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Bagasse Cogeneration in Tanzania: Utilization of Fibrous Sugarcane Waste

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Abstract – *This paper discusses the utilization of bagasse as an energy resource in Tanzanian sugar factories. While the energy potential of bagasse exceeds the energy demand of sugarcane factories, bagasse is used only to meet the energy demand because of inefficient facilities for surplus production. We estimated surplus electricity supply to the grid by assuming the replacement of existing systems with advanced bagasse cogeneration systems. As a result, annual electricity production was estimated to be 216–859 GWh/y. This can compensate for 100% of electricity from fossil-fuelled thermal plants and make up for a deficit of electricity generated by hydro during dry season in Tanzania. Advanced bagasse cogeneration is also expected to contribute to mitigation of* CO_2*, which was estimated to be* 1.68×10^{8} *kg-*CO_2*/y.*

Keywords – Bagasse cogeneration, CO_2 mitigation, sugar industries, Tanzania.

1. INTRODUCTION

Tanzania's energy sector is characterized by a low per capita consumption of commercial energy (petroleum and electricity) and a relatively large dependence on non-commercial energy, i.e. biomass (in the form of firewood, charcoal and biowaste) as well as human and animal waste. The primary energy balance of Tanzania shows that biomass use accounts for over 90% of energy consumption. Table 1 shows the share of total primary energy supply in Tanzania in 2004 [1]. To date, only about 10% of Tanzanian people enjoy electricity, which means that 90% of people have inadequate energy for cooking, lighting and heating their homes [2]-[4].

Over 90% of electricity supply in Tanzania is from hydro. The rest is from domestic fossil fuels and imports from neighboring countries. Table 2 shows the electricity status in Tanzania in 2004 [1]. In recent years, the Tanzanian economy has shown steady growth, and electricity demand has been increasing accordingly at an annual rate of 8%. There is an urgent need for new electricity supply resources in Tanzania to cope with increasing electricity demand.

Over a million tons of sugarcane is processed per year in Tanzania and 30% of it is disposed of as waste. Since bagasse, which is a by-product or waste, has sufficient heating value, it is generally used for cogeneration to produce power and steam for on-site demand. Although the energy potential of bagasse exceeds the energy demand of sugarcane factories, bagasse is actually only used to meet the energy demand because of inefficient facilities for surplus production. Improved efficiency of bagasse cogeneration by means of an advanced system would allow surplus electricity to be utilized on-site or connected to the grid for commercial use. Introduction of co-firing with other biomass like woody residue or coal should be considered if a sugar factory as power supplier is expected to export ubiquitous power during the off season also. But then sugarcane milling season in Tanzania is usually June to January which meets dry season in Tanzania, bagasse cogeneration would make up for a deficit of electricity generated by hydro. That is, bagasse cogeneration can at least maintain mutually complementary relations with hydro power.

Biomass is regarded as carbon neutral, that is, if CO_2 is emitted to the atmosphere by the combustion of biomass to produce energy, the CO_2 concentration in the atmosphere remains unchanged as long as the CO_2 is refixed by photosynthesis such as by replanting. The use of biomass does not contribute to the net emission of CO_2 and global warming. Since bagasse is an agricultural by-product of sugar from sugarcane, CO_2 emission from sugarcane farming and transportation is considered to be allocated to sugar production. Then, bagasse is considered as carbon neutral and using bagasse instead of fossil fuel as an energy resource would mean a reduction in CO_2 emission.

A study on bagasse cogeneration in Tanzania, conducted by AFREPREN (2004), analyzes the present biomass-based cogeneration and investigates the possible future modification of Tanzanian sugar factories [2]. According to the report, the current energy generation potential from excess bagasse in sugar factories is about 99 GWh per year and it could be about 127 GWh in the future.

The purpose of this study is to clarify how much surplus electricity could be produced by replacing existing boilers with new ones and how much CO_2 could be mitigated by using the system.

Table 1. Share of total primary energy supply in Tanzania, 2004 [1].

Production from:	Unit: ktoe (1000 tons of oil equivalent)
Coal	40
Oil	1209
Gas	107
Hydro	203
Biomass	17181
Total	18749

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Table 2. Electricity Data in Tanzania, 2004 [1].

	Electricity Unit: GWh	Percentage
Production from Coal	86	3%
Production from Oil	36	1%
Production from Hydro	2356	95%
Total Production	2478	
Imports	113	
Domestic Supply	2591	
Energy Sector	86	
Distribution Losses	578	
Total Final Consumption	1927	

2. SUGAR FACTORIES AND BAGASSE IN TANZANIA

Bagasse

Bagasse is fibrous biomass remaining after sugarcane stalks are crushed to extract their juice. Instead of being used as fertilizer, bagasse is usually burned and converted into heat and power in sugar factories.

Each ton of sugarcane can yield about 300 kg of bagasse. Generally, sugar factories use a great amount of energy in sugar processing. The fact that the sugar factories make use of bagasse as its own energy source for sugar production has long been a special feature of the sugar industry. Harnessing bagasse can reduce the cost of waste disposal and of purchasing energy for sugar processing. Since bagasse is transported to sugar factories in the form of sugarcane, its transportation cost can be regarded as minimal. On the whole, bagasse cogeneration benefits the sugar industry and the economic efficiency of the sugar industry depends largely on bagasse cogeneration [5].

There are four sugar factories in Tanzania: Kilombero Sugar Company (KSC), Mtibwa Sugar Estates (MSE), Tanganyika Planting Company (TPC), and Kagera Sugar Company (KSC). Kilombero Sugar Company has two plants, which we designated as K1 and K2, respectively [2]. These plants have bagasse cogeneration systems and are connected to the grid. This study discusses the further possibility of bagasse cogeneration in five sugar processing plants. Table 3 shows the technical data on sugar factories in Tanzania.

Table 3. Technical data on sugar factories in Tanzania.

Factories	MSE	K1	K2	TPC	Kagera
Annual harvested area (ha)	4200	2960	3400	6100	860
Sugarcane yield (t/ha)	80	70	70	80	70
Tones of sugarcane crushed(1000t/y)	336	207	238	488	60
Cane crushing capacity (TCH)	350	80	100	130	160

Current Facilities

The simplest plant setup involves the installation of a boiler producing higher steam pressure than required for the process. This steam is passed through a steam turbine where some of the energy is used to generate mechanical power for driving an alternator for electricity. The steam exits the turbine at a reduced pressure and is then returned to the boiler as condensate or hot water. This energy system is optimized for the production of steam and the produced electricity is governed by the demand for process steam. Boilers are typically run inefficiently to meet factories' own energy needs. Since the steam generated in this way is low in pressure and temperature, the energy obtained from bagasse, that is, power generation efficiency, is only 5–10%.

Cogeneration Options

Generally, large-scale power plants can achieve high power generation efficiency due to advantage of scale in the direct combustion system. However, plants which adopt biomass direct combustion systems are usually small and have comparatively low power generation efficiency. Then, increasing of power generation efficiency and effective utilization of by-products, i.e. heat should be considered in the direct combustion turbine system. Advanced boilers that have higher resistance to heat and pressure are also expected to be introduced because power generation efficiency increases as initial temperature and pressure rises.

IGCC is the power producing cycle that employs more than one thermodynamic cycle. The combined gas turbine and steam turbine processes allow an additional increase in electrical output as a consequence of more favorable thermodynamics. In this study, the IGCC system is considered as promising technology for the future and the scenario envisioned is the IGCC system installed in Tanzanian sugar factories. Though there is no known sugar industry using this technology today, reduction of initial costs and technology upgrade will realize installation of IGCC systems on a commercial basis. Copersucar operated tests in a gasification pilot plant that bagasse and cane trash could be used as feedstock to the gasification process in Brazil. IGCC technology should be installed in the timing of future replacement of facility after some technological innovations.

Two cogeneration options for producing electricity from bagasse, i.e. direct combustion and Integrated Gasification Combined Cycle (IGCC) were studied in this report.

3. METHODOLOGY

Scenario Making

Bagasse production and concomitant surplus electricity production depend on the sugar processing capacity of the factories. First of all, "TCH" (TCH: Tons of cane per hour) is defined as the cane crushing rate of sugarcane factories. Since bagasse cogeneration is often restricted by the short milling period of about 6 or 7 months in Tanzania, it is assume that the number of crushing days is 200 per year following the research method of AFREPREN [2].

According to the CDM/JI Feasibility Study report "Bagasse-based cogeneration project in Brazil" (Association of International Research Initiatives for Environmental Studies, Japan, 2004), the inefficient boilers traditionally used worldwide produce low pressure and temperature rated at about 21 kgf/cm2 and 300°C, respectively [6]. If these inefficient boilers are used, 530 kg of steam is needed for processing each ton of sugarcane, and the remaining steam is used for electricity generation. In this case, electricity generation may be as low as 12 kWh/t cane. Considering that the electricity from these inefficient boilers meets the electricity demand of sugarcane factories, it can be assumed that an electricity demand of 12 kWh/t cane is for sugarcane processing. In this particular case, there is no electricity supply from the sugarcane factories to the grid. In other words, the current electricity production of sugarcane factories is set in this study to 12 kWh/t cane, which is balanced with the electricity demand of these factories. Next, three scenarios as described below were created.

Scenario LEB (Low Efficiency Boiler)

With a 60 kgf/cm2 steam boiler, 72 kWh/t cane of electricity can be produced according to the CDM/JI Feasibility Study report "Bagasse-based cogeneration project in Brazil" by the Association of International Research Initiatives for Environmental Studies (2004) [6]. This boiler is as big as the new ones now commonly constructed in Brazil.

Scenario HEB (High Efficiency Boiler)

With an 80 kgf/cm2 steam boiler, 120 kWh/t cane of electricity can be produced according to the report by the Association of International Research Initiatives for Environmental Studies (2004) [6].

Scenarios IGCC (Integrated Gasification Combined Cycle)

If the IGCC system is installed in sugar factories, 250 kWh/t cane of electricity can be produced according to the research of Copersucar [6].

Table 4. Three scenarios in this study

	Temperature (°C)	Pressure (kgf/cm2)	Electricity Production (kWh/t cane)	Surplus electricity (kWh/t cane)
Current	300	21	12	0
Scenario LEB	480	60	72	60
Scenario HEB	480	80	120	108
Scenario IGCC	-	-	250	238

Table 4 shows electricity production and potential surplus production for three scenarios. This surplus electricity can be supplied from sugar factories to the grid. In Scenarios LEB, HEB and IGCC, the factories can supply 60, 108, and 238 kWh/t cane to the grid, respectively. It is very interesting that simply upgrading the factory boilers can bring huge quantities of surplus electricity.

4. SURPLUS ELECTRICITY AND ITS MAGNITUDE

Table 5 shows potential electricity production assuming 200 days per year and 22 hours per day under the same conditions. In table 5, total tonnage of sugar crushed in the future is expected to be about 3.6million tones in this study. This figure is calculated under the condition that all sugar mills run at full capacity and it is much larger than the tonnage of sugarcane crushed today as a result. But the figure of total tonnage of sugar crushed in the future calculated in this study is supposed to be realizable because sugarcane and sugar production in Tanzania has been increasing significantly and there are ambitious plans to double sugarcane production between 2005 and 2010 [3].

Figure 1 shows the total electricity supply in Tanzania in 2004 and the surplus electricity production calculated in this study. As seen, surplus electricity production in Scenario LEB is nearly equal to the amount of imported electricity plus the current electricity production from coal and oil. Moreover, electricity production from Scenarios HEB and IGCC greatly exceed the amount of imported electricity plus the current electricity production from coal and oil.

Figure 2 shows the surplus electricity production of the three scenarios in this study and the increase of electricity demand in Tanzania assuming that it continues increasing by 8% per year from 2004. If the main purpose of this study was only to employ a bagasse cogeneration system instead of thermal power generation, the best solution would be to introduce the system in Scenario LEB. However, the electrification rate of Tanzania is as low as about 10% in 2004 and it is predicted that electricity demand in Tanzania will continue increasing rapidly. In fact, electricity demand in Tanzania is increasing by 8% per year. Taking these facts into account, Scenario LEB is realistic for the short-term objective but HEB and IGCC are expected to be introduced in the future. As Figure 2 shows, not only Scenario LEB but also Scenarios HEB and IGCC are worth considering in the future. Scenario LEB can cover the increased electricity demand only in 2005. On the other hand, scenario IGCC can cover the increased electricity demand expected in 2007–2008.

Table 5. Surplus with potential power production from bagasse for the three scenarios

Factories		MSE	K1	K2	TPC	Kagera	Total
Cane crushing capacity (TCH)		350	80	100	130	160	820(3,608,000t/y)
Surplus electricity (MW)	Current (20 kgf/cm2)	0	0	0	0	0	0
	Scenario LEB	21.0	4.8	6.0	7.8	9.6	49.2 (217GWh/y)
	Scenario HEB	37.8	8.6	10.8	14.0	17.3	88.6 (390GWh/y)
	Scenario IGCC	83.3	19.0	23.8	30.9	38.1	195.2 (858GWh/y)

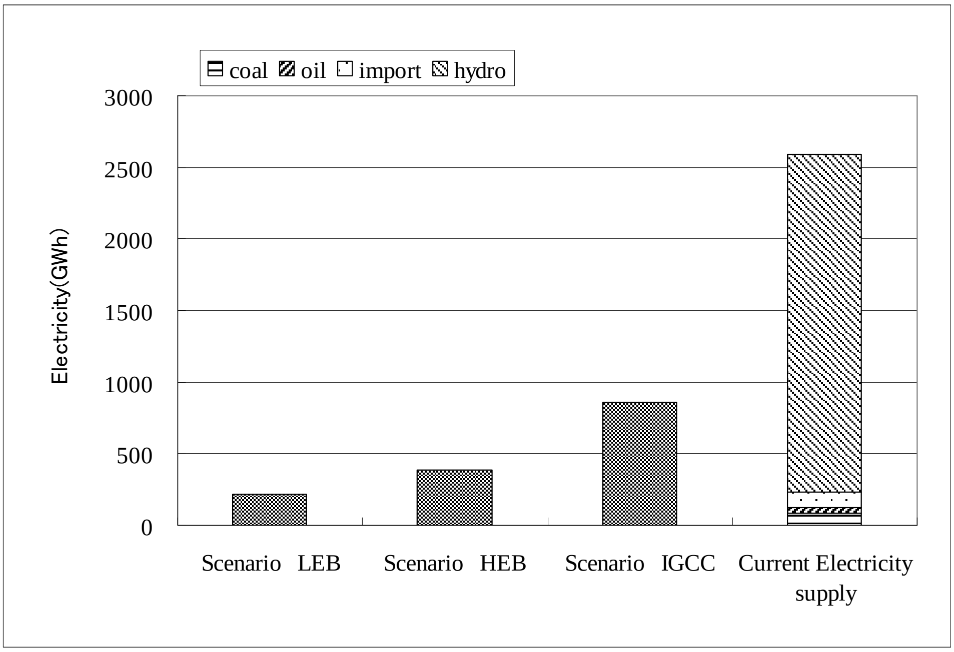

Fig. 1. Total electricity supply in Tanzania in 2004 and potential electricity production for the three scenarios

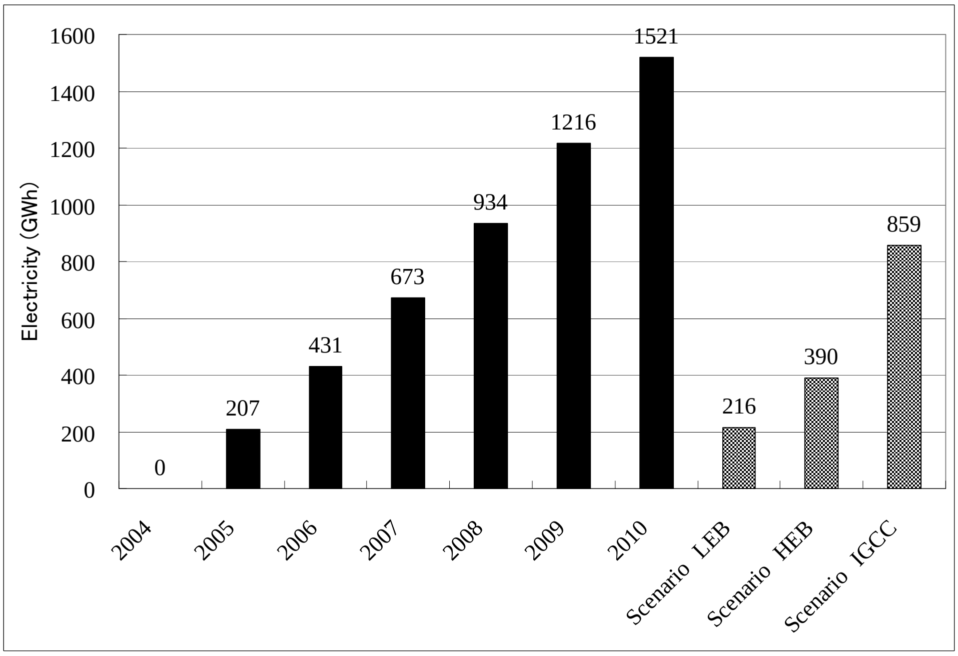

Fig. 2. Increase of electricity demand in Tanzania and potential electricity production for the three scenarios

5. CO_2 MITIGATION

We assume the CO_2 emissions from bagasse cogeneration to be zero in this study. So, the amount of CO_2 mitigation is calculated on the assumption that bagasse cogeneration replaces fossil-fuelled thermal power generation systems. Fossil-fuelled thermal power generation can be 100% replaced by bagasse cogeneration in Scenarios LEB, HEB, and IGCC.

According to "the Report on estimation for emission factor of electricity from all countries by "The Japan Electrical Manufacturers' Association (JEMA)" (2006), the CO_2 emission intensity of Tanzanian thermal power plant is 1.378 kg-CO_2/kWh in 2003 (latest data) [7]. From this data, we calculate the amount of CO_2 mitigation by employing the bagasse cogeneration system instead of fossil-fuelled thermal power generation to be about 1.68×108 kg-CO_2/y in 2004. Because CO_2 intensity of electricity imported from neighboring countries is unknown, the amount of CO_2 mitigation is not calculated in this case. However, imported electricity can be replaced in addition to domestic thermal power generation in the three scenarios. Then, the actual amount of CO_2 mitigation would be more than 1.68×108 kg-CO_2/y.

6. CONCLUSION

It was found from the results of this study that with the availability of advanced cogeneration technologies, sugar factories can harness the on-site bagasse resource to go beyond their own energy requirements and produce surplus electricity for sale to the national grid. It was also found that surplus electricity produced in Scenario IGCC is more than twice that in Scenarios LEB and HEB.

The amount of CO_2 mitigation by employing a bagasse cogeneration system instead of thermal power generation is estimated to be at least 1.68×108 kg- CO_2/y in 2004. Because bagasse cogeneration has more energy potential than what is required to replace thermal power generation, further CO_2 mitigation might be possible. These facts are very important in terms of the Clean Development Mechanism, an arrangement to promote greenhouse gas reduction under the Kyoto Protocol.

Advanced bagasse cogeneration can be an effective electricity supply resource to cover increasing electricity demand in Tanzania. To cope with future electricity demand, more efficient facilities or the IGCC system should be installed in the future.

A number of benefits and ripple effects from bagasse cogeneration can be expected in addition to the surplus electricity supply and CO_2 mitigation. Such expected benefits include increased income for sugar factories, job growth, technology transfer, improvement of energy security in Tanzania, and so on. These benefits will improve the Tanzanian standard of living and promote economic growth.

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