

FORESTRY DEVELOPMENT IN SUDAN

S U D A N

CARBONIZATION OF FRESH BAGASSE

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Khartoum, December 1993



Instead of wood charcoal this lady uses bagasse charcoal briquettes for coffee making. Her stove is a traditional square model.

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ACRONYMS

ERI Energy Research Institute

FNC Forests National Corporation

NEA National Energy Administration

Bagasse is the residue of crushed sugar cane out of which the sugar is extracted. It is partly used by the sugar factories for their own energy needs (electricity and heat). The annual bagasse surplus in Sudan (the amount of bagasse not used by the sugar factories) is probably about 150,000 t/yr. There is also a large resource of stored old bagasse available. If only the annual bagasse surplus would be converted into charcoal briquettes, an amount of 50,000 tonne of briquettes would result. The briquettes can be used to substitute charcoal made of wood. These quantities are quite substantial if considered at a regional level.

Four issues constitute the specific character of this project:

- **The environment:** The manufacture and use of bagasse charcoal briquettes will relieve pressure on degrading forest resources by providing an alternative to wood as a source of charcoal fuel. Substitution of wood charcoal by charcoal briquettes made from agricultural residues contributes to the reduction of greenhouse gas emissions (carbon dioxide and methane). The reasons are that (1) wood otherwise carbonized and burnt now becomes available for more durable applications like poles and timber or is left standing and growing, and (2) by utilizing residues which otherwise would be left for biological degradation (like bagasse), the very harmful methane emissions can be avoided.
- **The value of agricultural production:** The manufacture and use of bagasse charcoal briquettes will relieve sugar factories from the burden of managing large quantities of bagasse, thus giving value to an otherwise waste material;
- **Rural development:** The manufacture and use of bagasse charcoal briquettes will contribute to rural development by creating jobs in these areas.
- **Industrial development and employment:** The manufacture of bagasse charcoal briquettes will encourage small-scale industries involved in the production and maintenance of charcoal kilns and briquetting equipment;

The objective of this mission was to identify and test techniques for the carbonization and subsequent briquetting of bagasse and to draw conclusions with respect to:

- the technical feasibility,
- the economic feasibility (on a pre-feasibility level),
- further necessary action.

This mission has indeed resulted in technically and economically feasible options for the production of bagasse charcoal briquettes. The most convincing results were obtained with carbonization of baled bagasse in small metal kilns and subsequent briquetting by means of agglomerators and a molasses based binder. Also the use of a filling agent (clay) for density increase and as a burn-rate controller is recommended.

Although considerable scope for further production and product development was identified, it was concluded that already at this stage a pilot plant for commercial production is justified. It is recommended that the *Forestry development in Sudan* project (FAO in collaboration with

FNC) takes the responsibility to install and operate such a plant. For further technical developments and for the creation of a sound institutional framework at a technology level the collaboration with ERI is proposed.

A workplan, terms of reference and a budget are proposed for 1994, along with a framework (long-term perspectives) for the future development of this project activity.

The annual bagasse surplus (the amount of bagasse not used by the sugar factories for electricity production and generation of process heat) is probably about 150,000 t/yr. If this bagasse would be converted into charcoal briquettes, an amount of 50,000 tonne of briquettes would result. At the same time there is a large resource of stored old bagasse available which can be utilized similarly. These quantities are quite substantial if considered at a regional level. The lack of suitable technology for bagasse conversion was a reason for this consultancy.

The project activities reported here were executed from October 23 to December 15 in Sudan. In accordance with the ToR, presented in Annex A, the activities concerned basically technology development for the production of charcoal briquettes out of sugar cane bagasse (i.e. the crushed cane residue).

Upon arrival of the consultant in Khartoum it appeared that the biomass energy section of the project for *forestry development in Sudan*, of which the activities reported here constitute only a small part, had already made certain preparations, mainly concerning accommodation arrangements at Assalaya Sugar Factory. The reasons given were that the team preferred this location since other bagasse processing facilities had already been installed at two other sugar factories. Although these initiatives were very much appreciated by the consultant, he felt that the current project phase should concentrate on technology development rather than on its dissemination. He therefore decided to reconsider the location selected, to take one week for preparation of the work and to prepare a detailed workplan during this first week (presented in Annex B).

The relevant considerations were discussed by the project team and it was decided to execute most of the technical development activities at ERI premises (Soba). One reason was that a certain type of, and probably suitable, briquetting equipment (i.e. agglomeration machines) had been installed at this location. In addition, other useful equipment had to be constructed and adapted during the course of the mission, and it was felt that this could best be done in cooperation with workshops in Khartoum. Finally it was felt that the processing activities (carbonization and subsequent briquetting) had to be integrated at one location to the largest extent possible.

The consultant wishes to thank Mr. Akram Mirghani and Mr. Salman Doka, both of them FNC staff seconded to the biomass energy unit of the project (*forestry development in Sudan*), for their excellent guidance and assistance. The staff of ERI, in particular Ms. Sawsen (scientific staff), Ms. Ratiba (scientific staff) and Mr. Waleed (scientific staff) as well as Mr. Amin (technical staff) are gratefully acknowledged for their contribution to the laboratory experiments. Mr. Saleh (Sudan Sugar Corporation) and his staff at Guneid Sugar Factory (Mr. Bagri, Mr. Yousri) also gave excellent and mostly appreciated support. Finally, the consultant wishes to thank the ERI for its ready support to this project. ERI was prepared to provide all necessary services although collaboration was sought at very short notice.

6 MAIN FINDINGS AND CONCLUSIONS

6.2 TECHNICAL RESULTS

The production process of charcoal briquettes can be distinguished in a number of processing steps, i.e.:

- Carbonization, which can be distinguished into two steps:
 - Charcoal making of the fresh biomass feed-stock
 - Cooling of the charcoal produced
- Briquetting, distinguished into:
 - Compaction of the cooled charcoal
 - Curing of the compacted product

For each of these steps a variety of techniques can be identified (See Table 1). An appropriate combination of techniques will finally constitute the production process to be designed.

During this mission some of the alternative techniques were tested and evaluated (See Table 1).

Table 1. Technical options (Shaded alternatives will be tested and evaluated).

Processing step	Technical alternative			
Charcoal making of bagasse	Continuously operated rotary kilns or stirred beds for loose bagasse	Carbonization of bagasse bales	Manually operated systems for carbonization of loose bagasse	
Cooling	Cooling in kiln	Cooling in small airtight container	Cooling by quenching in water	
Compaction	Mixing with molasses binder followed by extrusion	Mixing with molasses binder followed by roll-pressing	Mixing with molasses binder followed by manual pressing	Grind char into powder followed by agglomeration by adding pulverized char and molasses binder in disk pelletizer
Drying and curing	Atmospherical drying on racks	Atmospherical drying on racks followed by post-carbonization in externally heated oven (bagasse fuelled)	Atmospherical drying on racks followed by post-carbonization in barrel placed inside carbonization kiln	

6.2.2 State-of-the-art of the technology

Mainly two types of processes are applied for carbonizing bulky biomass varieties like bagasse, i.e.:

- batch-wise carbonization of bales and
- continuously operated rotary kilns or stirred beds.

Some processes allow recovery or utilization of oil and/or gas that is produced during the process. In fact the choice of equipment is very wide.

Batch-wise carbonization of bagasse bales

In the batch-wise carbonization process bagasse bales are stacked inside a walled area with a series of small openings at the bottom of the walls for regulation of the air supply (An example is shown in Photo 5). Limited but adequate air circulation is ensured by stacking the bagasse bales with suitable overlap. Carbonization itself subsequently proceeds very similar to that of wood. There are only few references in literature about this technology (Paturau (Ref. 1), De Haer (Ref. 2) and Val (Ref. 3)), i.e. concerning the employment of 15 m³ brick kilns in the former Dutch East Indies. By employing bales this process overcomes one of the major difficulties for the carbonization of low-density and loose material, i.e. the slow transfer of heat into the bulk of the matter. This process can be applied at small as well as large scales. Investments are low, labour employment is large.

Continuously operated rotary kilns or stirred beds

Contrary to batch-wise bales carbonization, continuously operated systems are capital intensive and labour extensive. Production capacities are large. Suitable equipment can be obtained from European countries or from the USA.

One example is a continuous carbonizer in which dried loose bagasse is fed into an inclined pyrolysing reactor and carbonized continuously. The feedstock is fed by gravity and there are no moving parts inside the reactor which eliminates problems normally associated with moving grates, augers or conveyors. The process gas produced in the reactor is recovered and burnt in a burner to produce flue gases which may be utilized for briquette drying and/or for steam and power generation. **It should be remarked that continuous carbonization processes combine the production of charcoal with the generation of heat and power. This could prove to be useful if in the future Sudanese sugar factories would be interested in producing electricity for the power grid.** Since the ToR of this mission clearly restrict the current R&D to small scale capital extensive/labour intensive techniques, this option is not elaborated further.

Other carbonization processes

ERI has also some experience with a manually operated semi-continuous process for loose bagasse which reportedly is used for coffee husk in Kenia. Loose bagasse is spread layer by layer on top of a hot charcoal bed which rests on a grate. As the bagasse ignites it is chemically split into volatile matter and charcoal. The volatile matter is burnt by the air which flows down-draught through the bed. The hot flue gases flow through the growing charcoal bed, complete

the carbonization, pass through the grate and are released through a chimney. This process is extremely labour intensive. However it might be suitable if bagasse bales cannot be made available. It is not tested during this mission.

Briquetting

Briquetting of charcoal can be done by a variety of techniques including agglomeration, block-pressing and roll-pressing (Bhattacharya (Ref. 4) and Eriksson (Ref. 5)). In all these techniques charcoal is mixed with a binder and formed into the desired shape. With block-pressing and roll-pressing a mould is used in which the charcoal and binder mixture is compressed, with agglomeration the formation of briquettes is induced by tumbling, vibrating, shaking or paddle mixing and the use of a binder.

In Sudan the largest experience has been gained with the **agglomeration** technology (mainly with cotton stalk charcoal and wood charcoal fines). At a number of locations agglomerators with a capacity of 50 kg/hr are installed. This agglomerator type has been developed by Twente and ERI for cotton stalk charcoal (See Photo 10). So far, no set rules exist for determining which type of agglomerator should be used in a given situation. The final choice rests on a careful consideration of the particular application and extended testing. The agglomerator developed by Twente and ERI is attractive for application in a developing economy: it is relatively of smaller scale, less complex, involving lower equipment cost and is less sensitive to equipment controls. **Block-pressing** is a technique which is currently employed for the production of bagasse-molasses fuel blocks at two sugar factories in Sudan. These production facilities were developed by the FNC/FAO project of which this mission forms a part. This technology was not yet tested for charcoal briquetting (Refer to Photo 16 for an example of a block press). **Roll-pressing** of charcoal is a technology which is widely spread in the USA, Europe and India. It is not applied in Sudan. It is state-of-the-art industrial compacting technology. Capacities are usually 1-4 t/hr. In contrast with roll-pressing, agglomeration and block-pressing are characterized by low capital and high labour involvement.

Drying and curing: Usually water diluted binders are used. Therefore briquettes need to be dried after their formation. E.g. the agglomerates produced in the Twente/ERI agglomerator contain approximately 40% water (wet basis). The briquettes may be dried on top of racks (atmospheric drying, Photo 12) or in a forced-draught dryer (thermal drying). Atmospheric drying may be very attractive in Sudan because of the 34 weeks of dry season, high temperatures and low relative humidity throughout most of that season. However, it requires large areas and is labour intensive. A compact forced-draught drier, although more capital intensive, would allow all-year operation. The preferred binder is sugar cane molasses. To increase the durability of the product, it might be necessary to bake (cure) the dried briquettes in an oven before the final packing. The curing involves a chemical conversion of the molasses binder at a temperature of approximately 300 °C. Curing makes the briquettes strong and water resistant and also reduces the quantity of smoke released during ignition. De Haer (Ref. 2) and Val (Ref. 3)) report on the use of such an oven although in their case the oven is also used for drying the briquettes (drying and curing integrated in one process). Their ovens basically consist of a fire box fuelled by loose bagasse and a heat exchanger consisting of 100 mm

diameter pipes in which the fresh briquettes are placed. The pipes are positioned horizontally and are loaded by means of a scoop of the same length as the heat-exchanger pipes. The capacities of the respective ovens used by De Haer and Val are 1.5 and 2.5 tonne of cured briquettes per day. (Based on this principle a small curing oven for testing purposes was constructed during this mission, see Photo 15.)

6.2.4 Carbonization tests

It was decided to concentrate on carbonization of bagasse which is baled. Bales were obtained from the Guneid Sugar Factory. To this end the factory specially made an old baler operational and processed an amount of 10 tonnes of last year's and 10 tonnes of the new season's bagasse surplus. The dimensions of the bales were:

- Average size 0.30 m x 0.30 m x 0.45 m;
- Average density 164 and 193 kg/m³ for 1-year-old baled bagasse and freshly produced baled bagasse respectively.

It should be noted that Paturau (Ref. 1) mentions a density of 890 kg/m³ for this type of bales (of freshly produced and hence wet bagasse). The low density obtained in the bales delivered by Guneid Sugar Factory is probably due to the fact that the baler dearly needed rehabilitation.

Two kiln types were tested during this mission, i.e.:

- 6 m³ brick kiln (Built during this mission).
- 2 m³ metal kiln (since this kiln is made out of 3 used oil drums it is referred to as the 3-drum kiln). This kiln, originally designed for the carbonization of cotton stalk, was made available by ERI.

These kilns are shown in Photo 5 and Photo 6 respectively. In comparison with the carbonization of wood in this type of stationary kilns, the operation was quite different. While for wood carbonization the colour of smoke is a clear indicator of the carbonization rate, this was not exactly the same for the carbonization of baled bagasse. It appeared that even after a blue colour was achieved, carbonization was not always complete. Hence, air vents had to be opened for a longer period than expected on the basis of smoke colour. The proper operation of the kilns was mastered during the executing of several tests. Technical data are provided in Table 2.

After sufficient cooling the kiln is discharged with rakes and shovels into barrels. Since the charcoal is very reactive and may ignite easily the barrels are closed with a lid and sealed with mud. Finally for both kilns the measured yield of good quality charcoal was 25% of the bagasse input. (For a selection of kiln type, please refer to Section 3.2.1., where the economics are evaluated.)

It is important to state here that, the satisfactory test results are not yet a sufficient basis for commercialization of the technology. More experience as to the exact operation characteristics of this and similar kiln types are needed, before the technology can be handed over to the private sector. Especially the issue of process control needs close attention during a follow-up activity. Proposals are included in the recommended follow-up activities.

Table 2. Characterisation of kiln types used for bagasse bale carbonization.

	Brick kiln	3-Drum kiln
Volume (m ³)	6.44	2.00
Cost (LS)	85000	81000
Bagasse load (kg) (MC appr. 20%)	740	230
Efficiency (%)	25%	25%
Charcoal yield (kg)	185	57
Loading time (min)	45	15
Burning time (min)	180	165
Minimum duration of total production cycle: loading, burning, cooling, unloading (days)	3	0.5
Daily kiln cycles (cycles/day)	0.33	2.00
Cooling drum capacity (kg/drum/day)	30	30
No. of cooling drums (drums/kiln)	6.2	1.9
No. of bricks (bricks/kiln)	56	33
No. of operators (operators/kiln)	0.11	0.33
No. of shovels (shovels/kiln)	0.11	0.33
No. of buckets (buckets/kiln)	0.11	0.33
Minimum duration of total production cycle: loading, burning, cooling, unloading (days)	3	0.5

6.2.6 Briquetting tests

Compacting

For the production of agglomerates an agglomerator was utilized (See Photo 10 and Section 3.1.1). In addition to the agglomerator, a small hammer mill (Photo 8) and binder preparation tanks (used oil barrels) form part of the equipment. A manually operated block-press was used to test the manufacture of compressed briquettes. This press was imported from Belgium (See Photo 16). Similar block-presses have been constructed locally for the production of brick-shaped fuel blocks out of retted bagasse and molasses. Also an attempt was made to locally manufacture a roll-press. Unfortunately the timeframe did not allow to complete its construction and testing.

Agglomeration was the technique studied the most during this mission. Experiments concerned:

- The grinding ratio for the powder (two hammer mill screen types: 1 mm and 2 mm). With the 2 mm screen the hammer mill has a larger capacity than with the 1 mm screen. Also, due to the specific particle size distribution, the agglomeration is easier (quicker) when the 2 mm screen is used. Hence the 2 mm screen is preferred.
- The use of filling agents (sand, clay) in various quantities. The application of filling agents has several reasons:
 - In this manner the density of the agglomerated product can be enlarged.
 - The burn rate can be decreased by adding incombustible matter (It prevents fast oxygen transfer to the fuel).
 - By using cheap filling agents production cost can be reduced.

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- The amount of molasses binder. Molasses is a fairly expensive product. Lesser molasses used results in a cheaper product.

Criteria for satisfactory agglomeration performance were the production rate (kg/hr), the quality of the briquettes and the cost of the raw materials used (See Sections 3.1.4 and 3.2 for product quality and production cost estimates respectively). Good results were obtained by using the 2 mm screen, adding 10-15% river clay to the charcoal prior to grinding and diluting the molasses with 80% water. During the experiments all mass flows were measured. From the data obtained it was derived that a typical composition of good quality briquettes is the following (See also Annex E):

Bagasse charcoal	- 72%
Clay	- 8%
Molasses	- 20%

These are necessary data for the pre-feasibility calculations given in Section 3.2.

For this briquette type the production capacities of the grinder and the agglomerator were 200 and 50 kg/hr respectively (dry basis).

In addition the following should be remarked: This particular agglomerating machine was originally imported from the Netherlands. In the past various attempts were undertaken to manufacture this type of machine locally; unfortunately with unsatisfactory results. The consultant is convinced that with a proper design effort good quality agglomerators of the same production capacity or higher can be made in Sudan against attractive costs. Although the hammer mill used was imported, it has been proven that this type of machines can be made locally.

The block-press was tested by making use of two types of charcoal, i.e. the pulverized bagasse charcoal and the freshly produced bagasse charcoal (Photo 17). The two processes are technically feasible. However, due to man power and time limitations a detailed characterization of the production processes in terms of costing could not be made.

Drying and curing

Freshly formed briquettes were atmospherically dried on a rack (drying table) made of steel (Photo 12). Under the prevailing conditions it takes 2 days to obtain briquettes with a moisture content of 2% (wet basis).

A bagasse fired curing kiln for heat-treating the briquettes was designed and built during the stay of the consultant (Photo 15). Heat-treatment is necessary if briquettes are to be produced which can be stored and used during the rainy season (Non-treated briquettes disintegrate under humid atmospheric conditions). A second reason for heat-treating the briquettes is that in this manner a product can be made which does not yield smoke. The kiln built is suitable for testing purposes. The kiln can accommodate a volume of 0.32 m³ briquettes, which is equivalent to about 110 kg cured product. The kiln does not consume much fuel since the basic purpose of the fuel is to maintain a fairly low temperature of approximately 300 °C. The timeframe did not allow to carry out performance measurements. However a few test runs were made during which an excellent product was obtained. A sample of cured briquettes was included in the

water boiling tests (See below). If the curing process is to be adopted, more testing and development is necessary.

A much simpler heat-treatment technique was tested as well: A drum of briquettes was placed inside a carbonization kiln. Around the drum, bagasse bales were placed for subsequent carbonization. The briquettes were directly heated by the energy released during the carbonization of the baled bagasse. The process is cheap since there is no need for using additional fuel and a separate furnace, however time and temperature control of this process is difficult. More testing is needed to determine if this procedure is technically feasible.

6.2.8 Product quality

Various bagasse charcoal briquette types were produced and their quality tested. The tested types are the following:

- Agglomerates with various amounts of clay additives (10%, 15% and 20% respectively). Clay is a filling agent which serves as a burn-rate controller as well as a means to influence the appearance of the briquettes (ash content, density);
- Agglomerates which were given a heat treatment (to get rid of smoke during ignition and to achieve resistance to humid atmospheres);

It was the intention to also test manually compressed block shaped briquettes. However the timeframe appeared too short.

The quality characteristics can be distinguished in those which are of primary important to the consumer and those which are of primary importance to the producers and sellers. They are reviewed in Table 3. Most of these characteristics were measured for the briquettes produced (shaded areas in Table 3). One characteristic which is often mentioned with respect to the quality of fuels is deliberately left out of the summary given here, i.e. the heating value (or calorific value). The reason is that as an isolated characteristic the heating value is of little interest. A lower heating value does not necessarily imply a lower economic value. If a fuel performs more efficiently in a given stove, this may well compensate a lower heating value.¹

Table 3. Quality diagram (Shaded areas: measured during this project).

Characteristic	View-point for which quality characteristic is of primary importance	
	Consumer	Producer, wholesaler/retailer
Bulk density	X	X
Cleanliness	X	
Attractiveness of shape	X	
Consistence of quality	X	
Smoke release during ignition	X	
Time for uniform fuel bed lighting	X	

¹However, heating values are useful to analyze fuel performance tests. Therefore the heating value was determined (i.e. estimated on the basis of ash content). For the briquettes investigated here the heating value is linearly proportional to the ash content, which in turn depends on the ratio of filling agent. See also Appendix F.

Time to boil ²	X	
Total boiling time ²	X	
Ash content	X	
Strength		X

Results of the quality assessment are given in Annex F and summarized in Table 4. For comparison data for wood charcoal have also been generated. Although the project attempts to produce a wood charcoal substitute which is suitable for all types of stoves, these tests were carried out using the traditional square stove. The traditional stove was chosen because this is the most widely spread stove type, while time did not allow to also test the performance of the briquettes on the improved stoves promoted by the project. An issue which needs some more reflection is the time to boil, which is longer for briquettes than for wood charcoal. The reason is that the briquettes burn with approximately half of the thermal power output obtained with wood charcoal. This is due to the larger ash content (burn-rate controller). From the data measured it can also be derived that the efficiencies of cookstoves fuelled with briquettes are much higher than when fuelled with wood charcoal.

²The **time to boil** is the time needed for bringing a given amount of water to the boil. The **total boiling time** is the period, starting after the time to boil, during which the original quantity of fuel is able to maintain the water boiling.

Table 4. Qualities determined for bagasse charcoal briquettes and wood charcoal (Shaded: briquette types proposed for further development).

Fuel type	Bulk density (kg/m ³)	Cleanliness	Attractiveness of shape (a)	Consistence of quality	Smoke release during ignition	Time for uniform fuel bed lighting (min)	Time to boil (min) (b)	Ash content (% dry basis)
Wood charcoal	280	Bad	Bad	Bad	Low	8	19	4%
Uncured agglomerates								
- 10% burn-rate controller	320	Very good	Good	Good	High	7	33	37%
- 15% burn-rate controller	350	Very good	Good	Good	High	5-8	30-38	44%
- 20% burn-rate controller	395	Very good	Good	Good	High	10	60	54%
Cured agglomerates								
- 10% burn-rate controller	315	Very good	Good	Good	Low	7	24	37%
- 15% burn-rate controller	340	Very good	Good	Good	Low	5	27	44%
Manually compressed (block-press) (0% burn-rate controller, uncured)		Very good	Good	Good	High	NA	NA	NA

a) Consultant's expectation of consumer opinion.

b) Average value measured in traditional square stove while bringing 4 litres of water to the boil.

It is apparent that the qualities of the briquettes and wood charcoal differ considerably. However, it can be concluded that a good quality briquette can be produced. Rather than to assume that the briquettes are an inferior product due to certain properties it should be understood that the different quality of briquettes can be used for the development of an effective marketing strategy. To this end the following remarks are made:

- The bulk density of briquettes is higher than of wood charcoal. This fact has a number of implications:
 - Specific transport cost (LS/t/km) are **not** lower since lorries are generally loaded to their maximum weight capacity.
 - Care should be taken that the price setting and packaging does not favour wood charcoal over briquettes (Charcoal is usually sold on a volume basis). Packaging different from wood charcoal may be an attractive marketing option.
 - Many users tend to completely fill the fire chamber of their stoves. This means that they would give more fuel weight if briquettes are used. The marketing of the briquettes could be supported by the provision of information that less fuel volume is required for cooking.

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- The cleanliness, attractiveness of shape and consistence of quality are very favourable properties which should be used in marketing the briquettes.
 - The smoke release during ignition is a disadvantage which occurs for uncured briquettes. This is probably the most negative property in comparison with wood charcoal. If this results in a too low consumer price curing will be a necessity.
 - The time for uniform fuel bed lighting is similar with wood charcoal.
 - The time to boil is slightly longer for briquettes. The difference is not much and should not be a major disadvantage.
 - The higher ash content is immediately considered as a disadvantage. There is however no good reason for this low appreciation. Information should address this issue. It should be stressed that the ash is a burn-rate controller.

6.4 ECONOMIC COMPARISON OF PRODUCTION ALTERNATIVES AND PRE-FEASIBILITY CALCULATIONS

6.4.2 Carbonization

Production costs were calculated for the two tested kiln types as well as for a third and a fourth type for which production data were estimated based on the results of the tests carried out:

- 6 m³ brick kiln;
- 2 m³ 3-drum kiln;
- 4 m³ metal sheet kiln;
- 16 m³ brick kiln.

It is concluded that the 3-drum kiln performs best as a result of the low investment cost. Detailed calculations are given in Appendix G. In Figure 1 the cost comparison is graphically illustrated.

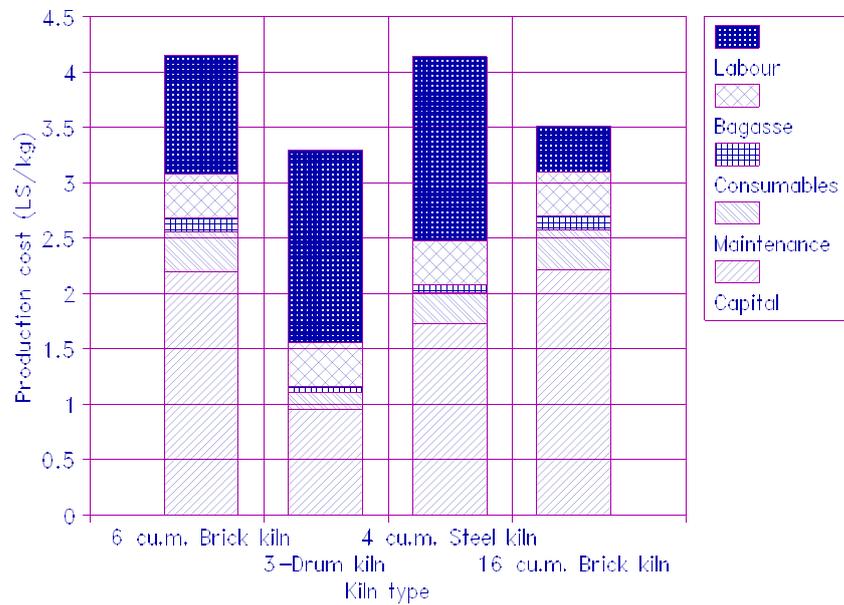


Figure 1, Production cost calculation for four different kiln types.

6.4.4 Briquetting

Agglomeration and block-pressing are economically compared on the basis of production cost. It can be concluded that agglomeration is probably the most attractive option (The respective estimated cost of production are 14 and 20 LS/kg for agglomeration and block-pressing). The main reason for the difference in production cost is the labour productivity (See Figure 2). Costing details are given in Appendix G.

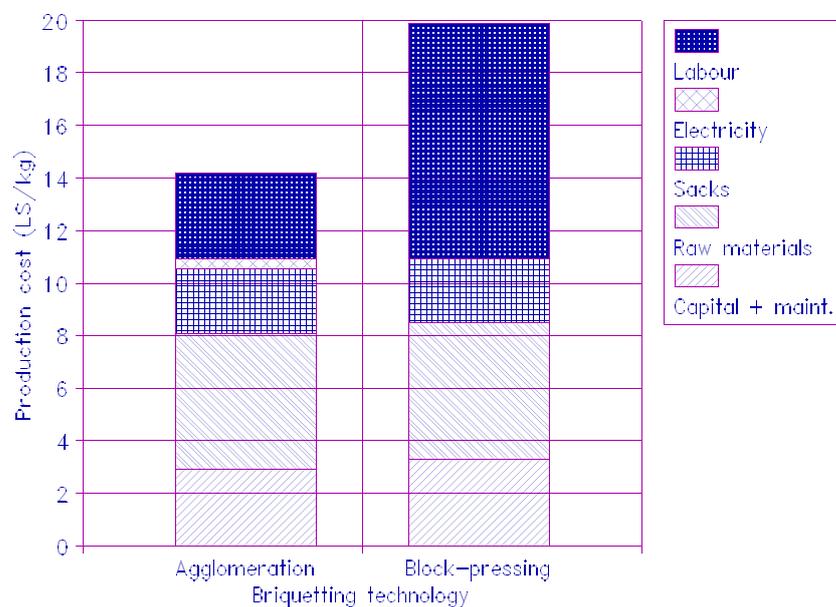


Figure 2, Production cost for two briquetting technologies.

6.4.6 An integrated production line

For one particular technical design of a production line the feasibility has been estimated. The production system is shown in Figure 3. The option of curing has not yet been taken into consideration since this technology is not yet fully mature.

Two important issues to discuss are the cost of bagasse, in particular of baled bagasse, and the cost of molasses. At present bagasse is not usually baled, although the sugar factories consider it as desirable since unbaled merely dumped bagasse residues constitute a nuisance and a large risk for fire hazards (A fire accident at Guneid Sugar Factory, May 1992, caused a damage of 30 Million LS, equivalent to 100,000 US\$ at the current exchange rate). Currently the Sudan Sugar Corporation is seriously evaluating possibilities of installing baling stations. A preliminary estimate of baling cost is given by Paturau (Ref. 1). Converting labour cost to the Sudanese circumstances and assuming that baling wire can be recycled once, baling cost would amount to approximately 825 LS/t (See Table 5). The cost of bagasse baling will probably be shared by the sugar companies and the users of the bagasse.

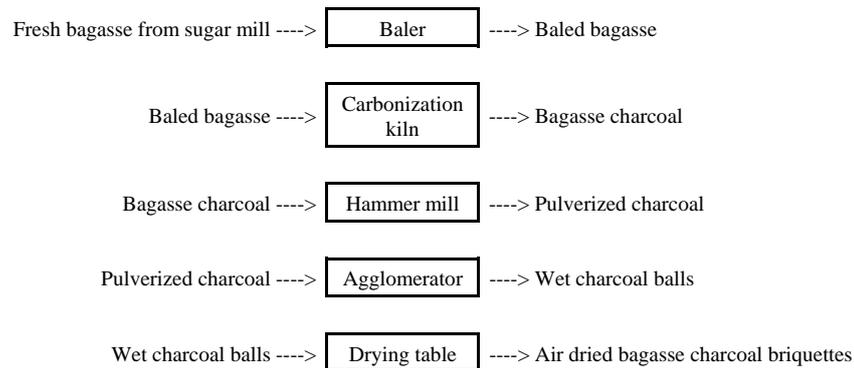


Figure 3. The considered production process of bagasse charcoal briquettes.

Table 1. Estimate of bagasse baling cost.

Cost item	Specific cost (US\$/t)	
	Paturau (Ref. 1)	Sudan
Baling wire	1.50	0.75
Baling station	0.40	0.40
Storage site	0.50	0.50
Equipment	0.67	0.67
Labour	5.00	0.34
Total	8.07	2.66
Labour cost (US\$/man hr)	3	0.20
Baling wire	not-recycled	recycled
Production (t/yr)	30000	30000

The second important cost item is the molasses binder. The major part of the Sudanese molasses is exported against hard currency. However the revenue does not cover much more than the transportation cost and thus does hardly contribute to the Sudanese economy. Under the current regulations of the Ministry of Finance the hard currency thus acquired can be largely used by the sugar companies. Molasses therefore constitutes an important resource for these companies. The Sudanese pound equivalent of the exported molasses is 16 LS/kg. Locally sold molasses, for animal fodder, yields only 1.20 LS/kg. Also for these cost a compromise must be found if molasses will be used in the production of bagasse charcoal briquettes. This study is not meant to advise on these issues, nor can a position be taken. For our calculations it is assumed that the export price for molasses is paid and that only a small share of the bagasse baling cost is covered (It can be shown that things do not change much if instead the full bagasse baling cost is paid, i.e. including the foreign exchange component for the equipment, whereas at the same time only the local molasses price is paid).

For the production process indicated a very favourable rate of return (60%) and pay-back period (2.5 yr) are calculated. Some key figures are given in Table 6. In Figure 4 a detailed analysis is shown for the raw material cost. It is clear that molasses constitute the largest share

of the raw material costs. However, this could be more balanced if more is paid for the bagasse bales and a lower price can be agreed for the molasses (See discussion above). Fully detailed calculations are reviewed in Appendix G. In the appendix also the assumptions for marketing the briquettes are summarized. It is concluded that bagasse carbonization and briquetting most probably is an attractive operation.

Table 6. Cost and revenues for a bagasse charcoal briquettes production plant.

Item	Cost	Revenue	Balance
Capital and maintenance	1654103		
Labour and management	2500000		
Raw materials			
Bagasse	120000		
Sand	45000		
Molasses	1104000		
Consumables			
Sacks	1035000		
Electricity	167400		
Other consumables (bricks, tools)	10945		
Total production cost	6636448		
Total revenue		9108000	
Net revenue			2471552
<hr/>			
Specific production cost (LS/kg)			16.03
Factory profit margin (LS/kg)			5.97
Pay-back period (yr) (investment/net revenue)			2.51
IRR (%)			61%

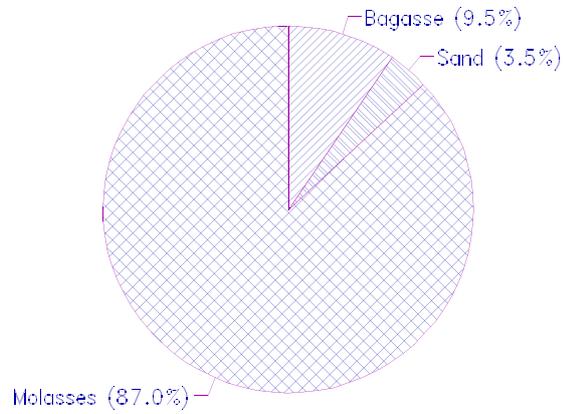


Figure 4. Break-down of material cost in the production facility considered (Molasses valued at export equivalent).

6.6 INSTITUTIONAL CONSIDERATIONS FOR FUTURE PROJECT DEVELOPMENT

6.6.2 Role of FNC

It is understood that FNC is a profit making organization which may consider to enter in the business of bagasse charcoal briquetting provided that it is a financially viable operation. At this moment there are clear indications that this will be the case. However it is not yet proven. At present FNC is involved by making available two of its staff members to the FAO project. If in the near future more FNC staff would be required for its collaboration with the project an agreement could possibly be reached on the allocation of revenues to FNC. This would be of particular interest when the installation and operation of a pilot plant is discussed (See below).

6.6.4 Cross-linking with interests of sugar factories

It is the interest of sugar factories to get rid of their bagasse surpluses in an acceptable manner. A recent report (Ref. 6) prepared on behalf of the Sudan Sugar Corporation for its factory at Guneid recommends to install a baling station at this sugar factory and to sell the bagasse bales. Also the production of charcoal is recommended in this report. The sugar factories' support for this project may therefore be expected.

The bagasse charcoal briquetting facility considered above consumes an amount of 1,200 tonne bagasse per year. This is not yet enough in view of the annual surplus of about 25,000 t/yr at a single Sudanese sugar factory. On the other hand, the production capacity of this type of facilities can be easily increased. As from a particular production capacity other carbonization and briquetting technologies should be considered as well. As the financial feasibility becomes proven for smaller capacities, such investigations into capacity enlargement would be justified.

It should not be expected that the sugar factories themselves enter the business of briquette production, sugar being their first concern. Given their interest in appropriate handling of its bagasse surplus the Sudanese Sugar Corporation is therefore suggested to continue its efforts in producing bagasse bales and to support the development of bagasse charcoal briquetting by offering adequate facilities as to production site development (a.o. water and electricity) as well as reasonable, and hence attractive prices for baled bagasse and molasses.

6.6.6 Collaboration with ERI

For the development of a new technology and well founded institutional support involvement of the ERI is recommended. In the future services of the ERI would be required to continue development of the technology and to provide technical assistance (Product development, operator training, commissioning of equipment, etc.).

6.6.8 Project involvement

This FAO project could help considerably to further develop the technologies discussed in this report and to facilitate the dissemination. At the moment business risks are difficult to estimate.

Immediate investments of Sudanese enterprises can therefore not be expected. The experience of a pilot plant is the first prerequisite for more private sector involvement. A more elaborated framework for the development of this project activity is suggested in Section 4.

This mission has demonstrated the technical feasibility as well as the high probability of financial and economic feasibility of the production of bagasse charcoal briquettes. Already at this moment we are able to produce a marketable product at a reasonable production scale (appr. 450 t/yr/production unit). At the same time there appears to be considerable scope for product and production improvement. It is therefore strongly advised:

- to continue activities to develop the technology in order to confirm its economic and financial feasibility of commercial operations, and;
- to demonstrate the technology of bagasse charcoal briquette production while aiming at large scale dissemination.

By making use of bagasse which is baled, the project makes itself dependent on a technology (baling) which is not implemented in all Sudanese sugar factories. For this reason it is recommended to include efforts on small scale carbonization of loose bagasse in future R&D activities.

The following framework is recommended for these activities:

- **Phase 1** (immediate action): Erection of a **pilot plant** operated by the project. Purpose:
 - Continued development of the technology according to the findings of this mission, including:
 - continued experimenting with bagasse carbonization techniques, including techniques for the conversion of non-baled loose bagasse;
 - the design of a locally manufactured agglomerator (Also construction and testing of a locally manufactured roll-press could be completed);
 - the development of a suitable heat-treatment technology;
 - Development of a suitable marketing strategy;
 - Refining the economic data and based on the results the preparation of site specific feasibility studies for a number of demonstration units.
- **Phase 2** (short-term): **Demonstration** of the self-sustainable production of bagasse charcoal briquettes by
 - Installation and operation of 3 or 4 bagasse charcoal briquetting units at different locations (**all** staff involved in the operation of these units to be paid on a production basis);
 - Monitoring of the technical and financial performance of these units (all costs made during preparation of full scale operation of these units (i.e. administrative and technical assistance costs) not to be included in the production cost);
 - Identification of potential producers of bagasse charcoal briquettes (i.e. those towards whom the subsequent dissemination phase is targeted)
- **Phase 3** (long-term): **Dissemination**, i.e. facilitation of the development of bagasse charcoal briquette production by:
 - Developing proper investment schemes (including tax exemptions, non-applicability of charcoal royalties on bagasse charcoal briquettes, administrative support with company registration, etc.);
 - Providing technical assistance (training) on level of equipment operators;

- Assisting and supervising the production of good quality equipment for carbonization and briquetting;
- Supporting market development for bagasse charcoal briquettes (radio, television, billboards, etc.).

It is recommended that the above activities be carried out by the project in collaboration with FNC and ERI. A possible division of tasks is indicated in Table 7. Phase 1 can be executed during 1994, phase 2 in 1995. It is strongly recommended to include these activities in the coming annual workplans. The dissemination phase (Phase 3) may last a number of years and can be devised during the demonstration phase.

Especially during the dissemination phase coordination with a number of administrative bodies will also be necessary (e.g. NEA, Ministry of Finance, Ministry of Justice, etc.). However, details of such collaboration may be clarified at a later stage.

Table 7. Possible division of tasks for development of bagasse carbonization and briquetting.

Activity	Institution responsible
Phase 1: Pilot plant	
Site selection (Coordination with Sudan Sugar Corporation and/or Kenana Sugar Company)	Project: <i>Forestry Development in Sudan</i>
Design, construction and installation of pilot plant	Project: <i>Forestry Development in Sudan</i>
Training of operators	ERI and Project: <i>Forestry Development in Sudan</i>
Operation of pilot plant	Project: <i>Forestry Development in Sudan</i>
Continued R&D	ERI and Project: <i>Forestry Development in Sudan</i>
Identification and testing of marketing strategies	Project: <i>Forestry Development in Sudan</i>
Monitoring and evaluation of pilot plant	Project: <i>Forestry Development in Sudan</i>
Preparation of a number of site-specific feasibility studies	Project: <i>Forestry Development in Sudan</i>
Phase 2: Demonstration	
Identification of 3 or 4 suitable sites for demonstration units at different locations with private investment	Project: <i>Forestry Development in Sudan</i>
Preparation of investment in the demonstration units	At least one of the investors should be FNC, preferably also others. Potential joint ventures with sugar manufacturers.
Installation of demonstration facilities	FNC, other investors, assisted by Project: <i>Forestry Development in Sudan</i> and ERI
Training of operators	Project: <i>Forestry Development in Sudan</i> and ERI
Operation of demonstration facilities	FNC and other investors
Market development, marketing support	FNC, other investors and Project: <i>Forestry Development in Sudan</i>
Monitoring of the technical and financial performance of these units	FNC, other investors and Project: <i>Forestry Development in Sudan</i>
Continued technology and product development	Project: <i>Forestry Development in Sudan</i> and ERI
Identification of potential producers of bagasse charcoal briquettes (i.e. those towards whom the subsequent dissemination phase is targeted)	Project: <i>Forestry Development in Sudan</i>
Phase 3: Dissemination	
Workplan to be prepared during Phase 2 (demonstration)	

The proposed budget for Phase 1 (execution in 1994) is indicated in Table 8. Proposed terms of reference are included in Annex D.

Table 8. Budget indication for Phase 1.

Activity	Consultant			Other cost (US\$)	
	Expertise	Duration (month)	Cost (US\$) (a)	Hardware (incl. 30% contingency)	ERI (man power cost)
Phase 1: Pilot plant					
Site selection (Coordination with Sudan Sugar Corporation and/or Kenana Sugar Company)					
Design, construction and installation of pilot plant	Engineer (carbonization and briquetting expert)	2	31896	25933	
Training of operators	Engineer (carbonization and briquetting expert)	1	17448		
Operation of pilot plant					
Continued R&D	Engineer (carbonization and briquetting expert)	2	31896	5000	PM
Identification and testing of marketing strategies	Business administration expert	2	31896		
Monitoring and evaluation of pilot plant	Business administration expert	1	17448		
Preparation of a number of site-specific feasibility studies					
Total cost					161516 + PM

a) Including fees, travel and DSA.

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The end product:

Photo 1, Bagasse charcoal briquettes used for coffee making.



and its raw material:...

Photo 1, Bagasse charcoal briquettes used for coffee making.



Photo 2, Fresh sugar cane bagasse.

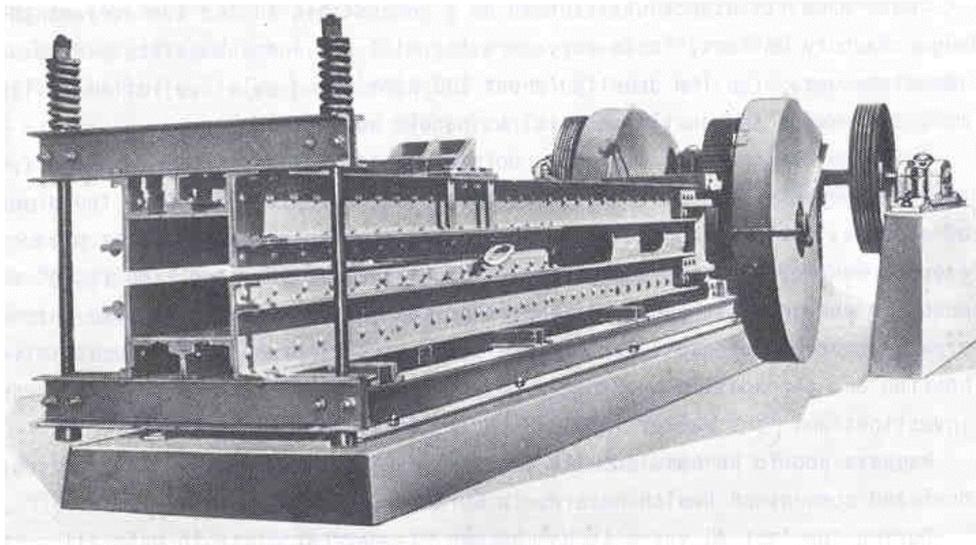


Photo 3, Bagasse baler (Photo: Paturau).

Photo 3, Bagasse baler (Photo: Paturau (Ref. 1)).



Photo 4, Baled bagasse.

Photo 4, Baled bagasse.



Photo 5, Brick kiln for bagasse carbonization constructed and tested during this mission.



Photo 6, A 3-drum kiln loaded with bagasse bales.



Photo 7, Bagasse carbonization in a 3-drum kiln. On the back-ground: drums for charcoal cooling.



Photo 8, Grinding the fresh bagasse charcoal in a hammer mill.

Photo 9, Pulverized fresh bagasse charcoal.



Photo 10, The agglomerator.

Photo 11. Agglomerating the pulverized charcoal with molasses binder in an agglomerator.

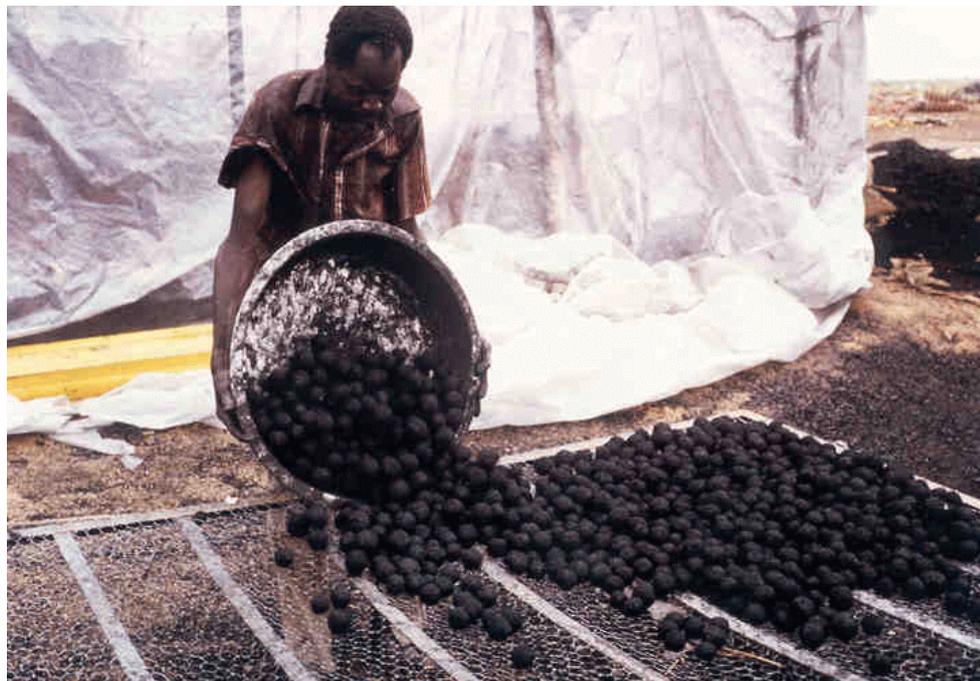


Photo 12. Drying bagasse charcoal briquettes on a drying table.



Photo 13, The drying bagasse charcoal briquettes.



Photo 14, Bagasse charcoal briquettes burning in an improved cookstove.

Photo 15, For further testing and development: A briquette curing kiln.



Photo 16, A block-press for the production of clay bricks; here used for compressing bagasse charcoal.



Photo 17, Drying blocks made of freshly produced bagasse charcoal.

REFERENCES

1. Paturau J. M., 1982, By-products of the cane sugar industry, 2nd. ed. Elsevier Scientific Publishing Company, Amsterdam.
2. De Haer, P. M. D., *et al.*, Koolbereiding uit ampas en melasse (*The manufacture of bagasse-molasses coal*, in Dutch), Arch. Suikerind. Ned. en Ned. Indië, 1 (1941), pp. 631-637.
3. Val, R, De fabricatie van ampas-melassekool (*The fabrication of bagasse-molasses coal*, in Dutch), Arch. Suikerind. Ned. en Ned. Indië, 1 (1941), pp. 638-644.
4. Bhattacharya S. C., Shrestha R. M. and Sett S., State of the art for biocoal technology, AIT-GTZ Biocoal Project, Division of Energy and Technology, Asian Institute of Technology, Bangkok, Thailand, 1988.
5. Eriksson S. and Prior M., The briquetting of agricultural wastes for fuel, FAO Energy and Environment Paper 11, FAO, Rome, 1990.
6. Yousri Anwar Youssif, *et al.*, The accumulated bagasse at Guneid Sugar Factory (in Arabic), Sudan Sugar Corporation, 1993.

ANNEX B

TERMS OF REFERENCE

Under the overall supervision of the Director, Forestry Operations, the direct guidance of designated technical support and project operations officers at FAO HQs, the direct supervision of the Chief Technical Adviser and in collaboration with the Biomass Energy Officer, the staff of the Forests National Corporation and relevant national/international institutions, the consultant will:

- 1 carry out carbonization trials on fresh bagasse, using low-cost, labour intensive techniques and units, with production capacity of about one tonne/day/unit.
- 2 carry out trials on briquetting the bagasse charcoal using:
 - (a) manually operated block presses;
 - (b) existing charcoal briquetting facilities at El Fau (Rahad Scheme) in collaboration with the Energy Research Institute, UNIDO and other institutions.
- 3 prepare a report including findings and recommendations which should be discussed and cleared with the Government authorities concerned before departure from the country; the consultant will then present the report to FAO/HQ (within one month of leaving the country), and will amend it in the light of comments received.

Duty station:

Khartoum, with field travel

E.O.D:

October 1993

Duration:

9 weeks

Language:

English

ANNEX D

PROJECT PLANNING AND EXECUTION

The planning schedule is presented on page 43. In summary the activities concerned the provision of baled bagasse from the nearest sugar factory where a baling machine could be made operational (Guneid) and the development of carbonization techniques as well as briquetting techniques at the ERI laboratory in Soba.

Nearly all activities could be executed as planned. A major problem appeared to be the unexpected repairs necessary for the baler at Guneid. Fortunately this machine could be repaired and operated satisfactorily. The roll-press was ordered however its construction could not be completed. The order was therefore cancelled at the end of the mission. Due to a lower counterpart staff availability than anticipated, tests with the manually operated block-press could not be fully completed. However experiments were executed to the extent that the technical feasibility of this technology was confirmed.

At the end of the mission a demonstration of the complete production process was given to a large number of institutions and enterprises, i.e.:

- FAO representative and programme officers
- Dutch Embassy
- ESMAG construction company
- French Embassy
- Friendship Company
- Kenana Sugar Company
- Ministry of Planning (Energy Department)
- Muaffaq Foundation
- Muaffaq Corporation
- NEA
- Rural Development Corporation
- Sudan Sugar Corporation
- UNDP representative and programme officers
- UNIDO country director
- UNSO/NEA (briquetting project)

The leaflet handed to the participants is included in Annex C.

Table 9. Planning schedule.

Activity	Week							
	43	44	45	46	47	48	49	50
Project preparation	[Shaded]							
Charcoal making	[Shaded]							
Construction of carbonization kiln	[Shaded]							
Bagasse supply	[Shaded]							
Production trials	[Shaded]							
Technical improvements and char production for briquetting	[Shaded]							
Laboratory tests of bagasse and of char (volatile matter, ash)	[Shaded]							
Briquetting	[Shaded]							
Construction of drying tables	[Shaded]							
Construction of curing kiln	[Shaded]							
Arrangement of ERI facilities at Soba	[Shaded]							
Construction of roll-press	[Shaded] .If possible within this timeframe .							
Transportation of manual block-press to ERI	[Shaded]							
Adaptation of manual block-press	[Shaded]							
Molasses supply	[Shaded]							
Agglomeration trials	[Shaded]							
Manual block-press trials	[Shaded]							
Roll-press trials	[Shaded] .Optional .							
Curing trials	[Shaded]							
Laboratory tests of briquettes (volatile matter, ash, comparative cooking test)	[Shaded]							
General	[Shaded]							
Technology assessment (economic analysis)	[Shaded]							
Future programme formulation	[Shaded]							
Preparation of final report	[Shaded]							

ANNEX F

LEAFLET DISTRIBUTED DURING DEMONSTRATION

DEMONSTRATION OF BAGASSE CARBONIZATION AND BRIQUETTING

FAO/FNC (Forestry development in Sudan) in collaboration with ERI

THE PROJECT

Biomass is the source of about 80% of the energy consumed in the Sudan. About 90% of the biomass based energy is consumed by the household sector, mainly in the form of charcoal. However, lack of forest resources, and controlled as well as uncontrolled cutting have resulted in a fast rate of deforestation, especially in the Northern provinces. Solutions to this problem are to be found in; conservation measures, reforestation, and the development of new resources. This project concentrates on the third of these options.

Four issues constitute the specific character of this project:

- **The environment:** The manufacture and use of bagasse charcoal briquettes (BCB) will relieve pressure on degrading forest resources by providing an alternative to wood as a source of charcoal fuel.
- **The value of agricultural production:** The manufacture and use of BCBs will relieve sugar factories from the burden of managing large quantities of bagasse, thus giving value to an otherwise waste material;
- **Industrial development and employment:** The manufacture and use of BCBs will encourage small-scale industries involved in the production and maintenance of charcoal kilns and briquetting equipment;
- **Rural development:** The manufacture and use of BCBs will contribute to rural industrialization and employment opportunities.

THE PRODUCT

In the table below product characteristics of BCB are compared to wood charcoal.

Product	Product description.							
	Bulk density (kg/m ³)	Cleanliness	Attractiveness of shape	Smoke release during ignition ^c	Time for uniform fuel lighting (minutes)	Power output (kW); time to boil (minutes) ^a	Ash content (Weight %)	Consistency of quality
BCB	320-350	Very good	Very good	High	5-8	3.5; 30 ^b	33% ^b	Good
Wood charcoal	280	Bad	Bad	Low	3-8	5-7; 20	4%	Bad

a/ Average power measured in traditional square stove while bringing 4 litres of water to the boil.

b/ BCB with burn-rate controller.

c/ The amount of smoke can be reduced by applying a special heat treatment.

Bulk density: Although the specific density of a single BCB piece is lower than the specific density of a single piece of wood charcoal the bulk density of BCB is higher than that of wood charcoal. The reason is the regular shape.

Cleanliness: You hardly get dirty when handling the briquettes.

Attractiveness: People like the round shape of the briquettes.

Smoke during the ignition phase: During the first 5-10 minutes after lighting the briquettes an unattractive smoke is emitted. In contrast wood charcoal hardly smokes at all. However, in pilot tests we have been able to produce smoke free BCB.

Power output and time to boil: Due to the applied burn-rate controlling agent the briquettes burn much more slowly than wood charcoal. For bringing food to the boil this may be considered as a disadvantage, on the other hand the power provided is certainly enough to complete food cooking. This feature provides a unique way of energy conservation. Changing the amount of added burn-rate controller will increase the power output and reduce the time before boiling. It is anticipated that boiling time and power output can be adapted for optimized consumer appreciation by adjusting the amount of this agent.

Ash content: The applied burn-rate controller results in an increased ash content. At first sight consumers may consider an ash rich fuel as of low quality. Effective promotion should address this issue by explaining that this feature helps to conserve energy.

Consistency of quality: All BCB pieces are of the same quality. Compared to wood charcoal, a sack of BCB does not contain fines (duga) nor incompletely carbonized wood.

THE PRODUCTION PROCESS

An appropriate way of bagasse charcoal production is the carbonization of bales in a kiln. The density of bales is 160-200 kg/m³.

In this project two kiln types were tested, i.e. a 6 m³ brick kiln and a 2 m³ metal kiln. Baling is necessary to provide proper circulation of hot gas and heat transfer into the bagasse. The measured yield of good quality charcoal is 25% (charcoal yield/bagasse input). With the metal kilns a maximum of 2 daily production cycles is possible. The brick kiln needs at least one day for cooling. There is scope for the employment of larger metal kilns (4 m³). The charcoal is stored in barrels to complete extinguishing and cooling.

The charcoal is mixed with burn-rate controller and some water before pulverization in the hammer mill. The addition of water prevents spontaneous ignition.

In the agglomerator charcoal powder is mixed with binder consisting of water and molasses. The dilution ratio of the molasses determines the binder content of the briquettes. The agglomerators shown have a production capacity of 50 kg dry briquettes per hour.

However, the briquettes taken from the agglomerator are wet and need to be dried. To this end the briquettes are placed on a drying table for 48 hours.

CONTINUED RESEARCH AND DEVELOPMENT ACTIVITIES

It is proposed that the continued research and development activities be focused on the following issues:

- Process integration and simplification:
 - Adaptation of agglomerator design for local production
 - Utilization of carbonization waste heat for briquette drying and curing
 - Design of integrated production lines for various production capacities
- Product improvement:
 - Use of burn-rate controllers (additives)
 - Briquette density optimization
 - Reduction of smoke release during briquette ignition phase
 - Improvement of briquette moisture resistance during the rainy season

Curing kiln

For testing purposes a curing kiln is demonstrated. In this kiln air-dried briquettes are given a heat treatment to achieve a smoke free and moisture resistant product.

ANNEX H

DRAFT TERMS OF REFERENCE FOR FOLLOW-UP ACTIVITIES

Carbonization and briquetting experts

Under the overall supervision of the Director, Forestry Operations, the direct guidance of designated technical support and project operations officers at FAO HQs, the direct supervision of the Chief Technical Adviser and in collaboration with the Biomass Energy Officer, the staff of the Forests National Corporation and relevant national/international institutions, the consultant will:

- 1 Design a pilot plant for the carbonization and briquetting of fresh bagasse located at one of the Sudanese sugar mills. This will include the design of a locally manufactured agglomerator;
- 2 Supervise the construction and installation of this plant.
- 3 Supervise installation trials.
- 4 Prepare a report concerning the plant design and its performance upon installation. The report should be discussed and cleared with the Government authorities concerned before departure from the country; the consultant will then present the report to FAO HQs (within one month of leaving the country), and will amend it in the light of comments received.
- 5 Train plant operators in the complete production process of bagasse carbonization and briquetting.
- 6 Prepare a report concerning the training carried out. The report should be discussed and cleared with the Government authorities concerned before departure from the country; the consultant will then present the report to FAO HQs (within one month of leaving the country), and will amend it in the light of comments received.
- 7 In collaboration with a Sudanese research institute prepare a suitable R&D programme on bagasse carbonization and briquetting. This will include the development of a suitable heat-treatment technology;
- 8 Collaborate with this institute to give an effective start to this programme.
- 9 Prepare a report concerning the proposed R&D programme and the first R&D activities carried out. The report should be discussed and cleared with the Government authorities concerned before departure from the country; the consultant will then present the report to FAO HQs (within one month of leaving the country), and will amend it in the light of comments received.

Duty station:

- Item 1-4: Home based preparations of design (2 weeks). Khartoum, with field travel.
- Item 5-6: Khartoum, with field travel.
- Item 7-9: Khartoum, with field travel.

Duration:

- Item 1-4: 2 months

Item 5-6: 1 month

Item 7-9: 2 months

Language:

English

Split-up into three missions.

Business administration expert

Under the overall supervision of the Director, Forestry Operations, the direct guidance of designated technical support and project operations officers at FAO HQs, the direct supervision of the Chief Technical Adviser and in collaboration with the Biomass Energy Officer, the staff of the Forests National Corporation and relevant national/international institutions, the consultant will:

- 1 Identify and test marketing strategies for bagasse charcoal briquettes produced by the pilot plant operated by the *Forestry development in Sudan* project.
- 2 Prepare a report concerning the activities carried out, with special reference to recommended marketing methods. The report should be discussed and cleared with the Government authorities concerned before departure from the country; the consultant will then present the report to FAO HQs (within one month of leaving the country), and will amend it in the light of comments received.
- 3 Monitor and evaluate the financial performance of the pilot plant for the production of bagasse charcoal briquettes operated by the project.
- 4 Prepare a report concerning the findings and recommendations. The report should be discussed and cleared with the Government authorities concerned before departure from the country; the consultant will then present the report to FAO HQs (within one month of leaving the country), and will amend it in the light of comments received.

Duty station:

Item 1-2: Khartoum, with field travel.

Item 3-4: Khartoum, with field travel.

Duration:

Item 1-2: 2 months

Item 3-4: 1 month

Language:

English

Split-up into two missions.

ANNEX J

TEST RESULTS OF AGGLOMERATION EXPERIMENTS

Table 11. Typical briquette compositions.

Hammer mill screen (mm)	Clay ratio (% basis: charcoal + clay)	Composition of dried briquette			Moisture content of wet briquette (wet basis)
		Charcoal	Clay	Molasses	
1	5%	75%	4%	21%	53%
	10%	74%	8%	18%	48%
	15%	74%	13%	13%	40%
	20%				
2	5%	78%	4%	18%	50%
	10%	75%	8%	17%	51%
	15%	69%	12%	19%	51%
	20%	69%	15%	16%	42%

ANNEX L

TEST RESULTS OF WATER BOILING TESTS

The water boiling tests were performed by Ms. Sawsen and Ms. Ratiba (ERI). Three similar traditional square stoves were used of 26 x 26 x 15 cm. 8 Litre pots were filled with 4 litres of water. For each test a stove was filled with 500 g of fuel. Standard VITA procedures were followed.

Calculated data

Test no.	Fuel type	Charcoal utilized during heating phase (kg)	Charcoal utilized during boiling phase (kg)	Water evaporated during heating phase (kg)	Water evaporated during boiling phase (kg)	Lower heating value (wet basis) (based on proximate analysis) (kJ/kg)
1	Wood charcoal	0.287	NA	0.0385	0.6260	28358
2	Wood charcoal	0.207	0.140	0.0356	0.4980	28358
Uncured agglomerates						
3	10% burn-rate controller	0.221	0.216	0.0164	0.2854	18516
4	10% burn-rate controller	0.291	0.142	0.0354	0.2552	18516
5	10% burn-rate controller	0.297	0.141	0.0465	0.2273	18516
6	15% burn-rate controller	0.237	0.174	0.0319	0.3008	16459
7	15% burn-rate controller	0.285	0.123	0.0148	0.2546	16459
8	15% burn-rate controller	0.282	0.128	0.0129	0.2198	16459
9	20% burn-rate controller	0.346	0.021	0.0244	0.0191	13520
10	20% burn-rate controller	0.383	0.050	0.0474	0.0432	13520
Cured agglomerates						
11	10% burn-rate controller	0.235	0.182	0.0263	0.3620	18516
12	10% burn-rate controller	0.216	0.193	0.0137	0.3810	18516
13	10% burn-rate controller	0.257	0.163	0.0140	0.3412	18516
14	15% burn-rate controller	0.309	0.142	0.0150	0.1959	16459
15	15% burn-rate controller	0.299	0.145	0.0389	0.1996	16459
16	15% burn-rate controller	0.290	0.166	0.0219	0.2824	16459
17	Manually compressed (block-press) (0% burn-rate controller, uncured)	NA	NA	NA	NA	NA

Results

Test no.	Fuel type	Average power output during heating phase (kW)	Efficiency during heating phase (%)	Average power output during boiling phase (kW)	Efficiency during boiling phase (%)
1	Wood charcoal	7.53	15.1%	NA	NA
2	Wood charcoal	5.14	20.8%	2.20	28.4%
	Uncured agglomerates				
3	10% burn-rate controller	2.07	28.7%	2.22	16.1%
4	10% burn-rate controller	2.72	22.6%	1.46	21.9%
5	10% burn-rate controller	2.78	22.6%	1.45	19.6%
6	15% burn-rate controller	2.17	31.0%	1.59	23.7%
7	15% burn-rate controller	2.06	24.6%	1.13	28.3%
8	15% burn-rate controller	2.15	25.2%	1.17	23.6%
9	20% burn-rate controller	1.30	26.3%	0.16	15.3%
10	20% burn-rate controller	1.44	24.7%	0.37	14.5%
	Cured agglomerates				
11	10% burn-rate controller	2.90	31.0%	1.87	24.3%
12	10% burn-rate controller	3.33	33.0%	1.99	24.0%
13	10% burn-rate controller	3.04	27.8%	1.68	25.5%
14	15% burn-rate controller	2.57	24.4%	1.30	18.9%
15	15% burn-rate controller	3.04	26.6%	1.32	18.9%
16	15% burn-rate controller	2.94	26.7%	1.52	23.3%
17	Manually compressed (block-press) (0% burn-rate controller, uncured)	NA	NA	NA	NA

ANNEX N

COST ANALYSIS

ECONOMIC PARAMETERS

Exchange rate (LS/US\$)	310
Effective interest rate (%/yr)	15%
Labour cost (LS/day)	600
Annual operational days (days/year)	250
Daily operational hours (hr/day)	6
Bagasse cost (LS/t)	100

CHARCOAL PRODUCTION COST

Investments	US\$	LS	yr	Annual cost (LS/yr)
6 cu.m. Brick kiln	274	85000	5	25357
3-Drum kiln	261	81000	5	24164
4 cu.m. Steel kiln	497	154000	5	45941
16 cu.m. Brick kiln		216628	5	64623
Cooling drum	15	4500	5	1342
Bricks	0.03	8	0.25	32
Shovel	6	2000	1	2000
Bucket	8	2400	2	1476

Technical characteristics	6 cu.m. Brick kiln	3-Drum kiln	4 cu.m. Steel kiln	16 cu.m. Brick kiln
Volume (m ³)	6.44	2.00	4.18	16.40
Cost (LS)	85000	81000	154000	216628
Bagasse load (kg) (MC appr. 20%)	740	230	481	1886
Efficiency (%)	25%	25%	25%	25%
Charcoal yield (kg/cycle)	185	57	120	472
Loading time (min)	45	15	30 (estimated)	115 (estimated)
Burning time (min)	180	165	170 (estimated)	
Minimum duration of total production cycle: loading, burning, cooling, unloading (days)	3	0.5	0.75 (estimated)	
Daily kiln cycles (cycles/day)	0.33	2.00	1.00	0.33
Cooling drum capacity (kg/drum/day)	30	30	30	30
No. of cooling drums (drums/kiln)	6.2	1.9	4.0	15.7
No. of bricks (bricks/kiln)	56	33	50	144
No. of operators (operators/kiln)	0.11	0.33	0.33	0.11
No. of shovels (shovels/kiln)	0.11	0.33	0.33	0.11
No. of buckets (buckets/kiln)	0.11	0.33	0.33	0.11

Operational cost for 1 kiln (LS/yr)

Cost item	6 cu.m. Brick kiln	3-Drum kiln	4 cu.m. Steel kiln	16 cu.m. Brick kiln
Capital cost (kilns, drums, buckets)	33799	27225	51812	85886
Maintenance (5%/yr)	5651	4521	8642	14381
Consumables (bricks, shovels)	2028	1738	2267	4824
Bagasse	6167	11485	12022	15560
Labour	16667	50000	50000	16667
Total	64312	94969	124742	137317
Annual production (kg/year)	15417	28713	30054	38899
Specific production cost (LS/kg)	4.17	3.31	4.15	3.53

Very much dependent on no. of kiln cycles/day

Operational cost, specific per kg of charcoal

Cost item	6 cu.m. Brick kiln		3-Drum kiln		4 cu.m. Steel kiln		16 cu.m. Brick kiln	
Capital cost (kilns, drums, buckets)	2.19	53%	0.95	29%	1.72	42%	2.21	63%
Maintenance (5%/yr)	0.37	9%	0.16	5%	0.29	7%	0.37	10%
Consumables (bricks, shovels)	0.13	3%	0.06	2%	0.08	2%	0.12	4%
Bagasse	0.40	10%	0.40	12%	0.40	10%	0.40	11%
Labour	1.08	26%	1.74	53%	1.66	40%	0.43	12%
Total	4.17	100%	3.31	100%	4.15	100%	3.53	100%

BRIQUETTING COST**Consumable and raw materials cost**

Charcoal (LS/kg)	3.31
Sand (LS/kg)	1
Molasses (LS/kg)	16 NB: 16 LS/kg is the price of exported molasses! Locally used molasses costs only 1.20 LS/kg!
Sacks (LS/sack)	100
Electricity cost (LS/kWh)	9

COMPARISON AGGLOMERATION AND BLOCK-PRESSING

Specific investments	US\$	LS	yr	Annual cost (LS/yr)
Grinder (200 kg/hr)	3000	930000	10	185304
Agglomerator (50 kg/hr)	900	279000	10	55591
Block-press (75 kg/hr)	2500	775000	10	154420
Drying table (12 m2)	210	65000	10	12951
Wheel barrow	50	15500	5	4624
Drums for molasses and binder preparation	15	4500	5	1342
Production shed, incl. electricity, water (75 m2)	4839	1500000	10	298878
Production characteristics	Agglomer ation	Block-pres sing		
Grinder (200 kg/hr)	1	0		
Agglomerator (50 kg/hr)	4	0		
Block-press	0	4		
Drying table (12 m2)	17	19		
Wheel barrow	6	5		
Drums for molasses and binder preparation	4	2		
Production shed, incl. electricity, water (75 m2)	1	1		
No. of operators	9	27		
Raw material consumption				
Charcoal (kg/hr)	200	217		
Sand (kg/hr)	30	33		
Molasses (kg/hr)	46	50		
Sacks (40 kg) (no./hr)	6.9	7.5		
Electricity (kWh)	18000	0		
Daily production (kg/day)	1656	1800		
Drying time (days/briquette)	2	2		
Dry briquette density (kg/bm3)	320	320		
Drying volume (m3)	10	11		
Layer thickness on drying table (m)	0.05	0.05		
Drying table area (m2)	207	225		
Annual production (kg/yr)	414000	450000		

Operational cost (LS/yr)

Cost item	Agglom- eration	Block- pressing
Capital cost	963072	1185202
Grinder (200 kg/hr)	185304	0
Agglomerator (50 kg/hr)	222365	0
Block-press	0	617681
Drying table (12 m2)	223411	242838
Wheel barrow	27743	23119
Drums for molasses and binder preparation	5370	2685
Production shed, incl. electricity, water (75 m2)	298878	298878
Maintenance (5%/yr)	238913	295263
Charcoal	992258	1078541
Sand	45000	48913
Molasses	1104000	1200000
Sacks	1035000	1125000
Electricity	167400	0
Labour	1350000	4050000
Total	5895643	8982919
Specific production cost (LS/kg)	14	20

Operational cost, specific per kg of briquette

Cost item	Agglom- eration	%	Block- pressing	%
Capital cost	2.33	16.34%	2.63	13.19%
Maintenance (5%/yr)	0.58	4.05%	0.66	3.29%
Charcoal	2.40	16.83%	2.40	12.01%
Sand	0.11	0.76%	0.11	0.54%
Molasses	2.67	18.73%	2.67	13.36%
Sacks	2.50	17.56%	2.50	12.52%
Electricity	0.40	2.84%	0.00	0.00%
Labour	3.26	22.90%	9.00	45.09%
Total	14.24	100.00%	19.96	100.00%

PRE-FEASIBILITY STUDY

Based on agglomeration

Investments	Quantity	Investment cost (LS)	Annual capital cost (LS/yr)
Carbonization equipment			
3-Drum kilns	11	891000	265799
Cooling drums	20	90000	26848
Buckets	4	9600	5905
Briquetting equipment			
Grinder (200 kg/hr)	1	930000	185304
Agglomerators (50 kg/hr)	4	1116000	222365
Drying tables (12 m2)	17	1121250	223411
Wheel barrows	6	93000	27743
Drums for molasses and binder preparation	4	18000	5370
Production shed, incl. electricity, water (75 m2)	1	1500000	298878
Tools			
Bricks	368	2945	
Shovels	4	8000	
Working capital (1 month of operational cost)		415195	82729
Total		6194991	1344353

Production characteristics

Annual production (kg/yr)	414000
No. of labourers	
Carbonization	4
Briquetting	9
Cost of production manager (LS/day)	2400
Raw material consumption (kg/yr)	
Bagasse	1200000
Sand	45000
Molasses	69000
Sacks consumption (no./yr)	10350
Electricity consumption (kWh/yr)	18000

Commercial characteristics

Wood charcoal price (LS/kg)	42.86
Estimated consumer briquette price (LS/kg) (25% less than wood charcoal)	32.14
Estimated delivered retailer price (LS/kg) (retailer profit margin 30%)	22.50
Average transport cost (50 km, 10 LS/t/km) (LS/kg)	0.50
Ex-factory price (LS/kg)	22.00

Annual costing (LS/yr)

Item	Cost	Revenue	Balance
Capital and maintenance	1654103		24.92%
Labour and management	2500000		37.67%
Raw materials			0.00%
Bagasse	120000		1.81%
Sand	45000		0.68%
Molasses	1104000		16.64%
Consumables			
Sacks	1035000		15.60%
Electricity	167400		2.52%
Other consumables (bricks, tools)	10945		0.16%
Total production cost	6636448		100.00%
Total revenue		9108000	
Net revenue			2471552
Specific production cost (LS/kg)			16.03
Factory profit margin (LS/kg)			5.97
Pay-back period (yr) (investment/net revenue)			2.51
IRR (%)			61%

Cash flow schedule

Year	Cash flow
0	-6194991
1	3815905
2	3815905
3	3815905
4	3815905
5	3815905
6	3815905
7	3815905
8	3815905
9	3815905
10	4231100

COST ANALYSIS

Production cost (LS/yr)	Capital	Investment	Annuity	Raw material cost		
		(LS)	(LS/yr)	(LS/yr)		
Capital and maintenance	1654103	Equipment	4268850	962747	Bagasse	120000
Labour and management	2500000	Production shed	1500000	298878	Sand	45000
Raw materials	1269000	Working capital	415195		Molasses	1104000
Consumables	1213345	Total	6184045		Total	1269000
Total cost	6636448					

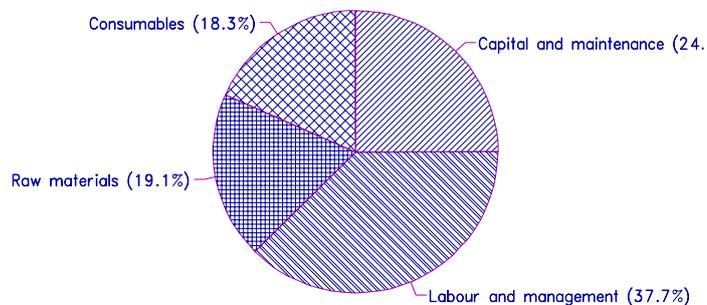


Figure 5, Production cost break-down for the production facility considered.

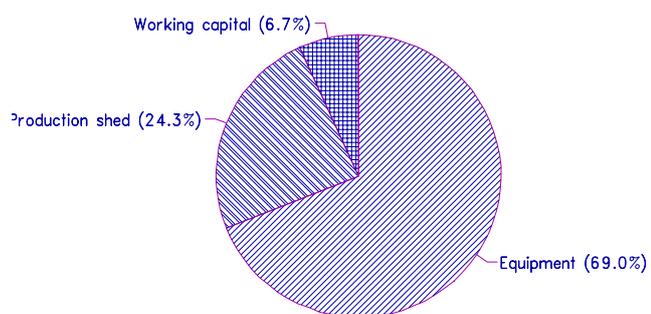


Figure 6, Break-down of capital involved in the production facility considered.
