THE ENERGY AND ENVIRONMENTAL IMPACTS OF A COAL AND BAGASSE-FIRED POWER PLANT IN THE SUGAR INDUSTRY

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Abstract

This paper presents a thermodynamic model of a proposed firm power plant co-fired with bagasse and coal under South African conditions. It proposes the energy conversion for a 2.5 million tonnes of sugarcane per year sugar factory and demonstrates that a power plant of up to 120 MW can be supported by such a facility. Carbon emissions are quantified and compared to a 120 MW coal only power plant, to establish expected environmental benefits. It demonstrates the technical feasibility of power plant development in the South African sugar industry and contributes to informed decisions on partly renewable energy power plants.

Keywords: sugar firm power, power plant model, emissions

Introduction

Cogeneration in the sugar industry

It has become standard to sequentially generate electrical power and thermal energy (steam) in the sugar industry. This production of combined heat and power or cogeneration can be done in a variety of cycles. The Topping Cycle, whereby primary heat at the higher temperature end of the Rankine Cycle is used to generate high-pressure and high temperature steam and electricity, has found wide usage in the sugar industry. The ratio of heat to electricity generated varies depending on the type of arrangement. The steam-electric power plant with the extraction-condensing turbine is ideally used because it can be arranged to give a wide range of energy type ratios to suit the processing requirements of the sugar factory. Sugar production involves sugar milling and extraction using a diffuser unit or milling tandem. When the sugar has been extracted, the remaining fibrous residue after dewatering, which is called bagasse, is conveyed to the boilers for burning as fuel or to storage facilities. Its moisture content is around 45 to 55% (Murefu, 2001; Nyamuzihwa, 1999). The sugar processes use low-pressure (exhaust) steam from the turbo-generators/alternators and other steam-driven prime movers like shredders, de-watering mills, drying-off mills and boiler feed water pumps. It is common for high pressure steam to be let down through a let down valve to exhaust steam pressure. After de-superheating this steam is used in the sugar processing or ethanol plants. This use of pressure reducing valves wastes energy, which could be used to power a turbo-alternator.

The bagasse percentage cane can vary from 23 to 37% and averages 30%. This depends on the fibre percentage cane, which normally ranges from 12 to 19%. The rest of the bagasse is made up of fibre (including pith) dissolved solids and water. Its moisture content can be reduced by better de-watering, improved processing or by simply leaving the bagasse to dry. At zero moisture, bagasse calorific value is about 19.25 MJ/kg. The net calorific value of bagasse with a moisture content of 50% is 7620 KJ/kg (Nyamuzihwa, 1999). The bagasse is burnt in boilers that can be designed to use both bagasse and/or coal. The average steam to bagasse ratio is normally 2.2. At a density of 130 kg/m^3, storing bagasse takes a lot of space, hence the need to use boilers that burn as much of it as possible (Murefu, 2001). The boilers generally range from 35 to 150 tonnes of steam per hour, at pressures varying from 15 to 100 bars gauge pressure (one bar = 100 kPa) and temperatures ranging from 300 to 525ºC (Quevauvilliers, 2001).

Traditionally, cogeneration was adopted as a means of incinerating bagasse in a useful way by generating steam in boilers for process heating. Later on electricity generation was introduced. This was regarded as a clever way of converting waste into useful energy and efficiency was not a priority. Higher efficiency created safety problems since bagasse is of low density, is flammable, can spontaneously combust, and ferments and loses calorific value when stored for long periods. In order to balance the factory properly, most systems put in place inefficient combustion low-pressure boilers and used backpressure turbines to convert steam energy into mechanical energy for electricity generation. High-pressure steam was also used for prime movers for the mills, cane shredder and for large pumps. Over time conventional sugar factories with integrated power plants evolved. In some cases the boiler and turbine were transformed to high efficiency units by changing the steam condition, that is, increasing the temperature to between 440 and 460 degrees Celsius and the pressure to between 45 and 60 bars and by using extraction/condensing steam turbines. Thermodynamic efficiencies of the order of 25% were achieved (Quevauvilliers, 2001).

Improving bagasse power generation

There is room for the sugar companies to improve the competitiveness of their operations and save energy, making it possible to export higher volumes of electricity to the grid. The sugar factories that want to export power to the grid can start with modifications and improvements at the factory level in order to improve steam efficiency and minimise internal power consumption. This can be done through measures such as electrification of all steam driven equipment, minimising breakdowns through improved maintenance, installing more efficient juice heaters, evaporators and pans, optimising equipment Mbohwa FFP19.authfinal such as electrical motors and training and educating workers. These activities are further supported by increasing boiler capacity, upgrading the boiler pressure, installation of an economiser, if it has not already been installed, to recover heat losses in flue gas and upgrading of the steam turbine. All these improvements ensure more efficient combustion of bagasse to create surplus power, which can be exported to the grid. Installation of electrically driven hydraulic drives on the mills and the replacement of inefficient single stage steam turbines that drive the cane preparation equipment with electric motors have been shown to reduce total power requirements of the plants. The specific steam consumption can drop from 10 to 6.55 kg/kW$_e$ or less (Rivalland, 2001).

Fitting variable frequency controllers for electric drives, especially those for the pumps, can reduce internal energy consumption in a sugar plant. These enable the motor to reduce power consumption when the liquid flow rate is reduced. Typical payback period for such systems, given the right set of conditions, is one year. Plate juice heaters can be used to replace conventional tube heaters, resulting in savings on specific steam consumption and on cleaning costs. Shell and tube heaters with the correct surface area can also be used. This system has positive effects since it can use steam bled from the first, second and third effect evaporators. The first set of evaporators can be retrofitted with falling film plate evaporators, which have been very successful in the sugar beet industry (Rivalland, 2001). These reduce steam consumption considerably. Rain tray condensers can be used to replace the traditional counter-current cascade condensers. These reduce cooling water requirements and in addition reduce electricity consumption of the cooling pond pumps. The use of continuous pans for first grade sugar boiling and high capacity batch pans for low grade boiling help to smooth steam-bleeding requirements from the evaporators, improve syrup quality and improve overall evaporator operation. The use of first grade continuous centrifugals in place of conventional batch centrifugals decreases the large peak power demand characteristics associated with the high capacity batch machines (Rivalland, 2001; Mutsambiwa, 2001).

Improvements in exhaust steam consumption can result in the reduction of the specific consumption rate of the evaporators to 415 kilograms of steam per tonne of cane processed or less. Typical plants operate at 450-600 kilograms of steam per tonne of cane processed (Martinot, 2000). The evaporator performance in sugar factories can be further improved by bleeding steam to juice heaters down to the last effect of the quintuple effect and the use of the more efficient continuous pans, centrifugals and crystallisers in place of batch processing systems. All prime movers normally consisting of single stage steam turbines should be replaced by electric motors or hydraulic drives where applicable. Steam consumption rate in the beet sugar industry is of the order of 300 kilograms per tonne beet sugar, and the improvements suggested here for the sugarcane industry can enable it to achieve similar efficiencies (Deepchand, 2000; Rivalland, 2001).

Proposed sugar factory power plant

The conversion of thermal energy into electricity can be estimated by a theoretical consideration of the related and possible thermodynamic cycles. The generation of electricity using steam involves the taking of heat from a high temperature source, converting a part of it into work and rejecting the rest to a low temperature sink. One example of such a power producing cycle is the Rankine Cycle, which is most suitable for electrical power production from fuels such as coal, furnace oil, natural gas, agricultural waste, biomass, wood and city waste. All thermal power plants are based on this cycle. It is made up of four components, a boiler, turbine, condenser and a pump. The arrangement is as shown in Figure 1.

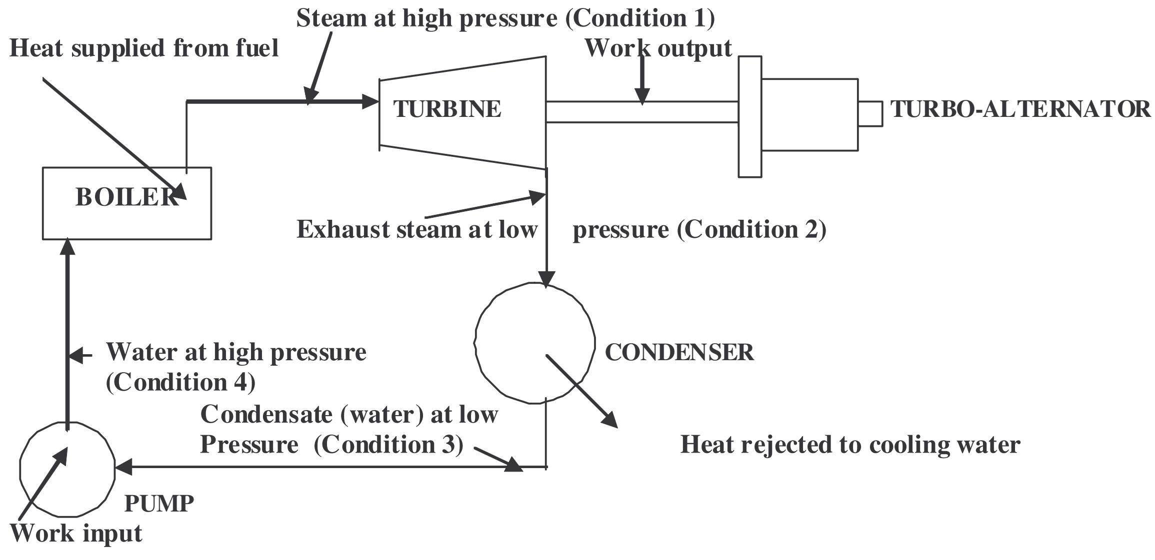

Figure 1. The basic components of the Rankine Cycle.

Thermodynamic equations for the steam power plant

The thermodynamic processes of the cycle are standard and have been widely published. (Iznkaran *et al*., 1989) The main stages of the process are:

- Constant pressure heat addition to the water, which is the working fluid. Water is heated to saturation point. The steam can be above saturation. Dry saturated steam is formed. The steam can also be superheated. This is regarded as condition 1.
- Isentropic expansion (condition 2) of the working fluid, involving reversible and adiabatic expansion of steam in a turbine to low-pressure steam. Work is done on the turbine shaft in the process, to generate electricity.
- Constant pressure heat rejection from the working fluid (condition 3), involving condensation of the low-pressure exhaust steam to saturated water.
- Isentropic compression or pumping of the working fluid (condition 4), which involves pumping of low-pressure water to boiler pressure by doing work on it.

Energy balance for the boiler, assuming 100% efficiency, for a unit mass of working fluid results in the following equation:

$$Q_s = h_1 - h_4 \quad (1)$$

Where Q_s is the heat supplied to the fluid, h_1, h_2, h_3 and h_4 are the specific enthalpy in kJ/kg of the working fluid at conditions 1, 2, 3 and 4 respectively. Energy balance for the turbine, assuming that the turbine casing is well insulated and it does not loose any heat, results in the following equation:

$$W_T = h_1 - h_2 \quad (2)$$

Where W_T is the turbine specific work output. Since this is assumed to be isentropic expansion and using s for entropy:

$$s_1 = s_2 \quad (3)$$

$$s_{f2} + x_2 s_{fg2} = s_1 \quad (4)$$

Where s_{f2} = entropy of the saturated state of water at condition 2
x_2 = dryness fraction of the steam
s_{fg2} = entropy of evaporation.

This is used to calculate the dryness fraction of the steam. The entropy values can be read from the steam tables. The dryness fraction is used in the next equation. The enthalpy at condition 2 is:

$$h_2 = h_{f2} + x_2 h_{fg2} \quad (5)$$

Where h_{f2} = enthalpy of saturated liquid state at condition 2
h_{fg2} = enthalpy of evaporation or latent heat of evaporation and condition 2.

Energy balance for the condenser results in the following equation:

$Q_R = h_2 - h_3$ (6)

Where Q_R is the heat rejected. Energy balance for the pump, assuming 100% efficiency, results in the following equation:

$W_p = h_4 - h_3 = v_w(p_4 - p_3)/1000$ (7)

Where W_p = the pump work input in kJ/kg
v_w = specific volume of water, which is about 0.001 m^3/kg
p_3 = pressure at pump entrance in N/m^2
p_4 = pressure at pump exit in N/m^2

The net plant work output is $W_{NET} = W_T - W_p$. This is equal to the net heat added to the power plant. The net power output of the plant P in kW can be calculated as the mass flow rate of the working fluid multiplied by W_{NET}

The Rankine efficiency or thermal efficiency of the plant is

W_{NET}/Q_s (8)

The effect of boiler pressure on steam power plant efficiency
The thermal efficiency of the power plant rises with an increase in boiler pressure, since this is associated with it an increase in the maximum cycle temperature. This efficiency increase occurs up to a maximum value around 160 bars. Beyond this pressure, the latent heat decreases drastically, resulting in less heat being transferred to the maximum cycle temperature, hence resulting in a slight fall in efficiency for higher pressures. This aspect is also easily noted on the temperature entropy diagram.

Estimating the sugar power plant capacity
The target factory is assumed to process 2.5 million tonnes of sugar cane. The plant is rated to have a maximum potential milling capacity of 600 tonnes of sugarcane per hour (Mbohwa, 2001). This at 30% bagasse on cane provides 180 tonnes of bagasse per hour, which when burnt in boilers provides 1380 GJ of energy per hour based on a bagasse net calorific value of 7670 KJ/kg. This is equivalent to a thermal power of 383.5 MW_t. The fibre in the cane is generally sufficient to enable bagasse produced during milling to supply all the steam necessary for power production and manufacture. With a well-balanced and well-designed factory, an excess of bagasse also remains (or of steam) which may be used for other purposes like supply of electrical energy to the regional network. The economic viability of the cane sugar industry largely depends upon the use of bagasse as a fuel to generate power and process steam. Unbalanced factories may experience a shortfall or surplus of bagasse, resulting in the use of costly auxiliary fuels in cases of shortfalls and costly bagasse disposal techniques when there is surplus bagasse. Where off-crop outside power and irrigation loads are needed they can be met by either increasing factory thermal efficiencies and stockpiling baled bagasse for use during off-crop or by burning an auxiliary fuel.

Table 1 presents the results of a bagasse power plant that consists of a boiler set at various pressures between 10 and 200 bars, while exhausting steam for sugar processing during the off-crop season. In this case it is assumed that the boiler creates saturated vapour, which is then used to power a turbo-alternator resulting in efficiencies in the range 24 to 37%. This is a worst-case scenario that assumes that the steam is not superheated. In reality the steam is superheated resulting in higher efficiencies. It is also assumed that during the off-crop feed-water is supplied to the boilers from the condensate at 60ºC. The off-crop scenario has been chosen for the assessment so that equivalent comparisons can be done for coal-firing and bagasse-firing under similar conditions. This is particularly important for the comparison of emissions. The steam extraction ports are closed and the saturated steam is condensed in the turbine's condensor.

Table 1. Performance of power plant with a condenser exhausting at 0.2 bar, 60ºC.

Pressure (bars)	s_1	x_2	h_1	H_2	W_p	h_4	Q_s	W_t	W_{NET}	Efficiency
10	6.5819	0.812	2777.9	2167.4	0.98	251.98	2525.92	610.48	609.50	24.13
20	6.3366	0.778	2797.5	2085.7	1.98	252.98	2544.52	711.82	709.84	27.90
30	6.1836	0.756	2802.4	2034.7	2.98	253.98	2548.42	767.70	764.72	30.01
40	6.0681	0.740	2800.4	1996.2	3.98	254.98	2545.42	804.19	800.21	31.44
50	5.9734	0.726	2794.2	1964.7	4.98	255.98	2538.22	829.55	824.57	32.49
60	5.8904	0.715	2785.1	1937.0	5.98	256.98	2528.12	848.11	842.13	33.31
70	5.8158	0.704	2773.4	1912.1	6.98	257.98	2515.42	861.26	854.28	33.96
80	5.7472	0.694	2760	1889.3	7.98	258.98	2501.02	870.72	862.74	34.50
90	5.682	0.685	2744.7	1867.6	8.98	259.98	2484.72	877.15	868.17	34.94
100	5.6199	0.676	2727.9	1846.9	9.98	260.98	2466.92	881.04	871.06	35.31
110	5.5594	0.668	2709.3	1826.7	10.98	261.98	2447.32	882.60	871.62	35.62
120	5.5	0.660	2689.1	1806.9	11.98	262.98	2426.12	882.19	870.21	35.87
130	5.441	0.651	2667.4	1787.2	12.98	263.98	2403.42	880.15	867.17	36.08
140	5.3807	0.643	2642.5	1767.2	13.98	264.98	2377.52	875.35	861.37	36.23
150	5.3181	0.634	2615.3	1746.3	14.98	265.98	2349.32	869.01	854.03	36.35
160	5.2531	0.625	2585.1	1724.6	15.98	266.98	2318.12	860.47	844.49	36.43
170	5.186	0.615	2552.1	1702.3	16.98	267.98	2284.12	849.83	832.85	36.46
180	5.1137	0.605	2514.4	1678.2	17.98	268.98	2245.42	836.22	818.24	36.44
190	5.0346	0.594	2471.4	1651.8	18.98	269.98	2201.42	819.58	800.60	36.37
200	4.9436	0.581	2420.1	1621.5	19.98	270.98	2149.12	798.60	778.62	36.23
$P_3 = p_2$ is	0.2									
Pressure $p_1 = p_4$			h_{f2} (.2 bar)	251.5						
s_{f2} at 0.2 bar is	0.8322		h_{fg2} (.2 bar)	2358.3						
s_{fg2} at 0.2 bar	7.0773									
$H_3=h_f$	251									

It is noted that the percentage point increase in efficiency after a pressure of 80 bars is very small, just above 1% and this suggests that it is better to size the boilers at that pressure. A pressure of 80 bars was therefore chosen for the proposed South African power plant. In reality, it is necessary to superheat the steam to improve the power plant efficiency and to set an optimal boiler operating pressure. Assuming that the steam requirements for sugarcane processing are based on 60% steam on cane (Mugadhi, 1999; Murefu, 2001), 360 tonnes of steam per hour are needed to process the sugar at a pressure of 2 bars. This can come from three boilers that are rated at a minimum of 120 tons of steam per hour.

The calculations were done for the performance of the proposed power plant using superheated steam for different temperatures between 300 and 1000ºC. The results are shown in Table 2. The expected efficiencies are calculated using equation (8). This way the degree of superheat can be set based on the desired or targeted efficiency. In this case a superheat temperature of 550ºC was chosen, and this sets the thermal efficiency at 36.66%. The thermal power from the bagasse combustion as discussed earlier of 383.5 MW_t results in 141.3 MW_e.

Table 2. Performance of a power plant using superheated steam and exhausting at 0.2 bar, 60ºC.

Temp ºC	s_1	x_2	h_1	h_2	W_p	h_4	Q_s	W_t	W_{net}	Efficiency
300	6.066	0.740	2784	1995.5	7.98	258.98	2525.02	788.49	780.51	30.91
325	6.21	0.760	2896	2043.5	7.98	258.98	2637.02	852.51	844.53	32.03
350	6.332	0.777	2986	2084.1	7.98	258.98	2727.02	901.86	893.88	32.78
375	6.441	0.793	3065	2120.5	7.98	258.98	2806.02	944.53	936.55	33.38
400	6.54	0.806	3138	2153.5	7.98	258.98	2879.02	984.55	976.57	33.92
450	6.72	0.832	3272	2213.4	7.98	258.98	3013.02	1058.57	1050.59	34.87
500	6.881	0.855	3398	2267.1	7.98	258.98	3139.02	1130.92	1122.94	35.77
550	7.029	0.876	3520	2316.4	7.98	258.98	3261.02	1203.60	1195.62	36.66
600	7.167	0.895	3641	2362.4	7.98	258.98	3382.02	1278.62	1270.64	37.57
650	7.298	0.914	3761	2406.0	7.98	258.98	3502.02	1354.96	1346.98	38.46
700	7.423	0.931	3881	2447.7	7.98	258.98	3622.02	1433.31	1425.33	39.35
750	7.542	0.948	4001	2487.3	7.98	258.98	3742.02	1513.66	1505.68	40.24
800	7.656	0.964	4122	2525.3	7.98	258.98	3863.02	1596.67	1588.69	41.13
850	7.766	0.980	4245	2562.0	7.98	258.98	3986.02	1683.02	1675.04	42.02
900	7.873	0.995	4368	2597.6	7.98	258.98	4109.02	1770.36	1762.38	42.89
950	7.976	1.009	4492	2632.0	7.98	258.98	4233.02	1860.04	1852.06	43.75
1000	8.076	1.024	4618	2665.3	7.98	258.98	4359.02	1952.72	1944.74	44.61
$P_3 = p_2$ is	0.2									
Pressure $p_1 = p_4$			h_{f2} (.2 bar)	251.5						
s_{f2} at 0.2 bar is	0.8322		h_{fg2} (.2 bar)	2358.3						
s_{fg2} at 0.2 bar is	7.0773									
$H_3=h_f$	251									

The proposed power projects are for three 40 MW_e turbo-alternators with a total capacity of 120 MW_e. This is because energy losses are expected in the turbine and throughout the system. An investment of at least US$120 million and at most US$240 million is expected, assuming a capital cost of between US$1000 and US$2000 per kilowatt of installed capacity. (Mbohwa, 2003). More power is expected to be available for export in the off-crop season than during the crushing season. The system can be sized so that the use of coal and bagasse in the off-crop season gives a maximum power output of 120 MW_e. It is also noted that efficiencies and power output during the on-crop season would present less problems, since efficiency would be higher due to the fact that water can be fed to the boiler at saturation point, which is at 2 bars and 120ºC.

Experiences in Mauritius and Reunion have shown that boilers operating at 82 bars and 525ºC fired by bagasse and with a maximum capacity of 140 tonnes of steam per hour, are feasible (Quevauvilliers, 2001). Table 3 compares performance characteristics of the proposed plant with those of an existing plant in Mauritius.

An environmental appraisal of the proposed project is shown in Table 4, in comparison to a baseline, whereby power continues to be supplied from a coal-fired thermal power station of the same size (Mbohwa, 2003). It is assumed that the sugar mill will invest in capacity expansion, sugarcane production expansion and bagasse handling so that they can process 600 tonnes of cane per hour. The proposed power plants are separate from the sugar mills, getting condensate and bagasse from them in exchange for electricity and steam. An electricity export level of 130-140 kWh per tonne of cane is assumed based on CTBV performance data (Quevauvilliers, 2001). South African coal thermal power plants are assumed to operate at 0.5 kg of coal per kWh using a calorific value of 28 MJ/kg and releases 2.62 kg of CO_2 for every kg burnt. (UNEP, 1997) The project results in carbon dioxide emission savings of close to 800 000 tonnes per year based on combustion only and considering bagasse replacement of coal. This is derived from results presented in Table 4 and considers the combustion of fuels only. Other possible areas of improvement at such a sugar plant include improvement of load profiles, plant availability, automation requirements and meeting environmental constraints through cleaner production. The use of coal in firm power plants would be reduced due to more efficient burning of bagasse. The use of renewable fuel like bagasse will mitigate net emissions of carbon dioxide.

Table 3. The sugar and power plant characteristics at CTBV and proposed power plant.

	Compagnie Thermique de Belle Vue (CTBV)	**Proposed sugar power plant charateristics**
TSC per year (mil)	.85	2.5
Sugar (000s tons)	75	290
TSC daily (000s)	7.44	11.76
TCH	310	600
Crushing season	6-7 months	9-10 months
Bagasse %Cane	30%	30%
Bagasse (000s tons)/year	245	750
Boilers	82 bars, 525˚C and 260-280 tons per hour (t/h) steam, 2 units single flue gas type.	80 bars, 3 boilers, 140 t/h steam per boiler at a superheat temperature of 550˚C.
Turbo alternators	11 kV, 5305 rpm, 2 units each 35.6 MW_e, condensing extraction turbines, multistage.	Condensing extraction turbines, multi-stage at 40-45 MW
Installed Capacity	70 MW_e, operates at 60-70 MW_e	135 MW_e operate 120 MW_e
Steam per kW_e	4 kg per kW_e at maximum output	4 kg per kW_e
Energy Exports 2002 target MWh	325	560
Exports kWh/TSC	130	130-150
Electrical energy per TSC	150	150-170

TSC = tons of sugarcane crushed; TCH = tons of cane per hour (Mbohwa, 2003; Murefu, 2001; Nyamuzihwa, 1999; Quevauvilliers, 2001; Mutsambiwa, 2001; Deepchand, 2000; Deepchand, 2001; Rivalland, 2001 and Mbohwa, 2001).

Table 4. Environmental performance of the proposed power plant and equivalent coal plant.

Plants specific assumptions	Baseline	Proposed project alternative
Installed capacity, MW_e	120	120
Total energy generation for the proposed new South African sugar industry power plant, GWh	1520 GWh	1520 GWh
	-	(Biomass) 815 GWh
	1520 GWh	(Coal) 705 GWh
Available power to grid	1320GWh	1320 GWh
Specific fuel consumption, t per GWh	500 tons coal per GWh	987 tons bagasse per GWh
Eletricity to the grid produced by: Coal Bagasse	 100% 0%	 705 GWh 615 GWh
Coal carbon content	Coal used in South African power plants has about 71.5% carbon content	
Power Plant emissions, t CO_2 per year	(from coal) 1,694,616	(from coal) 905,079

Mbohwa, 2003; Nyamuzihwa, 1999; Quevauvilliers, 2001; Mutsambiwa, 2001; Deepchand, 2000; Deepchand, 2001; Mangwengwende, 2002; UNEP, 1997.

Such a project will be fraught with risk, and Table 5 indicates how some of the risk can be reduced (based on previous experiences of investing in similar bagasse-powered plants in Mauritius and Reunion).

Table 5. Mitigating care of risks for the new plant (Quevauvilliers, 2001).

Type of risk and description	The way it was covered
Commercial risks in construction, like cost overrun, late completion and faulty design.	Engineering and procurement contract with a reputable company.
Commercial operational and maintenance risks. Ensure correct operations and repairs	South Afrcan management, with the technical partner taking most of the responsibility
Commercial risks regarding sales of electricity. If bagasse power is not considered as base load, power produced can be wasted.	Power purchase agreement with ESKOM, which has to be guaranteed by government. Take or pay contract for first 450 GWh and indexation of kWh price to reflect production costs.
Commercial risks related to the supply of bagasse, coal and water.	Contract has to be signed with coal supply company. Product exchange contract has to be signed with the sugar mill. Water supply and back-up agreements also need to be signed. Pay bagasse transfer price to farmers to promote production.
Political risks related to changes in law, changes in incentives and currency limits.	Necessary change in law clauses have to be included in the agreement with government. Concession agreement and guaranteed access to foreign currency have to be ensured too.

Conclusion

Bagasse power development has the advantages that it is environmentally friendly, uses renewable energy and it encourages the use of sugar trash in future. Leaving sugar trash to rot and provide compost manure has some environmental problems in that it releases methane gas, which is a greenhouse gas that is believed to contribute to global warming. Sugar factories in future may have to co-generate heat for sugar processing and power for normal usage in a factory and for sale if they are to remain viable in light of falling sugar prices on the world market. It is noted that co-generation for export to the grid in the sugar industry will help to save investment costs by the national utility while enabling the modernisation and rehabilitation of the sugar industry in South Africa. A 2.5 million tonnes of cane per year plant can support a plant of 120 MW capacity based on thermodynamic assessment. The legal and regulatory framework should to be made more favourable to private sector participation in power production by de-linking political decisions from commercial considerations. A long-term marginal cost, that is costing of electricity to include depreciation and capital replacement cost, can be used to price bagasse electricity if it is to become viable. The South African government could meet the portion of the capital cost that compensates for the fact that ESKOM is capitalised from taxpayers' contributions. That way a more level field would be created for all types of electricity production methods.

REFERENCES

Deepchand K (2000). Bagasse Energy Cogeneration in Mauritius and its Potential in the Southern and East African Region. Paper No. 272, Presented at an AFREPREN Workshop, Nairobi, Kenya, Sept. 2000.

Deepchand K (2001). Overview of Commercial Scale Cogeneration of Bagasse Energy in Mauritius. Paper Presented to the AFREPREN Energy Workshop on Power Sector Reforms- Implications for the Cogeneration Industry, Quatre Bornes, Mauritius, Aug. 2001.

Iynkaran K and Tandy DJ (1989). *Applied Thermofluids and Pollution Control*. Prentice Hall, New York, USA.

Mangwengwende S (2002). Power Sector Reforms and the Tariff Question: The case of the Zimbabwe Electricity Supply Authority and the implications for Sub-Saharan Africa. Prepared for the Uganda National Energy Policy Seminar, Entebbe, 2002.

Martinot E (2000). Renewable energy markets and the Global Environment Facility. Financial Times, Renewable Energy Report, Issue 12, Feb. 2000, pp18-22.

Mbohwa CT (2001). Adaptation, Development and Use of Modern Biofuel/Biopower Technologies: A Case Study of Cogeneration Technologies in the Sugar Industry in Zimbabwe and Lessons From the Mauritius Experience. Presented at an AFREPREN Workshop, Quarte Bornes, Mauritius, Aug. 2001.

Mbohwa CT (2003). Bagasse energy cogeneration potential in the Zimbabwean Sugar Industry. Renewable Energy, Elsevier. Science Ltd, 28 issue 2, pp191-204.

Mugadhi A (1999). Case Study on Steam Raising: A complete energy balance for Triangle Sugar Limited. A Report Prepared for Triangle Sugar Limited, Triangle, Zimbabwe.

Murefu M (2001). Steam Reticulation at Hippo Valley Sugar Estates. Publication of the Department of Mechanical Engineering, University of Zimbabwe, Harare.

Mutsambiwa S (2001). Sale of Power to the Grid: Challenges Faced by Sugar Factories in Zimbabwe. Paper Presented to the AFREPREN Energy Workshop on Power Sector Reforms-Implications for the Cogeneration Industry, Quatre Bornes, Mauritius, Aug. 2001.

Nyamuzihwa S (1999). Energy Management at Triangle Limited. Publication of the Department of Mechanical Engineering, University of Zimbabwe, Harare.

Quevauvilliers JM (2001). Implications for Cogeneration Industry: Description of an Advanced Cogeneration Plant. Paper Presented to the AFREPREN Energy Workshop on Power Sector Reforms- Implications for the Cogeneration Industry, Quatre Bornes, Mauritius, Aug. 2001.

Rivalland R (2001). Cogeneration - The IPP Perspective. Paper Presented to the AFREPREN Energy Workshop on Power Sector Reforms- Implications for the Cogeneration Industry, Quatre Bornes, Mauritius, Aug. 2001.

UNEP (1997). Implementation strategy to reduce environmental impact of energy related activities in Zimbabwe. Working Paper No. 5, January 1997.