. Traditional biomass includes; fuelwood and charcoal for domestic use, straw including rice husks, other vegetal residues, animal wastes etc (WEC,1992). Traditional biomass however, has never been used for electricity generation. Biomass in wood and pulp industries has been used increasingly worldwide especially in Europe where its contribution in Sweden and Finland was up to 16% and 18% of total energy used respectively (Hall and House, 1993).

Although some African countries have depended on biomass energy providing up to over 90% of their primary energy demand, it was not for electricity generation but for cooking using firewood and charcoal in an inefficient manner. This issue had led to localised deforestation with undesirable environmental repercussions in some places in the continent (*ibid*).

Modern biomass is understood to include all large-scale uses which seek to substitute conventional sources of energy. Modern biomass includes; wood residues (industrial), bagasse (industrial), urban wastes, biofuels (including biogas and energy crops) (WEC,1992). Bagasse has been available for a long time but its use as a resource for electricity generation is relatively new and even more recent is its use in higher efficiency technologies such as Condensing Extraction Steam Turbines (CEST). However, the advanced use of bagasse in Africa is limited to a few countries such as Mauritius which is one of the few countries with experience in this technology. Generation of power by means of bagasse using advanced technologies like CEST will utilise the sugar plant which has high productivity and is a noted scavenger (it absorbs carbon dioxide in the presence of sunshine to produce carbohydrate) of atmospheric CO_2 (Hall and House, 1993; Johnson, 2002; Deepchand, 2000; Twidell and Weir, 1986). As a consequence this would avoid the high cost of extending the grid to non-electrified places such as rural areas where the majority live.

1.2 Need for Power from Bagasse

Environmental issues are becoming increasingly important in the world. The continued high dependence of fossil fuels worldwide for power generation contributes to disruption of weather patterns globally and leads to a long-term negative impact on climate resulting in global warming (IPCC, 2000) .

Also adverse emissions from combustion of fossil fuels can cause serious local environmental problems. Therefore, introducing energy sources with less environmental problems can be useful.

The introduction of different sources will assist energy diversification and thus will be welcomed especially if it encourages power production using renewable energy resources. This is why production of power using biomass (bagasse in particular) a renewable resource, from sugar industries is the interest of this work.

Access to electricity in Africa in general and SADC in particular is low. Ten years ago in 1991, the World Energy Council estimated that only 2% of Malawians and 33% of South Africans had access then. In 2002, South Africa now has increased access to 70% (NER, 2000/01) while Malawi has increased to 4% of the population(SAD-ELEC, 2001). A UNEP study says that between 30% and 80% of the African population live in rural areas and only 3%-5% have access to modern energy services (UNEP, 2001). The need to increase access to electricity especially in rural areas of Africa, where sugar cane is primarily grown, would inadvertently promote rural development and generate employment where it has mostly been lacking. Generation of electricity using bagasse would make a positive contribution to the issues raised in the foregoing section.

Current global trends favour unbundling of large electricity utilities and promotion of Independent Power Producers (IPPs) for efficient service delivery. This would make the efficient production of electricity from bagasse attractive (Minett, 1999; Evans, 2000; Overend, 2000).

Table 1.1 below further exemplifies the need for electricity generation from bagasse. It gives estimated access figures for electricity in some countries in Africa.

Table1.1 Access to electricity in some Eastern and Southern African countries.

Country	**Electricity Utility**	**National Population (million)**	**Estimated Access to electricity (%)**
Botswana	BPC	1.6	29
Kenya	KPLC	30	9
Malawi	ESCOM	11	4
Mauritius	CEB	1.2	100
Mozambique	EDM	16	8
Namibia	Nam Power	1.7	27
South Africa	ESKOM	43	70*
Swaziland	SEB	1.0	21
Tanzania	Tanesco	32	9
Uganda	UEB	19	6
Zambia	ZESCO	10	12
Zimbabwe	ZESA	13	24

Source: Adapted from SAD-ELEC April 2001

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* This access figure for South Africa was given as 70.44% in the National Electricity Regulator (NER) 2000/2001 Annual Report on page 14.

Table 1.1 shows that access to electricity in countries in East and Southern Africa varies from as low as 4% for Malawi to a high of 100% for Mauritius. Other than Mauritius and South Africa whose access stands at 100% and 70% respectively, the rest of the region has low access with the highest, Botswana being 29%.

In view of the low access, Africa should explore the use of bagasse for power generation. This application can be useful also for rural areas as lack of development in these areas has been mainly responsible for the rural to urban migration as people search for jobs and better livelihoods. Concentration of large populations in urban areas creates problems for the government in provision of services.

These factors above make generation of electricity from bagasse important as it would be able to increase access to high quality energy.

1.3 Objectives

General objective; To study the feasibility of wide spread use of power generated from bagasse with the aim of diversifying electricity generation base and ensuring security of supply.

Specific objectives; i. To assess the potential contribution of bagasse to power generation generally in Africa with a focus on South Africa.

ii. To provide policies and measures regarding use of bagasse in Africa based on the analysis of (i).

This work will not include the agronomic impact of removing trash from cane fields, the socio-economic aspects, optimisation of sugar/bagasse/electricity and/or chemical or fibre products production, due to the limited scope of the work.

1.4 Organisation of the Report

The dissertation is organised in 8 different chapters describing the various activities undertaken in this work. The different chapters are arranged as follows;

Chapter 1 gives an introduction to the work by examining the contribution of bagasse to generation of electricity and shows its contribution to Africa in particular. This provides the rationale for work undertaken in the study.

Chapter 2 looks at the literature survey of past work that has been carried out in the production of electricity from bagasse. This provides the opportunity to review the different activities in various countries.

Chapter 3 briefly examines the availability of bagasse in Africa based primarily on sugar production in the continent. This is based largely on published information regarding production.

Chapter 4 reviews the different technologies for electricity generation from bagasse including those that are commercial and others being developed.

Chapter 5 uses production data of sugar in Africa to estimate the potential electricity production from bagasse in Africa using different technologies reviewed in chapter 4.

Chapter 6 describes a survey that was carried out at sugar production sites in South Africa as this provides the opportunity for testing the potential of the different assumptions made in chapter 5 when estimating power production from sugar.

Chapter 7 discusses the different policies and measures that will facilitate the use of electricity production from bagasse in the national system as a supply option .

Chapter 8 gives the conclusion of the study including recommendations for further work.

CHAPTER 2

LITERATURE SURVEY

A large number of countries all over the world grow sugar including some 80 developing countries and process sugarcane, generating a substantial amount of fibrous biomass (bagasse) that is used as a fuel for combined heat and power (CHP) generation (Kartha and Larson, 2000). Hitherto, most of the countries have been using conventional backpressure steam turbines and low-pressure boilers that have limitations on the amount of power that is being produced. This technology system was used purposely to produce energy for factory requirements and there was no interest in producing excess electricity. Therefore, to better understand the context of bagasse production for the use of producing excess electricity, a brief overview of the world sugar production will be surveyed in this chapter.

There are more than 100 countries that produce sugar (from sugarcane and beet) in the world (Illovo Sugar Limited, 2002). Approximately 72% of the product is from sugar cane grown chiefly in the tropical and sub-tropical zones covering latitudes 31°S and 37°N (Cornland *et al,* 2001). The remaining fraction is produced from beet sugar grown in the temperate zones. About three-quarters of the world's sugar is consumed in the country where it is produced while the rest is traded on the world markets. Sugar production for the 2000/01 season was estimated at 128 million tonnes (Illovo Sugar Limited, 2002). Deepchand estimated the world's sugar production for 1998/99 as 88.5 million tonnes which seems low when compared to the estimate of Illovo above (Deepchand, 2000). The estimate by Illovo Sugar is in agreement with another source which states that the production of sugarcane in the world is over 1200 million tonnes (Project brief, Cuba, 2000).

There is a factor of ten between the mass of sugarcane and the mass of sugar produced from the cane (Deepchand, 2000). World sugar production has led to about 250 million tonnes of bagasse which is 24% of the sugarcane produced (Deepchand, 2000; Project brief of Cuba, 2000). The amount of bagasse produced is equivalent in energy content to 78 million tonnes of coal or 48 million tonnes of fuel oil (Project brief of Cuba 2000). In terms of environment concerns, this amount of bagasse if used to produce energy can replace fuel oil that is being used for such purpose and that can lead to reduction of adverse carbon emissions by almost 40 million tonnes of carbon annually (*ibid*).

Five of the world's largest exporters of sugar (Brazil, the European Union, Australia, Cuba and Thailand) supply 70% of the world's free market exports (Illovo Sugar Limited 2002). Evident also is the fact that the price of sugar is one of the most volatile of commodities on the world market (*ibid*). Therefore, for continued business operation and profitability product diversification in the sugar industry is advisable. The use of electricity production using bagasse provides that opportunity.

Sugar has been grown and milled in the Southern African region for a long time because of the favourable growing conditions coupled with high yielding cane varieties and relatively low milling costs. Average annual sugar production in the Southern African Development Community (SADC) is 3.8 million tonnes (Illovo sugar Limited 2002). Mainly eight countries namely; Malawi, Mauritius, Mozambique, Swaziland, South Africa, Tanzania, Zambia, and Zimbabwe produce sugar in the sub-region.

Bagasse, when used as a renewable resource, has many uses such as raw material for heat generation and raising steam, making of particle board, raw material for gasification for electricity generation etc. The use of bagasse for producing electricity with little environmental damage among other advantages makes it an attractive resource. An overview of the status of bagasse as feedstock for power production in some countries in the world follows.

2.1 International Experience

Cuba.

Cuba is currently the world's sixth largest producer of sugarcane and its industries and energy sector are built around imported fossil fuel i.e. over 90% of conventional primary energy consumed is oil of which more than 80% is imported (Larson *et al,* 2001). This has not only contributed significantly to its energy related CO_2 emissions but has resulted in a lot of hardship for the country especially that since 1989 it has been under economic, financial and trade embargo from the USA. Cuba already has some experience in power generation using bagasse in sugar industry using low-pressure boilers and turbines for on-site power requirements in sugar mills where the installed capacity was 684 MW in 1998. The combination of factors mentioned before coupled with Cuba producing 70 million tonnes of sugarcane annually provides good prospects of using bagasse in high pressure condensing extraction steam turbine technology because it would also have a positive impact on the local and global environment. For successful participation of Independent Power Producers attention would need to be given to the following;

- Limited experience of harvesting and utilising sugarcane trash as a fuel
- Expanded use of bagasse on electricity services
- Lack of experience operating high pressure sugarcane co-generation facilities
- High capital costs associated with the adoption of new energy investments.

The sugarcane-crushing season in Cuba is 150 days and about 70% of the sugarcane crop is machine harvested without prior burning. This is the only country in the world where there is so much harvesting of cane by machine . Assuming that the net CO_2 emission reduction corresponds with the avoided emissions of not burning oil in the generation of electricity the saved CO_2 would be 0.22kgC/kWh generated (Larson *et al,* 2001).

Brazil.

Brazil is by far the largest country in South America and the world's largest producer of ethanol which in 1998 was half the world's production at about 16 billion litres. The ethanol programme was initiated in 1975 in the wake of the first oil price shock in 1973. Ethanol production grew at an average of about 25% per year from 1976 to 1989. By the mid 1980s ethanol consumption exceeded gasoline consumption on a volume basis, and more than 90% of new cars sold in Brazil then used ethanol. Although high volumes of ethanol are still produced today, new car sales have dramatically reduced from the mid 1980s levels. Lower oil prices in the mid 1980s and the trend toward deregulation of the sugar and ethanol industries have affected the Brazilian programme, but difficulties in maintaining sufficient supply eroded public confidence in the programme. However, this programme is undergoing a critical re-evaluation at present. Like the ethanol programme, biomass gasification was given impetus by the oil crisis of the early 1970s. A competitive market developed both for industrial and power gasifiers. With no governmental subsidies or incentives, more than 30 manufacturers emerged offering equipment of different conceptions and covering a range of sizes. Industrial wood gasifiers of up to 3 MW thermal came into operation and over 100 plants have been installed throughout the country (WEC,1992). One of the most advanced demonstration projects in combined heat and power generation at Bahia would come with the construction of a 32 MW BIG/CC power plant. The same source indicated that the plant was going to use plantation-grown eucalyptus as fuel in 2000. The facility would also test the use of sugarcane bagasse as a fuel. This would be a demonstration project supported by a grant from the Global Environment Facility. The vast experience of Brazil in the use of blended gasoline shows the wisdom for other countries wishing to use gasohol as a domestic fuel to start out with anhydrous ethanol which offers more versatility (Kartha and Larson, 2000; Cornland *et al,* 2001).

In Southeast Brazil the sugarcane crushing season lasts a length of about 214 days with about 20% of the sugarcane being machine harvested (Larson *et al,* 2001).

Lessons from the Brazilian experience show the need for maintaining sufficient supply of bagasse for project requirements and the impact that low cost alternatives can have on a project.

Thailand.

Thailand had an installed capacity of biomass cogeneration plants of about 130 MW in 1999. The electricity from biomass cogeneration plants was for onsite power and steam requirements for auto-consumption at the mills. This country is heavily dependent on fossil fuels as signified by the contribution of coal, gas and oil, which is 75% of the total energy consumption. In terms of electricity generation, hydro provides only 2% of the nation's total energy and renewable energy had a negligible contribution. The average conversion efficiency in electricity generation was given by the UNEP Project Brief for Thailand as 3.5%. Like Cuba, Thailand's consideration of co-generation using biomass identified the following barriers;

- Lack of information and services provided to the potential biomass power and co-generation project developers
- Little financial incentive policies for biomass power projects
- Uncertainties and difficulties of biomass fuel supply
- Lack of successful models to demonstrate large scale and efficient biomass co-generation/power systems and project development models
- Lack of regulatory mechanisms to ensure a level playing field to compete with established fossil fuels
- Lack of appropriate financing mechanisms to support biomass co-generation/power projects (Project Brief, Thailand 1999).

The Thai experience pinpoints the many barriers that should be overcome before successful implementation of bagasse technologies.

Barriers highlighted above are true for most African countries with the exception of Mauritius which has exported power to the grid since 1957 and has been using the state-of-the-art condensing extraction steam turbine (CEST) since 1980 (Deepchand, 2000).

Mauritius.

Since the introduction of sugar in Mauritius in the seventeenth century, it has been the main stay of the economy (GEF,1992).

Mauritius uses CEST in producing a significant share of the island's electricity (Beehary, 1996). Use of bagasse for electricity generation for sale to the national grid started in 1957 when around 0.3 GWh was supplied by one sugar factory, St. Antoine. After the oil crisis in the 1970s neither the electricity pricing nor the supply conditions were attractive enough to encourage large-scale investment in electricity production by the sugar industries. An encouraging sign however, was the active collaboration between the private and public sectors. 1985 saw the commissioning of a full-scale plant designed to produce 14,000 tonnes of bagasse pellets per year. The plant was finally found to be both technically and financially inappropriate and was abandoned in 1987 (Deepchand, 2000).

For a successful implementation of bagasse for electricity generation and selling it to the national utility, there is need for proper design of Power Purchase Agreements (PPAs) including price review in the electricity sector. Other considerations by Mauritius for developing bagasse powered electricity are;

- Reduce reliance on petroleum products
- Diversify the energy base
- Save foreign exchange by reducing fossil fuel imports
- Reduce greenhouse gases (GHGs) by displacing fossil fuels and thus reducing carbon dioxide emissions.

The introduction of co-generation in Mauritius necessitated careful consideration for the need for use of another fuel during the lull season when bagasse production is low, they decided on choosing coal and bagasse to be used during sugar harvest season. The choice of coal was largely based on the stability of coal supply.

Another point that merits attention is the distance of the bagasse resource to the milling plant. For bagasse power plants to be viable, it is best to have all the bagasse needed at one location as near to the plant as possible as this reduces transport costs and so improves the economics of power production. Usually the lifetime of such plants is 25 years (Deepchand, 2000).

It should be noted that the higher is the steam delivery pressure of the boiler, the more sophisticated the boiler becomes and so is the demand for strengthening managerial and technical skills of the power plant personnel (GEF,1992).

An interesting aspect of the Mauritian case is that revenue from the bagasse generated electricity was shared amongst all the stakeholders including cane growers as there was shared responsibility by all these stakeholders for the power generated.

The sugarcane-crushing season in Mauritius has a duration of 130 days (Deepchand, 2000; Baguant *et al,* 1992), but the production of electricity may be categorised as follows;

- Intermittent, i.e. only when the sugar factory is operational excluding Sundays. Or
- Continuous, where operation is during crop season (June to December) including Sundays when the sugar factory is not normally operational or
- Firm, when operation is all year round.

The yield of exportable electricity measured in terms of kWh per tonne-cane depends on a number of factors, some of which are;

- Fibre percentage of the cane, which in turn affects bagasse percentage
- Variety of the cane and climatic conditions
- Overall steam balance of the factory, measured in terms of the steam to bagasse ratio (r_{sb}) and specific steam consumption (ssc)
- Powerhouse efficiencies (furnace, boiler and turbo alternators)
- The technology used for steam and electricity production, as well as the type of equipment used for manufacturing raw sugar
- Incentives for the production of exportable electricity

Where, r_{sb} is measured in terms of tonne of steam produced per tonne of bagasse. This ratio varies from 1.8 to 3.1 and is directly related to the type of boiler and furnace indicating their overall efficiency. In Mauritius r_{sb} is 2.2 and could be improved to 3.0 and

ssc is a measure of process steam consumption represented in terms of tonnes of steam required per tonne of cane processed. It is a measure of the efficiency of process steam use and can be anywhere between 0.3 and 0.6. In Mauritius, the average ssc stands at 0.55 but it has been demonstrated that an ssc of 0.3 is achievable.

Bagasse needs to be dried to $\leq 30\%$ moisture content for combustion to occur at 1500°C which is required for running high-pressure boilers.
A boiler feed-water treatment plant would be required because the water must be free from any chemicals which would damage the water tubes and the boiler.

Air to fuel ratio has to be monitored very closely in order to enable almost complete combustion and flue gas temperature must be brought down to a minimum of 125°C. These measures among others would help bring the ratio of steam to bagasse to 3.0. Improvement and lowering of the ssc to 0.35 would require new equipment such as deep-vacuum crystallisers (Baguant *et al,* 1992).

Following were the salient points identified in the Mauritian experience; the need for proper design of Power Purchase Agreements (PPAs), environmental considerations, diversification of energy base, saving of foreign exchange, manpower retraining to handle high pressure boilers, proximity of resource to the factory and the need for adherence to technical standards for improved performance.

Kenya.

Kenya produces about 4.5 million tonnes of sugarcane annually. Kenya is one of the three countries in the Southern African region that has experience in the use of gasohol (a mixture of alcohol and petrol or gasoline) for transportation purposes (Cornland *et al,* 2001; Deepchand, 2000).

Malawi.

Malawi is currently the only country in the region that still blends ethanol on a large scale and has current experience in the large-scale use of gasohol (Cornland *et al,* 2001).

Tanzania.

Tanzania's sugar industry operates at 62% capacity and crushing about 2.3 million tonnes of sugarcane annually. It produces about 776,000 tonnes of bagasse, but suffers from under-utilisation which is due to; unfavourable weather for sugar production and inefficiencies of the boilers and turbo-generators. Replacing those equipments with those that can withstand higher pressures and temperatures such as 42bar and 425°C from 12bar and 225°C will make significant difference.

The sugar industry was reported to have about 13 MW cogeneration capacity installed at its respective sugar mills in Kagera, Moshi, Mtibwa, and Kilombero in Morogoro region. One analysis showed that a cogeneration plant using bagasse and trash could produce surplus electricity at US $ 0.06/kWh which is very economic (Gabra and Kjellstrom 1995; Ngeleja, 1991).

The case of Tanzania provides lessons about the impact of unfavourable weather and the presence of equipment inefficiencies in sugar industries.

South Africa.

South Africa produces a significant amount of ethanol synthetically from coal that is sold primarily for industrial applications. Bagasse, a waste of sugar refineries is used to produce steam and electricity for autonomous use. Electricity in excess of in-house use is sold under license to local distributors. Four licensed bagasse generators produced 0.2% of the electricity used in South Africa from five privately owned bagasse power stations in the year 2000. The stations had a capacity of 105 MW, and produced 307,498 MWh (Electricity Regulatory Journal, 2002). The rest of the power is provided by ESKOM, the giant national utility of South Africa which generates electricity primarily from coal.

Zambia.

Zambia cogenerates electricity of about 12 MW for in-house use at Nakambala Sugar Estate. Nakambala has the capacity to produce 200,000 tonnes of sugar per year but the average annual consumption and export stands at an average of 90,000 and 80,000 tonnes respectively. There is no clearly defined legal provision concerning production of power from bagasse other than that 'anyone producing power of more than 100 kW must be licensed and conditions apply' (ERB,2002) or that other renewable energy resources have the same incentives as Independent Power Producers (IPPs) in the hydro power sector according to the Ministry of Energy and Water Development (MEWD) (Cornland *et al,* 2001). Alternative uses of molasses at Nakambala for producing gasohol, potable and industrial alcohol, cattle fodder and yeast have been explored (Kaoma, 1991) but were abandoned due to uncertainties and difficulties including;

- insufficient availability of molasses
- reluctance by farmers to utilise concentrated molasses stillage that was to replace molasses for cattle fodder
- negative impacts on the Indeni oil Refinery operations due to a declining gasoline market
- a low anticipated rate of return on investment

Ethanol (as Ethyl Tertiary Butyl Ether (ETBE)) (Goswami *et al,* 2000) could be used as an octane booster instead of lead as Zambia uses leaded petrol which is a health hazard.. Another plant derived octane enhancer (Methyl Tertiary Butyl Ether (MTBE)) (*ibid*), a suspected carcinogen, which was used in industrialised countries at one time leaked from underground fuel tanks and contaminated drinking water.

Ethanol can be produced from an annexed or a co-designed distillery. Optimisation of a distillery is more difficult in an annexed than a co-designed distillery however; both types would have the advantage of flexibility of producing sugar, ethanol and/or electricity. This would result in reduced financial risk due to fluctuation of sugar prices (Cornland *et al,* 2001).

Generation of electricity from bagasse depends on the type of regulations for encouraging participation of Independent Power Producers (IPPs) and the terms of sale for the electricity generated (Cornland *et al,* 2001).

The Zambian Sugar factory (Nakambala) has since March 2001 been bought and become part of the Illovo group of Sugar Companies.

Zambia highlights the absence of specificity with regard to bagasse utilisation in the defined regulations, the need to consider social political issues and the many alternative uses of bagasse and other products from the sugar industry.

Zimbabwe.

Zimbabwe uses coal to produce steam and electricity to meet the distillery's energy needs during the non cane-harvesting season. Previously, there was a gasohol programme using ethanol produced domestically from sugarcane, but support for this programme has declined. Ethanol is still produced but it is exported and sold on the potable alcohol market (Cornland *et al,* 2001). Zimbabwe used to have a pilot electricity gasifier at Nijo Estate north of the city of Harare which was used for training people in the Eastern and Southern African region on gasifiers. It is most probable that experiments on this were discontinued sometime in the middle of the 1990s.

Experience in Zimbabwe shows the ravages that politics can have on a fledging sugar industry.

CHAPTER 3

SUGAR AND BAGASSE PRODUCTION

3.1 Resource availability

Sugarcane is a giant grass of the genus *Saccharum*, which is thought to have originated in the Burma-China-India region of Southern Asia. The cane then spread to other areas, with *S. Officinarum* developing in the area of New Guinea. This species was developed by Aboriginals to yield a sweet, soft and juicy cane propagated for chewing.

The earliest record dealing with sugarcane in the Hindu literature is about 3000 years old and crude sugar was developed by 400 B.C. It was introduced in Africa, in Egypt by 710 A.D., where clarification, crystallisation and refining were developed (Illovo, 2002).

Sugarcane is produced through the process of photosynthesis which can be represented chemically as;

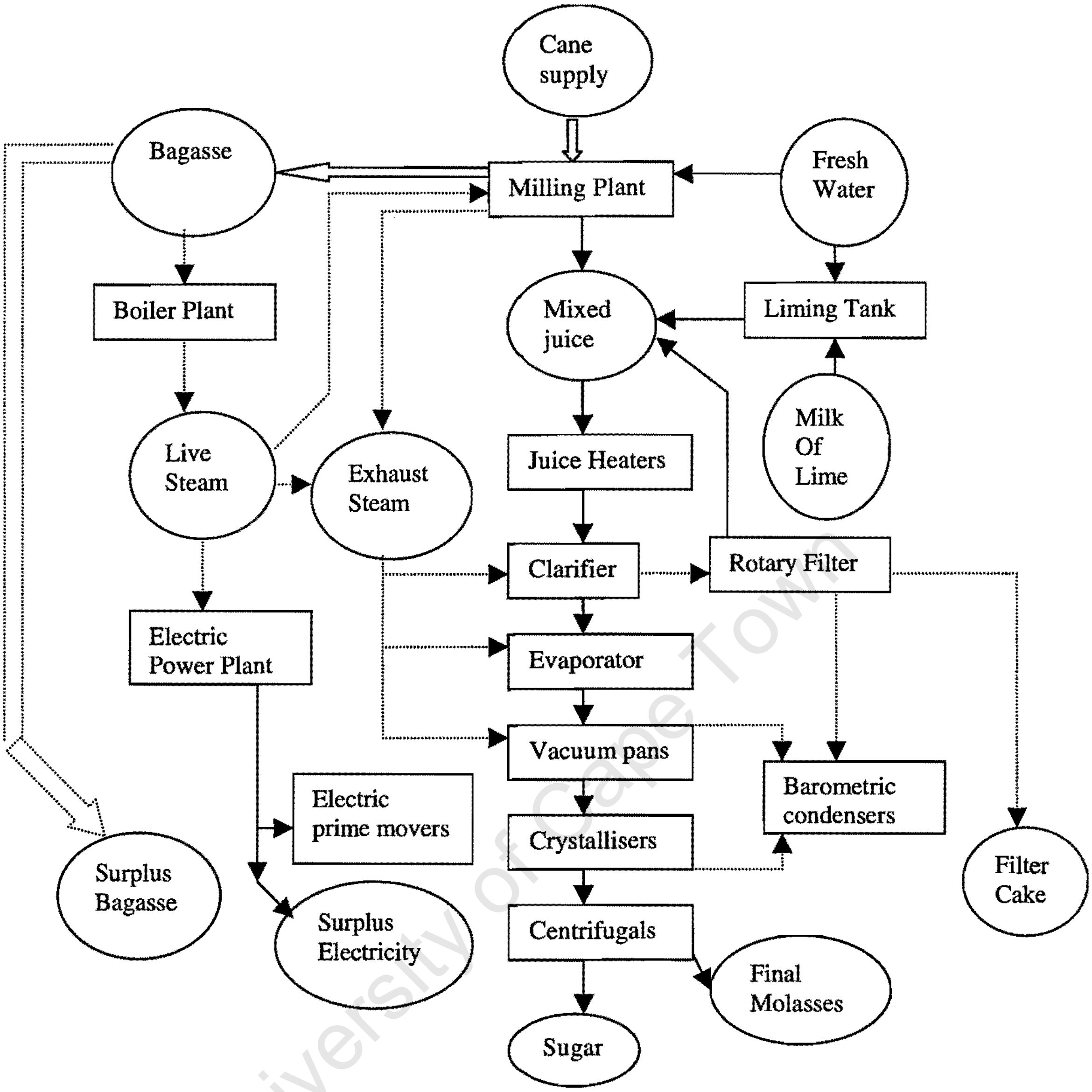
$$12CO_2 + 11H_2O + \text{sunlight} \longrightarrow C_{12}H_{22}O_{11} + 12O_2 + \text{Energy}$$

Energy is stored in the oxygen of the photosynthate, a carbohydrate.
Solar radiation is captured by the sugar plant through the absorption of at least 8 photons and an energy gain of 4.8 electron volts (eV) per atom of carbon amounting to about 470 kJ/mole of carbon atoms. Unlike combustion which requires temperatures around 400°C, catalytic enzyme reactions proceed at around 20°C. Uptake of carbon dioxide by a plant depends on many factors, especially the temperature, CO_2 concentration (directly proportional up to a limit beyond which it remains constant) and the intensity and wavelength distributions of light. Absorption of light is most marked in the blue and the red regions of the light spectrum resulting in the sensation of green as the colour of leaves (Twidell and Weir 1986). There are two pathways of solar capture, the C_3 and the C_4 pathways

(three and four-carbon compounds). The C_3 pathway has a maximum crop growth rate of 34-39 $gm/m^2/day$ while that of the superior C_4 pathway is 50-54 $gm/m^2/day$. The foregoing is another way of saying that in high light levels (about 0.5 kW m^2) and high temperatures (around 40°C) the carbon fixation and hence biomass production of C_4 plants may be twice that of C_3 plants. The sugarcane plant, like maize and sorghum, uses the C_4 pathway to produce its carbohydrates i.e. starch, sugar, fats, lignocellulose etc (Monteith, 1978; Twidell and Weir 1986).

Sugarcane is a perennial grass which grows in the tropics and subtropics. It can grow to a height of 3m to 5m depending upon type of variety (Sugar knowledge International, 2002). Roughly the plant can be divided into the cane-top, the stalk, the rhizome and roots, and the leaves which may be green or dry. The stalk is the main part that is used in the production of sugar (sucrose) while the leaves and the cane-top make up what is known as the 'trash'. Removal of the trash leads to loss of recycled nutrients and the weed suppressing quality of the trash blanket that remains on the field after conventional machine harvesting of the cane (Larson *et al,* 2001).

The production process begins with harvesting of the cane sugar where the extraneous materials like dry leaves, waxy coatings etc which facilitates harvesting of the stalks are burnt, though in many countries such burning is increasingly being disallowed for environmental concerns such as smoke and release of carbon particulates. The cane is then cut either mechanically or by human labour. However, cutting of cane by hand is dirty and laborious, but is preferred because it employs many people and reduces unemployment. The cane is then gathered and loaded into tractors or other available means of transport which conveys it to the factory. This is depicted as cane supply in Figure 3.1 shown below;



Source: Adapted from Bagasse Energy Co-generation (Deepchand, 2000).

Figure 3.1 Production of sugar and by-products

At the factory the stalk is first washed and then cut by means of rotating knives and shredded using hammer mills (shredders) before milling. The liquid portion (juice) produced contains impurities such as dirt from the soil from fields, small fibres and the green extracts from the plant that are all mixed with the sugar. During milling, water is added in order to extract a greater proportion of the sugar through diffusion. The dirty juice is heated to optimise clarification using slaked lime, $Ca(OH)_2$,which settles out the dirt. Clarification is accomplished by means of a gravitational settling tank. Mud and other solids from the Clarifier are filtered on rotary vacuum filters (Rotary Filters in Figure 3.1) to extract some of the remaining sugar giving the final product of mud and filter cake. The extracted clear juice has about 15% sugar content or has a concentration of 14 to 16° Brix (% solids by weight) (Larson *et al,* 2001). Sugar content is raised through evaporation in the Evaporator to about 60-70% or 65 to 70° Brix (*ibid*). Since saturated sugar should have close to 80% sugar content before crystallisation can occur the juice now called 'syrup' is put into vacuum pans for further concentration to around 91-93° Brix in either a continuous or a batch process. The concentrated liquor at a temperature of 65-75°C is discharged into Crystallisers where sugar dust is thrown in to initiate crystallisation through provision of nucleation centres. The mixture of syrup and crystals is called 'massecuite'. Non-sugars in the liquor inhibit crystallisation but the liquor is cooled down to continue crystal growth before leading the mixture to the Centrifuges where the solid crystals are washed and separated from the liquid portion. The sugar is discharged from the centrifuges at a temperature of 65-85°C and moisture content of 0.5-1.5% before being directed to the driers. The crystals are dried in hot air and then cooled in ambient air before storage and dispatch. It is normal to boil the massecuite three times in a raw sugar factory giving molasses classified as A, B (also called magma) and C or 1, 2 or 3 massecuites or strikes. Molasses classified as A and B are recycled while C molasses also called final molasses may be used as cattle feed or as the input raw material for alcohol production (See Figure 3.1) (Sugar Knowledge International, 2002; Larson *et al,* 2001).

A lot more steam is used in the processes mentioned above in sugarcane factories than in processing beet sugar because in the latter process energy is provided using more expensive methods which utilise fossil fuels. Therefore, adoption of the more energy efficient methods of beet-sugar industries would lead to a reduction in the steam requirements of sugarcane processing factories. Some studies to this effect have shown that there are possibilities of reducing steam consumption even to half what is used in these industries today. The steam thus saved could be used in the generation of electricity (Ogden *et al,* 1990/91).

The solid product of milling, bagasse, is used in raising steam, which is used in the processing of sugar (in evaporators, juice heaters, dryers etc) and driving some of the prime movers. Excess steam is used in the production of power in the backpressure turbine and generator systems. There is need for balance between the bagasse used and steam and electricity generated. Burning of little bagasse results in huge volumes of excess bagasse which lead to storage problems while using much bagasse may result in shortage of bagasse for steam and electricity requirements. The setting of the mills is also crucial to the stable working of the system as too dry bagasse leads to a lot of fly-off and bagasse which is too wet is difficult to burn in the boiler. Mostly the electricity generated is for in-house use. In some factories power in excess of autonomous requirements is intermittently exported to the main grid (surplus electricity in Figure 3.1). The bagasse that remains (surplus bagasse in Figure 3.1) is taken as waste and is sometimes incinerated or burned to avoid the problem of auto-combustion. Generally bagasse has poor keeping quality and is prone to fermentation and associated chemical reactions that may lead to fire out breaks, this explains why it is generally kept in the open or under cover (Sugar Knowledge International, 2002; Deepchand, 2000).

Possibilities also exist of producing genetically modified cane, which would result in cane with more fibre. The disadvantage of this type of cane is that it would have a lower sugar content per tonne cane than with conventional cane (Larson *et al*, 2001;Twidell and Weir, 1986).

Estimation of biomass energy potential requires information about its composition, heating value or calorific value, production yields and bulk density. Composition is defined in terms of biochemical analysis, proximate analysis and ultimate analysis.

Biochemical analysis gives information about the kinds and amounts of plant chemicals as proteins, oils, sugars, starches, and lignocellulose (fiber). The lignocellulosic component shows the fractional composition among cellulose, hemicellulose and lignin, which are useful in designing biological processes that convert plant chemicals into liquid fuels.

Proximate analysis gives products like moisture, volatile matter, fixed carbon and ash. Knowledge of volatile matter is important in designing burners and gasifiers for biomass. The relatively high volatile content of biomass (50-70% by mass) makes it very suitable for gasification. And also its relatively low ash content in comparison with coal, eases ash disposal problems.

Ultimate analysis yields the elemental composition of biomass such as carbon, hydrogen, oxygen, nitrogen, sulphur, chlorine along with moisture and ash. This type of information is important in performing mass balances on biomass conversion processes (Goswami *et al,* 2000; Twidell and Weir, 1986).

Moisture content is assessed on a wet, dry or dry and ash free basis. If *m* is the total mass of the biomass and m_0 is the mass when completely dried,

the dry basis moisture content $d_{mc} = \frac{(m-m_o)}{m_o}$

where *m* is the total mass of the biomass,

m_o is the mass when the biomass is completely dried and

the wet basis moisture content is $w_{mc} = \frac{(m-m_o)}{m}$

The calorific value measures the net energy released upon reacting biomass with oxygen under isothermal conditions and is useful in performing energy balances on biomass conversion processes.

Alkali metal content such as potassium and sodium which are particularly concentrated in fast-growing biomass are important as they may lead to ash fouling of boiler tubes (Goswami *et al,* 2000)

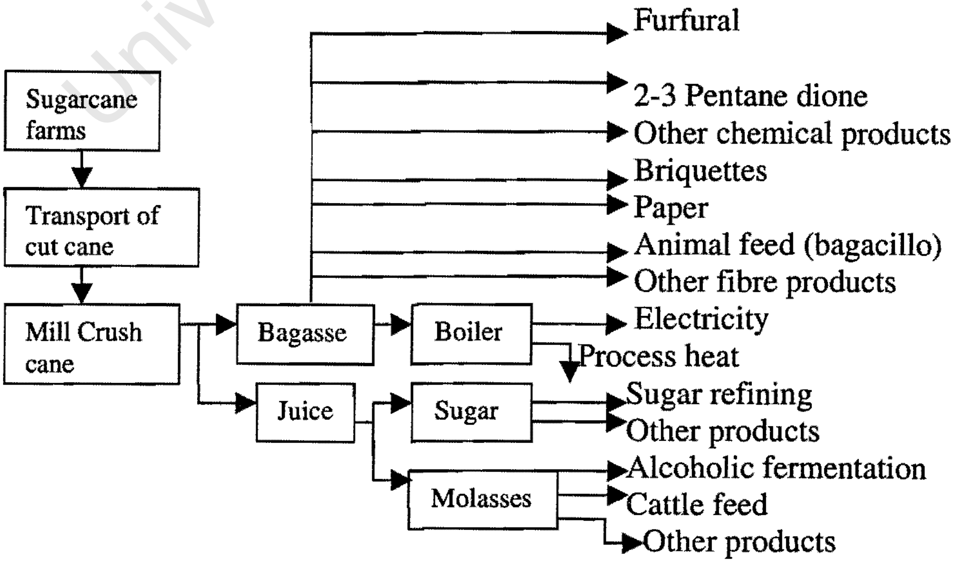
'Bone-dry' or oven-dry biomass has a calorific value of about 19,250 kJ/kg (Deepchand, 2000) but mill run bagasse has moisture content varying from about 45% to 52% (*ibid*) on a wet basis. Because of this high moisture content more excess air is used to increase circulation and hence rapid evaporation of moisture to enhance combustion. The high moisture content also results in high stack losses through sensible heat (Deepchand, 2000; Wilbuswas, 1988). Other losses are due to radiation, air heating, and incomplete combustion.

Land productivity of biomass in kilograms per hectare per annum and the distance between the field and factory are important in determining the economics of production of electricity from biomass. However, land productivity has many variables like, plant variety, soil type, climate, landscape, water drainage etc (Goswami *et al,* 2000).

Bulk density is important in the determination of transportation costs, size of fuel storage and handling equipment (Goswami *et al,* 2000), and so with a bulk density of about 130 kg/m^3 bagasse requires huge storage space and equipment for handling which makes it a costly resource to collect, transport and store (Deepchand, 2000; Twidell and Weir, 1986).

3.2 Present Uses of bagasse

Presently, bagasse is used for heat generation in raising steam and electricity generation in conventional backpressure turbines and is also used in the production of particleboard, manufacturing of paper, provision of animal feed, and making of briquettes as shown in Figure 3.2) below (Khalema *et al,* 1998).



Source: Adapted from Twidell and Weir, 1986.

Figure 3.2 Production sugar to end uses of bagasse.

Figure 3.2 shows a schematic of the bagasse and sugar production process. It shows both the present and some emerging uses of bagasse. A more detailed outline of alternative uses of bagasse is described in the next section.

3.3 Alternative uses of bagasse.

Bagasse can be used in the production of;

i. waxes (used for casting in foundries)
ii. flavourants (strawberry, rosenut, candy floss etc.)
iii. sweeteners (xylotol used in chewing gum)
iv. lacturose (laxative)
v. anti cholestrol drugs
vi. lipstick
vii. furanone (flavour compound)
viii. dihydropyran
ix. furan
x. furoic acid and esters
xi. high purity furfural (nematocide and solvent for lubricating oil extraction) and furfuryl alcohol
xii. dextran (a polyglucose molecule used as a lubricant, flocculant etc.)
xiii. cosmetics
xiv. emulsifiers
xv. insecticides
xvi. cake presevatives
xvii. methyl furfural
xviii. fusel oils (flavourants)etc.
xix. diacetal (natural butter flavour)
xx. 2-3 pentane dione

There are about 50 or more products that have been identified by Illovo Sugar Company and some are used in the pharmaceutical and food industries etc. and the economic returns of some of them are higher than that of sugar . With so many valuable products from bagasse, a stage might be reached when it will no longer be regarded as a by-product of sugar production. This also raises the need for process optimisation to find the most economic path, whether to go for electricity production, fibre products, chemical products etc. and in what combination for profit maximisation.

3.4 Electricity generation from bagasse

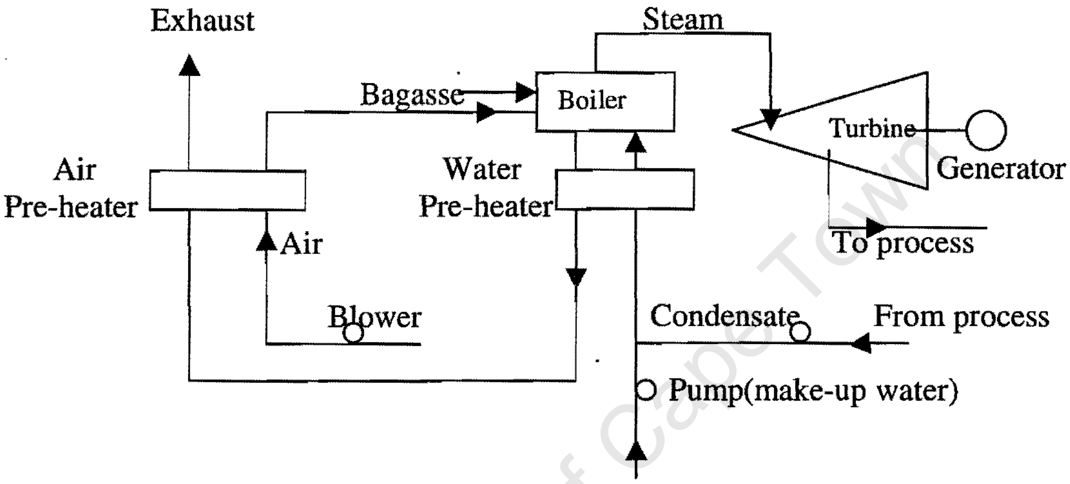
Electricity generation from bagasse has been practised for a long time by using commercial backpressure turbines to produce enough electricity for autonomous requirements and so high power generation efficiencies have not been a priority.

The use of centralised (grid) electricity generation however, has not been able to provide increased access to electricity for the majority of the people in most of Africa, apart from South Africa. The need to increase access coupled with the global trend pointing to reforms in the power sector which would be favourable to Independent Power Producers (IPPs) and the coming on stream of efficient technologies like CEST has provided the necessary impetus to consider more efficient forms of power generation.

CHAPTER 4

TECHNOLOGIES FOR ELECTRICITY PRODUCTION FROM BAGASSE

4.1 The Conventional Back-pressure Turbine System



Source: Adapted from Kartha and Larson, 2000.

Figure 4.1 Bagasse fired steam Rankine cycle for combined heat and power production.

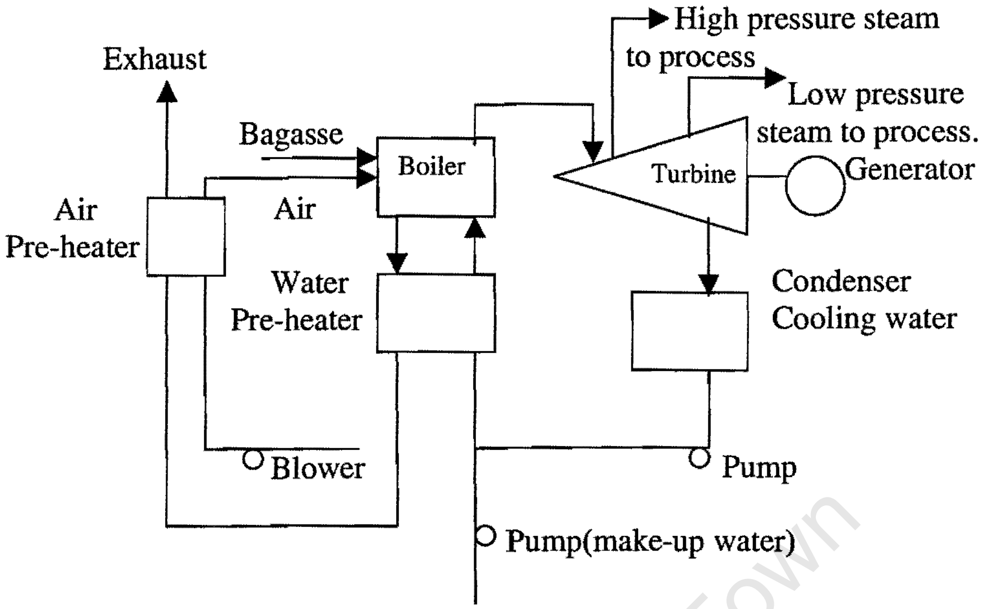
Figure 4.1 shows a backpressure turbine system which can be divided into air and steam cycles. The air cycle starts with the induction of air into the air inlet by the blower. The air is then preheated in the air pre-heater before it is fed into the boiler together with fuel in form of bagasse. The bagasse and air mixture is ignited to produce a thermo-chemical reaction, which produces heat for raising steam. The hot gases i.e. products of the thermal-chemical reaction or combustion pass through the water pre-heater after which they go through the air pre-heater before being exhausted through the stack into the atmosphere.

The condensate from the steam cycle and de-aerated make-up water are pumped into the boiler inlet line in which the water is pre-heated by the hot combustion gases on its way into the boiler. In the boiler, steam is raised before being expanded in the turbine before further heat extraction takes place. Finally the steam is cooled in the condenser before being pumped into the boiler intake line to resume the cycle again. Extraction of the heat in the condenser may be through a cooling tower or water spray open to the atmosphere. Some water is lost in the process and is replaced with de-aerated and de-mineralised make-up water. De-aeration of the water and de-mineralisation are important to avoid fouling of the boiler pipes, which can reduce the efficiency of heat transmission and lead to blockages of the pipes. Impurities can also lead to damage of turbine blades through scouring by solid particles and cavitation by air at high pressures. Steam is a wetting fluid, unlike toluene, methanol, ammonia etc which are drying fluids. This means that as it is expanded in the turbine, once it reaches saturation, any further expansion increases the moisture content, that is, steam becomes wetter as it expands. It is because of this characteristic that steam is normally superheated. A major disadvantage with steam is its low molecular weight which requires very high turbine speeds in order to get high turbine efficiencies (Goswami *et al,* 2000).

A generator coupled to the turbine shaft transforms the shaft power into electrical energy. Typically, traditional backpressure turbines operate at medium pressures in the range of 15-25 bars.

The back-pressure turbine will be the first technology type to be used in estimating the potential from bagasse. Efficiency improvements in the backpressure turbine i.e. using higher pressure boilers, reducing steam vapour losses, and making other technical improvements, gives the second technology type. The third type of technology is the Condensing Extraction Steam Turbine which is explained below;

4.2 The Condensing Extraction Steam Turbine (CEST).



Source: Adapted from Kartha and Larson, 2000.

Figure 4.2 Biomass fired steam Rankine cycle for combined heat and power production using a condensing extraction steam turbine.

Condensing extraction steam turbines exhaust at pressures below atmospheric (under vacuum). They have a much higher efficiency than backpressure steam turbines (Coates, 2002).

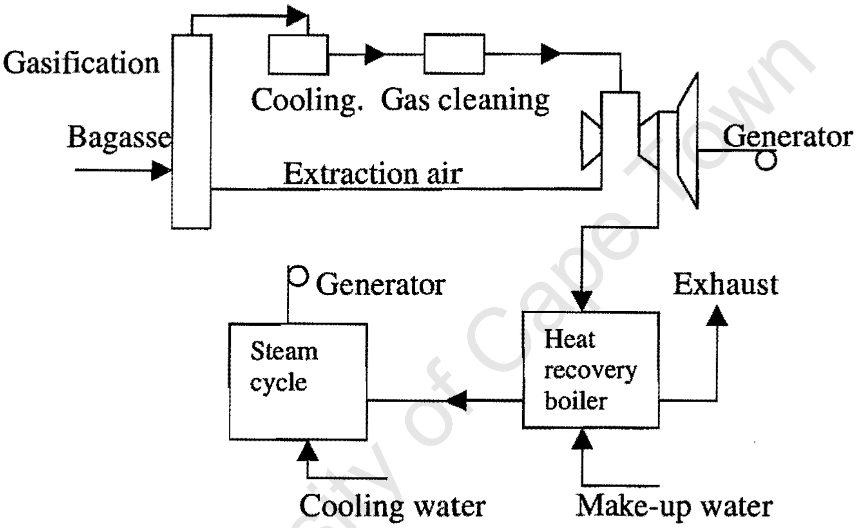
In the schematic above the process is similar to the back pressure turbine, with the difference that the boiler pressures are much higher and the turbine exhaust pressures are lower than those in the back-pressure turbine. This variation in pressures and hence temperatures leads to attainment of higher efficiencies in the Condensing Extraction Steam Turbines (CEST) in comparison with the backpressure turbines.

Figure 4.2 also shows that steam is sometimes tapped off on the turbine at two points, the high pressure and the low-pressure lines to the process. This is possible because of the much higher pressures at which steam is generated in the boiler. The Condensing Extraction Steam Turbines (CEST) operate at 40-85 bars (Cornland *et al,* 2001; Deepchand, 2000).

The fourth technology type which will be used in estimating the potential of bagasse for electricity generation is the basic BIG/CC (and not its variants) which is explained in the first part of the section below;

4.3 Other Technologies (BIG/CC, BIG/STIG, BIG/CC-Fuel cell)

Technologies based on Biomass Integrated Gasifier (BIG) are in the Research Design and Demonstration (RDD) phase and not commercially matured yet. They however, hold promise for large gains in efficiency when they become commercially mature.

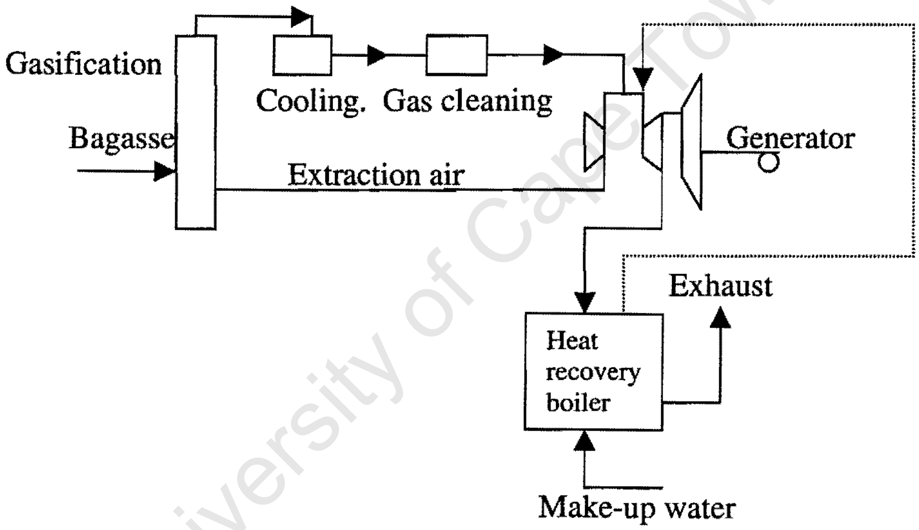


Source: Adapted from Kartha and Larson, 2000.

Figure 4.3 Configuration of a Biomass Integrated Gasifier/Combined Cycle.

In the Biomass Integrated Gasifier/Combined Cycle (BIG/CC), the bagasse, is transformed into a gas (a combination of hydrogen, carbon monoxide, methane, carbon dioxide (and nitrogen if air is used)) which after cooling and cleaning is directed into the compressor turbine assembly. The compression side admits and compresses air into the gasifier air intake as extraction air that is used in partial burning of the bagasse to produce a combustible gas which is burnt in the turbine combustion chamber before expansion in the gas turbine. A generator coupled to the gas turbine produces electricity in what is known as the topping cycle. The hot gases, after expanding in the gas turbine are passed through the heat recovery boiler in which steam is raised and used to produce electricity in the steam cycle as explained in Figure 4.1. Two points can be observed, at which electricity is produced; at the gas turbine and the steam turbine. The overall thermodynamic efficiency from this turbine is around 47% (Goswami *et al*, 2000). Larson *et al* say that the BIG/CC will be able to produce double the amount of electricity per unit of biomass consumed and at lower capital investment per kW of capacity than CEST systems but there were no demonstration projects ongoing presently operating on sugarcane bagasse (Larson *et al*, 2001).

The gasifier is sometimes pressurised to increase the methane fraction. Instead of air, the gasifier is fed with pressurised oxygen to remove the inert nitrogen fraction and its compounds.

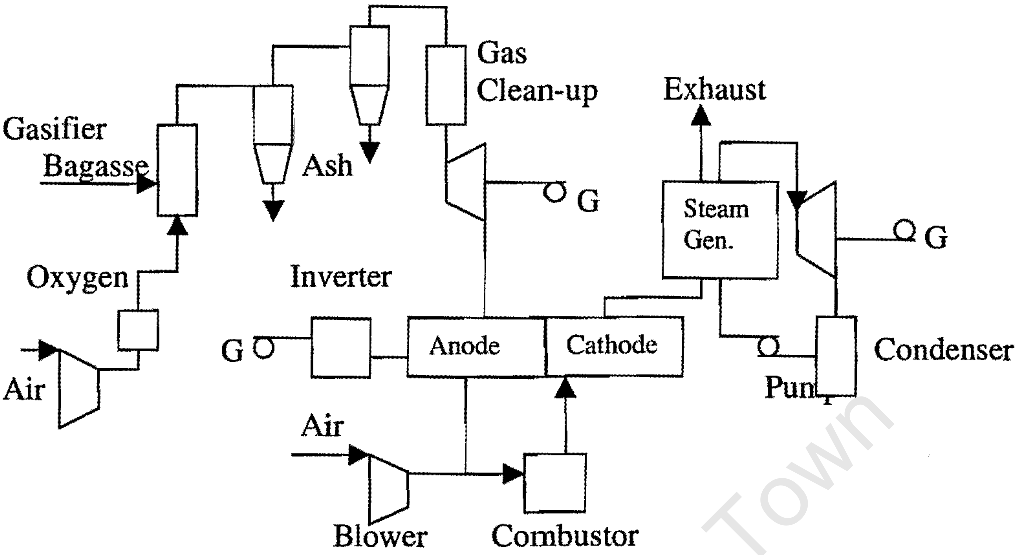


Source: Adapted from Kartha and Larson, 2000

Figure 4.4 The Biomass Integrated Gasifier/Steam Injected Gas Turbine

After the gas turbine the steam that is raised is sometimes introduced into the combustor of the gas turbine (see dotted line in Figure 4.4) instead of being used to turn a steam turbine. This eliminates the expensive steam turbine assembly while retaining the high efficiencies through the higher density charge in the gas turbine. This alteration or modification results in the turbine configuration being termed a Biomass Integrated Gasifier/Steam Injected Gas turbine (BIG/STIG).

When the combined cycle is augmented by the fuel cell the BIG/CC-Fuel Cell is produced which is shown below;



Source: Adapted from Goswami *et al,* 2000.

Figure 4.5 BIG/CC-Molten Carbonate Fuel Cell

The BIG/CC-Fuel Cell operates on the same principle as the BIG/CC. The difference is that the gasifier is normally pressurised and would be fed with oxygen and bagasse which after partial combustion would be passed through cyclones to remove solids from the gas. The gas would then be cleaned up as it was going for expansion in the gas turbine where a generator would transform the shaft power into electricity. The exhaust gases would form an input to the anode of the fuel cell from where direct current would be generated which would be converted to alternating current through the inverter and the electricity would then be ready for onward transmission. The gases from the anode would be mixed with air and burnt in the combustor before going through the porous cathode and on to the steam generator where steam would be raised to turn a steam turbine from where the last generation of electricity would take place. Thus electricity would be generated at three points leading to an overall thermodynamic efficiency of about 60% or more (Goswami *et al,* 2000). However, the BIG/CC, BIG/STIG, and the BIG/CC-Fuel Cell are not commercially mature and have higher capital costs (Cornland *et al* 2001; Larson *et al,* 2001) at present than CEST technology.

In future there are possibilities of cost reductions due to improvements in technology, technology scale-up and learning by doing i.e. gains in experience (Larson *et al,* 2001). Following is a look at the contribution of bagasse to electricity production in Chapter 5.

CHAPTER 5

POWER PRODUCTION FROM BAGASSE IN AFRICA

5.1 Introduction to Sugar Production in Africa

It has been reported that the sugarcane plant came to Africa through Egypt in the eighth century by A.D 710. Although the earliest record dealing with sugarcane in the Hindu literature is about 3000 years old and crude sugar had been developed by 400 B.C., it was only when sugar came to Africa that clarification, crystallisation and refining were developed (Illovo Sugar Limited, 2002).

However, not much progress was achieved thereafter, especially with regard to utilisation of bagasse which has always been regarded as waste. Only in the 20th century with the rise and growth of sugar industries was bagasse used, but in small quantities, for power production. Following on from there, it is necessary to make an assessment of the contribution that bagasse can make to electricity production in Africa. This begins with an assessment of the sugar and bagasse resources, then an estimate of electricity potential that can be generated from this resource follows before finally comparing with current electricity production to determine the potential.

Table 5.1 Sugar production in Africa from the 1995/96 season to the 2000/01 season (Thousand tonnes).

Year Country	1995/6	1996/7	1997/8	1998/9	1999/0	2000/1	2001/2	Average sugar production
Egypt	1092	1156	1170	1180	1390	1336	1375	1243
Morocco	436	438	406	490	500	523	545	477
Sudan	500	540	600	630	720	747	775	645
Tunisia	30	30	25	14	11	11	11	19
Cote d'Ivoire	130	150	115	137	179	177	185	153
Ethiopia	185	100	200	270	275	275	280	226
Kenya	386	388	480	449	471	402	420	428
Malawi	200	225	210	215	190	210	210	209
Mauritius	572	625	658	670	391	600	680	599
Nigeria	30	15	15	16	20	21	40	22
South Africa	1769	2408	2560	2646	2685	2895	2690	2522
Swaziland	447	502	518	504	571	528	547	517
Tanzania	130	125	90	125	130	145	150	128
Uganda	70	97	103	104	124	138	134	110
Zaire (DRC)	83	85	90	70	70	70	70	77
Zambia	200	200	200	200	200	300	300	229
Zimbabwe	524	338	573	570	583	537	594	531
Others	444	450	469	510	477	358	406	445
Total	**7228**	**7872**	**8482**	**8800**	**8987**	**9273**	**9412**	**8579**

Source: Adapted from the Internet webpage fasonline,
http:// www.fas.usda.gov/htp/sugar/2001/Nov/psdf.pdf

Table 5.1 above shows sugarcane production figures for sugarcane seasons from 1995/6 to 2001/2 for selected countries in Africa. The data was used for the analysis of this work because it was the most reliable available. It was also assumed that the seven year period was enough to give a reasonable picture of sugar production in a country and could capture possible changes in sugar production with climate. Such variations could be studied better if more detailed data that gives the variation of sugar production between seasons in an annual form were available.

Hence, data available for Uganda was used to study the monthly variation of sugar production. A seven year data of monthly production of sugar is shown in figure 5.2.

The average for the seven year period is also included to give the mean for the period.

Table 5.2 Sugar production statistics for Uganda from 1995 to 2001 in Tonnes

year Month	1995	1996	1997	1998	1999	2000	2001	Average sugar production
Jan	1405	8761	7296	9550	14588	14018	11797	9631
Feb	1476	7215	8737	8574	13086	12379	12229	9099
Mar	1562	8159	10753	8832	11051	13217	14380	9708
Apr	2484	6940	9655	3785	9245	11219	7845	7310
May	5201	7371	4118	3754	10926	7751	5684	6401
Jun	5807	6909	8957	10291	6075	9197	9574	8115
Jul	8084	6118	11018	10656	11105	15739	13425	10878
Aug	7064	7103	10425	11846	11631	14708	13049	10832
Sept	9191	8774	9710	8534	8896	13152	13762	10288
Oct	9450	9988	7764	7291	7438	7579	8879	8341
Nov	9310	10022	6994	8544	8897	7877	8766	8630
Dec	8720	9211	7827	12006	11492	10951	14461	10667
Total	**69752**	**96571**	**103254**	**103663**	**124430**	**137787**	**133851**	

Source: Uganda Bureau of Statistics, 2002

Table 5.2 shows that sugar production has been increasing substantially between 1995 and 2001, more than double in absolute terms. The monthly figures for 1995 cannot be used to study the monthly variation as it shows that there must have been some disruption to the production as only a low value of 1405 tonnes was produced in January reaching peak production of 9450 tonnes in October. Hence, the effect of these low values was smoothed out by calculating the average from 1995 to 2001. This is shown in the last column in table 5.2. The variation of the average monthly production is shown in Figure 5.1;

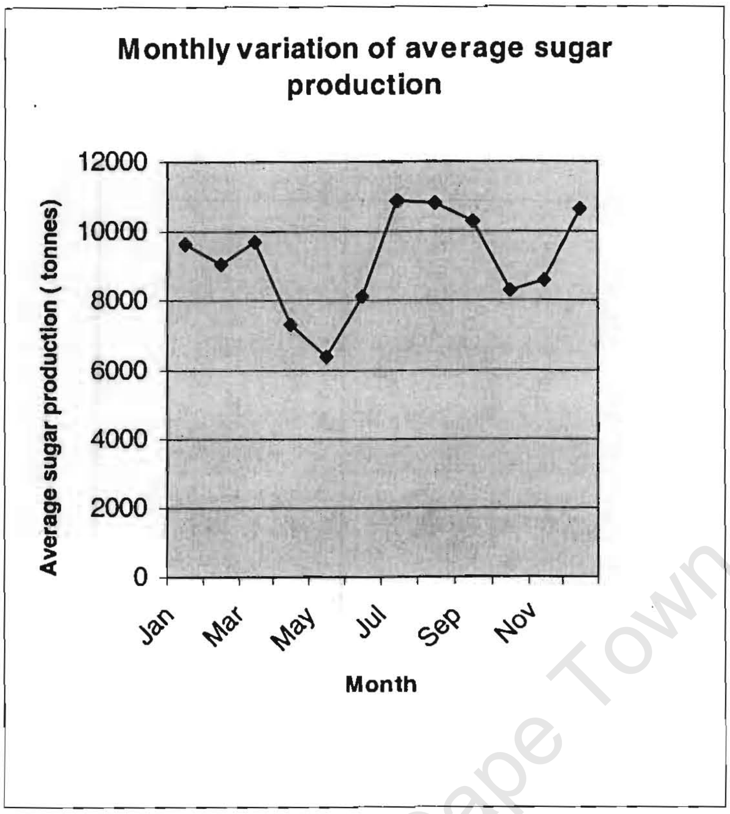


Figure 5.1 Monthly variation of average sugar production

The characteristic in Figure 5.1 shows that sugar production has two peaks. The peaks in January and August seem to follow but lag those of the equatorial rainy seasons whose peaks are in March-May and October-November. This is in agreement with the fact that sugar content in the cane reaches a maximum just before the rainy season peaks. The months from April to July show that this is an off-season for sugar production because of the low sugar values as production would be from stored stocks. Sugar production variation in Uganda seems to suggest that it may be reasonable to expect similar rain dependent variation of sugar production in other countries. The variation would follow the rainfall pattern in those countries and droughts which are common in the region would also affect sugar production .

The countries listed in Table 5.1 do not cover all countries on the continent but they give a fair representation of the continent as they do represent all the sub-regions.

Almost all countries other than Tunisia and the Democratic Republic of Congo (DRC) recorded an increase in sugarcane production. The decrease in production in the DRC can most probably be attributed to on-going political disturbances but the reason for the decrease in Tunisia is not very clear. Perhaps that could be due to unfavourable climate. The rest of the countries recorded increase in production. South Africa's increase can be described as phenomenal as it was 52% of the 1995/6 sugarcane production in 2001/2.

The last column in Table 5.1 shows average sugar production figures which were used in the calculation of the estimated bagasse production in Table 5.3 below;

Table 5.3 Average bagasse production

Country	**Average Annual Sugar Production (Thousand Tonnes)**	**Average Bagasse Production (Thousand Tonnes)**
Egypt	1243	3729
Morocco	477	1431
Sudan	645	1935
Tunisia	19	57
Cote d'Ivoire	153	459
Ethiopia	226	678
Kenya	428	1284
Malawi	209	627
Mauritius	599	1797
Nigeria	22	66
South Africa	2522	7566
Swaziland	517	1551
Tanzania	128	384
Uganda	110	330
Zaire (DRC)	77	231
Zambia	229	687
Zimbabwe	531	1593
Others	445	1335
Total	**8580**	**25740**

Estimates of sugar production are taken as 10% of the amount of sugarcane while bagasse values are 30% of sugarcane by weight (Deepchand, 2000). From the calculated amounts of bagasse the energy that could be generated was determined noting that each technology type has a different energy transformation rate. The rate of energy transformation is taken as the exportable energy in excess of that required by the sugar factory .

The different technologies for producing power from bagasse described in chapter five were used to evaluate the amount of the different electricity values that could be produced. The first technology used existing traditional backpressure turbines which operate in the medium pressure range of 15-25 bars. An improvement in the turbine through fine tuning and other adjustments to increase efficiency of the traditional turbine was the second option. The third was the Condensing Extraction Steam Turbine (CEST) and the last technology type was the Biomass Integrated Gasifier Combined Cycle (BIG/CC).The energy transformation rates of exportable energy used in the evaluation were as follows:

- backpressure turbines 15 kWh/tc
- CEST - 110 kWh/tc
- BIG/CC - 200 kWh/tc,

These values were determined from various sources (Chang et al, 1999; Wienese, 1999; Deepchand, 2000). It should be noted that exportable electricity is a function of many variables some of which are; size of plant, boiler capacity, specific steam consumption, steam to bagasse ratio, type of turbine etc (Baguant *et al,* 1992). The electricity generating potential for exportable electricity of these technologies is shown for selected African countries in Table 5.5 below. In this instance the potential that is being referred to is the technical, the meaning of which is explained under Table 5.6.

5.2 Electricity generation from sugar

Electricity can be generated from bagasse by using a number of different technologies as shown above. Presently this is being done using the backpressure turbine giving exportable electricity of about 15 kWh/tc (Chang, 1999), and is the first option indicated above. When this backpressure turbine is improved to work at higher efficiency through decalcification of the boiler and fine tuning and adjustments of burners and other components, a gain in efficiency of about 40% can be achieved (Chang, 1999). This is the second option. The third and fourth type of technologies require higher capital investment to use the Condensing Extraction Steam Turbine (CEST) with exportable electricity of 110 kWh/tc and the Biomass Integrated Gasifier Combined Cycle (BIG/CC) with exportable power of about 200 kWh/tc (Deepchand, 2000; Wienese, 1999). Using these values, electricity that can be generated from these technologies is shown in Table 5.4.

Table 5.4 Electricity generation potential from bagasse using different types of transformation technologies.

Country	Average Annual Sugarcane Production (Thousand Tonnes)	Average Annual Bagasse Production (Thousand Tonnes)	Backpressure Turbine (GWh)	Backpressure Turbine with efficiency improvements (GWh)	CEST (GWh)	BIG/CC (GWh)
Egypt	12430	3729	186.45	261.03	1367.3	2486
Morocco	4770	1431	71.55	100.17	524.7	954
Sudan	6450	1935	96.75	135.45	709.5	1290
Tunisia	190	57	2.85	3.99	20.9	38
Cote d'Ivoire	1530	459	22.95	32.13	168.3	306
Ethiopia	2260	678	33.9	47.46	248.6	452
Kenya	4280	1284	64.2	89.88	470.8	856
Malawi	2090	627	31.35	43.89	229.9	418
Mauritius	5990	1797	89.85	125.79	658.9	1198
Nigeria	220	66	3.3	4.62	24.2	44
South Africa	25220	7566	387.3	529.62	2774.2	5044
Swaziland	5170	1551	77.55	108.57	568.7	1034
Tanzania	1280	384	19.2	26.88	140.8	256
Uganda	1100	330	16.5	23.1	121	220
Zaire (DRC)	770	231	11.55	16.17	84.7	154
Zambia	2290	687	34.35	48.09	251.9	458
Zimbabwe	5310	1593	79.65	111.51	584.1	1062
Others	4450	1335	66.75	93.45	489.5	890
Total	**85800**	**25740**	**1287**	**1801.8**	**9438**	**17160**

Amount of bagasse is taken as 30% that of sugarcane production.

Table 5.4 shows that the energy generating potential of the backpressure turbine can be increased by 40% by optimising turbine operation through efficiency improvements by increasing boiler pressure, replacement of worn parts and fine tuning of burners and other adjustments in equipment. This is one of the economic routes at present. The CEST technology can be used but requires added investments, but though BIG/CC will generate much more energy, this option will require major investments for added equipment involved. Also, while the CEST technology has reached commercial maturity, this is not the case with BIG/CC which is only being demonstrated in selected sites. The potential of the various technologies for some countries is given in Table 5.5. The availability of data particularly for energy production for 1999/2000 which was used as the base year limited the number of countries included in this table. However, the results give a flavour of the general situation in Africa.

Table 5.5 Generation Potential as a fraction of the 1999/2000 energy production

Country	Energy Production for year 1999/2000* (GWh)	T1/t	T2/t	T3/t	T4/t
Kenya	4461	0.014	0.020	0.106	0.192
Malawi	1065	0.029	0.041	0.216	0.392
Mauritius	1527	0.059	0.082	0.432	0.785
Mozambique**	1141	0.004	0.005	0.026	0.047
South Africa	190053	0.002	0.003	0.015	0.027
Swaziland	846	0.092	0.128	0.672	1.222
Tanzania	2293	0.008	0.012	0.061	0.112
Uganda	1554	0.011	0.015	0.078	0.142
Zambia	7794	0.004	0.006	0.032	0.059
Zimbabwe	12365	0.006	0.009	0.047	0.086

Where; T1-backpressure turbine with no adjustments

T2-improved backpressure turbine

T3-CEST

T4-BIG/CC

t-Energy generated in 1999/2000

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[*] Figures in this column were taken from SAD-ELEC, 2000

[**] The average sugar production figure of 27,000 metric tonnes for the decade 1988-98 used in the calculations for Mozambique was taken from Deepchand (2000)

Power generated in 1999/2000 was taken as representing the average value of the power produced in the countries listed above and these figures were used to make a comparison with the different technology options tested. Ideally what needs to be done is to use an average figure of energy generated over a number of years to smoothen out fluctuations and give a more accurate picture of each country's energy production.

Taking South Africa as an example, the technologies in Table 5.5, starting with T1 to T4 in that order, give the potential as 0.2%, 0.3%, 1.5% and 2.7% respectively.

Figure 5.2 below shows a graphical representation of the information given in Table 5.5 by means of a bar chart.

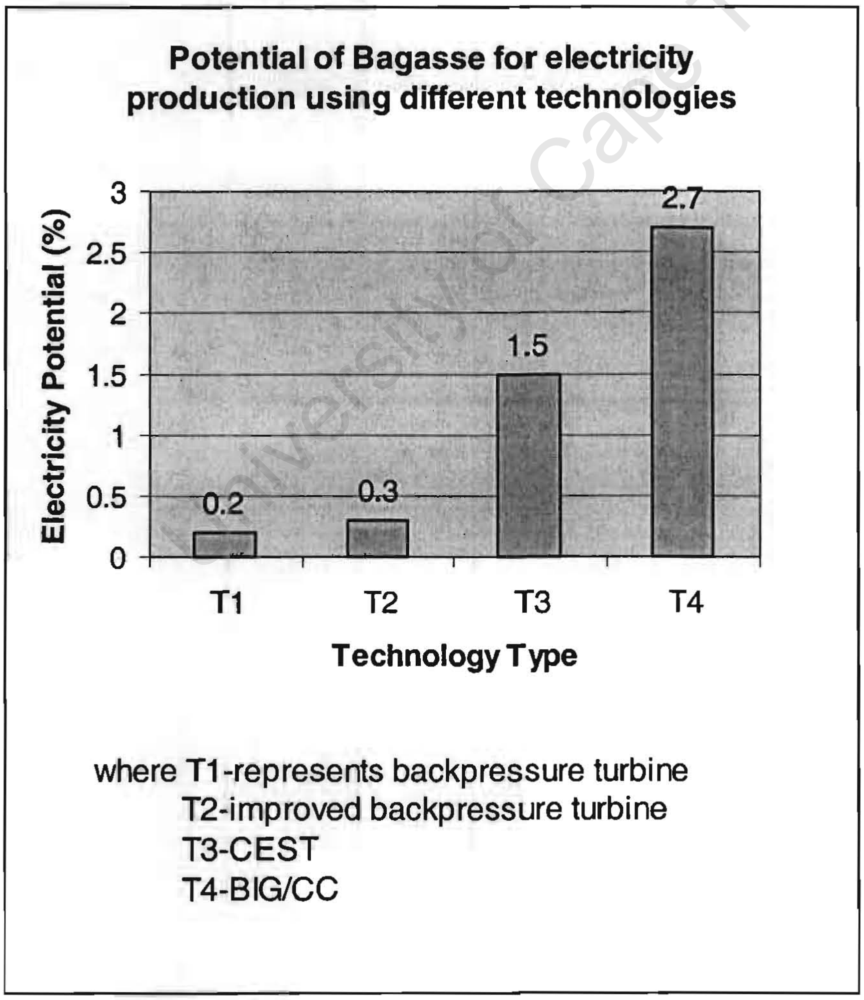

Figure 5.2 Graphical representation of South Africa's potential for electricity generation from bagasse.

Having shown the potential of bagasse for electricity generation, it is important to examine further the various types of potential that are associated with different technologies. This is done in Table 5.6 below;

Technology Type Potential	T1	T2	T3	T4
Theoretical	✓	✓	✓	✓
Technical	✓	✓	✓	
Economic	✓	✓		
Market	✓	✓		
Environmental		✓		

Table 5.6 Potential levels of different types of technology

Table 5.6 shows the potential levels of different technologies that can be used in producing electricity from bagasse. It should be noted that potential can be defined in a number of ways. It is theoretical, when ideal conditions are assumed, technical, when practical considerations and transformation efficiencies are incorporated, economic when financial viability is considered, market when demand realities are taken into account and environmental when there is a positive impact on the environment.

Alternatives to the present Backpressure Turbine will be examined. Improving the performance of the Backpressure Turbine by raising the boiler pressure and making other technical adjustments is feasible but improves performance by only 40% (see Figure 5.2 which shows rounded off figures). Whereas investing in the Condensing Extraction Steam Turbine (CEST) increases the potential by about 8 times. Comparative costs of investing in CEST need to be weighed against those of investing in improvements to the Backpressure Turbine. The alternative with higher gains per unit cost qualifies as the practical alternative to improving the Backpressure Turbine. Other alternatives, the BIG/STIG and BIG/CC-Fuel cell are based on the Biomass Integrated Gasifier Combined Cycle (BIG/CC). Since BIG/CC and its derivatives have not reached commercial maturity, they were not considered possible avenues for adoption in Africa at present. Furthermore, the estimated cost for a 30 MW BIG/CC unit at US $ 2450/kW is far higher than for an equivalent CEST unit at US $ 1500/kW (Larson *et al,* 2001). The CEST technology has immediate applicability and so has practical significance in the generation of electricity from bagasse. The 9.4 TWh potential from CEST indicated in Table 5.4 for Africa therefore compares favourably with the figure found by Deepchand in which his potential was estimated at 8.3 TWh considering the state-of-the-art CEST technology using a conversion factor of 100 kWh/tc. However, the estimates above do not agree with that given by Biomass Users Network, who estimated Africa's potential at 30 TWh and that of Eastern and Southern Africa at 13 TWh. (see chapter 1). The apparent anomaly seems to arise because the Biomass Users Network (BUN) estimates are likely to be the theoretical potential which did not take into account the conversion efficiency of generation technology and other losses like residual sugar in molasses etc. When a conversion of about 30% for the Rankine cycle from thermal to electricity and other losses are taken into account the figures come within the same order of magnitude and would therefore be in agreement.

Table 5.5, under the column for CEST, shows that the potential of bagasse generated electricity varies from 1.5% for South Africa to 67% for Swaziland. Access to electricity as indicated in Table 1.1 shows that this varies from 4% for Malawi to 100% for Mauritius. However, with the exception of South Africa, there seems to be an inverse relationship between population and access. Kenya and Tanzania with populations of 30 and 32 million people respectively have low access of 9% each while Swaziland and Mauritius with low populations of 1.0 and 1.2 million people respectively have electricity access of 21% and 100% respectively. Swaziland and Mauritius are both small countries in terms of land area and population; it is therefore easier in these countries for the grid to cover most of the land.

South Africa's energy supply market is huge because of the level of industrial activities in the country, and this accounts for the low potential for electricity generation from bagasse, at only 1.5%. However, access to electricity in South Africa is the highest in the sub-Saharan region with the exception of Mauritius. 1.5% electricity potential for South Africa is numerically greater than the national energy supply for most of the countries in sub-Saharan Africa for the year 1999/2000 with the exception of Kenya, Zambia and Zimbabwe. It can therefore, be observed that if the South African potential were to be used solely for electrification purposes for domestic housing, the impact would be larger than what can be achieved in other countries.

Additionally, most sugar plantations are in the rural parts of the countries mentioned. It would therefore be advantageous to the rural population if power were generated near to them as this would make access easier and costs of transmission lower. Electricity generation for rural areas would have other spin-off effects like promotion of cottage industries, building of schools and clinics in addition to providing employment.

The foregoing can only be a reality however, if proper and relevant policies are already on the ground. This entails a clear enunciation of policies which should not just be inferred or 'extrapolated' from existing legislation. Some of these requisite policies are elaborated in the following section in Chapter 7. However, before that a case study of utilisation of bagasse in South African Sugar industries will briefly be examined in Chapter 6.

CHAPTER 6

A CASE STUDY OF BAGASSE IN SOUTH AFRICA

6.1 Introduction

A case study of sugar refineries in South Africa was undertaken in order to get a better understanding of the sugar and bagasse production process so that effective comparison can be made with the information in the previous chapters. The general situation of South Africa is provided to give the background to the case study.

South Africa has a population of about 43 million people and lies between Meridians 16°E and 35°E and Parallels 22°S and 35°S with an area of 1.2 million square kilometers. With average rainfall being less than 450mm a year and unpredictable, droughts are common leading to the country being classified as semi-arid or water-stressed. The economy of South Africa is vibrant as compared to the economies of its neighbours. However, the economy of South Africa is based on the mining sector that is dominated by diamonds, gold, coal, iron, platinum and uranium.

6.2 Energy Supply

The energy supply sector is dominated by coal resources which apart from being used for the production of electricity are also used in small amounts for making synthetic liquid fuel at Sasolburg and Secunda. Coal supplies about 70% of South Africa's energy and is used in the production of amongst the cheapest electricity in the world (Clive van Horen *et al* 1996). However, coal from South Africa has high ash content varying from 15% to 50% resulting in particulate and gaseous emissions that have a negative impact on local air quality and contribute to global warming. Of note among the gaseous emissions is coal-bed methane which has twenty times more global warming potential than carbon dioxide over a hundred year horizon. Consequently, the country is among the world's top 20 emitters of greenhouse gases in the world (van Horen and Simmonds 1996; Brown, 2001).

Other energy resources used in the supply sector include imported liquid fuel (15%), other than synthetic fuel produced, natural gas (2%), located off the south coast at the F-A gas field which is all converted to liquid fuel. There are large reserves in Mozambique at Pande and Namibia at Kudu, which might be transmitted by pipeline to South Africa in the near future. Nuclear power at Koeberg forms 3% of supply, and renewable resources form 10% of supply including solar, wind, hydro, biomass (bagasse) etc. The primary energy supply situation is summarized in Table 6.1. below;

Table 6.1: Primary energy supply for South Africa (1995)

Energy Resources	**Percentage of total supply of 1.2 Exa joules (%)**
Coal	70.6
Liquid fuel	15.0
Natural gas	1.7
Nuclear (Uranium)	2.7
Renewable (Solar, Hydro, bagasse…)	10.0
Total	**100.0**

Source: Adapted from Wienese (1999)

6.3 Energy Consumption

The energy demand shows that most of the energy is consumed by the industrial (which includes mining and commerce) sector that used just over half of the total energy consumption. The next high energy consuming sector is transport that accounts for a share of 24% of total energy consumption and the household sector uses 22% of the total energy. This sector has a very big potential for growth as electrification of formerly disadvantaged groups continues to be given higher priority. Finally, the agricultural sector derives three quarters of its total energy consumption from liquid fuels and the remaining fraction from electricity and accounts for the remaining 3% of total energy consumption. The consumption pattern is shown in Table 6.2. below;

Table 6.2. Final energy consumption for South Africa (1995)

Energy demand sector	**Percentage of total consumption (%)**
Industry	51.0
Transport	24.0
Households	22.0
Agriculture	3.0
Total	**100.0**

Source: Adapted from Wienese (1999)

There are 15 mills available in South Africa. Of these 7 are owned by Illovo Sugar Company, 5 belong to Tongaat-Hulett Sugar Company, 2 are for the Transvaal Sugar Limited and 1 is for the Cooperative owned by sugar growers. Contact was much easier with Illovo Sugar Company which explains why the study was conducted in their factories. Also the Illovo Sugar Company is the largest in South Africa. The factories visited namely Eston, Sezela and Merebank were those nearer to the organisers of the visits at the Company headquarters from where the visits were arranged. This made it easier to organise transport and other logistics.

A conducted tour of the factories during normal weekday operations was done and information was obtained by visual observation and on the spot questioning of the tour conductor.

6.4 The Survey at Illovo Sugar Company

The Illovo Sugar Company Headquarters is in Mount Edgecombe in Durban, Kwazulu, Natal and it is one of the largest in the world with the capacity to show different aspects of sugar processing as well as other auxiliary activities in its sugar factories.

This survey area was chosen because it demonstrates the complete sugar production process, from harvesting to sugar production and this provides the opportunity to observe the process easily. Additionally, there was ease of communication with the Company authorities and this assisted the planning of the visits to the production sites.

6.4.1 Survey Methodology

Three methods were employed in undertaking the survey to obtain the information required. These methods were as follows:

i. observation during visits to factories
ii. interviews with selected members of staff
iii. use of a questionnaire shown in the Annex.

6.4.2 General Information

Two sugar factories and one alcohol distillery were visited. The sugar factories were Eston and Sezela and the alcohol distillery was Merebank. Sugar processing in these plants was observed and points of interest noted.

Interviews with the members of staff were done informally. In addition, the company provided literature that explained the general points in sugar processing and also the personnel met during the visit were willing to provide answers to questions raised .

The questionnaire used in the field visit was designed to elicit information from the sugar industry. It provided answers of significance to the project, though some sensitivity was exhibited as the company was sensitive about certain confidential information (see copy of questionnaire in the Annex) .

It was observed that only slight variations exist in sugar processing between factories and that they largely follow the standard pattern discussed in chapter 3 (see section 3.1)

Production of power from bagasse fulfils all the government's objectives as spelled out in the white paper which promotes the diversification of energy resources and the development of renewable energy resources. Presently, the major barrier however, is the lack of agreement between the national electricity utility ESKOM and private producers such as Illovo.

However, though South Africa is not considering generation of electricity using bagasse as a viable option at present, there is no decision of not doing so in the foreseeable future (Wienese, 1999).

6.5 Results of Illovo survey

The Illovo Sugar Company has 14 factories located in 13 different places. These factories are in Malawi, Mozambique, Swaziland, Tanzania, the USA in Michigan and Zambia. Of these, only two sugar milling factories and one alcohol distillery were visited in South Africa, in Durban. The sugar milling factories were Eston and Sezela and the distillery was Merebank. As mentioned in the first paragraph of chapter 5, clarification, crystallization and refining were developed in Africa in the 8th century, the visit to factories at Illovo Sugar Company provided an opportunity to observe what was actually obtaining in the field.

6.5.1 Eston Sugar Mill at Illovo.

The raw sugarcane processing at Eston mill from sugarcane involved the following processes;

i. Cane preparation
ii. Milling
iii. Clarification
iv. Evaporation
v. Crystallisation and
vi. Steam and electricity production.

The factory has a cane crushing capacity of 256 tonnes of cane per hour (tch) and crushed a total of 1.43 million tonnes of cane in 1998. The electricity production potential translates to 157.3 GWh at 110 kWh/tc, if using CEST (Deepchand, 2000). The different stages of sugarcane processing done in the factory are explained below after a brief introduction.

The sugarcane breeding programme in South Africa started in 1925. Since then cane varieties have been continuously improved to current production of 54 tonnes/ha/yr. The total area under cultivation is about 400,000 ha which is harvested over a period of 8-9 months, from Mar-April to December and sugarcane density varies between 200 and 400 kg/cubic metre.

Harvesting begins with burning of the cane fields due to the following advantages;

- It is a cheap way of removing leaves (trashing)
- It promotes new growth by warming the ground
- It assists in fighting against diseases and pests (eldana)
- It results in a higher payload and therefore cheaper transportation of cane
- It enables processing of cleaner cane in the factory

Field burning on the other hand has some disadvantages which include;

- The absence of trash blanket increases soil erosion
- " " " " " weed growth
- " " " " " water evaporation
- Strong winds which prevent farmers from burning resulting in uncontrollable fires
- Increased cane delay and temperature which results in quality deterioration of the cane.

Because of the undulating topography of the land cane harvesting is done manually and this assists employment of more people. The cut cane stalks are arranged in stacks of 4-6 tonnes and transported to the factory-receiving bay by either road, railway or tramway. The share of transportation carrying the stalks are as follows; trucks (62%), tractor and trailer (21%), rigid trucks (9%), and railway or tramway (8%). After washing and removal of extraneous materials like sand, rocks etc., the cane is cut to suitable condition for feeding into heavy duty shredders without chopping into short fibres. The knifed cane is then passed through magnetic tramp iron separators to remove any ferrous materials before being conveyed to the shredders which maximize sucrose bearing cell rupture and exposure without pulping the cane fibres.

Sugar is removed from the cane fibres by diffusion with water in the diffuser from where the cane juice is conducted to the clarifier and the wet bagasse to the dewatering mills. The dewatered bagasse of about 50% moisture content (wet basis) is directed to the boiler for raising steam and excess bagasse is stored for future use. Milk of lime is added to the heated juice in the diffuser and the clarifier to settle out the dirt. The rotary vacuum filters complete the removal of solid impurities from the juice. Next, is the juice concentration, sugar crystallization, centrifuging, and drying. Juice is concentrated from 14 - 16° Brix (% solids by weight) to 91-93° Brix and is now termed 'massecuite', a mixture of thick juice called syrup and sugar crystals (Larson *et al*, 2001). This is accomplished in the multiple effect evaporators and the 'A' vacuum pan. From the 'A' vacuum pan the massecuite is taken to the 'A' centrifuges. Sugar crystals are first separated in 'A' centrifuges. The sugar (top quality) is then dried and cooled before bagging and/or storage and finally dispatch. The liquid portion is conducted to 'B' seed pans and then on to 'B' centrifuges where separation of solids is again accomplished. The 'B' sugar crystals which are smaller and have a stronger yellowish brown colour than the 'A' crystals are melted again and provide the seed for the 'A' seed pan before going on to the 'A' centrifuges. The liquid part from the 'B' centrifuges is taken to the 'C' seed pan where after concentration the 'C' massecuite is led into crystallizers. From the crystallizers the massecuite is led to the 'C' centrifuges where the sugar crystals (smaller than 'A' and 'B' crystals), are separated from the liquid portion called 'C' or final molasses, which may be used as cattle feed, or as input raw material for alcohol production. The 'C' sugar crystals are mixed with the 'A' massecuite and continue the process after concentration on to the 'A' centrifuges.

A major feature in almost all the processes mentioned above is the requirement of steam. About 500 kg of steam per tonne of sugarcane crushed (kg/tc) at a pressure of around 2 bars above atmospheric and 130°C (Larson *et al*, 2001). The steam is produced at a temperature of 400°C and an absolute pressure of around 30 bars and expanded in turbines of 70% efficiency (Wienese, 1999).

Adverse climatic conditions in South Africa resulted in sugar production of 2001/2 being the lowest since 1997/8. In 2000/1 the amount of sugarcane crushed was

23.9million with a corresponding sugar production of 2.7million tonnes while in 2001/2 the sugarcane crushed was 21.2 million tonnes with a corresponding sugar production of 2.4 million tonnes. Exports amounted to more than 1.16 million tonnes of sugar and earned R2 billion while sugar sales in the local market earned R3.2 billion. Market price fluctuations led to the sugar price losing 40% of its value in US dollar terms. The sugar industry employs more than 350,000 people with small scale growers cultivating about 27% of the total area under cane. The rest is cultivated by 2000 large scale growers (Makaringe,2002).

6.5.2 Sezela Mill

The sugar milling process is similar to that for the Eston Mill. The factory has a cane crushing capacity of 445 tonnes cane per hour (tch) and crushed a total of 2.52 million tonnes of cane in 1998 with a corresponding electricity potential of 277.2 GWh at 110 kWh/tc, using CEST, respectively (Deepchand, 2000). Additionally, however, Sezela has the only existing continuous furfural plant in the world. This is the largest integrated plant in the world while the largest single process plant is in the Dominican Republic.

Furfural is a yellowish brown liquid chemical that is extracted from pentils like hemicellulose in the bagasse at high pressure. The bagasse is first cooked in a pressure cooker for 2 hours after which it is reacted with steam at 10 atmospheres in a reactor. The reactor among other products yields, acetic acid, formic acid, alcohols, aldehydes and ketones. The reactor yields only 3% furfural which is condensed and distilled to give the final product. Generally, furfural is used as a solvent in lubricating oil extraction and furfural alcohol resins have been found useful for casting in foundries. Use of furfural as a nematocide is currently on the verge of commercialisation and is set to replace methyl bromide, a more toxic chemical that is presently used as a nematocide. Annual furfural production of Sezela is 20,000 tonnes.

Sezela not only leads in furfural production, it is also a world leader in other bagasse products like diacetal and 2-3 pentane dione, natural flavourants. Other flavourants include 5 methyl furfural, acetoane etc. In all almost 50 chemical products from bagasse have been identified at Sezela. In general, the down stream products have been found to be more profitable than sugar production.

6.5.3 Merebank Distillery

This distillery is mainly occupied with product development and making potable alcohol.

Potable alcohol is used in making various brands of wine and as a solvent in the pharmaceutical industries. Yeast is added to the molasses and then fermented. The fermented liquid is distilled to yield an azeotropic alcohol concentrate of 95%-96.6%. The azeotropic alcohol is further purified by use of cyclohexane an entrainer for water which yields 99.9% pure alcohol. Annual production is 41million litres of which 70% is exported.

Product development is concerned with developing secondary products from the waste streams of sugar production and the possible products identified so far are;

Waxes
Flavourants
Sweeteners
Lecturose (a laxative)
Furfural (commercially the nematocide will be known as Cropguard).

Bagasse, the solid remains of sugar production contributes only 0.2% of the power that is generated (Electricity Regulatory Journal, 2002). However, this does not reflect the potential that bagasse has to contribute to electricity production which can be increased to ten times present production, but there are a number of constrains identified as follows;

i. apparent large power capacity in ESKOM
ii. low energy tariff charge
iii. low priority on the environment
iv. lack of concrete government support
v. need to internalise environmental costs

Apparent Excess Power Capacity

Presently ESKOM is said to have capacity to supply power in excess of demand. And the existing generation capacity is projected to run out within the next 5 years or so (Business report, 2002). However, this needs to be questioned in view of the fact that about 30% of the population has no access to electricity. Lack of recognition of this unsatisfied demand may be one of the hindrances to entry by Independent Power Producers.

Low Energy Charge

The energy tariff for ESKOM is at present low at 4 cents/kWh in comparison to published data which gives power produced from baggase at about 15 cents/kWh (Coates, 2002; Wienese, 1999). If this cost which seems very high is true then it will discourage sugar mills from producing electricity for export to the national grid as ESKOM will only be willing to buy bagasse generated electricity at its marginal cost of about 4 cents/kWh.

The Environmental Aspect

While admitting that coal will be the main energy base for the foreseeable future it should be realised that coal has a negative impact on the environment and that efforts should be made to make more use of energy resources with lower negative impacts where feasible. Power produced by ESKOM has low cost because the early investments that were made have been paid for and also as in most parts of the world these charges do not reflect environmental costs . The inclusion of these costs may make production of power from bagasse competitive..

6.6 Analysis of survey results

The survey at Eston, Sezela and Merebank showed that electricity from bagasse is already being produced in sugar mills. Diversification of the energy base in South Africa to include bagasse would not be difficult because it will be an off-shoot of the present practice in sugar industries. The potential contribution of bagasse to power generation in Africa is small for most countries and for South Africa the potential ranged from 0.2% to 2.7% using technologies from backpressure turbines to BIG/CC as evaluated in the last chapter .

A way of introducing power produced by bagasse is to get the Government of South Africa to introduce environmental quotas in the production of electricity that compel consumers to purchase a portion of their electrical power from a renewable resource, that would provide facilitation for generation of electricity from bagasse. A comparison of some environmental issues to consider is given in Table 6.3 below.

It was assumed that the ratio of sugar to cane was 1 to 10 in this work, and this is reasonable because the actual production figures for the years 2000/1 and 2001/2 show this to be 1 to 9.

It has been shown that widespread use of bagasse for electricity generation in Africa and South Africa is feasible as sugar industries are already generating electricity for in-house use, however, the potential contribution of bagasse to present electricity is small and needs government support to be realised.

Table 6.3 A comparison of environmental issues relating to Coal and Biomass.

	AIR POLLUTION	CLIMATE CHANGE	LAND USE AND DEGRADATION	WATER USE AND QUALITY	WILDLIFE	RADIATION
COAL	**Very High** • PM,SO_2, NO_X **Moderate** • Hazardous metal (e.g.mercury) and organic air pollutants.	**Very High** • CO_2 from combustion • Coal-bed CH_4 • Energy to mine and transport coal, and manufacture equipment	**High** • Land disturbed by mining • Acid mine drainage • Toxic solid waste and sludge • Nitrogen deposition	**High use** • Coal mining. **Moderate** impact on water quality • Nitrogen deposition • Acid rain **Very high** non-consumptive use for once-through cooling systems • Thermal pollution of rivers, coastal waters. **Low** use in closed cooling systems	**High** • Air pollution • Habitat destruction from acid mine drainage, nitrogen deposition thermal pollution of river and coastal habitat • Fish and mammal kills in cooling systems. **Potentially high** • Climate change	**Low** • Uranium, thorium and daughter products in solid waste
BIOMASS	**Low** to **moderate** depending on technology and fuel • NO_X • Hazardous metals, organic pollutants **Near zero** in virgin wood, **potentially higher** in waste wood • SO_2	**Very low** if growth sustainable otherwise **high** • Transport • fertilizer production • Energy for manufacturing. **Potentially high** benefits if avoids open burning and decomposition.	**Low** or **near zero** use for urban, forest and crop waste; **high** for plantations **potentially moderate benefit** if plantations buffer habitat, protect watershed and topsoil etc.	**High** use, but **very low** impact on water quality. **Potentially moderate** advantage • Watershed protection	**Potentially high** depending on fuel • Habitat destrucpion **Low** to **moderate:** • Air pollution **Potential moderate advantage** • Habitat buffer zones	**Near zero**

Source; Adam Serchuk, 2000.

Notes on the table;

Comparisons are vertical, and the table is qualitative, labelling impacts in order from worst to best as high, moderate, low or near zero.

The table includes life cycle impacts, based not only on power plant operation but fuel production and transport, waste disposal, and other operations (Adam Serchuk, 2000).

CHAPTER 7

POLICIES AND MEASURES

In order to effectively use bagasse for electricity generation, there are certain policies and measures that need to be considered;

7.1 Africa

Africa has abundant renewable energy resources but there has been very little use of these resources for electricity generation. One of the reasons is that there has been very little interest by African governments and clear policy statements outlining plans for using these resources for power generation. Unlike non-renewable energy resources which have been in use for a relatively longer time, renewable energy resources have had very few clearly stated policies . Therefore;

- There is need for clear policies specifically dealing with bagasse and renewable energy resources.

Awareness of the potentials regarding certain renewable energy resources has been low in several African countries because communication in Africa between those with such knowledge and others is generally poor. This has had a negative impact on information flow and awareness with regard to the use of bagasse as an energy resource.

Consequently, availability and potential of bagasse for electricity generation is mostly known by people working in the sugar industries and such knowledge needs to be transferred to a wider community. Based on this lapse, a policy on awareness and information flow is proposed. This is summarised below:;

- Information awareness of the existence, potential and contribution of bagasse to electricity generation in general should be encouraged.

Electricity generated through conventional energy sources such fossil fuels and hydro have formed the main source of grid electricity in most of Africa, but such electricity sources are finding it to be expensive to provide energy for the wider population. This situation also contributes to the large number of people relying on charcoal or firewood for energy activities.

Generation of electricity from bagasse would be even more expensive. The high cost would be exacerbated by the small scale of the emerging electricity generation. In order to cope with these bottlenecks;

- There is need for appropriate financing mechanisms to support bagasse co-generation.

In order to compete favourably with established technologies and to ensure uptake of bagasse technologies;

- Regulatory mechanisms need to be put in place to ensure financial incentives are provided to bagasse power projects.

Facilitation of access for bagasse projects to credit and favourable fiscal incentives can only be assured if;

- Government support is available for enabling successful implementation of biomass-based projects.

7.2 South Africa

South Africa is almost entirely dependent on coal for electricity generation. Being a non-renewable resource it is depleting and has a negative impact on the environment, therefore;

- There is need for diversifying the energy base

Coal mining results in the emission of particulates which are detrimental to human health. But that is not all as there are other

- Dysgenic effects of coal that need to be highlighted

Carbon dioxide is one of the products of coal utilisation which has been found to be the main contributor to global warming. In order to reduce this negative impact

- Increased emphasis should be made of environmental issues

To enhance competition which if properly managed can lead to giving better service to the people

- There is need to bring on board small Independent Power Producers which include power generators from bagasse

Since large scale electricity generation from bagasse is a new undertaking which will inevitably be more expensive than conventional technologies, there will be need that

- Fiscal and financial incentives should be put in place to encourage electricity generation from bagasse

There will also be need that the field be levelled for equal entry of all technologies into the market. This will be ensured if

- Government acts as facilitator to level the playing field and encourage participation of Independent Power Producers.

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

The foregoing chapters have shown that in Africa generally the population has low access to electricity, varying from Malawi at 4% to a maximum of about 30% for the majority of countries in Africa. South Africa's access stands at 70% and Mauritius alone has 100% access (see Table 1.1). The low access is particularly evident in rural areas where the majority of the people live as only 5%-10% of the people have access to modern energy services (UNEP, 2001). Fortunately, most sugar industries are located in areas of need and can contribute to increasing access to electricity. The potential for electricity generation from sugar industries using CEST ranges from 1.5% for South Africa to 67% for Swaziland (see Table 5.5). Even if some of the power generated were to be used for autonomous needs a potential of 40% to 50% would still be available for a country like Swaziland. Other countries with potentials between those of South Africa and Swaziland need to be evaluated on a case by case basis.

The energy generated however, is not proportional to the potential. This is clearly shown in the case of South Africa whose 1.5% potential by CEST is almost 3000 GWh, an amount which is larger than the actual energy generated for most countries in sub-Saharan Africa for the year 1999/2000.

For countries like South Africa, the main driver for advocating use of cleaner or green energy resources and technologies is for environmental reasons. Having signed the UNFCCC in March 1997 , South Africa is committed to look for ways of reducing greenhouse gases. Furthermore for increased security, there is need to diversify the energy supply base using other resources other than coal. Again sugar industries are able to supply these needs provided there is facilitation by the government.

Mauritius is the only country in Africa that has 100% access to electricity (see Table1.1). Yet because of the use of coal off-season for power generation, they too have to strive to find ways of reducing environmental impact by using cleaner resources. There is also the need to reduce vulnerability to imported coal by diversifying to cleaner locally available resources.

Based on reasons stated above, the following recommendations need to considered

i. information about the potential of bagasse be made available
ii. clear enunciation of policies regarding bagasse utilisation for power production
iii. emphasis on reduction of environmental pollution
iv. diversification of the energy base with clean resources
v. increased stress on the need for increasing access to electricity especially in rural areas
vi. provide fiscal and financial incentives for bagasse utilisation
vii. establish appropriate financing mechanisms
viii. facilitate the promotion of bagasse

It has been shown that widespread use of power generated from bagasse is feasible especially for smaller countries in Africa. Bagasse can also play a contributory role in raising access to electricity while diversifying the energy base and ameliorating environmental pollution by providing a clean energy resource. And finally, some policy issues that need to be in place for successful utilisation of bagasse have been given. Yet, in the limited time, scope and financial resources available it was not possible to cover other aspects like the social, financial, agronomic, optimisation of sugar/bagasse/electricity and/or chemical or fibre products production etc. these are left for future research.

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ANNEX

QUESTIONNAIRE USED AT ILLOVO SUGAR COMPANY DURING THE VISIT FROM 01/07/02 TO 05/07/02.

1. What are the stages in your sugar production process?
   (the Raw Sugarcane factory flow diagram by Fletcher and Smith was given in answer to this question, the diagram is similar to that shown in section 3.1 of Chapter 3).

2. Are the legal measures at present favourable for power production from bagasse?

3. What is your experience with Power Purchase Agreements (PPAs)?
   (no experience)

4. If you were to produce more electricity than required for in-house use, what policy measures in your company and at national level need to be in place?

5. Are there any advantages which you can outline of producing power from bagasse in comparison to electricity from the national grid?
   (bagasse can be used renewably and is environmentally friendly)

6. What measures would be required in order to operate boilers at higher pressure (i.e. greater than 40 bars) say for Condensing Extraction Steam Turbines (CEST)?
   (higher water purity, safety measures)

7. What is the factory's energy transformation rate (kWh/tc)?

8. What are your feelings in discussing private power production with ESKOM?

9. If you were to generate electricity for export to the grid, would it be possible to do so throughout the year?

10. What are the drivers that would favour production of power from bagasse? (Acceptable tariffs from ESKOM, financial viability, environmental considerations)

11. Do you know of any existing factories producing power from bagasse and exporting to the national grid? If so, give details.
(Komatipoort, Felixton, Amatikulu and Maidstone. All these factories are not part of Illovo Sugar Company. More details could be obtained from Tongaat-Hulett Sugar Company).

12. Give the characterisation of Illovo Sugar bagasse in terms of; i. Composition (C 24%, H 3%, O 22%, Moisture 50%, Ash 1%)

ii. heating value

(nett heating value = 8 MJ/kg

iii. bulk density

(130 kg/m^3)

iv. production yield

(30% of cane harvest by weight)

13. How long is your cane harvesting season? (Mar,April-Dec i.e 8-9months)