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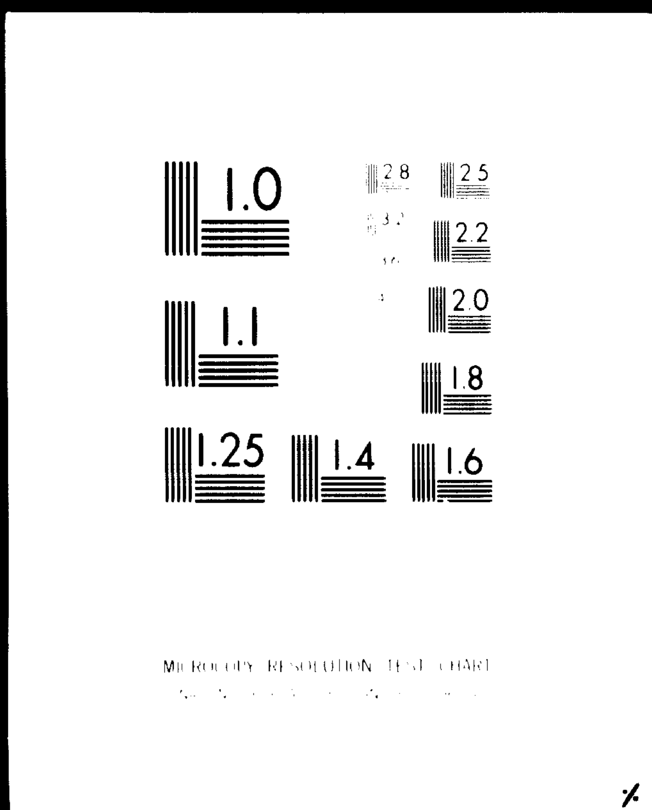
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ENERGY CONSUMPTION IN THE SUGAR INDUSTRY 1/

by

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INTRODUCTION

The question of energy consumption in any industry is very complex and wide ranging. Various studies have been undertaken which trace the entire network of energy inputs and outputs. The present paper, however, is based on a much narrower definition of energy in that it is mainly concerned with the consumption of oil, electricity and firewood in the production of sugar and its distribution. In this way it is hoped to illustrate the differences in 'bought in' fuels between the technologies and scales of production.

For the purposes of this study the sugar industry has been subdivided into three distinct phases; namely the agricultural production of the raw material including harvesting and transport to the factory, the conversion of cane to sugar in the factory, and the distribution of the final product to the consumer.

The paper is divided into four main sections. Firstly the three stages are described in turn, identifying the major uses of energy and possible alternatives particularly in the agricultural stage. The second and third sections present the parameters and calculations for the total energy requirements for a large-scale vacuum pan factory supplied by a rainfed plantation and a small-scale open pan factory supplied by a rainfed factory farm. These alternatives are also considered at long and short crushing seasons (216 and 112 days respectively). The fourth section discusses possible alternatives within the large-scale factory for either the production of surplus bagasse or surplus electricity.

I. ENERGY CONSUMPTION IN THE SUGAR INDUSTRY

In the agricultural stage the calculation of energy requirements has been based on the fuel and lubricant consumption in a semi-mechanized form of agriculture i.e. the main operations are mechanical but weeding, fertilizer application and cane cutting are carried out manually. Work rates for each operation have been taken from data collected during visits to various sugar estates in the course of the UNEP/UNIDO study; the operations and work rates are given in Annex 1. These average rates, however, are subject to considerable variation depending on such factors as soil type, weather conditions, field layout and terrain. The state of repair of agricultural equipment and the skill of the drivers are also important factors. The cane harvesting system is based on manual cutting of burnt cane, grab loading and tractor-trailer transport to the factory cane yard, in the large-scale situation and cutting of green cane, manual loading and tractor-trailer transport to the small-scale factory.

The scope for choice in the agricultural operations is very wide, varying from a sophisticated fully mechanized system including planting and harvesting to the simpler and widely practised fully manual/animal powered system. In the context of this paper this range of possibilities represents a trade-off between fuel consumption and manual/animal power. Broader environmental and social questions of increased mechanization are discussed more fully elsewhere (1). In order to fairly compare the energy use with varying degrees of mechanization it would be necessary to include man and animal power. This presents problems of measurement of the 'fuel' input, land required to produce the food, energy inputs required to till that land etc. etc. Using data from the paper on mechanization the diesel fuel consumption and the manpower requirements on a per tonne cane basis have been calculated. The results are presented in Annex 2 and clearly show the differences in efficiency between long and short season, plantation and outgrowers and irrigated and rainfed regimes. The introduction of mechanical harvesting in the large-scale situation has a marked effect on the fuel and manpower requirements.

In the second stage in the process i.e. the production of sugar the major source of energy comes from the sugar cane itself in the form of bagasse. In the factory, energy is required in two forms namely for process heating and for power. In a vacuum pan factory it is possible to achieve a balance between the production of bagasse and the steam consumption so as to minimize the need for supplementary fuels. Steam economy can also be taken further to create a surplus of bagasse for further processing or to produce surplus electricity. This will be discussed in Chapter IV.

Typically live steam is used for power generation and exhaust steam for process heating. The most obvious example of steam economy is the multiple effect evaporator where steam is maintained in a closed system for further use.

Complete self sufficiency, however, is not possible due to the uneven nature of the power demand. For example the start of a new season will require the use of oil-fired boilers until the mills begin to run and sufficient bagasse is available. Power for lighting etc. is needed from the National Grid until the bagasse-fired boilers are in full operation. Supplementary fuel must also be available to maintain the juice, syrup and massecuite processing while the mills are stopped. In the closed season alternative sources of power are required and it is for this reason that factories would normally be linked to the National Grid. The longer the crushing season the greater is the reliance on a renewable resource i.e. bagasse with a lower consumption of supplementary fuel per tonne cane.

The parameters used in the calculations are based on field data and should be representative of a typical, efficiently run factory.

The energy consumption within the small-scale open pan factory is very different. As the name implies the open boiling pans preclude steam economy. Coupled with the lower milling efficiency and hence higher moisture content of bagasse and the use of simple furnaces, this technology has to import a much greater proportion of its fuel needs.

As the bagasse, along with firewood and any other agricultural waste that may be available, only provides enough energy for the pan boiling, electricity or diesel motors must be used to drive the mills, crystallizers and centrifugals. The data used in the calculations represent the supplementary fuel requirements of a 100 tcd unit working 16 hours per day and with an available source of electricity.

The distribution of sugar to the consumers is a stage which is very difficult to measure with accuracy and reality. There are three major factors to be considered. Firstly, the location of the sugar producing unit in relation to the markets; sugar factories tend to be isolated from centres of population. Secondly, the population density and its variation throughout a region or country; the more concentrated the population the lower the energy requirements for distribution. Thirdly, probably the most influential factor is the institutional constraint. Sugar is typically a highly taxed and controlled commodity and as such centralization of distribution is likely to cause double journeying and handling etc. As these factors are very country-specific calculations have been based on simple models which assume direct distribution from the factory to an evenly distributed population with an average sugar consumption per capita.

II. CALCULATION OF ENERGY REQUIREMENTS
- LARGE SCALE TECHNOLOGY

The calculations in this section are based on a factory crushing capacity of 200 tonnes of cane per hour (tch) or 4800 tcd. Two situations are examined, namely the long and short crushing seasons. The annual requirement of cane is 1,036,800 t in a 270 day season with 216 crushing days and 576,000 t in a 150 day season with 120 crushing days.

A. Agriculture and harvesting

The agricultural operations, listed with work rates in Annex 1, are the same for both long and short season in terms of plant crop and ratoon crop cultivations. The cane cycle however is different, being plant plus two ratoons in the long season and four ratoons in the short season. It has been assumed that cane yields are 110 t/ha (plant) and 90 t/ha (ratoons) in the long season, rainfed regime. The yields in the short season, rainfed situation are taken to be 52 t/ha (plant) and 44 t/ha (ratoons)

Assuming that the land has previously been cleared or cultivated and so the first agricultural operation is ploughing, the number of machine hours per hectare are as follows:-

Plant crop	12.4 hrs	75 hp wheeled tractor		
	4.4 hrs	62 hp	-	-
	4.1 hrs	grab loader		(110 t/ha)
	2.3 hrs	-	-	(52 t/ha)

<u>Ratoon crop</u>	2.4 hrs	75 hp wheeled tractor
	6.0 hrs	62 hp - -
	3.3 hrs	grab loader (90 t/ha)
	1.9 hrs	- - (44 t/ha)

<u>Final ratoon</u>	5.4 hrs	75 hp wheeled tractor
	8.0 hrs	62 hp - -
	3.3 hrs	grab loader (90 t/ha)
	1.9 hrs	- - (44 t/ha)

In order to calculate the diesel fuel consumption during these operations the following consumption rates have been used.

75 hp wheeled tractor	- 10 l/hr
62 hp - -	- 8 l/hr
grab loader	- 20 l/hr
crawler tractors	- 15 l/hr
lighting units	- 6 l/hr

Diesel consumption in the P+2R cycle is therefore

20.2 hrs x 10 l/hr	=	202
18.4 hrs x 8 l/hr	=	147
10.7 hrs x 20 l/hr	=	214
		563 litres

This quantity of fuel is used to produce a total of 290 tonnes of cane per ha per cycle which is equivalent to 1.94 l/tc. A further 0.1 l/tc is added to allow for transport of seedcane and fertilizer. This has been calculated on the basis of a planting rate of 5 t/ha on 3575 ha/yr and a fertilizer application of 200 kg/ha/yr on 17,518 ha.

Diesel consumption in the P+4R cycle is therefore

25.0 hrs x 10 l/hr	=	250	
20.4 hrs x 8 l/hr	=	243	
9.9 hrs x 20 l/hr	=	198	
		691	litres

This quantity of fuel is used to produce a total of 228 tonnes of cane/ha per cycle which is equivalent to 2.03 l/tc. A further 0.14 l/tc is added to allow for transport of seedcane and fertilizer. This has been calculated on the basis of a planting rate of 5 t/ha on 2526 ha/yr and a fertilizer application of 540 kg/ha/yr on 12,421 ha.

Cane transport calculations have been based on the areas, numbers of tractors and average journey lengths presented in the economic viability paper. (2)

In the long season situation machine hours are as follows:-

29, 75 hp tractors	x 216 days	x 18 hrs/d	=	112752	hrs
3, 62 hp -	x "	"	=	11664	hrs
14, crawlers	x "	"	=	54432	hrs
6, lighting units	x "	12 hrs/d	=	15552	hrs

Diesel consumption is therefore

112752 hrs	x 10 l/hr	=	1,127,520
11664 "	x 8 l/hr	=	93,312
54432 "	x 15 l/hr	=	816,480

15552 hrs x 6 l/hr	=	93,312
		2,130,624 litres

This quantity of fuel is used to transport 1,036,800 tc/yr which is equivalent to 2.055 l/tc.

Total fuel consumption in the production, harvesting and transport of 1,036,800 tc/yr from a P+2R cycle is thus 1.94 + 0.1 + 2.055 = 4.095 l/tc

In the short season situation machine hours are as follows:-

26, 75 hp tractors	x 120 days	x 18 hrs/d	=	56,160 hrs
4, 62 hp "	"	"	=	8,640 hrs
14, crawlers	"	"	=	30,240 hrs
8, lighting units	"	x 12 hrs/d	=	11,520 hrs

Diesel consumption is therefore

56,160 hrs x 10 l/hrs	=	561,600
8,640 hrs x 8 l/hrs	=	69,120
30,240 hrs x 15 l/hrs	=	453,600
11,520 hrs x 6 l/hrs	=	69,120
		1,153,440 litres

This quantity of fuel is used to transport 576,000 tc/yr which is equivalent to 2.002 l/tc.

Total fuel consumption in the production, harvesting and transport of 576,000 tc/yr from a P+4R cycle is thus 3.03+0.14+2.002 = 5.172 l/tc

In both cases an allowance for lubricating oil is assumed to be 15% i.e. 0.61 l/tc and 0.78 l/tc respectively.

B. Factory processing

Supplementary fuels are taken to be furnace oil, lubricating oil and electricity.

The parameters used are as follows:-

long crushing season

0.6	l/tc	furnace oil
0.1	l/tc	lubricating oil
2.1	kwh/tc	electricity

short crushing season

0.8	l/tc	furnace oil
0.1	l/tc	lubricating oil
9.2	kwh/tc	electricity

The difference between the two is entirely due to the length of the closed season as it is assumed that during normal running time consumption of fuel would be the same.

C. Sugar Distribution

In order to construct a simple model two basic assumptions have been made for each of the long and short season situations. Calculations in this section are based on per tonne sugar basis.

The long season, rainfed regime could represent Kenya. As such sugar consumption has been assumed to be 13.6 kg/head which is the case. Similarly population density has been taken as 150 persons per km^2 which could represent Western Kenya, although obviously not in the homogeneous manner assumed in the model. Sugar production from 1,036,800 tonnes of cane is 110,000 t/yr. At 13.6 kg/head this would satisfy the needs of 8,088,235 people. With an even population distribution around the factory of 150 per km^2, these people would be found within an area of 53,922 km^2 or within a radius of 131 km. Average trip length is $\frac{2}{3}$ r as the crow flies = 87.3 km. This can be doubled to 175 km.

It is assumed that the sugar is distributed in 10 t trucks with a fuel consumption of 3.5 km/l.

Therefore 110,000 t can be distributed in 11,000 return journeys of 175 km each on average.

Fuel consumption = 11,000x175x2x3.5
= 13,475,000 litres
= 122.5 l/t sugar.

The effect of a fourfold increase in population density, to represent distribution in a town for example, is to half the average journey length. Fuel consumption would also be halved to 61.25 l/t sugar.

The short season, rainfed regime could represent Ghana. Sugar consumption has therefore been taken as 10 kg/head and population density as 75 persons per km^2 which is representative of southern Ghana.

Sugar production from 576,000 tonnes of cane is 61,000 t/yr. At 10 kg/head this would satisfy the needs of 6,100,000 people. These people would be located in an area of 81,333 km^2 or within a radius of 161 km Average trip length is 107.3 km, which is doubled to 215 km.

Therefore 61,000 t can be distributed in 6,100 return trips of 215 km each on average.

Fuel consumption = 6,100x215x2x3.5
= 9,180,500 l
= 150.5 l/t sugar

The effect of a fowfold increase in population density is to half the fuel consumption to 75.25 l/t sugar.

In both cases lubrication is taken as 10% i.e. 12.25 l/ts and 15.05 l/ts respectively.

In order to summarize the fuel requirements it is necessary to convert each type of energy to a common unit - the kilojoule (KJ). The following conversion factors have been used (see reference (3)),

Diesel	-	0.84 SG, 42,000 KJ/kg net calorfic value
Lubrication	-	0.88 SG, 40,400 " " " "
Furnace oil	-	0.93 SG, 39,000 " " " "
Electricity	-	1 kw = 1KJ/second.

Long season, 200 tch factory - summary

Agriculture

4.095 l diesel/tc	=	144,472 KJ
0.61 l lub. oil/tc	=	21,687 KJ
		166,159 KJ

166,159 KJ/tc is equivalent to 1,561,895 KJ/t sugar.

Factory

0.6 l furnace oil/tc	=	21,762 KJ
0.1 l lub. oil/tc	=	3,555 KJ
3.1 kwh/tc		11,160 KJ
		36,477 KJ

36,477 KJ/tc is equivalent to 342,884 KJ/t sugar.

Distribution - low population density

122.5 l diesel/t sugar	=	4,321,800 KJ
12.25 l lub. oil/t sugar	=	435,512 KJ
		4,757,312 KJ

At high population density	=	2,378,656 KJ
Total Energy Consumption	=	6,662,091 KJ/t sugar
or		4,283,435 KJ/t sugar at high population density

Short season, 200 tch factory - summary

Agriculture

5.172 l diesel/tc	=	182,468 KJ
0.78 l lub. oil/tc	=	27,731 KJ
		210,199 KJ

210,199 KJ/tc is equivalent to 1,975,871 KJ/t sugar

Factory

0.8 furnace oil/tc	=	29,016 KJ
0.1 lub. oil/tc	=	3,555 KJ
9.2 kwh/tc	=	33,120 KJ
		65,691 KJ

65,691 KJ/tc is equivalent to 617,495 KJ/t sugar

Distribution - low population density

150.5 l diesel/t sugar	=	5,309,640 KJ
15.05 lub. oil/t sugar	=	535,058 KJ
		5,844,698 KJ

At high population density	=	2,922,349 KJ
Total Energy Consumption	=	8,438,064 KJ/t sugar
or		5,515,715 KJ/t sugar at high population density.

III. CALCULATION OF ENERGY REQUIREMENTS

- SMALL SCALE TECHNOLOGY

The calculations in this section are based on a factory crushing capacity of 100 t per 16 hour day. The annual requirement of cane is 20,200 t in a 270 day season with 202 crushing days and 11,200 t in a 150 day season with 112 crushing days.

A. Agriculture and harvesting

In this case it has been assumed that the agricultural operations are the same as for the large-scale with the exception of cane loading. After cutting of green cane the cane is loaded by hand onto trailers for transport to the factory. Cane yields have also been reduced to 88 t/ha (plant) and 72 t/ha (ratoons) in the long season and 37.5 t/ha (plant) and 27.5 t/ha (ratoons) in the short season.

Using the list of operations and work rates given in Annex 1, without mechanical loading the machine hours per hectare for land preparation and cultivation are as follows.

Plant crop	12.4 hrs 75 hp	wheeled	tractor
	4.4 hrs 62 hp	"	"
Ratoon crop	2.4 hrs 75 hp	"	"
	6.0 hrs 62 hp	"	"
Final ratoon	5.4 hrs 75 hp	"	"
	8.0 hrs 62 hp	"	"

With fuel consumption as 10 l/hr in the larger tractor and 8 l/hr in the smaller the diesel requirement for the P+2R cycle

20.2 hrs x 10 l/hr	=	202
18.4 hrs x 8 l/hr	=	147
		349 litres

This quantity of fuel is used to produce a total of 232 t/ha per cycle which is equivalent to 1.50 l/tc. A further 0.02 l/tc is added to allow for the transport of seedcane and fertilizer. The planting rate has been taken as 5 t/ha over 87 ha/yr and the fertilizer application rate as 120 kg/ha/yr over 429 ha.

Diesel consumption in the P+4R cycle is

25.0 hrs x 10 l/hr	=	250
30.4 hrs x 8 l/hr	=	243
		493 litres.

This quantity of fuel is used to produce a total of 142.5 t/ha per cycle which is equivalent to 2.46 l/tc. A further 0.04 l/tc is added to aloow for the transport of seedcane and fertilizer. Planting rate is 5 t/ha over 79 ha/yr and fertilizer application is 400 kg/ha/yr over 386 ha.

Cane transport calculations have been based on the areas, numbers of tractors and average journey lengths presented in the economic viability paper (4).

In the long season situation, machine hours are as follows:-

3, 62 hp tractors x 202 days x 12 hrs = 7,272 hrs.

Diesel consumption is therefore 7,272 x 8 l = 58,176 l which is used to transport 20,200 tc/yr. This is equivalent to 2.88 l/tc.

Total fuel consumption in the production, harvesting and transport of 20,200 tc/yr from a P+2R cycle is thus 1.50+0.02+2.88 = 4.40 l/tc

In the short season situation, machine hours are as follows:-

3, 62 hp tractors x 112 days x 12 hrs = 4,032 hrs.

Diesel consumption is therefore 4,032 x 8 l = 32,256 l which is used to transport 11,200 tc/yr. This is equivalent to 2.88 l/tc.

Total fuel consumption in the production, harvesting and transport of 11,200 tc/yr from a P+4R cycle is thus 3.46+0.04+2.88 = 6.38 l/tc

In both cases an allowance for lubricating oil is assumed to be 10% i.e. 0.44 l/tc and 0.64 l/tc respectively.

B. Factory processing

In the small-scale open pan factory the major sources of supplementary fuel are firewood and electricity. If unavailable the latter would be replaced by a diesel generator. During the closed season the factories would require very little power as the time spend on maintenance at this time will be minimal. Unlike the large-scale factory, therefore, the fuel requirements per tonne cane are taken to be the same irrespective of the length of cruching season.

The parameters are:-

0.01 t/tc firewood

20.00 kwh/tc electricity

C. Sugar Distribution

The models used in this section are 13.6 kg/head, 150 persons per km^2 in the long season situation and 10 kg/head, 75 persons per km^2 in the short season situation. Calculations have not been made for higher population densities as it is reasonable to assume that this type of factory is more likely to be able to distribute sugar within a local area, whereas the large-scale factories would rely on transport to major centres of population before distribution.

Sugar production in the long season is 1,313 tonnes from 20,200 t cane. At 13.6 kg/head this would satisfy the needs of 96,544 people. With a population density of 150 per km^2 the area involved would be 644 km^2 or a circle with radius 14.3 km. Average trip length ($\frac{2}{3}r$) is 9.5 km, which is doubled to 19 km.

Using 10 t trucks with fuel consumption of 3.5 km/l, the total diesel requirement for sugar distribution in 132 return trips is

132x19x2x3.5 = 17,556 litres

= 13.37 l/t sugar

In the short season sugar production is 728 t from 11,200 tc. At 10 kg/head this would satisfy the needs of 72,800 people. With a population density of 75 persons per km^2 the area involved would be 971 km^2 or a circle with radius 17.6 km. Average trip length is 11.7 km, which is doubled to 23.5 km.

The sugar would be distributed in 73 return trips of 23.5 km each. Total diesel requirement is therefore

73 x 23.5 x 2 x 3.5	=	12,008 l
	=	16.49 l/t sugar

In both cases lubrication is taken as 10% i.e. 1.34 l/ts and 1.65 l/ts respectively.

In order to convert the various types of fuel to a common unit the conversion factors previously mentioned are used plus firewood which as a net calorific value of around 15,000 KJ/kg.

Long season, 100 tcd factory - summary

Agriculture

4.40 l diesel/tc	=	155,232 KJ
0.44 l lub. oil/tc	=	15,643 KJ
		170,875 KJ

170,875 KJ/tc is equivalent to 2,628,058 KJ/t sugar.

Factory

0.01 t firewood/tc	=	150,000 KJ
20.00 kwh/tc	=	72,000 KJ
		222,000 KJ

222,000 KJ/tc is equivalont to 3,414,360 KJ/t sugar

Distribution

13.75 l diesel/t sugar	=	471,694 KJ
1.34 l lub. oil/t sugar	=	47,640 KJ
		519,334 KJ

Total Energy Consumption = 6561,752 KJ/t sugar.

Short season, 100 tcd factory - summary

Agriculture

6.38 l diesel/tc	=	225,086 KJ
0.64 l lub. oil/tc	=	22,753 KJ
		247,839 KJ

247,839 KJ/tc is equivalent to 3,811,764 KJ/t sugar.

Factory

0.01 t firewood/tc	=	150,000 KJ
20.00 kwh/tc	=	72,000 KJ
		222,000 KJ

222,000 KJ/tc is equivalent to 3,414,360 KJ/t sugar.

Distribution

16.49 l diesel/t sugar	=	581,767 KJ
1.65 l lub. oil/t sugar	=	58,661 KJ
		640,428 KJ

Total Energy Consumption = 7,866,552 KJ/t sugar.

IV. ENERGY SAVING POTENTIAL IN LARGE SCALE FACTORIES

In the large-scale, vacuum pan technology where the major source of energy is bagasse there are two main areas with considerable energy saving potential.

The first of these is by steam economy measures to achieve a surplus of bagasse rather than a balance. In the past disposal of bagasse was only a nuisance and so factories were designed in such a way that all bagasse would be required for the boilers. More recently, however, there has been increased interest in further processing of bagasse and it is now more common to design the factory to economize on the steam consumption and leave a surplus of bagasse.

The output of bagasse is related to the fibre content of the cane by roughly a factor of 2 i.e. cane with 15% fibre will give bagasse as 30% of the weight of cane. Typically the steam: bagasse ratio is in the range of 2.0-2.25 depending on the efficiency of the boilers. A higher ratio can be achieved by using high pressure boilers: low pressure boilers are being replaced in Mauritius sugar factories for increased steam production per unit bagasse and so supply the fibre to various by-product industries. High pressure boilers are not widely used however, in developing countries due to the need for a higher level of expertise in operating and maintenance.

The factory steam: cane requirement is normally in the range of 0.5-0.6 again depending on boiler efficiency and factory design. It is reasonable to assume that this ratio would not exceed 0.55 under normal operating conditions.

With a steam: bagasse ratio of 2.1 for example and bagasse: cane of 0.3 the available supply of steam: cane is 0.63. This can be reduced to 0.6 to allow for bagasse wastage, use of bagacillo as a filter aid etc. Therefore there is a potential saving of about 8% bagasse or almost 5 tonnes surplus wet bagasse (50% moisture) per hour.

As an alternative to using the surplus bagasse as a raw material for further processing it is possible to use the surplus in the boilers to create surplus steam and consequently electricity which could be fed back into the National Grid or used for local supply.

The surplus of 5 t bagasse per hour, with a steam: bagasse ratio of 2.1 would produce 10.5 t steam per hour. The steam required by a back pressure turbo alternator is 12 kg per kw (see reference 5) hence the additional electricity production would be

$$\frac{10,500}{12} = 875 \text{ kw/h} = 21,000 \text{ kwh/d}$$

Over a crushing season of 216 days, for example total production could be of the order of 4.5 million kwh.

V CONCLUSIONS

Despite the limited nature of the approach taken in this paper the main results illustrate the differences between the technologies and season lengths.

First of all to compare season lengths, the large-scale system has a difference of around 27% between the long and the short season. On the small-scale however the difference is only 20%. This variation is entirely due to the use of power in the closed season.

To compare the technologies in similar seasons the saving due to higher population densities for the large-scale becomes important. For example in the long season, the energy consumption is marginally lower in the small-scale when the low population density is used. However the difference in energy consumption rises to 53% if the large-scale factory can distribute to a concentrated population.

In the short season the total energy consumption is actually 7% lower in the small-scale at the low population density, but 43% higher when the large-scale factory distributes to the more density populated area.

The distribution of the energy consumption in the three phases also shows an interesting comparison between the technologies. On the large-scale, the energy is consumed roughly 35% in the agricultural phase, 10% in the factory and 55% in distribution (high population density). The proportions are similar between the seasons. On the small-scale however, the proportions are very different. Long season is 40%, 52% and 8% and short season is 49%, 43% and 8%. Note the reversal in importance between factory and distribution. This does illustrate the scope for energy saving by further research and development in the open pan factory process. The difference in the agricultural phase is due to the lower yields per hectare in the short season while the same amount of land preparation and cultivation has to be carried out.

ANNEX 1

Agricultural operations and work rates

Operation	Equipment	Rate hrs/ha*
PLANT CROP		
Ploughing	75 hp tractor	3.0
Heavy harrowing	"	2.4
Light harrowing	62 hp	2.4
Furrowing	75 hp	3.0
Planting	Manual	-
Ridge flattening	75 hp	2.0
Moulding	"	2.0
Inter-row cultivation	62 hp	2.0
Burning, cutting, stacking	Manual	-
Loading	Grab Loader	4.1 (2.3)
RATOON CROP		
Trash-raking	62 hp tractor	2.0
Chisel ploughing	75 hp	2.4
Ratoon reshaping	62 hp	2.0
Inter-row cultivation	62 hp	2.0
Burning, cutting, stacking	Manual	-
Loading	Grab Loader	3.3 (1.9)
FINAL RATOON		
as above plus		
Trash-raking	62 hp tractor	2.0
Uprooting	75 hp	3.0

* It is assumed that operations are carried out 12 hrs/day except for loading. Grab loader has a capacity of 684 tcd, therefore rate depends on crop yield. The first figure represents long season (higher yield) and the figure in brackets, short season (lower yield).

ANNEX 2

Diesel fuel consumption and manpower requirements at various degrees of mechanization (large-scale factory)

Regime*	Fully mech. agriculture, harvesting & loading **		Fully mech. agric, manual harvest & mech. loading		Semi-mech. agric, manual harvest. & mech. loading		Fully manual agric & harvest, mech. loading	
	l/tc	mandays /tc	l/tc	mandays /tc	l/tc	mandays /tc	l/tc	mandays /tc
1	3.6	0.7	3.4	0.9	3.3	1.1	2.5	2.0
2	5.4	0.6	4.3	0.9	4.1	1.3	3.0	2.4
2A	8.3	0.8	5.7	1.2	5.3	1.7	4.6	3.7
3	5.8	0.9	4.1	1.3	3.8	1.7	2.6	3.9
4	9.8	1.0	5.9	1.4	5.2	2.1	5.3	3.8
4A	18.7	1.3	8.0	2.0	7.3	3.1	5.3	8.2

* 1 = long season, irrigated plantation.
2 = long season, rainfed plantation.
2A = long season, rainfed outgrowers.
3 = short season, irrigated plantation.
4 = short season, rainfed plantation.
4A = short season, rainfed, outgrowers.

** l/tc = litres per tonne of cane.

REFERENCES

1. Pickett J. and Duguid Fiona, Environmental and Economic Impact of Alternative Agricultural Sugar Technologies, paper presented at the UNEP/UNIDO Seminar on the Implication of Technology Choice in the African Sugar Industry, Nairobi, Kenya, 18-22 April, 1977.
2. Alpine R. and Duguid Fiona, Economic Viability in African countries of the Large Scale Vacuum Pan Sugar Technology, paper presented at the UNEP/UNIDO Seminar ....
3. Francis W., Fuels and Fuel Technology, Vol. 1, Pergammon Press, London, 1965.
4. Alpine R. and Duguid Fiona, Economic Viability on African Conditions of the Small Scale Open Pan Sugar Technology, paper presented at the UNEP/UNIDO Seminar ....
5. Chatterjee A.C., Cane Sugar Factories can add to Energy Resources, Indian Sugar, Jan. 1974.

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