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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Division of Industrial Operations

"Gasification of Agricultural Residues"

Ref.: SI/SUD/82/802

Final Report

Prepared by
FWAR
Geisenheim-W.-Germany

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1.0 Abstract

a. Background and Objectives

In view of increasing oil shortage and energy demands the Government of the Democratic Republic of the Sudan has initiated a program for the development of alternative energy resources. To meet the energy requirements necessary for development of small-scale industries and rural communities suitable technologies are being investigated using agricultural residues as raw material for the generation of electricity and the production of charcoal.

The present project aims to investigate the possibilities for the application of modern gasifier technology and the performance of wood gasifiers to be fed with crop residues including cotton stalks for the generation of energy. Additionally the present study covers the technical and economical aspects of electricity generation as well as charcoal production from cotton stalks and other agricultural residues in the Democratic Republic of the Sudan.

b. Work on the Study

In two field missions in March and April 1983 to the Democratic Republic of the Sudan the necessary data for the preparation of the study were collected. Subsequently tests were carried out with an available briquetting machine in order to evaluate possible direct combustion of briquetted material. Due to the positive results of these tests this system was added to the scope of investigations.

The following parameters were investigated for this study:

A. Availability in quantity and quality of agricultural residues suitable as fuel for energy production. Priority was given to cotton stalks but later local availability of groundnut shells, dura straw, sugar cane bagasse and rice husks was also examined.

B. Application of agricultural residues for conversion into fuel using centralized or decentralized systems.

C. Methods of fuel conversion and the specific applications thereof, such as

- Briquetting,
- Carbonization,
- Gasification.

Within the scope of this study two Sudanese specialists obtained first-hand information from process owners and manufacturers of equipment in the Federal Republic of Germany. They studied different methods of fuel conversion and participated in practical experiments.

c. The investigations confirmed that agricultural residues in the Sudan represent a large energy potential. Utilization of this potential of renewable energy, however, is limited because of the low energy density per unit area. Therefore, very high transport costs are involved for collecting, so that only decentralized, small collection centers can be considered.

The rather limited quantities which can be collected, will restrict technical applications of methods of fuel conversion mainly to briquetting, carbonization and gasification. As to cotton stalks applications are also limited because of the strict plant health regulations which have to be observed. Practically, no utilization will be possible without alteration of the existing regulations.

Thus, only decentralized briquetting stations can be recommended for cotton stalks under the condition that the briquetting process applied guarantees the necessary destruction of parasites.

Agro-industrial residues such as sugar cane bagasse and groundnut shells, available at site in large quantities, will not incur high collection costs and may be used for energy purposes by means of briquetting, combustion and gasification. Surplus sugar cane bagasse may find likewise a useful application by conversion into roughage for animal feed.

Rice husks are available as agro-industrial residues. For the time being, however, no process is commercially available yet to use such material economically for combustion or gasification, because of the high SiO_2 contents and the low ash melting point.

d. Recommendation and Project Identification

In the scope of these studies three projects have been identified and are recommended for further consideration:

1. Briquetting of cotton stalks,
2. Carbonization of cotton stalks,
3. Gasification of groundnut shells.

2.0 TABLE OF CONTENTS   Page

1.0	Abstract	1
2.0	Table of Contents	2
3.0	Introduction	9
4.0	Collection of Data	10
5.0	Population	11
6.0	Sources of Energy	11
6.1	Cotton Stalks	13
6.2	Sorghum (Dura)	15
6.3	Millet (Dukha)Wheat/Maize/Sesame	16
6.4	Groundnuts	16
6.5	Rice	17
6.6	Sugar Cane Bagasse	18
7.0	Technical Utilization of Cotton Residues	19
7.1	Collection	20
7.2	Transportation	23
7.3	Plant Health	25
7.4	Storage	26
7.5	Purchasing Price of Cotton Stalks from Tenant Farmers	27
8.0	Energy Production from Agricultural Residues	28

9.0	Energy Conversion Routes	30
9.1	Direct Combustion	31
9.2	Carbonization	31
9.2.1	Earth Kilns	32
9.2.2	Masonry Kilns	33
9.2.3	Transportable Metal Kilns	34
9.2.4	Retorts	37
9.3	Gasification	41
9.3.1	Up-Draught Gasifier	41
9.3.2	Down-Draught Gasifier	42
9.3.3	Cross-Draught Gasifier	43
9.3.4	The Fluidized-Bed Gasifier	44
9.4	Briquetting	45
9.4.1	Piston Press	46
9.4.2	Pellet Press	46
9.4.3	Screw Press	47
9.4.4	Roller Press	47
10.0	Energy from Cotton Stalks	48
10.1	Briquetting and Combustion	48
10.2	Carbonization	50
10.3	Gasification of Cotton Stalks	50
11.0	Gasification Test with Cotton Stalks from the Sudan	52
11.1	Gasification of Cotton Stalks Realization of a Test	52
11.2	Gasification in a Fluidized-Bed Gasifier	55
12.0	Energy from Groundnut Shells	56
12.1	Briquetting and Combustion of Groundnut Shells	56
12.2	Carbonization of Groundnut Shells	58
12.3	Gasification of Groundnut Shells	59

13.0	Energy from Sugar Cane Bagasse	60
13.1	Briquetting of Bagasse	60
14.0	Economic Evaluations	61
14.1	Carbonization of Cotton Stalks with a Cusab Kiln	61
14.2	Briquetting of Cotton Stalks	63
14.3	Briquetting of Groundnut Shells	64
14.4	Gasification of Groundnut Shells	66
15.0	Recommended Projects	68
15.1	Energy Supply for a Remote Ground-nut Oil Mill	68
15.2	Cotton Stalks Briquetting Center	71
15.3	Cotton Stalks Carbonization Project	74
15.4	Organization of the Projects	76
16.0	Training of two Sudanese Specialists for one (1) month	77

A N N E X E S
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17.0	Annexes	78
17.1	Map of Sudan, Figure 1	79
17.2	Regional Distribution, Table 1	80
17.3	Major Agricultural Crops, Table 2	81
17.4	Area and Production of Major Agricultural Crops, Table 3	82
17.5	Types of Agriculture, Figure 2	83
17.6	Map of Sudan, Figure 3	84
17.7	Map of Sudan, Population, Figure 4	85
17.8	Energy Consumption, Table 4	86
17.9	Household Energy Consumption, Table 5	87

17.10	Region - TOE, Table 6	88
17.11	Crop Collection, Table 7	89
17.12	Cotton Growing Centers, Table 8	90
17.13	Map of Sudan, Figure 5	91
17.14	Oil Mills, Table 9	92
17.15	Map of Sudan, Figure 6	93
17.16	Agricultural Residues, Table 10	94
17.17	Cotton Stalk Removal, Table 11	95
	Cotton Stalks Puller, Table 12	95
	Cost per Feddan, Table 13	96
17.18	Masonry Kiln, Figure 7	97
	Earth Kiln, Figure 8	97
17.19	Mark V Metal Kiln, Figure 9	98
	Drum Kiln, Figure 10	98
17.20	CUSAB-Kiln, Figure 11	99
17.21	Continuous SIFIC Process, Figure 12	100
	Herreshoff Process, Figure 13	100
17.22	Up-Draught Gasifier, Figure 14	101
17.23	Down-Draught Gasifier, Figure 15	102
17.24	Cross-Draught Gasifier, Figure 16	103
17.25	Fluidized-Bed Gasification Plant, Figure 17	104
17.26	Manufacturers of Briquetting Presses, Table 14	105
17.27	Cotton Stalks Carbonization, Table 15	109
17.28	Composition of Cotton Stalks, Table 16	111
17.29	Gasification of Cotton Stalks at Beijer Institute, Sweden, Table 17	112
17.30	Gasification Analysis of Sudan Cotton Stalks, Table 18	114
17.31	Composition of Groundnut Shells, Table 19	131
17.32	Program arranged for the Experts	132
17.33	Glossary, Table 20	140
17.34	References, Table 21	141
17.35	Photos	146

3.0 Introduction

The Democratic Republic of the Sudan faces growing difficulties in meeting the steady increase of its energy requirements, affecting all sectors of industry, agriculture, transport and private households. In order to cope with this energy crisis the Government of the Sudan has ordered various governmental institutions to accelerate the assessment of renewable energy and to identify any such project which would improve the energy situation.

Within this objective, FRITZ WERNER INDUSTRIE-AUSRÜSTUNGEN GMBH, Geisenheim, West Germany, has been contracted by UNIDO to carry out a survey on the availability of agricultural residues as feedstock for conversion into energy, applying modern technologies for briquetting, carbonization and gasification. Furthermore a study should be prepared identifying special projects, giving the technical and economical feasibility of the project, considering different feedstocks available with special emphasis to cotton stalks.

The scope of work on this study was phased into two (2) sections, the

- In-field assessment of feedstock carried out in two field missions, and
- The technical and economical definition on account of the findings and samples.

Whereas the first field mission should identify the major agriculture growing centers with high proportion of agricultural residues, the second field mission was defined for project identification. A total of more than 10 man weeks were spent on the two missions, involving in the first phase Dr. Ing. Agr. Heinz Büchner and Dip. Ing. H.J. Müller and including as gasification expert Dipl. Ing. Kurt Jaster in the team for the second mission.

4.0 Collection of Data

Agriculture is the backbone of the economy of the Democratic Republic of the Sudan and its contribution to the Gross National Product (GNP) comes up to 80%. Approximately 90% of the export proceeds from cotton alone exceed 60%. A total of 80% of the population are living directly or indirectly from agriculture.

Out of the total surface area of 2.5 mio. square km only 76,264 square km or 18,158,000 feddans (3%) are under agricultural cultivation. Whereas 3,065,000 feddans (17% of the cultivated area) are cultivated under irrigation, a total of 15,093,000 feddans (83% of the cultivated area) are mechanized, rainfed or traditional agriculture. (Figure 1, Annex 17.1).

Gezira constitutes 12% of the total area cultivated in the SUDAN and produces nearly 50% of the country's total cotton and 60% of the groundnuts. The population density is the highest of all agricultural areas; the infrastructure in the Gezira is adequately developed, and there are plans for further agricultural industrialization.

Table 1 (Annex 17.2) shows the regional distribution of feddans under cultivation in 1980 (also Figure 2 and 3, Annex 17.5, 17.6). In Table 2 and 3, (Annex 17.3, 17.4) the area under cultivation and the respective crops, besides sugar cane, are mentioned.

5.0 Population

The population of the Sudan is approx. 19 mio. people. The average growth rate is estimated at about 2.5% p.a. Roughly 25% of the total population is urban, whereas 75% of the population are living in rural areas (Figure 4, Annex 17.7).

6.0 Sources of Energy

The rural population consumes 78% of the total energy, mainly traditional fuels. Main sources of energy are fire wood and charcoal. The present consumption is estimated at 2.5 mio. tons of charcoal per year and the projected consumption of charcoal for the year 1990 is 3.8 mio. tons. Consumption figures of fire wood have always been 3 times higher than those of charcoal.

Since charcoal production has always been done in the traditional way depleting local forests, the price of charcoal varies between LS 0.150 - 0.250 (Khartoum) per kg, a price which is rather discouraging for other types of fuel.

Table 4 (Annex 17.8) states the projection of energy consumption from wood and charcoal in households. It is interesting to note that households represent 75% of the total energy demand.

The consumption of crop residues and animal wastes as fuel in comparison to the consumption of wood and charcoal is fairly low (Table 5, Annex 17.9).

Comparing energy resources in the 7 regions it can be seen that consumption of energy from renewable sources, specially charcoal and fire wood increases with the distance from the Sea Port, source of supply of petroleum products. In Khartoum region 54% of energy consumption is met by petroleum products, whereas Southern, Kordofan and Darfur Regions consume only between 1% to 3.5% fossile products. Hydropower is only available for Central and Eastern Regions.
(Table 6, Annex 17.10).

Applying the traditional methods of charcoal production 6 tons of fire wood will yield only 1 ton of charcoal. The devastating effect on the forest potential can be witnessed already for some time. Under these circumstances ways and means should be found to utilize the large energy potential contained in agricultural residues by application of new technologies.

In order to estimate available agricultural residues crop residue factors and availability factors which are stipulated in the literature have been applied. Such factors could be confirmed widely during the field missions (Table 7, Annex 17.11).
(Source of Information: Renewable Energy Assessment.)

Some crops show a relatively low availability, which is due to the fact that substantial parts are either left on the ground, are used as animal feed (grazing on the fields) or even as building material.

6.1 Cotton Stalks

Considering the wide propagation of cotton cultivation in the Sudan with approximately 1 mio. feddans (420.000 ha) and the considerably high residue yield factor of 1,5 tons per feddan, cotton stalks should be a very attractive resource for renewable energy. Theoretically 1,5 mio. tons of cotton stalks should be available for fuel conversion if appropriate measures for their safe handling existed.

However, plant health regulations demand the complete removal of cotton residues within 6 to 8 weeks after harvesting.

Infestation of pest varies from year to year as to their occurrence and seriousness as well as from region to region. Meanwhile cotton varieties resistant to white fly infestation have been developed and likewise bacterial blight resistant varieties are very promising as well.

Cotton growing is widespread over the Sudan, various areas growing predominantly cotton and cultivating different varieties. (Table 8 and Figure 5, Annex 17.12, 17.13).

The plant population per feddan varies according to variety, cultivation practice (irrigated/rainfed), stage of mechanization, etc... In the Gezira, the standard spacing is 80 cm between the cotton ridges and 50 cm between the plants in the ridges. Planting in Gezira is still done by hand, and thinning to three plants per hole is recommended, resulting in a plant population of 31,500 per feddan. A random sampling in different areas has shown that there is a considerable variation in the number of plants left, thus varying between 1 - 3 plants per hole so that the real plant population is coming to approx. 20,000 - 25,000 per feddan.

Samples of cotton stalks which had been piled up in the fields for 2 - 3 weeks after uprooting have been weighed. The weight of a single cotton plant is in average about 90 gms. As the cotton plant population per feddan comes to 20,000/25,000 plants, the quantity of usable air-dried material will be 1.8 - 2.2 tons/feddan. Considering some losses caused by cattle grazing in the cotton fields and by small amounts of stalks being carried away for household fuel, it seems reasonable to assume 1.5 tons of air-dried cotton residues being available per feddan.

6.2 Sorghum (Dura)

In relation to the cultivated area dura growing is the most important crop in the Democratic Republic of the Sudan. Estimating an average area of 7.5 mio. feddans of sorghum and applying a conversion factor of 2.14 tons per feddan of residues, a total amount of 16 mio. tons of dura straw would be available.

Sorghum is mainly cultivated within the savannah regions of the Democratic Republic of the Sudan. The largest cultivated area is in the Gedaref district (Figure 3, Annex 17.6).

The residues of dura are, however, entirely utilized as feed stock for cattle, building material (mud walls, roof thatching) as well as household fuel.

The cultivation of sorghum is usually combined with cattle raising and such residues represent a valuable roughage for cattle. Therefore, any use of dura residues for energy conversion has to compete commercially with the use as livestock feed and consequently with food supply. It is, therefore, evident, that any type of energy production will not compete with the higher added value in food production. Surplus dura residues are even sold as animal feedstock and transported by lorries, or tenants are letting their dura fields after harvest for animal grazing, for which prices of up to LS 400 are paid per hawashar (5 feddans).

In addition to the use as cattle feed, the dura residues serve as cover against the parching sun and therefore, are very often left as a mulch on the ground until the next sowing season.

6.3 Millet (Dukha)/Wheat/Maize/Sesame

What has been mentioned for dura applies also for above crops. They are all completely utilized as cattle feed, building materials or household fuels.
Residues from millet are estimated at roughly 3 mio. tons, from wheat approx. 1.2 mio. tons whereas maize yields about 0.250 mio. tons and sesame produces around 2.5 mio. tons of residues per year.

6.4 Groundnuts

Groundnuts are mainly cultivated in the savannah regions of the Sudan (Figure 3, Annex 17.6). The total area planted is estimated at approx. 2.3 mio. feddans. Calculated with a residue yield factor of 1.26 tons/-feddan groundnut field residues yield almost 3 mio. tons.

The plant residues (hay) are an excellent livestock feed and, therefore, too valuable to be utilized as energy resources. The shells, obtained at the collecting centers or at the oil mills at the rate of 30% - 35% of the whole nuts, are used partially as cattle feed or as boiler fuel in oil mills.

The total amount of shells available can be estimated at about 300.000 tons per annum. Whereas oil mills normally do their own shelling in order to use the husks as boiler fuel, the shelling is partly done in collecting centers. For sanitary reasons the shells have to be removed from inhabited areas as soon as possible because of a likely built-up of maggot infestations, pathogenic agents, etc. Such collecting centers, therefore, offer the possibilities of installation of briquetting units for the production of household fuel from groundnut shells or gasification for electricity and heat production.

Out of the 62 major oil mil's half of them are located in towns like Khartoum, Omdurman and Port Sudan, whereas others are installed in centers of groundnut cultivations. As to location and capacities of major oil mills in the Sudan refer to table 9, Annex 17.14.

The price paid per 25 kg bag at the oil mill or deshelling center is reaching LS 1.500 and one (1) lorry load of shells may cost up to LS 90.000. Such high prices are paid for groundnut residues because of lack of other feedstock for animals. Therefore, only any surplus of groundnut husks could be usef for conversion into energy.

6.5. Rice

Rice growing ist, als already mentioned, still in a developing stage. The provinces where presently rice is cultivated are:

Upper Nile (Malakal)
White Nile
Gezira
Bahr El Ghazal (Aweil Scheme)
Equatoria (upland rice in the Zaned area).

Trial plantings have also commenced in the Sennar/ Kosti area (White Nile). The Aweil scheme seems to be the most developed. The net area is estimated at 6'000 feddans. It is expected to harvest twice a year with yields of 2.1 tons/feddan in the main season and 1.3 tons/feddan in the off-season yielding a total of 3.4 tons/feddan.

The total area planted with rice is given at 30'000 feddans which is, however, very much doubted. The target for the Malakal area has been set for 10'000 feddans. If piloting is successful in the White Nile province, an area of 85'000 feddans may be developed. So far there is not very much expansion foreseeable in the near future.

Rice straw is chiefly utilized as cattle feed. The rice husks, obtained at a rate of about 20% at the mill, are however a possible source for the generation of electricity and may lead to energetic self-sufficiency of the rice mill.

6.6 Sugar Cane Bagasse

The bagasse discharged by the milling tandem is the traditional fuel for the boilers of sugar factories. Normally, the energy household of a raw sugar factory should be laid-out in such a way that the bagasse supply will be sufficient as boiler fuel. Besides New Halfa sugar factory, there is no surplus bagasse available at present in the factories operating in the Sudan. Surplus bagasse in New Halfa has been stored for years. This old bagasse without any nutritious potential could be briquetted and used for household fuel. Fresh bagasse, however, when available from other sugar factories as well, is a potential feedstock for cattle. Steam treating of bagasse will improve digestibility factors up to 60% and will provide high energy feedstock.

Large amounts of surplus bagasse can also be used for generating electricity during the off-season which will be fed into the national grid. In this case, however, the efficiency factor has to be considered, which can be improved by installation of condensate turbines.

Total bagasse produced in the 6 sugar factories is well above 1 mio. tons, used as boiler fuel. The bagasse piled up at the factory site in New Halfa already for years, is estimated alone at 400,000 tons (Table 10, Annex 17.16). Part of the bagasse is already decomposed and can hardly be utilized, but the bulk still could be compacted into briquettes and used as household fuel. There are different geographical locations of sugar factories (Figure 6, Annex 17.15).

7.0 Technical Utilization of Cotton Residues

As long as cotton has been cultivated industrially in the Sudan, ways and means have always been investigated about utilization of residues and waste material as a source of energy. Such investigations have been favoured by the enormous potential of energy, theoretically available. The large demand of the rural population for energy and lack of other suitable energy products in an environment without fossile fuel reserves have sponsored new ideas and investigations.

The main obstacle against utilization of this large energy potential lies in the logistics, especially in the collection and storage of the raw material. Although cotton is grown over large areas, the cotton stalks are a very bulky low-value material that cannot easily be handled and transported over large distances.

Moreover, cotton stalks must be collected within a two-months period before the next sowing, so that the supply for the whole year has to be stored which represents a difficult problem both in magnitude and specially in preservation.

7.1 Collection

The pulling of cotton stalks is the most strenuous part of the entire operation.

As basic operation all the cotton stalks have to be pulled out with a pincer-like hand tool, the standard equipment of the tenants known as "KAMASHA". The stalks are collected and piled for burning. Thereafter the soil surface is raked and swept clean of small trash, boll cases and fallen seed and piled on top of the stalks for burning. After the first burning the fields are swept again, so as to achieve a complete and thorough removal of all plant residues. According to investigations the hand pulling and collecting of stalks accounts for some 40% of the total work, whereas the two sweeping operations and the burning itself represent 60% of the costs. The labour demand for post harvest operations is rated with 5 man-days per feddan or a daily output of 0.2 feddan per man. At a daily wage rate of LS 1.500, the total costs for this operation amount to LS 7.500 per feddan.

According to the newly introduced individual accounting system for cotton in Gezira, the tenant receives for the collection of cotton stalks and debris LS 5.500 per feddan. The Farmers' Union calculates the costs for post harvest operations between LS 9.000 - 10.000 per feddan, a difference of 3.500 - 4.500 which must be borne entirely by the tenants.

For years special attention was given to the possibility of mechanizing the arduous, time consuming operation. As an alternative to pulling the complete cotton plant out of the ground, the possibility of cutting the plant sufficiently deep for easy removal by hand was investigated. This method is put into practical operation today in the Rahad Scheme. Two-U-shaped, tractor-mounted, 400 mm wide blades are cutting the plant about 150 mm below ground level. Thus 1.2 feddans/h of cotton stalks are loosened, leaving the stalks upright for easy collection. The tenants are charged with LS 8.500/feddan for this mechanical operation. Assuming that collecting and burning amounts additionally to LS 3.000/feddan, the total operation costs the tenant LS 11.500/feddan. About one day per person should be calculated for clearing and collecting the mechanically uprooted stalks. Gezira Board Authorities have, however, rejected this method of uprooting, reasoning that cutting the rootes will excessively disturb the soil surface so that the subsequent sweeping-up of the soil becomes very difficult or rather unfeasible.

Other systems developed for mechanical uprooting such as two and four row pulling machines of different designs have not found the acceptance of the Tenants' Union in Gezira, because still 10% of the handpulling costs are incurred to clear manually stalks missed by the stalk puller. The pulling machine apparently imitates the hand pulling resulting in low soil disturbance so that trash may be gathered as easily as after hand pulling.

Trials by the National Institute of Agricultural Engineering, England, (Table 11, Annex 17.17) comparing machine pulling versus root cutting/hand pulling have given encouraging results. Work rate of machine pulling was 2.5 times that of root cutting units. Moreover, fuel consumption of tractors operating the blades for root cutting had been found 2.5 times higher per unit area than fuel consumption of pulling machines.

Performance of the mechanical systems for uprooting in Gezira and Rahad was quite different (Table 12, Annex 17.17).

In Gezira the actual costs for mechanical pulling of stalks/feddan were almost half the cost experienced with manual operation, handpulling by "KAMASHA" (Table 13, Annex 17.17).

Mechanical stalk pulling in Rahad has proven costwise advantageous over mechanical root cutting, so that root cutting costs can be brought down to half. Machine pulling of stalks definitely represents a large cost saving in comparison to handpulling or root blading.

Machine pulling, unfortunately, did not yet develop out of the experimental stage.

Any possible utilization of stalks, by collecting and briquetting for energy conversion, will depend on further mechanization, in order to overcome the logistical problems.

Considering an average capacity of 30 feddans a day (3.77 feddan/h and 8h net of operation in a 10h working day) at about 45 working days (phyto-sanitarian regulations) a total area of 1.350 feddans can be cleared by postharvest uprooting. Thus for mechanization 370 machines would be required for the total cotton area of 500,000 feddans in the Gezira, whereas Rahad would be need some 100 machines on 130,000 feddans for uprooting.

For breakdowns, repairs and other down times additionally 10% are required, allowing for Gezira 400 machines, for Rahad 110 respectively. At a price of LS 10,000 C.I.F. Port Sudan for each pulling machine including spares, a total investment of LS 4,000,000 for Gezira alone, LS 1,100,000 for Rahad would be involved.

Leaving aside that the technical standard of the machine is not yet achieved completely, such investment has to be considered as too costly.

For the sake of completeness it has to be mentioned that trials have been made to replace as well the sweeping-up operation. Two different systems have been tested, a tractor mounted burning equipment and tractor mounted suction fan, but both have been abandoned for the time being. Since this part of the operation, however, accounts for some 60% of the postharvest costs, the trials have to be reviewed again for Gezira and Rahad.

Although it was beyond the normal scope of work this subject has been given some attention. Because of the very low wage rate for agricultural labour and the hard manual work involved in pulling the stalks, labour shortage becomes increasingly more serious from season to season. In addition, the clean-up of cotton residues is a highly seasonal operation. Since the basis for any industrial utilization will be the collecting and handling of stalks, the demand for mechanization becomes more and more imperative.

7.2 Transportation

In addition to the removal operation, the transport of uprooted cotton stalks creates a serious logistical problem due to huge quantities of uncompacted residues. Furthermore scattering of material when loading and along the way has to be strictly avoided in order to prevent spreading of further infestations.

To meet the respective requirements for transport and storage, cotton stalks have to be compacted into a transport-suitable and storable form such as pressed bales (approx. 90 kg/m³), chips (approx. 120 kg/m³) or compacted briquettes (600 kg/m³). In the latter case the briquetted cotton residues could directly be used as household fuel or for steam generation in industrial boilers.

A number of different systems could be proposed for the removal of stalks to collecting or processing centers:

- Tenants deliver stalks to collecting centers where they are weighed, pressed and then transported to the plant site;
- Tenants put the stalks in piles on the side of fields where they are either baled, chipped or briquetted, and transported either to a collecting center or directly to the plant site by hired transport;
- Tenants deliver stalks to collecting centers where they are weighed, baled, chipped or briquetted and trucked to the plant site;
- Tenants hire mobile compacting machines and deliver the briquetted cotton residues to the collecting centers or directly to the plant site.

Because of the bulky nature of cotton stalks, transport and storage facilities have to be considered carefully. We therefore came to the conclusion that tenants should uproot and deliver the stalks to a collecting center where they are weighed and compacted by means of a briquetting machine. This would also minimize the physical problems of handling and transporting the raw material for further operations. Assuming that the stalks would be brought to the collecting center mainly in ox carts or tractor pulled trailers (60%) and secondarily by donkeys (40%), the average load has been assumed to be 0.5 tons carts and trailers, and 0.1 tons for donkeys.

Calculating with this figure a tenant has to do 3 round trips to carry the stalks of 1 feddan = 1.5 tons to the collection center. Taking a truck with a carrying capacity of 40 m^3 or 10 tons, the amount of stalks carried at 30 kg/m^3 density is 1.2 tons.

7.3 Plant-Health Aspects

As already mentioned before, the plant-health regulations forbid the storage of any cotton residues into the ney crop season (i.e. beginning June, when sowing will start), in order to prevent any infestation of the new crop.

The briquetting operation proposed will not only compact cotton residues into size and volume to be handled commercially but should likewise bring advantages for longer storage possibilities.

Following s[illegible] the plant-health requirements law by law, a com[illegible]ation of fungicide/insecticide has to be added during the briquetting operation. Such presticide treatment will be commercially too costly and not feasible. Other trials treating cotton residues with insecticides to have same stored for a year's supply (AROMA cardboard factory) did not turn out to be feasible as well. Storing cotton stalks under plastic covers, however, to expose same to heat of over 80° C in the sun, proofed at least to a certain extent to be practical and efficient, killing, for example, the pink bollworm, which cannot resist heat of more than 55° C.

Based on this experience it can be assumed that different kinds of pests will not withstand the briquetting operation, i.e. the high pressure together with heat exposure of more than 80°C. The scientific opinion about this method and the possibility of killing all types of pest was not unanimous. Whereas scientists in the Sudan have different opinions, Prof. Schmutterer, Head of Department of Phytopathologie at the Justus-Liebig-University of Gießen, expressed the opinion that the briquetting itself would probably be sufficient. He is a wellknown authority on cotton pests and had worked for some years in the Research Station of the Gezira Board.

In order to obtain scientifically proven results about the possibility to make cotton residues immune and storable by briquetting it is suggested that Gezira Research Station will be officially asked to carry out respective tests.

More dangerous for carrying over pest infestations into the next season are the remains which might be left on the ground or in the cracks of the cotton field. This danger is potentially by far higher than any cotton residues briquetted.

7.4 Storage

The practice to store cotton stalks in the villages in limited quantities for use as household fuel is greatly discouraged by government due to the phyto-sanitarian regulations.

Any industrial plant intending to use cotton residues as fuel has to solve this problem, besides the logistic difficulties as to low density factor, volume and low density factor per area, as well as volume and energetic value.

These difficulties will render any industrial use of cotton stalks as basic fuel the year round uneconomical.

Therefore decentralized energy conversion by briquetting or carbonisation in small scale for household fuel will be the only answer to the logistic difficulties.

7.5 Purchasing Price of Cotton Stalks from Tenant Farmers

As long as mechanical uprooting will not be introduced, so that collection of stalks could be combined with the uprooting operation, any collection of cotton residues can only be handled manually by the tenants, which likewise requires manual uprooting and drying. Both operations, however, have to be carried out anyhow.

The cost for uprooting and gathering of the stalks is rated at LS 10.000/feddan or LS 6.670/ton. To cover at least nominally the cost for loading and transport of the stalks at an average distance of 1,25 km = 2,5 km round trip we should allow for LS 0,500 per ton/km including return trip, which amounts to LS 3.750 per ton delivered to collection center or LS 5,600 per feddan (1.5 ton/feddan) respectively (3 round trips = 7.5 km transport).

The purchase price per ton of stalks sums up to LS 10.500 per ton or LS 15.600 for 1.5 ton of stalks coming from one (1) feddan.

8.0 Energy Production from Agricultural Residues

Projects during the Past

A British consultant to the Gezira Board, Mr. D. Hepburn, tested methods in the fifties, still in the era of the British Administration, concerning the utilization of cotton stalks for the production of various products. In January 1956, Mr. Hepburn left the Sudan, after many years of activity. His work has been presented in several reports, which are recordered partially in Barakat, Applied Engineering Department. As it was impossible to obtain copies of these reports, only a few extracts can be mentioned here, which were made during the study.

During the stay of Mr. D. Hepburn a costly experimental station in Barakat had been set up. The station was constructed to produce various products derived from cotton stalks like briquets as domestic fuel, fibrous material for the production of fabrics and building material, pulp as feed for the manufacture of paper.

Essentially the plant consisted of a steam boiler, heated with cotton stalks and other waste materials like groundnut shells, a two cylinder steam engine for the generation of electricity, a plant to briquet cotton stalks including all sorts of equipment for the preparation of the stalks for briquetting, comprising:

Shredder, Hammer Mill, Storage and Measuring Silos.

Furthermore, there was an installation for the production of fiber board from cotton stalks and other agricultural residues.

Following the departure of Mr. Hepburn, the project was not pursued further. As the income from the cotton crop declined, too little resources were available to finance such a complex experimental project any further.

Furthermore, the Gezira Board withdrew from the industrial transformation of agricultural products. Only the cotton ginning continued to be supported.

Mr. Hepburn was aware of the problems related to cotton stalks especially with reference to pulling, transport and pest control. He planned to improve the pulling machine to avoid hand pulling. The profit from sale of products out of cotton stalks should have improved the income of the tenants.

After pulling, the stalks should be pressed into bales in a machine still to be constructed and then transported by the Gezira Board Light Railway to the Central Processing Station. To this day, there is no suitable bale press available. The Light Railway exists, however, it urgently requires an extensive rehabilitation. The Gezira Board is not able to support the railway on its own. Already now the transport capacity is insufficient for the cotton cultivation.

Referring to pest control, he considered a treatment by means of fumigation and sterilization.

He also was aware of the storage problems of cotton stalks and conducted tests on storage in Khartoum. Results at hand are showing in one case that the stalks were approx. after three months entirely destroyed by wood worms. In another case the cotton stalks were treated with DDT and it was thus possible to control the wood worm.

9.0 Energy Conversion Routes

There exist many energy conversion routes to convert wood into energy. Only thermal conversion has been considered here, in the form of

- Direct combustion
- Carbonization
- Gasification.

This report deals with agricultural residues which have characteristics similar to wood only. The conversion techniques valid for wood are, however, not directly applicable due to differences in the physical structure of the residues. Adaptation and new development became necessary to use cotton stalks, groundnut shelles, straw etc... as feedstock.

Agricultural residues from annuel plants contain in general a high percentage of SiO_2 which causes low ash melting temperatures and in consequence slagging. Furthermore, the feedstock is very often a bulky material with a low energy content per production area calling in consequence for costly collection and transport.
As to cotton stalks, additional problems arise because of the necessary plant-health control and wood worm infestation during storage.

A brief description of actual energy conversion techniques for agricultural residues is stated in the following chapters.

9.1 Direct Combustion

The types of feedstock dealt with in this report are suitable for direct combustion in household stoves. Size reduction by briquetting to minimize transport costs will be necessary. For industrial boilers, the slagging problems have to be taken into account. Technical solutions exist, however, suitable processes are only economical at high capacities.

9.2 Carbonization

Carbonization is a process to obtain from biomass a fuel of reduced size, reduced weight, smokeless fire and a higher calorific value per weight. When wood is heated up in an atmosphere not containing oxygen, it is thermically split into a mixture of gaseous components (wood gas and vinegar) and charcoal.

The pyrolysis reaction is endothermic until reaching 280°C and then exothermic. This means that for wood drying and heating up to 280°C energy has to be supplied.

Two basic processes exist:

The Kiln Process

The energy needed to dry and heat the wood is produced by partial combustion of the wood to be carbonized. The produced hot stack gases transport the heat energy to the wood charge. The efficiency of this process is about 10% - 15% by weight of the dry-matter to be carbonized.

The Retort Process

A hot flue gas is conducted through a retort drying and heating the stored wood. No combustion takes place in the retort due to absence of oxygen.

The efficiency of this process is about 20% - 35% by weight.

9.2.1 Earth Kilns

In earth and pit kilns a cover out of mud and leaves serves to isolate the kiln against the atmosphere. Air may only enter the kiln through holes provided for this purpose. The carbonization zone is "conducted" through the kiln by help of opening and closing of the holes.
When the carbonization process has ended - no more smoke development - the kiln is completely sealed and left for the necessary cooling period.

There are distinguished:

- Round Kilns (Figure 8, Annex 17.18)

  The kiln is ignited in the middle and the carbonization zone is conducted from bottom to top and from center to wall. The wood should be of equal length and of straight pieces.

  Feedstock: Pieces, blocks of wood and branches, Diameter min. 5 cm
  Yield: Up to 15% by weight
  Investment: Low

- Pit Kilns

They are arranged underground. The cover consists either of an earth layer or of ondulated steel sheets. The advantage of this kiln is that no leaves are needed for the sealing cover but the "conduction" of the carbonization zone is more difficult than in the round kiln.

Feedstock:	Pieces or blocks of wood and branches, Diameter min. 5 cm
Yield:	10%
Investment:	very low

9.2.2 Masonry Kilns (Figure 7, Annex 17.18)

They are easier to seal and the carbonization is better to control than in earth kilns. The process is faster and the efficiency up to 20% higher but also the investment costs. These kilns may normally be constructed of locally available bricks.

Feedstock:	Pieces or blocks of wood and branches, Diameter min. 5 cm
Yield:	up to 20% by weight
Investment:	approx. LS 1000,--
Cycle:	11 - 13 days
Lifetime:	5 years
Diameter:	5 m
Volume:	approx. 25 m^3

9.2.3 Transportable Metal Kilns

The Mark V Kiln (Figure 9, Annex 17.19)

The Mark V kiln combines the mobility of earth kilns with the higher efficiency of masonry kilns. The kiln consists of two interlocking cylindrical sections and a conical cover. The cover has steam release ports and there are provisions to install smoke stacks.

The construction of such a kiln is described in:
Tropical Products Institute
Rural Technology Guide 13
London WC1 x 8 LU

Feedstock: Pieces or blocks of wood and branches
Diameter min. 5 cm
Yield: 20% by weight
Investment: Approx. LS 2000.---
Cycle: 2 days
Lifetime: 3 years
Diameter: 2,50 m

Cusab Charcoal Kiln (Figure 11, Annex 17.20)

(Charcoal from useless scrubs and bush)
was developed by Dr. E.C.S. Little 1971 and improved by Mr. Rudolf D. Faust within the framework of a UNIDO project in Kenya 1972.

The cusab kiln has been designed to cope with bushy and small light and bulky material. It is therefore also capable to carbonize cotton stalks. The kiln is of a sheet-metal construction and weighs approx. 1.5 tons. As it is mounted on skids, it is movable by oxen or tractors.

The kiln functions as follows:

- The material to be carbonized is charged into the kiln through the top opening.
- The material is ignited, the supply of air is assured by various rows of closable air holes.
- When the kiln is burning further material is filled in. As soon as the vessel is filled up to the first rows of air holes, they are closed to prevent further combustion.
- The air supply holes are closed gradually as the kiln is being filled up to the top. When the kiln is completely filled all air supply holes are closed.
- The kiln is then left without any air supply overnight to achieve the carbonization process and the subsequent cooling.
- The charcoal is discharged through the door in the lower part of the kiln.
- A full cycle counts for 24 hours.

The kiln offers several advantages as to:

- Carbonizing bushy material
- Good mobility
- Great efficiency where a rate of 30% by weight has been reported. An average of 20% rate of efficiency can be definitely assumed.

The disadvantages of the kiln are:

- High Price
- Difficult charging of material when the kiln is burning (strong heat radiation for the operator).

With bushy material carbonized in Kenya, the kiln produced between 300 and 800 kg of charcoal in a cycle of 24 hours.

Feedstock:	Bush wood, small branches
Yield:	20% by weight
Investment:	LS 4000.---
Cycle:	24 hours
Lifetime:	3 years
Diameter:	2,50 m
Volume:	8 m^3

Drum Kiln (Figure 10, Annex 17.19)

They are miniaturized metal kilns made from used oil drums. These kilns are very suitable for the carbonization of coconut shells. Other materials should be tested. The drum kiln is widely used in the Philippines.

Feedstock:	Coconut shells, other material should be tested
Yield:	More than 20%, even 35% are reported, which seems possible because of the high lignin content of the coconut shells.
Investment:	Low
Cycle:	24 hours
Lifetime:	Not reported in the literature
Diameter:	57 cm
Volume:	210 litres

9.2.4 Retorts

The Discontinuous Process

Retort types are Cornell, Reichert.
Dry wood (18% moisture max.) is filled into a reactor. It has to be of equal size between 5 and 30 cm of length and 5 cm of width. An inert hot gas heats the wood charge up to the temperature where the exothermic process starts.

The efficiency of this process is high compared to kilns and reaches 20% - 34% depending on wood moisture, quality and process temperature.
The investment costs are high. The equipment is economically feasible for capacities starting from 10,000 tons of wood per year.

Within the retort processes, the condensables are usually recovered. When using wood with a moisture content of 10% - 15% approx. 180 kg - 200 kg of pyrolysis oil per 100 kg of charcoal are produced.

The composition of the pyrolysis oil is approx.:
12% vinegar
3% wood spirit
10% liquid tar
75% water

It depends very much on the local situation, if the refining of the pyrolysis oil is economically feasible.

The production of 100 kg of charcoal consumes:
250 MJ of thermal energy
27 MJ (7,5 kWh) of electricity
5 m^3 of cooling water

Feedstock:	Pieces and blocks of wood (no fines)	
Yield:	Charcoal	34%
	Tar	13%
	Vinegar	7%
	Spiritus	2%
	Gas	19%
	Water	24%
Investment:	LS 1,000,000.--- retort of 100 m^3 volume produces 8 tons of charcoal per day.	
Lifetime:	10 years	

Continuous SIFIC Process (Figure 12, Annex 17.21)

Main features of this process are that the flue gas is used to heat the wood charge contained in the retort.
The gas moves in the countersense of the wood which is filled into the reactor vessel through a gas-tight double gate charger.
The process is very energy efficient. Wood with a moisture content of up to 23% may be carbonized witout supplementary energy supply. The non-condensable wood gas produced during the process is sufficient to maintain the process.

Feedstock:	Pieces and blocks of wood (no fines)
Yield:	Same as discontinuous process
Investment:	LS 250,000.--- per ton of charcoal per hour output.
Lifetime:	Estimated 10 years min.

The Herreshoff-Carbonizer (Figure 13, Annex 17.21)

It is common to all the described carbonization processes that they can only use block wood. For the carbonization of granular wood and similar waste products the Herreshoff-Carbonizer has proven its suitability. In 4 to 7 floors the feedstock is carbonized step by step. A sweeping auger moves the fuel from floor to floor.

In this process no condensates are recovered. The produced charcoal is of a fine grain and has to be briquetted with the help of a press under addition of a binder, usually starch.
The efficiency of the Herreshoff is comparable to good kilns (about 22% - 25%) because the energy necessary for the endothermic reaction is produced by partial combustion of the feedstock. The process is feasible only in industrial applications with a minimum capacity of 1,000 tons of charcoal per month.

Feedstock:	Granular biomass as saw dust, wood chips, shavings, fruit grains etc.
Yield:	22% - 25%
Investment:	LS 1,000,000.--- for an output of 2 tons of charcoal per hour. The briquetting process has to be added.
Lifetime:	Estimated min. 10 years.

Resume

Only the Cusab kiln and the Herreshoff oven are suitable for bushy or granular biomass carbonisation i.e. for agricultural residues. The Herreshoff oven represents a proven technology but the equipment is expensive and needs well trained operators to produce a good yield. Modern rotary kilns which may replace the Herreshoff are described in the literature but no process is thoroughly tested until now.

For the carbonization of cotton stalks in decentralized plants we recommend tests with the Cusab kiln.

Chapter 14.1 evaluates the carbonization of cotton stalks.

9.3 Gasification

Gasification of biomass is handled in this report meaning the thermochemical transformation of biomass into low BTU gas with air as a gasification medium and a calorific value of approx. 5,000 kJ/m³n.

There are four main gasifier types:

- Up-draught gasifier
- Down-draught gasifier
- Cross-draught gasifier
- Fluidized-bed gasifier

9.3.1 Up-Draught Gasifier (Figure 14, Annex 17.22)

In an up-draught gasifier or counter current gasifier the feedstock moves from top to the bottom of the reactor vessel whereas the gas passes upward through the incoming fuel. Within the gasifier four zones are distinguished, from top to bottom:

- Drying zone
- Pyrolysis zone
- Reduction zone
- Oxidation zone

The advantages of the system are:

- High thermal efficiency
- Simple design
- Accepts a variety of fuel and fuel sizes

The disadvantages are:

- The produced gas is not clean and contains many condensates.
  Therefore, it requires costly and complex cleaning.
- The dust and condensates filtered from the gas are unacceptable environmental loads for most countries.

9.3.2 Down-Draught Gasifier (Figure 15, Annex 17.23)

The down-draught or co-current gasifier was used in hundred of thousands units during the years 1935 to 1950 in Europe to substitute liquid fuel in vehicles and stationary engines.

The gasifier was named because of its characteristic that feedstock and gas move downward. The four zones described in the chapter "Up-Draught Gasifier" are situated differently here:

From top to bottom:

- Drying zone
- Pyrolysis zone
- Oxidation zone
- Reduction zone

The gasifying air is introduced in the reactor vessel almost at its bottom. The gas has to pass the hot hearth area before entering the reduction zone. The gasifier is therefore able to produce a practically tar-free gas suitable to power internal combustion engines.

The geometrical design of the hearth zone is most important for the gas output and gas quality of this gasifier.

The advantages of the system are:

- Good thermal efficiency
- Reactor of simple design
- Tar-free gas

The disadvantages are:

- Accepts only dry fuel of block size (match box to cigarette box size); granular or even briquetted biomass is unsuitable.
- Hearth zone and air intake nozzles have to be from heat resistant steel or refractory lined.

9.3.3 Cross-Draught Gasifier (Figure 16, Annex 17.24)

Cross-draught gasifiers have been developed for vehicles because they are light and of quick response to load changes.

The air in this gasifier enters on one side and the gas leaves on the opposite side. As the residence time of the gasification medium in the vessel is short, there is only a reduced transformation from CO_2 to CO. Furthermore, the condensate loaded gases do not pass the oxidation zone; therefore this gasifier can only be fed with charcoal. In the oxidation zone temperatures are up to 2,000°C, thus air- and water-cooled nozzles for the air intake are mandatory.

9.3.4 The Fluidized-Bed Gasifier (Figure 17, Annex 17.25)

The fluidized-bed gasifier is applied more and more in process and energy technology. The intensive and homogeneous mixture of feedstock and gas leads to an extensive heat and gas exchange. High specific outputs are obtained leading to compact dimensions for high capacities.

The fuel has to be of granular size in determined dimensions to allow an easy fluidization of the bed. Some systems use sand or similar products to support the heat exchange between the feedstock particles.

To obtain a gas of a continually equal quality constant mass streams are necessary. This calls for a high investment in controls and equipment.

The produced gas is almost tar-free but has to be purged from dust and ash in adequate high and low temperature filters. The conditioned gas is of high purity and is suitable to power internal combustion engines.

The advantages of the system are:

- Good thermal efficiency
- High thermal efficiency when heat is recovered from gas cooling
- Accepts dry biomass of granular size as fuel, i. e. saw dust, shavings, peat, lignite
- Sulphur in the stack gas can be minimized by adding lime to the feedstock.

The disadvantages are:

- The fuel has to be reduced in size
- The complexity of the design makes it only feasible for capacities of more than 250 kWel.

9.4 Briquetting

The availability of feedstock and the need for fuel are very rarely coordinated with regard to time and geographical distributions. Therefore, two conditions have to be fulfilled:

- Storage possibilities
- Easy transport

Transformation of biomass into briquets or pellets is a key to meet these requirements.

The aim of the compression of the feedstock is:

- Higher density
- Almost homogeneous size
- Reduction of moisture content for storage purposes
- Pest control (in case of cotton stalks)
- Produce a fuel which burns smoothly and without molesting smoke emissions in a stove.

The disadvantage of briquetting agricultural residues is the high abrasion experimented on all types of presses; such abrasion might still be increased by feedstock containing sand and earth.

The industry offers different systems and the currently ones used are: (Table 14 pages 1 - 4, Annex 17.26).

- Piston press
- Pellet press with vertical or horizontal pressing wheels
- Screw press
- Roller press

9.4.1 Piston Press

A screw feeder conveys the feedstock into the press-canal. A horizontal moving piston pushes the material through the canal, where the necessary counter-pressure is developed through friction. Pressure values up to 1,500 bar may be reached.

The movement of the piston may either be produced by a fly-wheel or by hydraulic system.

The briquets are cooled when leaving the press. The piston press is the most suitable system for the applications in the Sudan i.e. briquetting of cotton stalks, groundnut shells, sugar cane bagasse and similar biomass.

The piston press is of simple design, inexpensive, has a long service life, is economic with regard to energy consumption and has proved to be reliable under difficult working conditions.

9.4.2 Pellet Press

In this press the feedstock is pushed by vertical or horizontal working wheels through a die.
The press produces cobs of a diameter between 6 mm and 25 mm. The press is mainly used for the production of industrially made animal fodder.

9.4.3 Screw Press

The necessary pressure is produced by two screwfeeders turning one clockwise and the other counter-clockwise. This press is able to dry and to compact in one process step. The suitable moisture content of the feedstock is 40% to 50%. The material leaves the press at a temperature of approx. 100°C. The size of the produced briquets is formed by a briquetting head. The press is rather expensive, high energy consuming and sensitive to tear and wear.

9.4.4 Roller Press

The feedstock passes between two rollers. The system provides only a short residence time in the compacting area and is therefore not recommended for compacting biomass with its high redressing behaviour.

10.0 Energy from Cotton Stalks

10.1 Briquetting and Combustion

It is recommended to briquet cotton stalks with piston presses and to use the briquets for direct combustion in boilers and as household fuel. The tests made in Germany at Messrs. ZENO, Norken/Westerwald, a manufacturer and operator of piston presses showed the high suitability of cotton stalks to form briquets, due to their high content of long fibres.
The phyto-sanitarian problems with regard to pest control and storage have to be solved prior to any solution for cotton stalks. During briquetting physical pressure and heat are applied to the stalks. This will definitely solve the problem to a certain extent (pink bollworm). A series of tests are to be carried out by the Barakat Research Station in order to investigate all the different scientific aspects.

The National Council of Research in Khartoum, Sudan, has recently acquired a hydraulical piston press made by Messrs. R.S.N. which stands for:

R.S.N. Maschinenbau GmbH
Finninger Straße 46
D-7910 Neu-Ulm
Tel.: 0731 - 172165
Tlx.: 712402

The press has its own power supply by a built-in Diesel engine.

As this machine is mounted on a single axle trailer it can be moved to different test areas.

The stalks have to be reduced in size before entering the press. A suitable machine for this purpose is a shredder mill. For the tests, hand-chopped samples are sufficient.

Under the assumption that the tests with the R.S.N. machine will show positive results a project for a cotton stalks briquetting center is drafted in chapter 14 "Recommended Projects".

10.2 Carbonization

Cotton stalks were carbonized in a laboratory converter. The stalks produce a good charcoal and preserve their form in this process. In a metal kiln a high percentage of granular coal will accumulate and briquetting might be necessary.

Charcoal production out of cotton stalks would consist of the following steps:

- Pulling
- Collection and transport
- Carbonization
- Briquetting (as option)

The results of the carbonization of cotton stalks in Germany in a laboratory retort is reported in Table 15, Annex 17.27.

The cotton stalks used for the tests were dried at 105°C in a drying chamber and subsequently carbonized in an electrically heated laboratory retort at 435°C. The residence time in the retort was 3 hours.

Chapter 14 evaluates the charring of cotton stalks in the Sudan.

10.3 Gasification of Cotton Stalks

Cotton stalks are similar to wood and they can be gasified. However, they present limitations as to the applications of different gasificaiions systems (Table 16, Annex 17.28).

- The cross-draught system is only applicable for charcoal.
- The down-draught system needs the build-up of blocked charcoal in the reduction zone which cannot be obtained from cotton stalks even when briquetted because of the high temperature.
- The up-draught system can be used for gasification. However, gas with a high content of corrosive condensates is produced.
- The best applicable system is the fluidized-bed, however, for high capacities only.

The silica content in the Sudanese stalks (19.6%) is not too high and qualifies the material as suitable for gasification. However, the ash content is higher than in wood. The heating value varies with the ash content and depends on a variety of conditions including the harvesting methods (sand and other enclosures). More samples of stalks should be analysed in the future to determine primarily the ash variations.

Due to their bushy appearance and small diameter the stalks cannot be gasified as they are collected, in a down-draught gasifier. Prior to gasification the stalks have to be briquetted. Even so they do not form the required block charcoal, necessary for the reduction zone. Thus, other types of block charcoal have to be added.

By courtesy of the Beijer Institute, Sweden, we obtained results of gasification tests performed in a down-draught system [illegible] briquetted stalks from Nicaragua. They are recorde[illegible] Table 17, Annex 17.29.

11.0 Gasification Test with Cotton Stalks from the Sudan

Cotton stalks are a material of bushy character and therefore only available in small pieces. For this reason, from the beginning, a test gasification in a fluidized-bed gasifier was intended. A gasification in a non-polluting down-draught fixed-bed gasifier is only limited possible since the fuel does not form lump charcoal. The 400 kg delivered as a sample quantity were not sufficient for a test in a fluidized-bed gasifier. Therefore a compromise was made for a test in a down-draught gasifier adding charcoal and briquetting the stalks.

11.1 Gasification of Cotton Stalks
Realization of a Test

Within the scope of the Terms of Reference a gasification test with cotton stalks was conducted.

The Fuel

From the Gezira Scheme, Sudan, 400 kg of stalks were disposed of as fuel. The cotton stalks were of shrubby character and had a diameter of 5 to 15 mm. The material was chopped into pieces of approx. 5 cm length and packed in bags for air transport.

The stalks were prepared for the gasification in a co-current fixed-bed producer by further chopping in a hammer mill and by pressing them into briquets of a diameter of 10 cm in a piston press.

The characteristics of the fuel have been examined in an ash analysis (Annex 17.28), in a carbonization test (Annex 17.27), and in an elementary analysis (Annex 17.30). The calorific value of the material turned out to be 3300 kJ/m^3n.

The Gasifier

A co-current fixed-bed gas producer was at hand to conduct the test. The exact test schedule is described in Annex 17.30.

This type of gasifier has been designed to gasify lump wood from thumb to fist sized pieces. Therefore, for a gasification test of stalk briquets compromises had to be made.

The formation of lump charcoal is a prerequisite for the reduction of the CO_2 which develops in the gasifier. Even briquetted stalks do not form charcoal in lumps. For this reason charcoal from beech wood must be applied in the reduction zone.

The run of the test has confirmed that the stalks are not suitable for the gasifier mentioned. The process stopped after the beech coal in the reduction zone was used up.

The Results

Even though the gasifier could only be used with restrictions for the tests, the results are still characteristic for the gasification of cotton stalks (Annex 17.30).

Despite of the high SiO_2 content (19,2%) the material has a good calorific value and did not develop slags. However, in long-term tests the development of slags should be examinated. The Swedish Beijer Institute reports about potential development of slag using cotton stalks from Nicaragua and Spain.

For the time being such gasifier is only economically feasible for capacities starting from 1000 m³ of gas per hour and more with corresponding fuel consumption of 500 kg per hour upward.

Cotton stalks are suitable for the gasification. The only gasification process to be recommended is the fluidized-bed gasification process.

The low energy density per area of cotton stalks practically excludes them from economical gasification fuels.

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12.0 Energy from Groundnut Shells

Groundnut shells are directly available at oil mills or processing stations. They are not burdened with collecting and transportation costs. Normally they serve as animal feed and in small quantities as fuel in oil mills. Oil mills were visited generating their process steam for the presses burning shells in old locomotive boilers. The necessary electric power is taken from the utilities or generated by diesel gen-sets.

Messrs. Omnical analysed groundnut shell samples from Senegal. The results are presented in Table 19, Annex 17.31.

The ash analysis shows a rather high $SiSO_2$-content and the investigation of ash properties in oxydising atmosphere gave the following results:

- Sintering point = 1,100°C
- Softening point = 1,140°C
- Melting point = 1,210°C
- Pour point = 1,270°C

Under such conditions they are suitable for combustion and gasification. Similar tests have to be carried out for material from the Sudan.

12.1 Briquetting and Combustion of Groundnut Shells

Several years ago, Messrs. Ismirlian in Khartoum installed a piston press to produce briquets as domestic fuel from the shells. When the briquets were burned, they produced a large amount of smoke and were therefore not accepted by the clients such as private households and bakeries.

The heavy smoke was mainly due to the fact that too many components of broken nuts were contained in the shells.

Today deshelling machines of higher efficiency are used reducing the content of the broken nuts. Ismirlian now intends to produce again groundnut briquets as domestic fuel. Problems may arise in competition with the low priced charcoal on the fuel market.

From the socio-economic point of view, the introduction of groundnut shell briquets should definitely be supported. The low price of charcoal is possible simply because of devastating exploitations of wood reserves in the Sudan.

It is therefore proposed that UNIDO may finance a marketing campaign for briquetted groundnut shells in Omdurman. Shells are available abundantly at the deshelling center just outside of Khartoum, The Sudanese Oil Seeds Processing Co., Khartoum. The combustion of groundnut shells in industrial boiler plants is possible. Like many annual plants, groundnut shells contain a portion of ash with a low ash melting point. Boiler plants must therefore be designed to cope with the low ash melting point. In 1979, Messrs. Omnical, delivered two boiler plants for oil mills to Senegal which so far run quite satisfactorily.

Recently, fluidized-bed boiler plants are offered for the combustion of fuel with low ash melting point. They are specially designed for lignite and start with an output of about 5 MWth. As oil mills require a relatively low output and run only during seasonal operations, a detailed study will be necessary for each project to determine the economic feasibility of this technology.

12.2 Carbonization of Groundnut Shells

In chapter 9.2 methods and procedures for the carbonization of wood in lumps and with limitation of granular biomass is described.

For the carbonization of groundnut shells the Herreshoff oven is suitable. This kiln is a proven technology applied in the United States. Today the process is considered outdated. Unfortunately the various modern equipment described in the specialized literature exists only as prototype and has not for the time being shown its reliability and suitability for an operation in developing countries.

Anyway the Herreshoff or a modern rotary kiln are only applicable for industrial operations, e.g. in combination with a groundnut oil mill due to the high investment costs and the capacity of an economically feasible equipment.

The smallest Herreshoff kiln produces 1,000 tons of charcoal/month which corresponds to 4,000 - 5,000 tons of shells as feedstock monthly.

As shown in chapter 15.1, 1 ton of seed produces 0.428 tons of shells, so that an oil mill with a capacity of about 12.000 tons/month of seed will produce enough shells for a Herreshoff kiln.

For the economic evaluation it has to be taken into account that charcoal out of groundnut shells has to be briquetted adding approx. 5% of a binder.

12.3 Gasification of Groundnut Shells

Groundnut shells can be applied as fuel in fluidized-bed gasifiers. The ash melting point must be taken into account when designing the gasifier.

Within the scope of this study no shells for gasification purposes were available, so that their specific application could not be tested.

In order to determine the definite application, respective tests have to be conducted still in the future.

Contrary to boiler plants, fluidized-bed gasifiers may be economically feasible from an output from 1 MWth or 0.250 MWel onward. To assure a good return on investment a fluidized-bed gasifier plant should work the whole year round and should not be considered for seasonal operation.

Under the assumption that the gasification of groundnut shells will technically not cause specific problems a tentative project is drafted in chapter 15.1.

13.0 Energy from Sugar Cane Bagasse

Sugar cane bagasse is generally used for the generation of energy in sugar factories. Usually, the old boiler plants has a low efficiency utilizing the entire bagasse.

Modern factories with new boiler plants have a surplus of bagasse. Such bagasse surplus could be used for electricity generation or, in view of the increasing shortage of animal feed, for the production of roughage.

The bagasse is treated with wet steam at a pressure of 13 bar with a residence time of approx. 20 min. in an autoclave. This process delivers an animal feed with the quality of good hay without any addition of chemicals.

When the roughage thus produced is enriched with molasses, a complete feed for the fattening of cattle and the dairy production can be obtained.

13.1 Briquetting of Bagasse

Twenty-one (21) kg of bagasse from the Sudan have been received recently. A test conducted showed the good suitability of this bagasse to form briquets. The material was chopped in a hammer mill and then compressed in a mechanical piston press (Photos in Annex 17.35).

The briquetting is a recommended solution to use the surplus bagasse stored at the New Halfa Sugar Factory as household fuel.

14.0 Economic Evaluations

14.1 Carbonization of Cotton Stalks with a Cusab Kiln

Input data:

- Yield of the kiln 20%
- Production of charcoal during one cycle of 24 hours 300 kg corresponding to 1,5 tons of stalks
- Price of the kiln LS 4,000.---
- Collection cost of stalks: LS 10.500 per ton
- Working period per year: 90 days.

The kiln produces in 90 days:
90 x 300 = 27,000 kg of charcoal and consumes
1,5 x 90 = 135 tons of stalks

Value of the charcoal: LS 0.250 per kg in Khartoum

Production costs:

Kiln			
Capital interest p.a. LS 4,000.--- x 10%	=	LS	400.---
Depreciation (assumed lifetime 5 years)	=	LS	800.---
		LS	1,200.---
Collection cost per season			
135 tons x LS 10.500 (Chapter 7.5)	=	LS	1,417.500
Labour costs: 270 man days x LS 1.---	=	LS	270.000
	=	LS	1,687.500
T O T A L	=	LS	2.887.500

Produced charcoal (incl. fines) 27,000 kg
Costs of 1 kg: LS 2,887.500 /27,000 kg = LS 0.107
Price of 1 kg of charcoal: = LS 0.107

Without consideration of:

- Costs for the dislocation of the kiln
- Costs eventually for briquetting because the produced charcoal contains a certain amount of fines.

For the economic evaluations we assume that the tenants use the fines in their own households.

This calculation shows that under the assumptions made, the charcoal production is economically of marginal result. It is necessary to perform tests with the aim to assess the costs and yields with more precision.

The advantages of the carbonization are:

- All requirements of the pest control can be met
- The tenants can earn some money by selling their man power and/or
  as entrepreneur for charcoal production
- Urgently needed energy is supplied from waste material

We therefore recommend a project with a cusab kiln carbonization in the area of the Gezira Board; please find details under chapter 15.3.

14.2 Briquetting of Cotton Stalks

The process comprises the following steps:

- Harvest and transport to a briquetting center
- Size reduction (shredding) of the stalks
- Briquetting

The approximate price for the production of 1 kg of briquets can be determined as follows:

- Investment	Press :	LS	35,135.---
	Shredder:	LS	13,513.---
both incl. motor		LS	48,648.---
- Depreciation and interest 20%		LS	9,730.--
- Spare parts and maintenance 5%		LS	2,432.---
- Diesel fuel for shredder and press 6 l x 2,000 h x LS 0.270 l		LS	3,243.--
		LS	15,405.---

- Working time p.a. = 2,000 h
- Production rate = 200 kg briquets/h
- Yearly production of briquets
  2,000 h x 200 kg = 400,000 kg

- Collection cost (Chapter 7.5) per ton	LS	10.500
- Cost of 1 kg of briquet incl. labour cost ex press:		
Briquetting: $\frac{\text{LS } 15,405.---}{400,000 \text{ kg}}$	LS	0.039
Collection charges	LS	0.010
	LS	0.049
Price per kg of briquets	LS	0.049
		===========

Costs for transport to consumer centers, commission for the retailer and any profit for the farmers have to be added.

The calculation shows that under full consideration of the collecting costs, the stalk briquet could compete with the charcoal price.
(Comparison of energetic value:

1 kg briquet .approx. 3000 kcal at	LS	0.049
1 kg charcoal approx. 6000 kcal at	LS	0.107)*

* Chapter 14.1

However, all the collecting costs have to be paid anyhow to clear the field and in view of pest control measures, so that such costs should be charged to the costs of cotton cultivation and not to briquetting costs. Thus the net costs for briquetting could be reduced to LS 0.039 per kg of briquet.

14.3 Briquetting of Groundnut Shells

The feedstock is available at the deshelling centers without further collection and transport costs for example at "The Sudanese Oil Seeds Processing Co.", Khartoum.

For the processing only a briquetting press will be necessary.

The cost would be as follows:

Investment:

Press:	LS 35,135.---	
Depreciation and interest 20%		LS 7,027.---p.a.
Spare parts and maintenance		LS 1,982.---p.a.
Diesel fuel		
2,000 h x 4 l x LS 0.270		LS 2,160.---p.a.
Manpower		LS 4,000.---p.a.
		LS 15,169.---p.a.

Assumption

2,000 working hours p.a.	
Hourly capacity of the press:	200 kg
Annual production:	
2,000 h x 200 kg	= 400,000 kg of briquets

Price per kg of briquet:

LS 15,169.--- / 400,000 kg	LS 0.038/kg
Value of the shell (indicated by oil mills)	LS 0.021/kg
Price of the briquet	LS 0.059/kg
(for reference the charcoal costs at Khartoum)	LS 0.250/kg

14.4 Gasification of Groundnut Shells

The groundnut shells are probably a suitable feedstock for a gasifier gen-set plant to supply an oil mill.

- They are available without further cost at the oil mill,
- The mill requires electrical and thermal energy,
- The energy requirement is large enough to reach an economical size for the gas plant.

Assumptions

Investment costs per kWel	LS 1,891.---
Fuel costs/kWel; 1.4 x 0.021 (shells)	LS 0.029
(to generate 1 kWhel, 1.4 kg of shells are gasified)	
Maintenance and lubricants etc.	LS 216.000/year

Operating hours

300 days x 24 hours = 7,200 hours per year

Thus resulting:

15% depreciation and interest of	
LS 1,891.--- = LS 283.650	
Per hour at 7,200h per year	LS 0.039
Fuel costs	LS 0.029
Maintenance a [illegible].	LS 0.023
Price per kWl	LS 0.098

In comparison [illegible] nerated with a diesel unit would cost per 7,200 hours per year:

Estimated investment:	LS 540.000/kWel
Diesel oil price:	LS 0.270/l
Diesel oil consumption:	250 kg/kWhel

Specific weight of diesel:	1 l =	0.8	kg

<u>Costs per kWhel:</u>

0.250 x 0.270 x 1/0.8 =	LS	0.084 kWhel

<u>Depreciation</u>		
15% x 540/7,200	LS	0.013
<u>Maintenance</u>		
Costs for maintencance and lubricants	LS	0.014

<u>Total costs for diesel operation:</u>

Depreciation	LS	0.013
Fuel	LS	0.084
Maintenance and lubricants	LS	0.014
Price per kWhel	LS	0.111

This comparison shows:

One (1) kWhel generated from groundnut shells is less expensive under the above assumptions even when considering that diesel oil is quite inexpensive in the Sudan when available.

15.0 Recommended Projects

15.1 Energy Supply for a Remote Groundnut Oil Mill

In the following chapter the energy supply for a remote oil mill is being studied, assuming the following parameters:

- Capacity of the oil mill: 100 tons seed per day
- Working time: 300 days/year, 24 hours a day
- 1 ton groundnut corresponds to 700 kg seed and 300 kg shells

  or

  1 ton seed corresponds to 428 kg shells
- To treat 1 ton of seed, the oil mill requires 350 kg steam and 60 kWh electricity
- Calorific value of shells: 3.6 - 4.4 kWhth/kg
- To produce 1 kg steam, 0.750 kWhth is necessary
- To produce 1 kWh electricity, 4.0 kWhth are necessary as fuel. However, with the generation of 1 kWhel-energy of 2 kWhth may be recovered as secondary heat from the gas cooling and the gas engine cooling.

The energy requirements of the mill are as follows:

100 tons seed per day: 24 hours = 4.16 tons seed per hour requiring:

4.16 x 60 kWh = 250 kWhel

4.16 x 350 kg steam x 0.750 kWhth = 1100 kWhth

Further calculations are based on a gasifier - electric power unit of 250 kWel output.

This unit produces 435 kWhth secondary heat, so that there is still a thermal deficit of 1100 - 435 = 665 kWhth.

This deficit will be compensated by choosing a larger gas producer capable to supply gas simultaneously to the gas engine and the steam boiler.

To produce 665 kWhth the following gas capacity is required:

665 kWhth : 1.38 kWhth per m³n of gas = 481 m³n/h of gas

The total energy demand is as follows:

250 kWhel output	=	575 m³n gas/h
665 kWhth	=	481 m³n gas/h
		1,056 m³n gas/h

1 kWhel	=	2.3 m³n gas/h
1 m³n gas	=	1.38 kWhth
1 kg shells contains	=	4.0 kWhth
Efficiency of the gasifier	=	0.75.

$$\text{The consumption of shells} = \frac{1{,}056 \text{ m}^3\text{n} \times 1.38}{0.75 \times 4.0} = 486 \text{ kg/h}$$

Available shells are:

4.16 tons x 428 kg = 1,780 kg per hour of shells available.

Surplus of shells:

1,780 - 486 = 1,294 kg per hour

Even at a lower efficiency there will be a surplus of shells. As already shown in chapter 14.3, the price of a kWhel produced from shells is lower than the price of a kWhel produced from diesel fuel at LS 0.270 per l, thus showing that the project is economically feasible.

The investment costs for a power station as described above will amount to LS 550,000.--- price basis 1983.
A more detailed evaluation of the investment costs is only possible in the framework of a definite project.

The kWh from utilities is considerably cheaper - in May 1983 its price was LS 0.043. This price, however, does probably not cover the cost and will therefore rise shortly to LS 0.086.

Therefore, it can be stated that energy supply of oil mills by means of gasification of groundnut shells will be a feasible and economical proposition substituting diesel gen-sets.

In addition to the lower price imported energy will be substituted thus relieving the foreign currency exchange balance.

The official price of diesel oil was taken as a basis for the overall profitability study. However, diesel oil can be obtained at this price only in central areas. Remotely situated oil mills pay much more for their diesel fuel and do not always have supply at hand.

15.2 Cotton Stalks Briquetting Center

As a second project, the installation of a small center for the production of cotton stalk briquets as fuel for domestic purposes, is recommended.

The following assumptions are made for the center:

Output:	1,500 tons per year
Capacity of shredder and press:	10 tons per day
Working hours per day:	10 hours
Working hours per year:	1,500 hours

To supply 1,500 tons of stalks to the center, the collection area is calculated on the following assumptions:

According to the investigations, one feddan produces an average of 1.5 tons of stalks with approx. 15% moisture.

In order to calculate the respective catchment area out of the total available arable land, the following has to be considered:

1. That only 70% of the total available land is cultivated,

2. That only 50% of the total cultivated land is under cotton,

3. That only 90% of the cotton in this area are available for briquetting.

The catchment area for 1.5 tons of stalks corresponding to 1.0 feddan net will be considered with respect to the following factors:

1/0.7 x 1/0.5 x 1/0.9 = 3.17 feddan gross

1,500 tons correspond to 1,000 feddan net or 3,170 feddan gross. Such a surface has a radius of approx. 2 km. It is assumed that the tenants are able to supply the center within the catchment area with the necessary feedstock. The average transport distance would be 2.5 km.

Assuming a briquetting capacity of 1 ton per hour and a working day of 10 hours, the collection center should process 10 tons x 150 days. If the transport is done by tractor//trailer (loading capacity 0.5 tons) only two (2) loads per hour or 20 loads per day can be processed by the center.

All these activities are to be supervised by the Gezira Board Research Station in order to assume that the phyto-sanitarian requirements are observed. At the same time, the impact of shredding and compacting on pests identified in the raw material should be determined. The stored material snould be continuously controlled for primary and secondary pest infestations.

The briquets should weigh approx. 600 kg/m^3.
Therefore, it is necessary to transport a volume of 10/0.6 = 17 m^3 per day from the center to the marketing place.

This can be carried out either by lorry or by the Gezira Board Light Railway if the center is implemented in an area covered by this transport system.

The practical experience gathered with the briquetting center will supply the following information:

- Whether the tenant farmers are willing to deliver cotton stalks to collection centers and whether the farmers find the proposed purchase price for cotton stalks acceptable,
- How to establish the logistic for cotton stalks transportation and delivery,
- How to select an appropriate cotton stalks storage system including measures to satisfy plant-health regulations,
- How to prepare procedures for the production of high quality cotton stalks briquets,
- How to prepare means for proper marketing of cotton stalks briquets including economic and financial appraisal.

15.3 Cotton Stalks Carbonization Project

As described in chapter 9.2.1 and 14.1, the Cusab kiln is technically and economically suitable for the carbonization of bushy feedstock as cotton stalks.

Experiences in Kenya in the early seventies partially sponsored by the UNIDO - haver underlined the possibilities of this kiln. To our opinion the Cusab kiln can be manufactured locally.

We recommend to buy the first prototype in Nairobi. Mr. Rudolf D. Faust (Annex 17.34, Table 21, Page 4), who tested and improved the kiln in 1972 in the framework of a UNIDO project, mentioned Messrs. Burns & Blane in Nairobi as manufacturers. According to Mr. Faust an improved Cusab kiln would cost LS 4,000.--.

To gain experience with cotton stalks, we suggest to install one kiln in a block center of the irrigated areas near the workshop of the Gezira Board Applied Engineering Department in Barakat near Wad Medani.

Under consideration that all requirements of the law requesting the burning of the pulled cotton stalks in two months after the cotton harvest have to be met, we assume the following:

- Working time: 90 days per year
  (one cycle lasts for 24 hours, thus the kiln ca be charged 90 times during this period)
- Yield of the kiln: 20%
- One charge of the kiln: 1500 kg
- Catchment area for 1,5 tons of stalks: 3,17 feddan gross
  (Chapter 15.2).

In 90 days the kiln can carbonize the yield of
90 x 3,17 = 286 feddan gross or 120 ha gross. To minimize transport distance the kiln should be displaced on skids.

- Charcoal production in 24 hours
  1500 kg x 0,2 = 300 kg
- Necessary personnel: 3 men
- Production costs of the charcoal: LS 0.107 per kg (Chapter 14.1)

The aim of the Cusab kiln project is:

- Prove the suitability of the kiln especially for cotton stalks,
- Determine the necessary training for the operators,
- Assess the costs and yields,
- Determine whether the produced charcoal can be used as such or if further briquetting is necessary,
- Check the willingness of the farmers to work as kiln operators or even as entrepreneurs for charcoal production,
- Check if the utilization of the charcoal is possible without briquetting,
- Determination of an appropriate briquetting method if necessary.

Remark:

Normally fine grain charcoal can be used without briquetting. However, the customers have to get used to this fine fuel. In case this acceptance cannot be achieved, a briquetting process has to be added. One briquetting press has to be provided for 10 Cusab kilns. According to Mr. Faust, he developed a simple briquetting press in Kenya in 1972 in the framework of a UNIDO project. This machine can be manufactured either in the workshops of the Gezira Board or in Khartoum.

As binders for the briquetting, various products have to be tested; such as molasses, starch or similar available products. The ash produced during the carbonization process should be used as an extender.

15.4 Organization of the Projects

The Administration of the Gezira Board may act as coordinator for the projects. The project management should be provided by the Applied Engineering Department of the Gezira Board located in Barakat near Wad Medani.

On the premises of this department also the installations described in chapter 8.0 are located.

The necessary personnel can be made available from this department if a respective budget can be allocated.

For technical assistance we recommend to employ one expatriate expert. Mr. Rudolf D. Faust, the expert who made the tests in 1972 in Kenya, may be available for a certain period to transfer the know-how for operating the Cusab kiln and the briquetting press.

16.0 Training of two Sudanese Specialists for one (1) months

According to the terms of reference, the training of

- Dr. Ahmed Hood

and

- Miss Igbal Ahmed

was organized during the stay in the Federal Republic of Germany.

The aim of this training was to inform both specialists on the progress of methods to convert agricultural residues into energy and on the research and development of modern procedures and technology in energy conversion.

Therefore, a detailed program of visits to operation centers and equipment manufacturers had been elaborated. (Annex 17.32, Pages 1 - 8).

17.0 ANNEXES

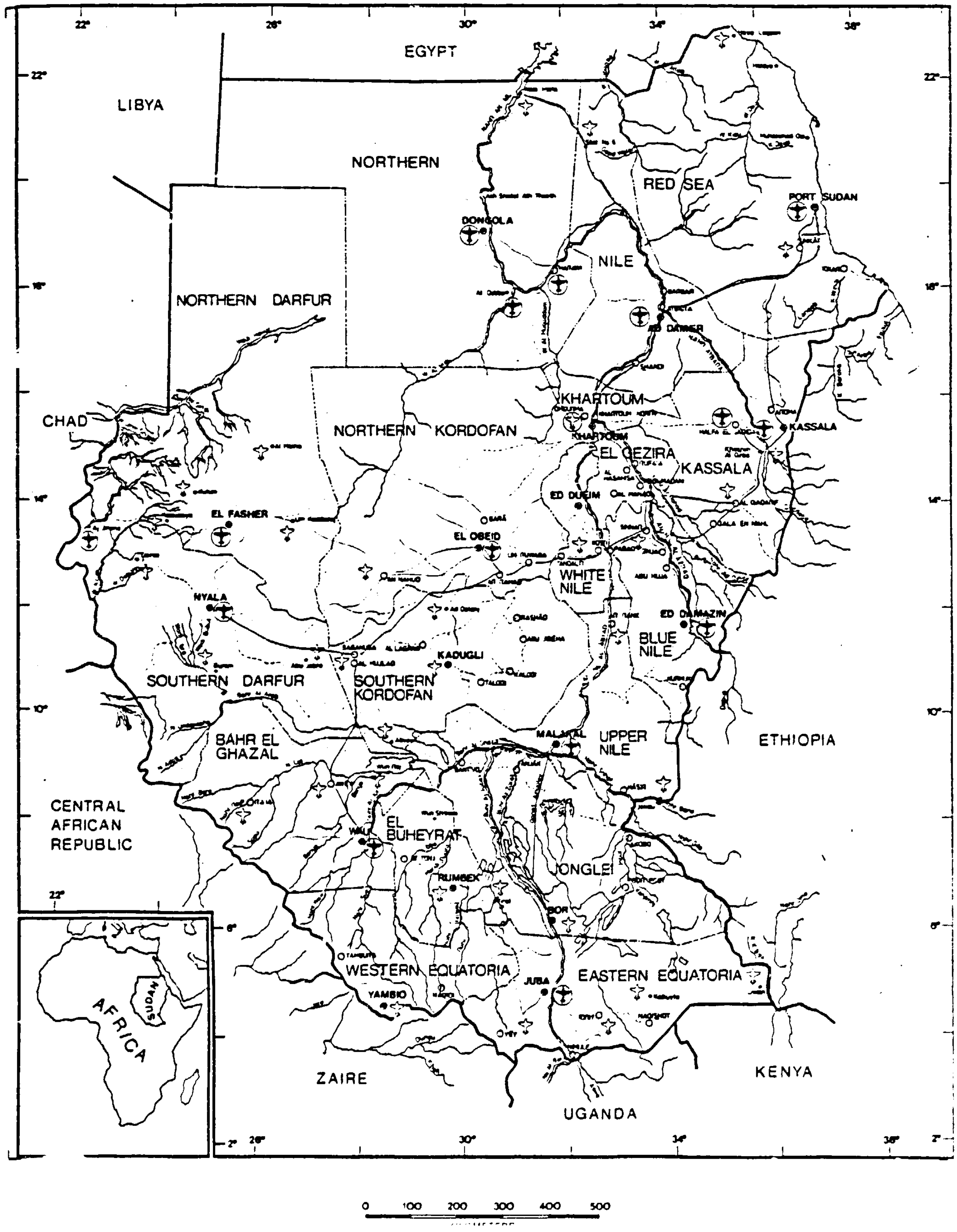
Annex 17.1

Map of

SUDAN

(1983)

Figure 1



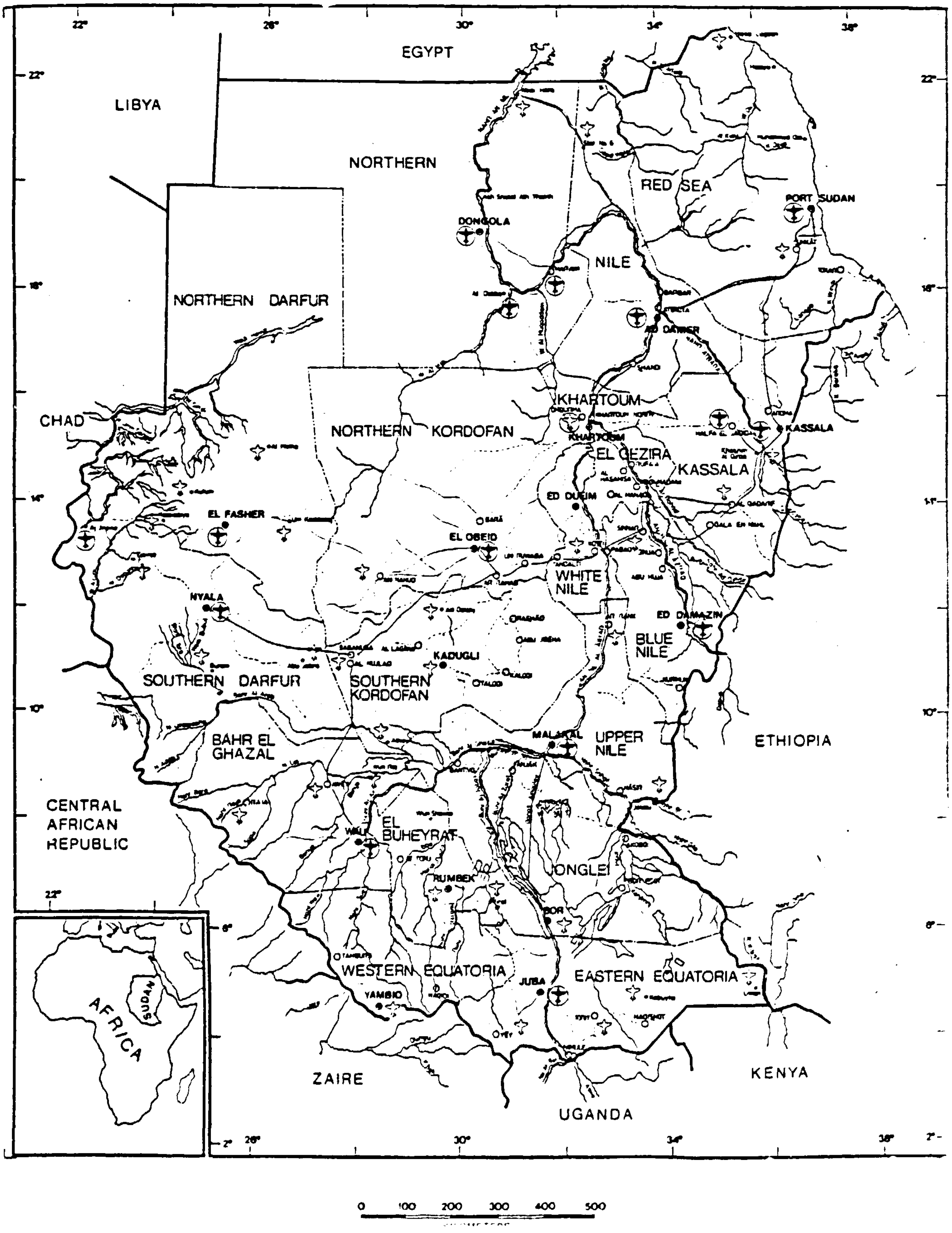
Annex 17.1

Map of

S U D A N

(1983)

Figure 1



Cultivated Surfaces and Production

Annex 17.3

Table 2

Agricultural Crops: Estimates of Cultivated Area (000 Feddans) (1)

Production (000 Tons) and Average Yield (KG/Feddan)

	1975/1976			1976/1977			1977 / 1978			1978 / 1979		
	Area	Production	Av. Yield	Area	Production	Av. Yield	Area	Production	Av. Yield	Area	Production	Av. Yield
Cotton	931	316	322	1006	459	456	1120	559	499	1036	407	392
Sorghum	6311	1991	315	6287	1800	287	6662	2017	303	7202	2408	334
Millet	2701	370	136	2773	472	170	2948	487	166	3078	550	179
Wheat	690	255	370	639	294	460	602	317	527	586	177	302
Rice	17	7	411	23	11	478	28	13	464	20	10	500
Maize	210	53	252	149	42	281	139	42	303	145	45	310
Ground-nuts	2321	796	342	1880	748	391	2661	1027	391	2328	798	343
Sesame	2216	218	98	2288	247	108	2349	245	104	2057	214	104

Table 3.5 Agricultural Crop Residues in Sudan (1978 / 1979)

Crop	Area (1) (000Feddans)	Residue (3) Yield Factor (t / feddans)	Total Amt. of Residues (000 tons)	Available Factor	Net Amt. of Residues for Energy purposes (000 tons)	Calorific Value of Residues (6) (GJ/tons)	Energy Potential of Residues (10^{15}J)
Cotton	1036	1.5	1,554	1.0	1,554	13.3	20.7
Sorghum	7202	2.15	15,484	0.5	7,742	14.3	110.7
Millet	3078	1.06	3,263	0.4	1,305	14.3	18.7
Wheat	586	2.06	1,207	0.5	604	17.5	10.6
Rice	20	1.6	32	0.5	16	5.9	0.1
Maize	145	1.85	268	0.8	214	11.6	1.5
Ground nuts	2328	1.26	2933	0.8	2346	23.3	54.7
Sesame	2057	1.29	2654	0.8	2123	14.3	30.4
Total	16452		27,395		15,904		248,4

SOURCE: National Energy Administration
Renewable Energy Assessment for Sudan, Septmeber 1982

Cultivated Surfaces and Production

Annex 17.4
Table 3

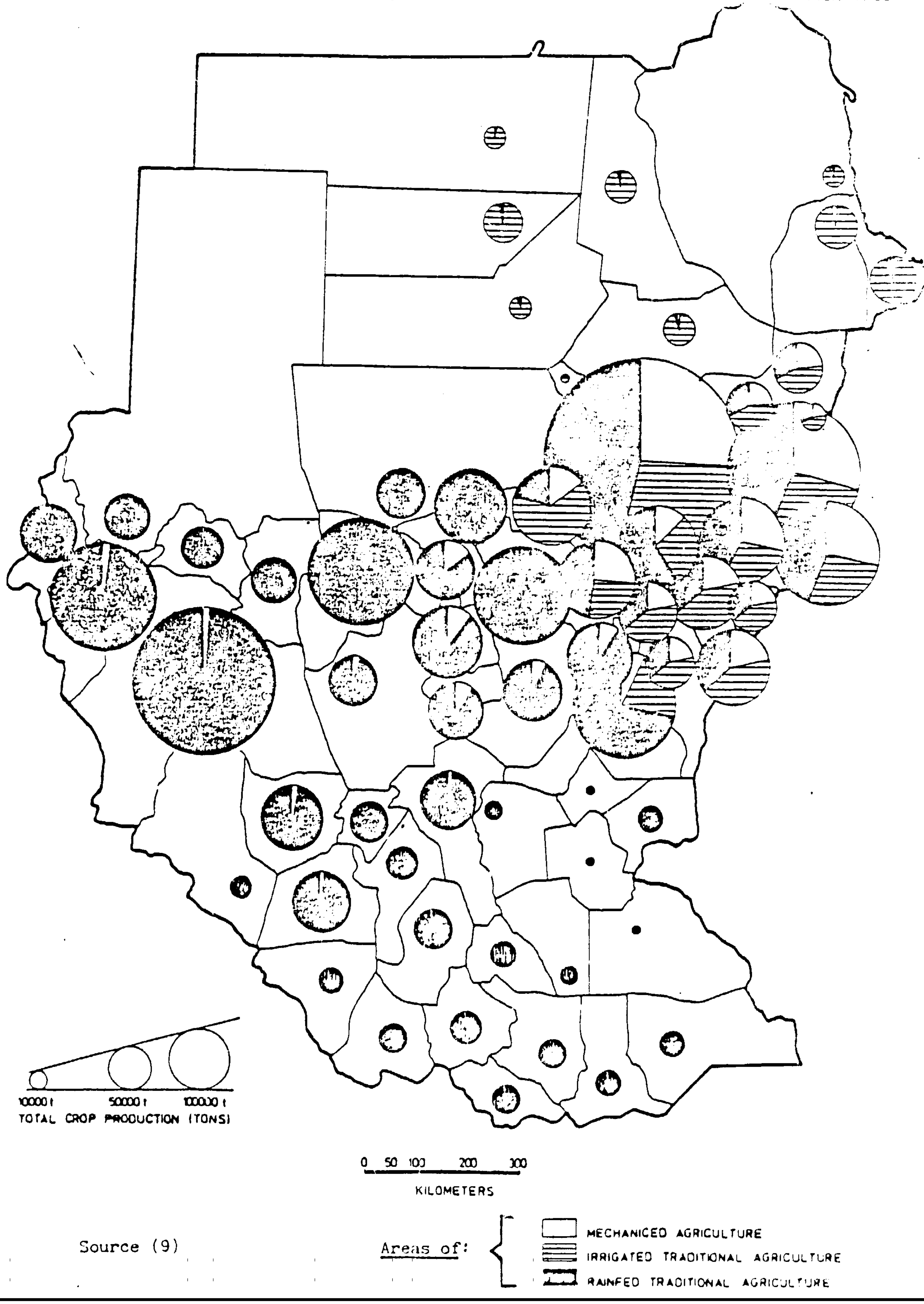
Area ('000 Feddans) and Production ('000 tons) of Major Agricultural Crops

C R O P	1979/80		1980/81		1981/82		1982/83	
	Area	Production	Area	Production	Area	Production	Area	Production
Cotton	996	317	964	287	962	384	985	-
Sorghum	6'349	1'669	6'956	2'068	9'258	3'345	8'980	-
Millet	2'320	309	2'598	491	2'618	573	2'500	-
Wheat	457	233	437	218	371	182	310	-
Rice	30	8	30*	12*	30*	12*	30	12
Maize	145*	45*	145*	45*	145*	45*	145	45
Groundnuts	2'352	852	2'129	709	2'346	721	1'620	-
Sesame	1'989	209	2'011	221	1'970	242	1'330	-
Total	14'638	-	15'270	-	17'700	-	15'900	-

* Estimates

Source: (1-7)

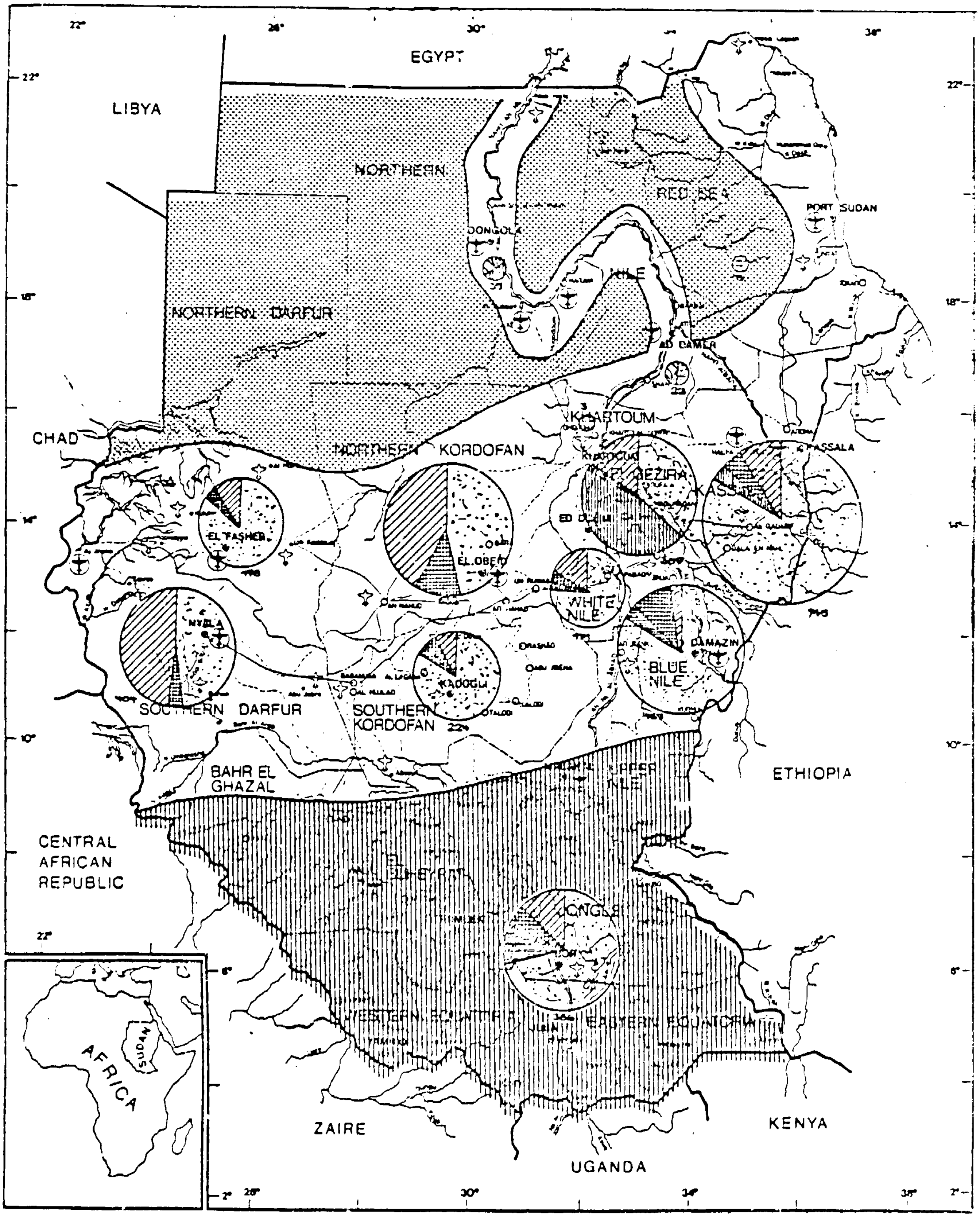
Types of Agriculture, SUDAN, Figure 2



Source (9)

Areas of:

SUDAN



1982

Source (9)

0 100 200 300 400 500
KILOMETERS
SCALE 1:4,000,000

Areas of selected crops:

- SORGHUM / MILLET
- WHEAT
- BEANS
- MAIZE
- RICE
- SESAME

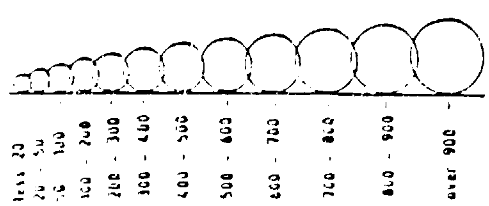
- ARID ZONE
- SAVANNAH REGION
- ZONE OF HEAVIER RAINFALL

MAP B.5.2 ESTIMATED POPULATION DISTRIBUTION, 1990

• REPRESENTS 15.000 RURAL/NOMADIC INHABITANTS

URBAN INHABITANTS (IN 1.000)

Source (9)



Projection of Energy Consumption in Sudan from Wood and Charcoal (1 + 7) / Quantity and TOE in '000 t

	1980				1985				1990			
	WOOD		CHARCOAL		WOOD		CHARCOAL		WOOD		CHARCOAL	
	Quantity	TOE	Quantity	TOE	Quantity	TOE	Quantity	TOE	Quantity	TOE	Quantity	TOE
HOUSEHOLDS	7'828	3'367	2'449	1'763	8'865	3'812	3'008	2'166	10'040	4'317	3'696	2'661
OTHERS	419	180	121	87	372	160	74	53	437	188	86	62
TOTAL	8'247	3'547	2'570	1'850	9'237	3'972	3'082	2'219	10'477	4'505	3'782	2'723
TOTAL Wood / Charcoal Households	TOE = 5'130'000 = 75% of total energy consumption				6'191				7'228			
TOTAL Energy Consumption all regions	TOE = 6'827'000											

Sudan, Energy Consumption

Annex 17.8
Table 4

Projection of Household Energy Consumption from Crop Residues and Animal Wastes

REGION	1980				1985		1990	
	CROP RESIDUES		ANIMAL WASTES		BIOMASS	BIOMASS	BIOMASS	BIOMASS
	Quantity	TOE	Quantity	TOE	Quantity	TOE	Quantity	TOE
EASTERN	48'000	9'600	35'000	8'750				
NORTHERN	44'000	8'800	35'000	8'750				
KHARTOUM	Small	-	Small	-				
CENTRAL	210'000	42'000	348'000	87'000				
SOUTHERN	44'000	8'800	749'000	188'000				
KORDOFAN	Small	-	Small	-				
DARFUR	Small	-	Small	-				
TOTAL	346'000	69'200	1'167'000	292'000	1'712'500	408'809	1'941'000	463'356
TOTAL crop residues and animal wastes	1'513'000 t = TOE 361'200 TOE = Tons of oil equivalent				1'712'500	408'809	1'941'000	463'356

REGION TOE = Tons of oil equivalent	WOOD		CHARCOAL		Other BIOMASS		TOTAL 1 + 2 + 3		Other Energy Resources		TOTAL Energy 4 + 5	
	'000 TOE	%	'000 TOE	%	'000 TOE	%	'000 TOE	%	'000 TOE	%	'000 TOE	%
	1	1	2	2	3	3	4	4	5	5	6	6
EASTERN	280	42,4	183	27,7	42	6,3	505	76,4	155	23,6	660	100
NORTHERN	90	32,0	101	35,9	23	8,1	214	76,1	67	23,9	281	100
KHARTOUM	108	17,0	184	29,0			292	46,0	342	54,0	634	100
CENTRAL	648	40,6	442	27,7	231	14,5	1'321	82,8	275	17,2	1'596	100
SOUTHERN	1'270	72,0	273	15,5	201	11,4	1'744	98,9	20	1,1	1'764	100
KORDOFAN	549	59,6	336	36,5	5	0,5	890	96,6	31	3,4	921	100
DARFUR	603	62,1	342	35,2	4	0,4	949	97,7	22	2,3	971	100
TOTAL	3'548	52,0	1'861	27,3	506	7,4	5'915	86,7	912	13,3	6'827	100

Energy Sources, Sudan / Table 5 Annex 17.10 88

Annex 17.11
Tabie 7

Factors for crop collection

Crop	Residue Yield Factor (t/feddan)	Availability Factor
Cotton	1.50	1.0
Sorghum	2.15	0.5
Millet	1.06	0.4
Wheat	2.06	0.5
Rice	1.60	0.5
Maize	1.85	0.8
Groundnuts	1.26	0.8
Sesame	1.29	0.8

The relatively low availability factor of some crop residues for energy production is due to the fact that substantial parts of the residues are left on the ground, used as animal feed or building material etc.

Centers of Cotton Growing, Sudan

Annex 17.12
Table 8

Main Centers of C O T T O N Growing in S U D A N (1)

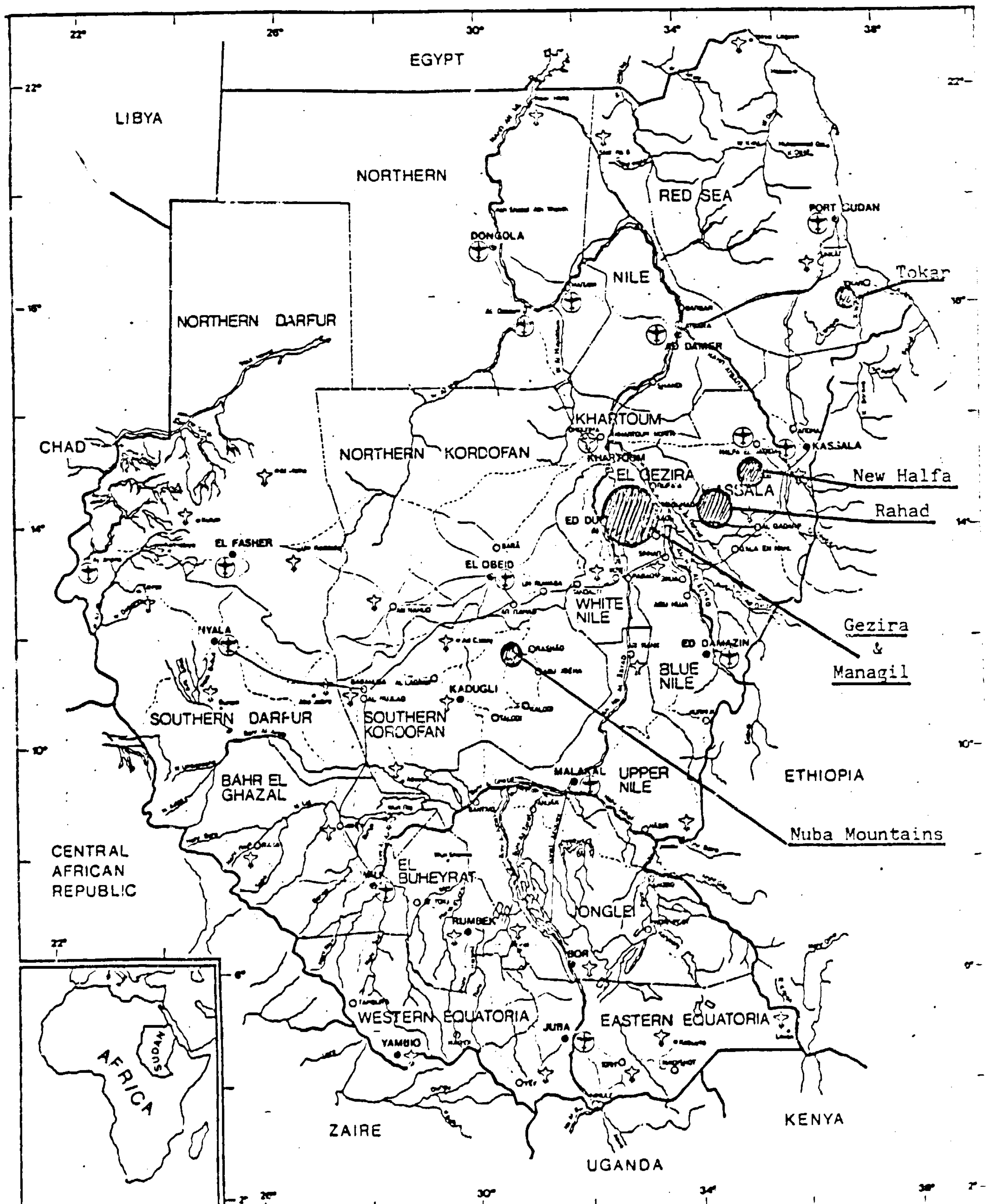
REGION	PROVINCE	SCHEME	'000 Feddans irrigated	'000 Feddans rainfed	TOTAL
CENTRAL	El Gezira	- Gezira & - Managil	245 & 255 (500)		665
	Blue Nile	- Blue Nile & - Suki	70 & 25 (95)		
	White Nile	- Kosti-Renk & - El Dueim	50 & 20 (70)		
Eastern	Kassala	- Rahad	130		235
		- New Halfa	85		
		- Tokar	20		
Kordofan	Southern Kordofan	- Nuba Mountains		55	55
Southern	Equatoria			30	30
Gross Total			900	85	985

Annex 17.15
Figure 5

SUDAN

Main cotton growing areas

1983



Annex 17.14
Table 9

LOCATION AND CAPACITIES OF MAJOR OIL MILLS IN SUDAN 1982

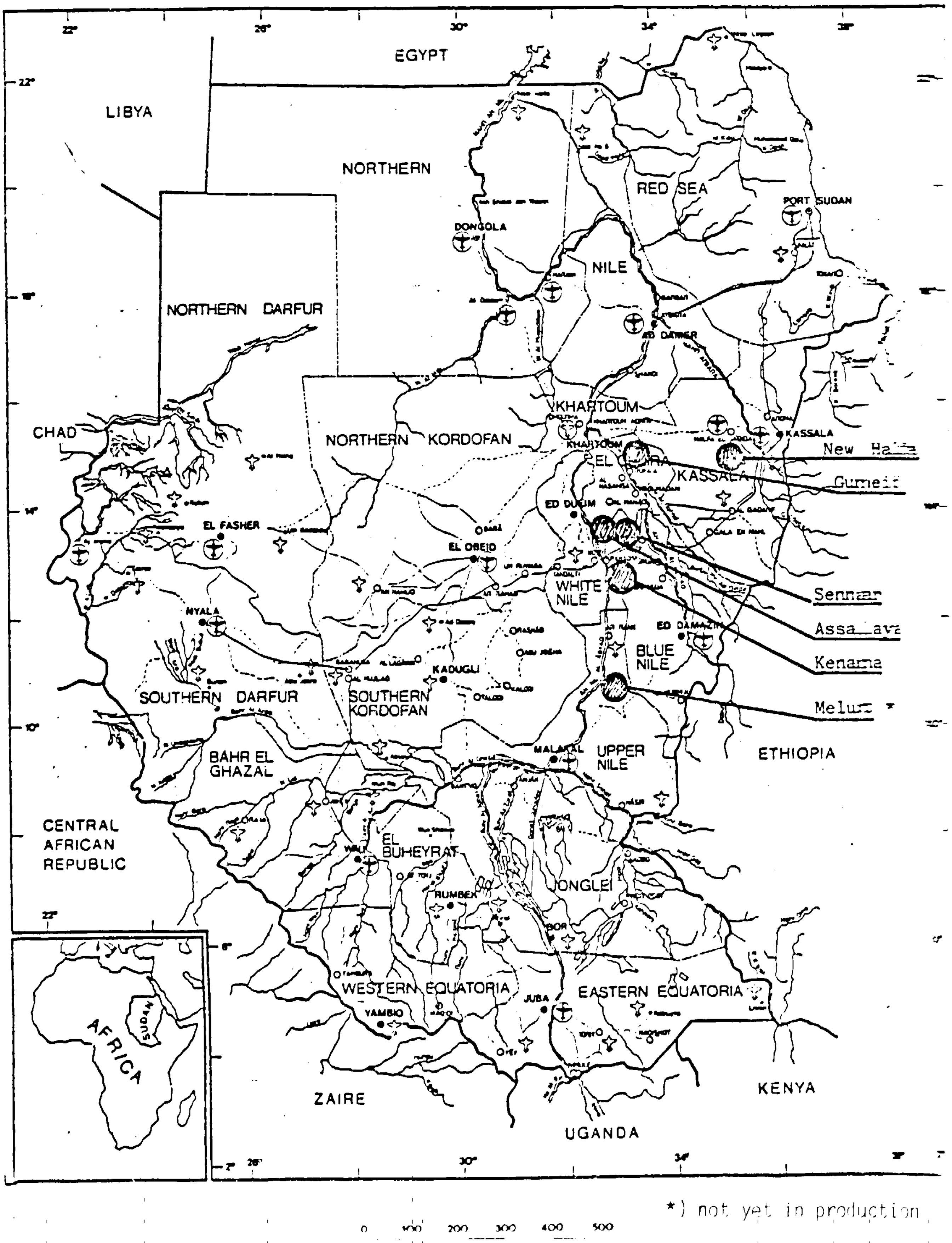
LOCATION	Total Nos.	Annual Capacity (1.000t)
Khartoum North	15	394.500
Omdurman	8	87.000
Wad Medani	3	44.550
El Dueim	1	16.875
Rabak	2	33.800
Sennar	5	25.380
Senja	2	6.480
Karkog	1	10.800
Managil	1	8.340
Hashesa	3	29.560
Port Sudan	7	292.950
Gedaref	2	3.660
Genina	1	2.700
El Fasher	1	2.600
Nyala	5	36.180
Eldien	4	12.960
Singa	1	9.000
Total	62	1.017.335

Source: Agricultural Bank of Sudan, 1982

Annex 17.1?
Figure 6

SUDAN

SUGAR FACTORIES
1983



*) not yet in production

Agricultural Crop Residues in Sudan for Fuel Briquetting Applications (8)

CROP	Amount of Residues ('000 t)	Availability Factor	Net Amount of Residues ('000 t)	Harvesting Periods	AREAS
Cotton	1'500	1.0	1'500	Dec./April	Gezira, Rahad, Blue Nile
Sorghum	16'000	0.5	8'000	Oct./Nov.	Kassala, Blue Nile, Gezira
Millet	3'000	0.4	1'200	Aug./Sept.	North Kordofan, Darfur
Wheat	1'200	0.5	600	Mar./April	Gezira
Rice	30	0.5	15	Oct./Nov.	Gezira, Soutern Region
Maize	250	0.8	200	Aug./Oct.	Blue Nile, Southern Reg.
Groundnuts	3'000	0.8	2'400	Nov./Jan.	North Kordofan, South Darfur, Gezira
Sesame	2'500	0.8	2'000	Oct./Nov.	North Kordofan, Blue Nile Southern Region, Kassala
Sugar Cane Bagasse (New Halfa)	400	1.0	400	-	-
Total	27'880	-	16'315		

Annex 17.17
Table 11
Table 12

Alternative Methods of Cotton Stalks Removal - Gezira 1975

Table 11

Method	Forward speed m/s	Net rate of work fed/h	Specific fuel consump. l/fed
Hand operated "KAMASHA"	-	0.03	-
Stalk puller 4-rows	1.28	3.77	0.82
Root cutter 2-rows	1.48	1.54	2.09

Table 12 summarizes the performance of the pulling machines in Gezira Rahad. The difference in the fuel consumption recorded in the two areas is due primarily to greater distances travelled between base and field in Gezira. Ir Rahad, the long-furrow irrigation technique provides smooth passage for the machine, whereas the transverse water channels of Gezira necessitate the use of a low forward gear ratio for much of the pulling time.
Hence, a higher net work rate is obtained in Rahad (Table 12).

Performance of a 4-row Cotton Stalk Puller in Gezira and Rahad 1979

Table 12

Average daily output (of 14 machines	32.8	feddans
Average fuel consumption Gezira	2.0	l/feddan
Average fuel consumption Rahad	0.91	l/feddan

In Gezira, the actual cost to the user per hectar of machine pulling and additional hand work was to be found almost half those of hand-pulling with a "KAMASHA", and in Rahad operating a pulling machine cost less than half of root cutting with tractor-mounted blades. The final conclusion stated is that machine pulling represents a large saving over hand-pulling or root-blading to the tenant (Table 13).

Annex 17.17
Table 13

Cost per Feddan of Alternative Methods of Cotton Stalk Removal 1979

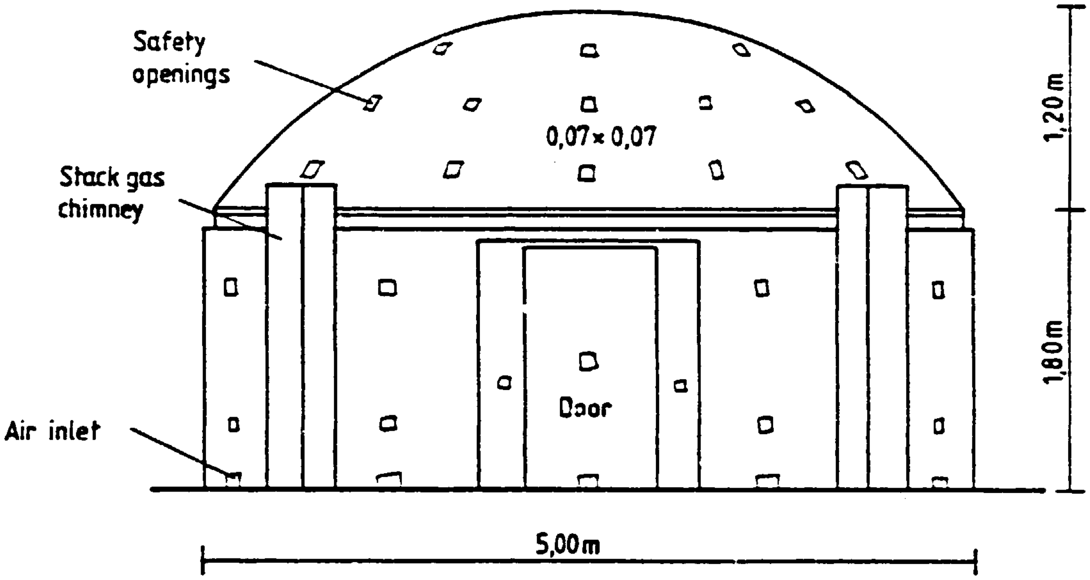
Table 13

Gezira

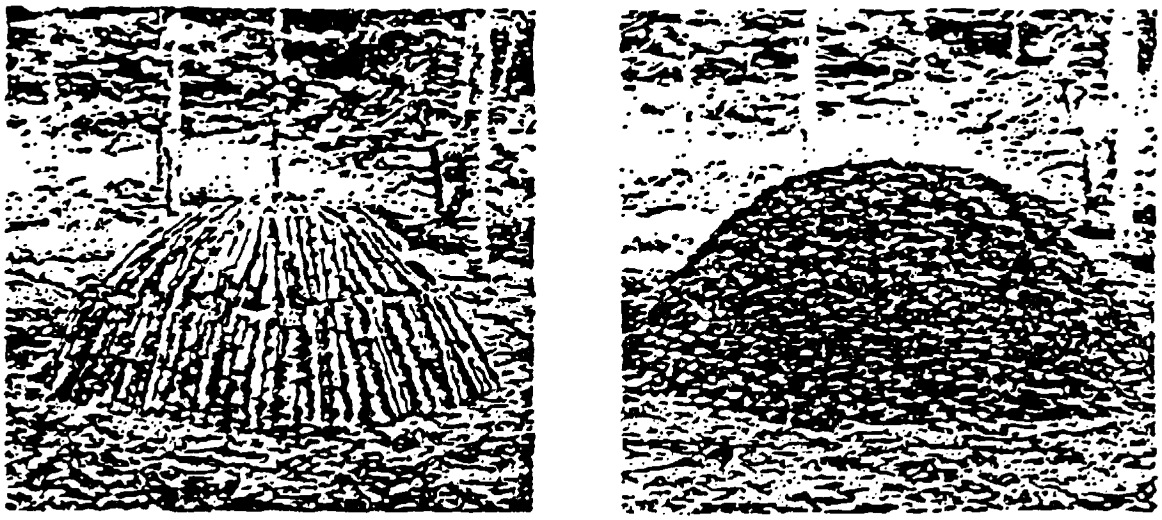
Tractor and puller and additional hand work	LS 1.480 / feddan
Hand-pulling with a "KAMASHA"	LS 2.700 / feddan

Rahad

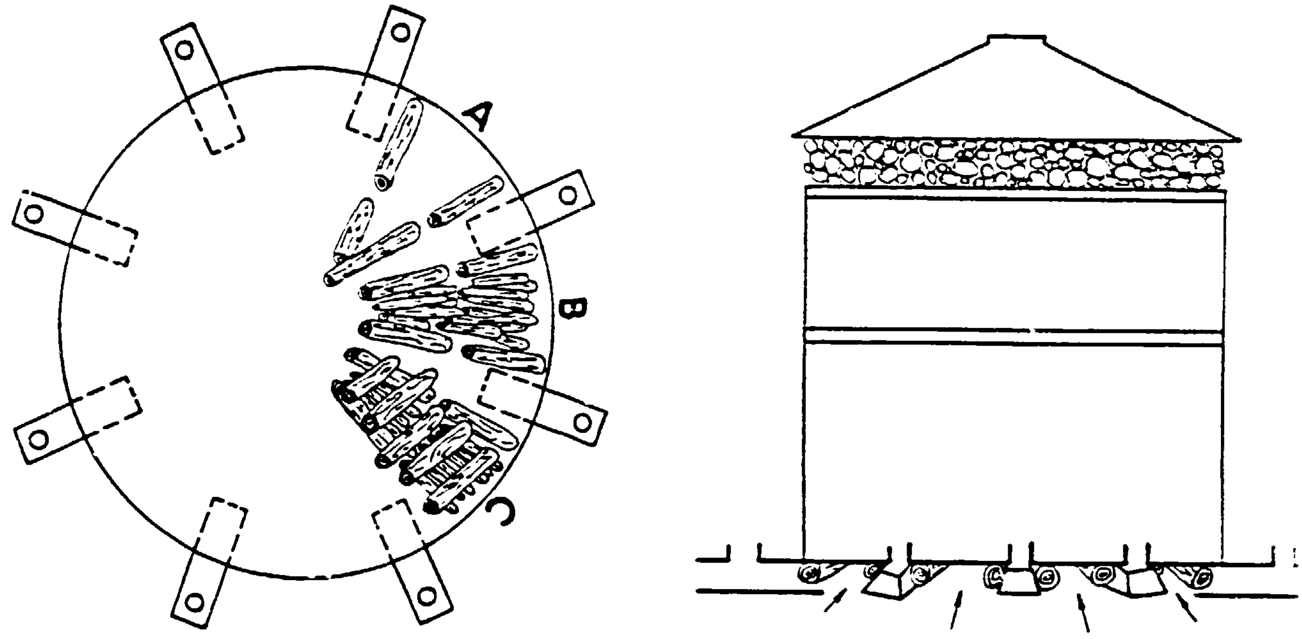
Tractor and puller and additional hand work	LS 1.780 / feddan
Tractor and root cutter and additional hand work	LS 9.680 / feddan



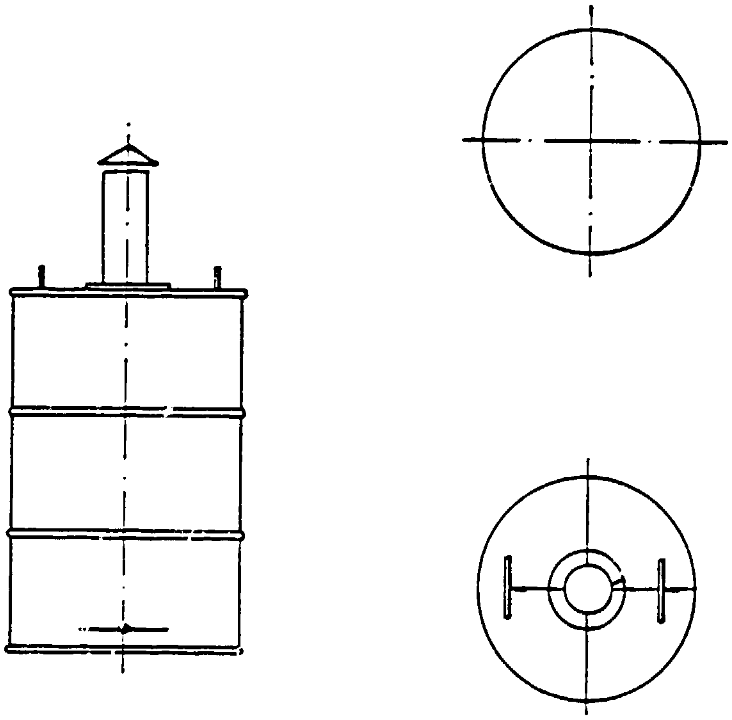
Masonry Kiln Figure 7



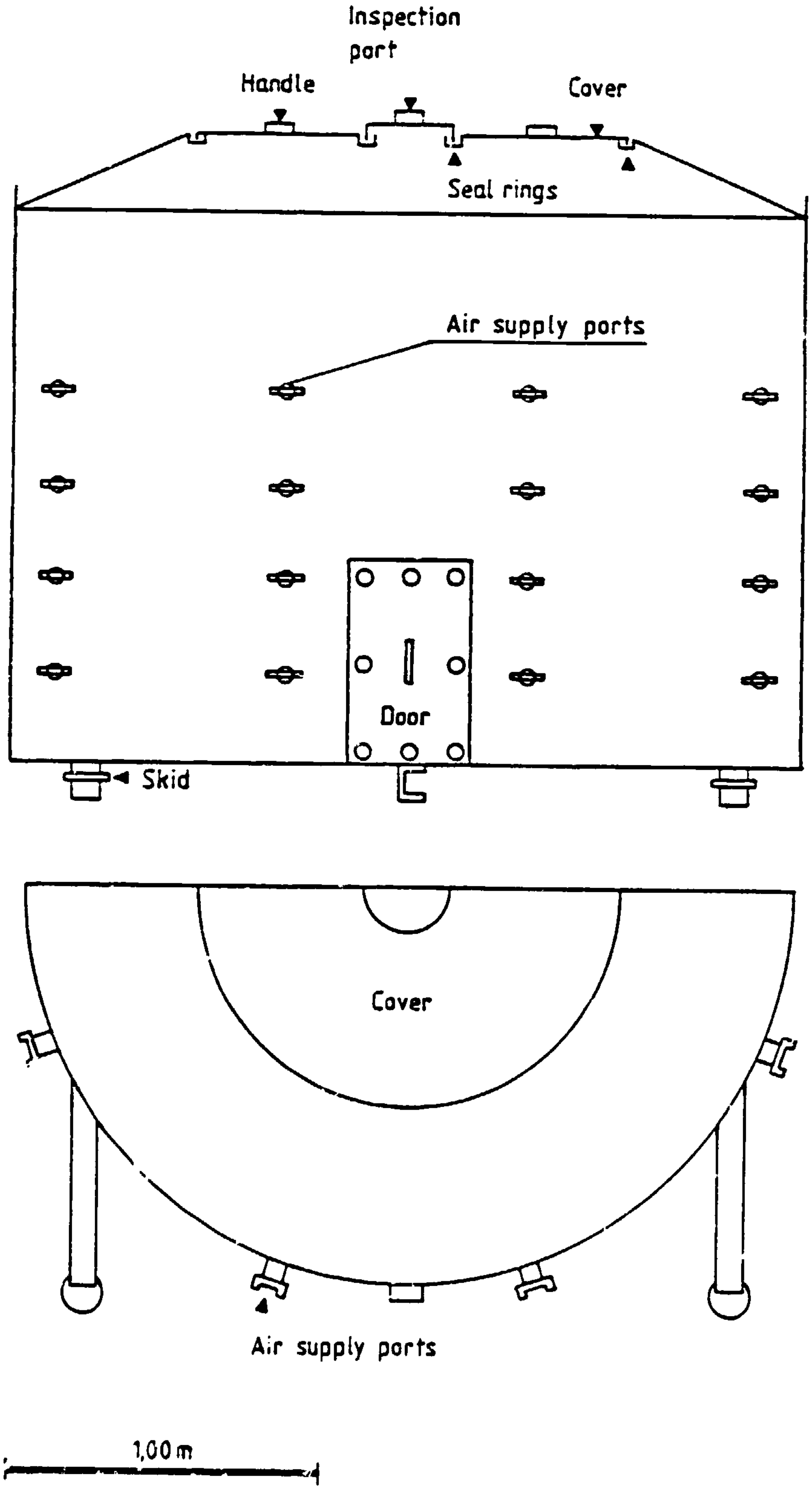
Earth Kiln Figure 8



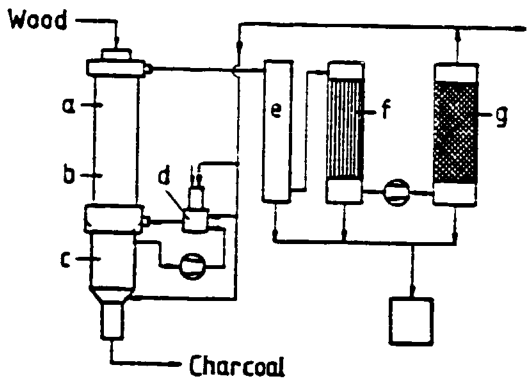
Mark V Metal Kiln Figure 9



Drum Kiln Figure 10

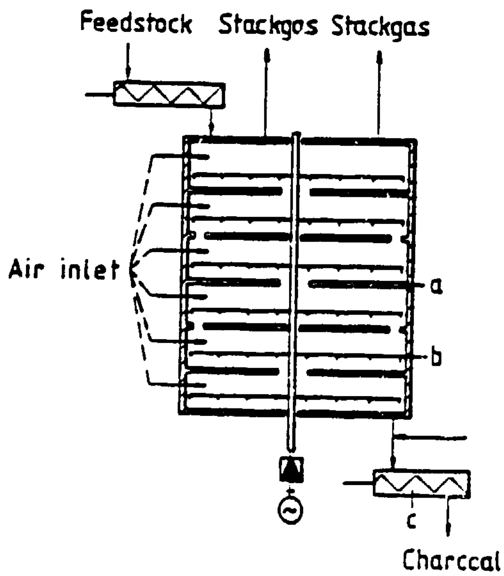


CUSAB - Kiln Figure 11



Continuous SIFIC Process Figure 12

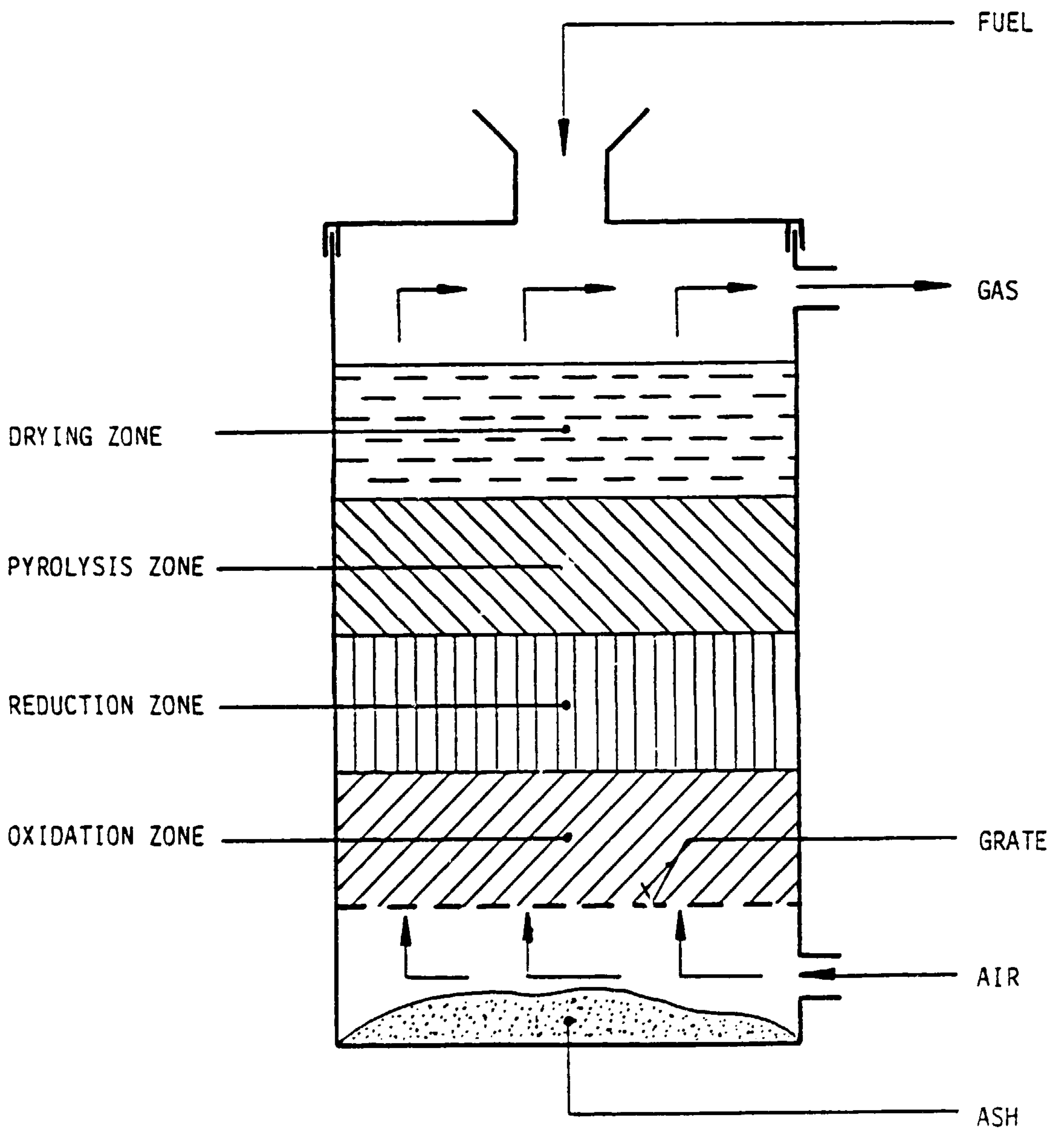
a Preheating zone, b Carbonization zone, c Cooling zone, d Gas heater, e Gas washer, f Condenser, g Scrubber



Herreshoff Process Figure 13

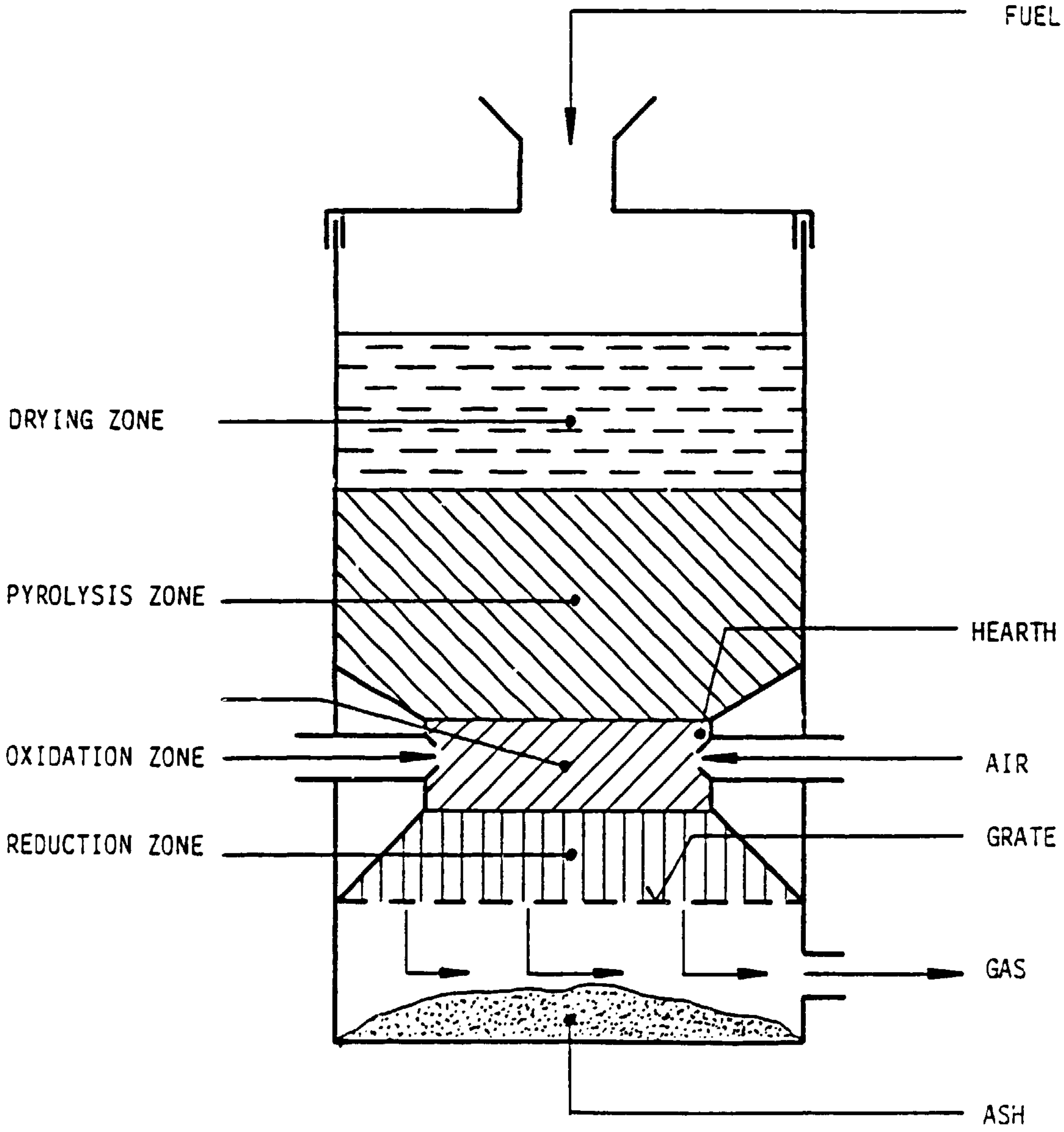
a Grate, b Sweeping auger, c Screw extractor, watercooled

Annex 17.22



Up-Draught Gasifier Figure 14	Gezeichnet	Datum 21.02.84
	Geprüft	Blatt Nr

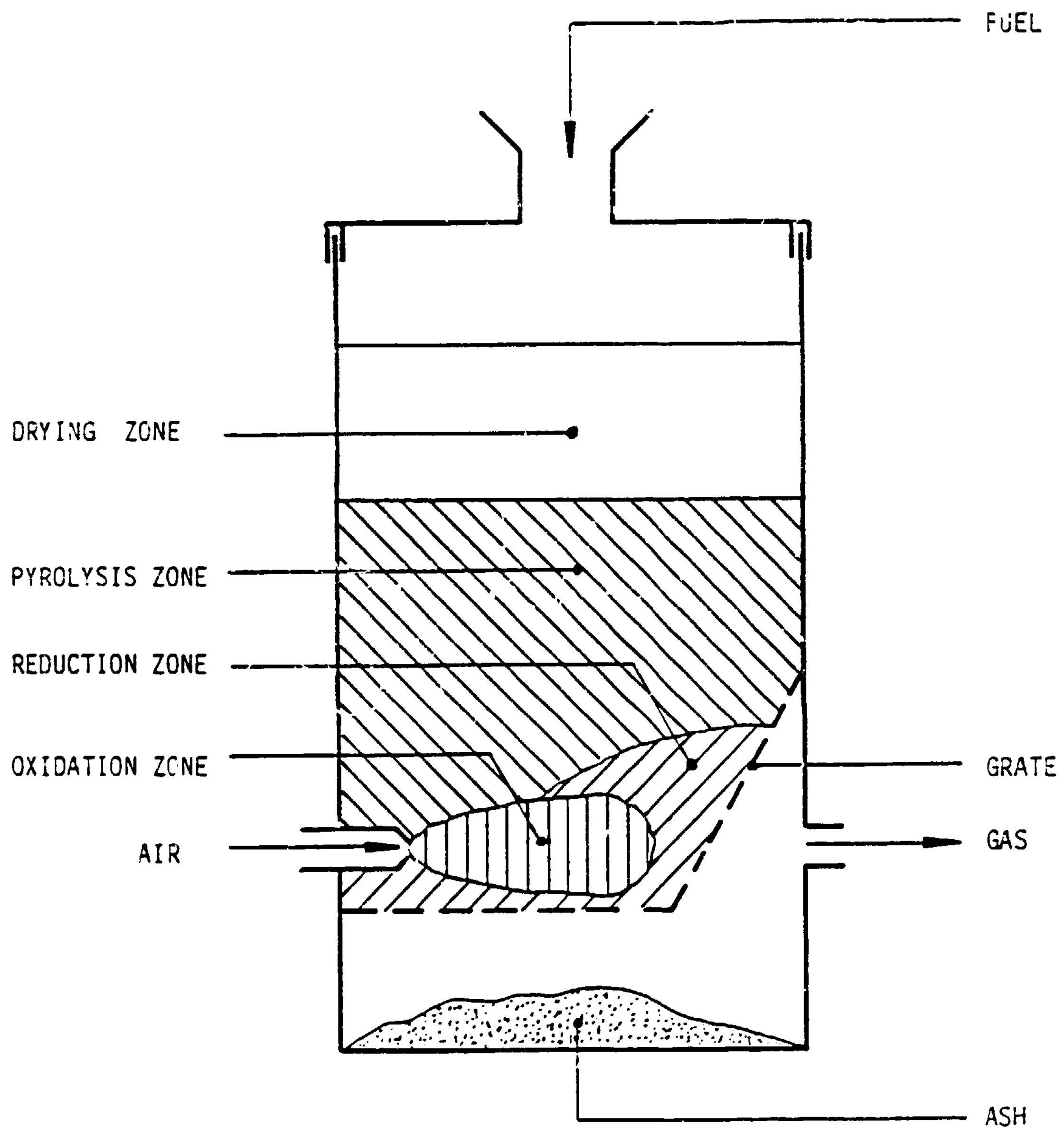
Annex 17.23



Down-Draught Gasifier

Figure 15

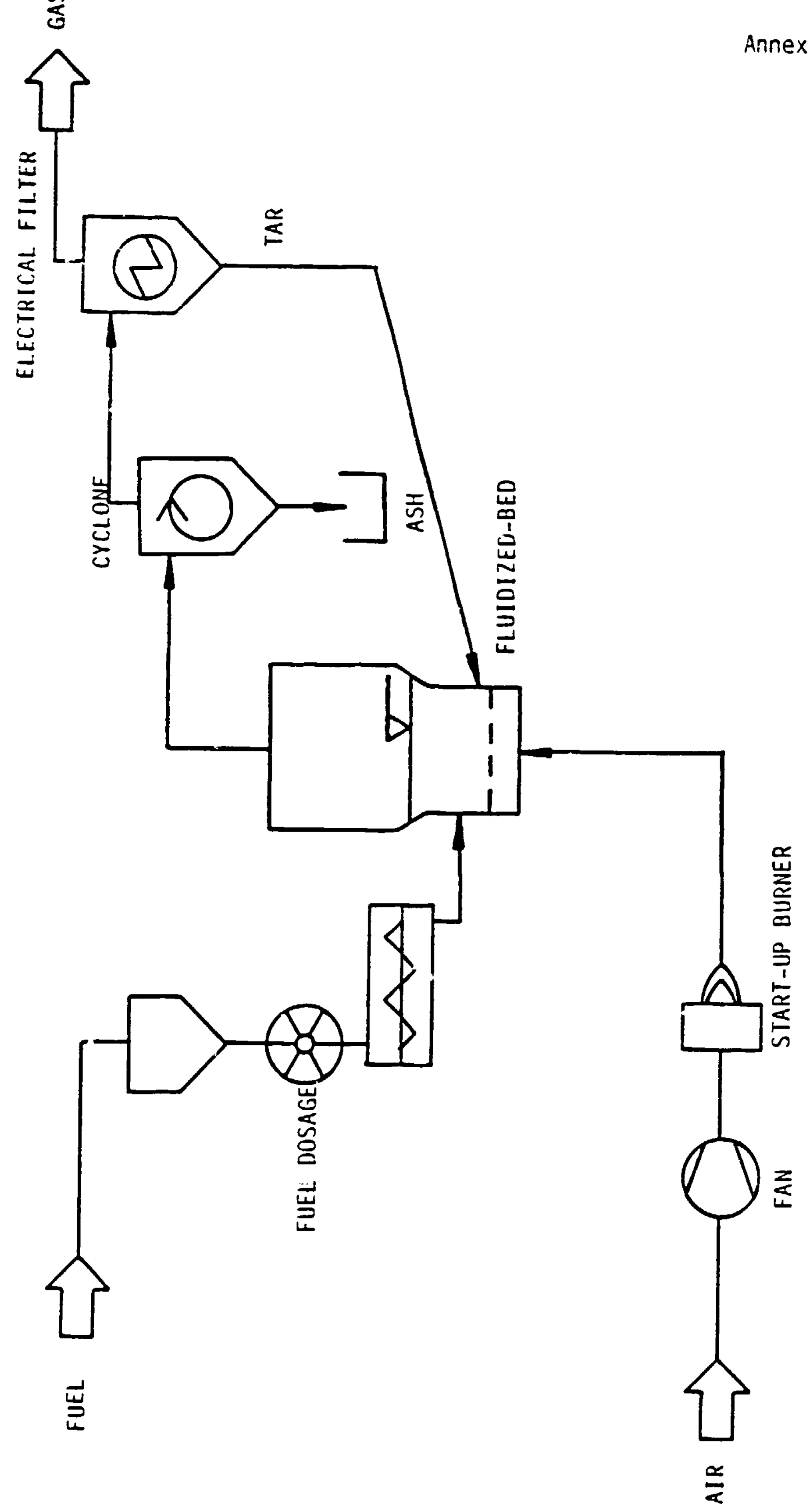
Gezeichnet	Datum
Mertens	21.02.84
Geprüft	Blatt Nr.



Cross-Draught Gasifier
Figure 16

Gezeichnet: Mertens
Datum: 21.02.84
Geprüft:
Blatt Nr.

Annex 17.25



Fluidized-Bed Gasification Plant Figure 17	Gezeichnet	Datum 21.02.84
	Geprüft	Blatt Nr.

MANUFACTURERS OF BRIQUETTING PRESSES

E	=	Extruding Press Piston	S	=	Screw Press
ER	=	Edge Runner - ring type die	R	=	Roll Press
D	=	Disc Type Die	G	=	Gear Press

Manufacturer Adress	Type of Press	Capacity ton/h
1. ATS-Alternativ-Technik-Systeme CH-8546 Ellikon TCH 05494567	S	
2. Bavaria, Gebr. Hofmann, Eisengießerei D-8701 Eibelstadt-Würzburg Tel.: 09303 / 312	ER	0,1 - 0,3
3. Bepex GmbH Postfach 9 D-7105 Leingarten Tel.: 07131 / 40082 - 86	R	1 - 50
4. Biomass Development Europe SA (Biomat) Avenue de Tervueren 36 B-1040 Bruxelles	S	0,6 - 1,0
5. Bühler-Miag GmbH T. D-3300 Braunschweig Tel.: 0531 / 5941	ER	1 - 10

MANUFACTURERS OF BRIQUETTING PRESSES - Continuation

Manufacturer Adress	Type of Press	Capacity ton/h
6. CPM / Europe Wesel GmbH Hafenstraße 28, Pf. 189 D-4230 Wesel 1 Tel.: 0281 / 23852 + 23877	ER	0,5 - 6
7. Claas O.H.G. Postfach 1140 D-4834 Harsewinkel / Westfalen Tel.: 05247 / 121 (2156)	E	0,3
8. Debbeler Droste-Hülshoff-Straße 4 D-4590 Cloppenburg Tel.: 04471 - 82526	ER	1 - 4
9. De Smithske Postboks 179 DK-9400 Nørresundby Tel.: DK-08-178111	E	1,5
10. Eco Briquette Aps P.O. Box 720 DK-9900 Frederikshavn Tel.: 458421000	E	bis 1,6
11. F. Hausmann Hammerstraße 46 CH-4005 Basel Tel: 061 / 264200 Vertretung: Hartlapa, 2082 Tornesch	E	0,2 - 3

MANUFACTURERS OF BRIQUETTING PRESSES - Continuation

Manufacturer Adress		Type of Press	Capacity ton/h
12.	Hutt-Bepex GmbH Postfach 9, Daimlerstraße 8 D-7105 Leingarten Tel.: 07131 - 40082	R , G , ER	0,1 - 10
13.	Kahl, Amandus Nachf. Hamburg Dieselstraße 5 D-2057 Reinbek Tel.: 040 / 7222024	ER	1 - 5
14.	Kunz W. AG Maschinenfabrik CH-5606 Dintikon	ER	1 - 5
15.	Pini + Kay Maschinenbaugesellschaft Lingrienergasse 4-6 A-1120 Wien 12	E	n.a.
16.	Ottevanger Moerkappelle / Holland Tel.: 01793 - 314	ER	n.a.
17.	RSN Maschinenbau GmbH Postfach 1749 D-7910 Neu-Ulm Tel.: 0731 / 79681	E	0,15

MANUFACTURERS OF BRIQUETTING PRESSES - Continuation

Manufacturer Adress		Type of Press	Capacity ton/h
18.	Simon Heesen BV St. Antonstraße 24 D-4150 Krefeld Tel.: 02151 - 1466	ER	n.a.
19.	Spänex Sander GmbH + Co. KG Postfach 2140 Volpriehausen D-3418 Uslar 1 Tel.: 05573 / 304	E	0,3
20.	Spoerri & Co. AG Schaffhauser Straße 89 CH-8042 Zürich Tel.: 01 - 3629470	E	1 - 2,5
21.	Wirth Max (Blitz-Hersteller) D-7081 Essingen/Aalen Tel.: 07365 / 5051	E	0,2 - 0,5
22.	ZENO Zerkleinerungsmaschinenbau GmbH Waldboden D-5239 Norken /Westerwald	E	0,2 - 0,5

Sudan, Cotton Stalk Carbonization in a laboratory retort by courtesy of Messrs. Degussa

Yield referring to feedstock dry-basis:

Charcoal:	36,1	%
Acetic Acid:	4,1	%
Wood Spirit (Methanol):	1,5	%
Wood Tar:	7,3	%
Wood Gas:	168	l/kg dry-basis

Analysis of charcoal ash and by-products:

Charcoal:

Ash:	11,2	%
Volatile Substances:	13,2	%
Fix C-Content:	75,6	%

Sudan, Cotton Stalk Carbonization

Acetic Acid (determined as volatile acid)	10,3	%
Wood Spirit (as mentioned through transformation into ester)	3,1	%
Wood Tar (determined as evaporating residue on the water bath)	18,6	%

Wood Gas:

H_2	0,2	%
O_2	0,4	%
N_2	3,3	%
CH_4	15,8	%
CO	24,3	%
CnHm	2,2	%
CO_2	53,8	%
Calorific Value*)	10100	kJ/m^3n

* was calculated from the gas analysis

Composition of Cotton Stalks and their ashes by Messrs. Beijer, Sweden, (*) and Messrs. Fresenius (for Sudan)

		SUDAN	Nica 1*	Nica 2*	Spain 1*	Spain 2*
Heating Value	MJ/kg	18.3	18.3	19.4	19.0	18.2
Volatiles	%	n.a.	75.8	n.a.	74.3	68.7
Ash	%	5.6	8.0	3.0	4.7	8.0
Fixed C.	%	n.a.	16.2	n.a.	20.9	23.3
Ash SiO_2	%	19.2	6.3	9.4	54.5	45.0
K_2O	%	n.a.	31.8	30.2	21.1	6.6
Na_2O	%	11.2	0.5	3.0	n.a.	1.5
Fe_2O_3	%	4.3	1.0	2.0	n.a.	3.2
Melting Point	° C	n.a.	1640	1615	n.a.	1230

Annex 17.29
Table 17
Page 1

Gasification of Cotton Stalks at Beijer Institute, Sweden

Date of Testing:	December 14, 1983
Fuel:	Cotton Stalk
Dimension:	Briquets 60

Atmospheric:

Pressure 1016.0 (mbar)
Temperature: 20.0° C
Relative moisture: 44.0 %

Properties of Fuel:

Moisture content:	8.5 %
Ash content:	5.1 %
Calorific heat value (on dry matter)	18.20 MJ/kg
Effective heat value	14.53 MJ/kg

Test results

Operating time	5.00 h
Consumed amount of fuel (dry)	127.85 kg
Consumed energy quantity	2029.85 MJ
Produced amount of ash	11.00 kg
Combustible in ash	40.73 %
Loss of energy in ash	120.96 MJ
Primary air flow	41.77 m^3n/h
Producer gas flow (dry)	58.37 m^3n/h
Heat value producer gas	4.299 MJ/m^3n
Produced amount of energy in gas	1254.58 MJ
Available power in gas	70.68 kW
Gas/fuel ratio (m^3n, gas/kg, dry fuel)	2.32 m^3n/kg
Air/fuel ratio (kg, air/kg, dry fuel)	2.08 kg/kg
Moisture content in hot gas	94.09 (g/m^3n)

Moisture content in cold gas	19.09	g/m³n
Volume ratio CO_2 in dry gas	8.9	%
Volume ratio in CO in dry gas	17.7	%
Volume ratio H_2 in dry gas	14.6	%
Volume ratio O_2 in dry gas	0.3	%
Volume ratio N_2 in dry gas	55.0	%
Volume ratio CH_4 in dry gas approx.	1.5	%
Volume ratio CmHn, Ar, ... in dry gas	1.0	%
Volume ratio H_2O in gas	2.4	%
Temperature throat	1001.2°	C
Temperature hot gas	638.4°	C
Temperature cold gas	19.1°	C
Loss of energy in gas cooling (total)	356.94	MJ
Heat loss in water condensation	45.57	MJ
Hot gas efficiency	79.39	%
Cold gas efficiency	61.81	%
Combustion zone load	0.84	m³n/h/cm²
Combustion zone const.(duration of stay)	0.0932	(sec.)
Gas velocity through throat	2.32	m/s
Air velocity in nozzles	29.54	m/s
Tar content	> 0.0	g/m³n, gas

Annex 17.30
Table 18

Gasification Analysis of Sudan Cotton Stalks at

Messrs. FRITZ WERNER Industrie-Ausrüstungen GmbH
Geisenheim
West-Germany

T E S T R E P O R T

Gasification Test with Cotton Stalk Briquets in a
Fixed-Bed Down-Draught Gasifier

The aim of this test was to examine the suitability of cotton stalk briquets as a gasifier fuel.

With briquetted cotton stalks from the Sudan a test run of 15 hours has been conducted.

Characteristics of the used gasification plant

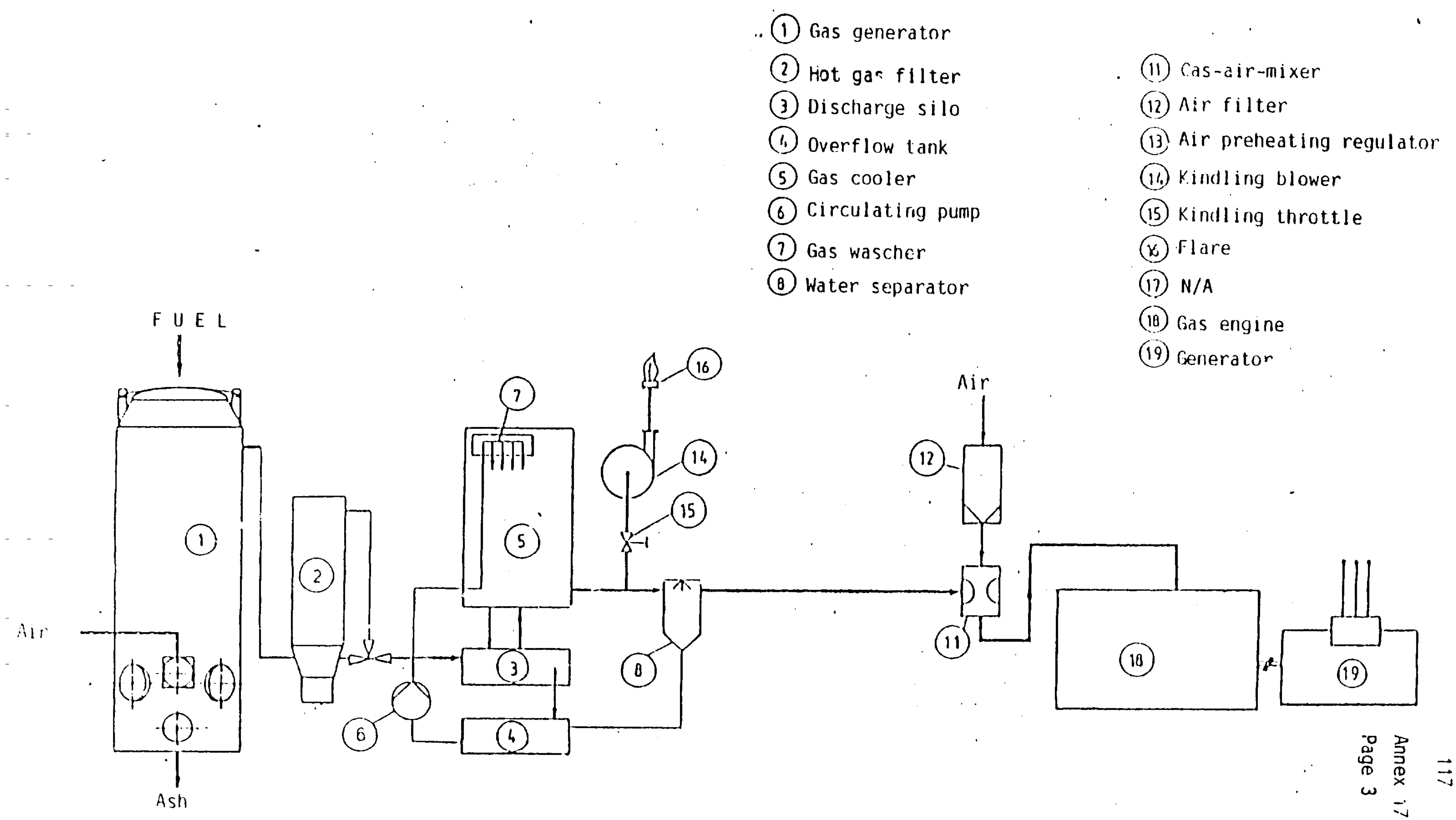
The unit consists of a fixed-bed gas producer, a gas cooling and purification train and a gas engine gen-set of 20 kWel max. output.

The gas producer:

Outside	Ø	mm	650
Height		mm	1800
5 Nozzles for gasification air supply	Ø	mm	11,6
Contracted hearth section	Ø	mm	100

The gas cooling and purification train:

- Bag filter with pulsed air cleaning system
- Finned tube cooler with condensate collection tank
- Water separator



Flow chart: Fixed-Bed Gasification with gas preparation and gas engine

Projekt- und Zeichnungsnummer	Projektbezeichnung	1982	Datum	Name
		Bearb.	82.	
		Geprüft		

Gas engine gen-set:

- Gas-air-mixer
- Engine: DEUTZ Type F4L912,
  Displacement: 3,77 l
  1500 min^{-1} continuous rpm
- Three-phase alternator (Leroy Somer) 30 kVA, 50 Hz.

The output of the plant was measured with resistors immerged in a water bed of:

3 x 6,0 kW
1 x 4,5 kW

The electrical work was registered with a kWh counter hooked up between generator and resistors.

Fuel:	Briquetted cotton stalks Ø 80 x 40 mm
(Pic. 2)	Moisture: 14% dry-basis was found in several drying tests at 105° C according to DIN 52183.
	Ash content: 2 %
	Calorific Value: 17500 kJ/kg

Preparation of the gas producer:

Prior to the start:

Beech charcoal was placed from grate zone up to the contracted part of the hearth outside and inside up to approx. 5 cm above the nozzle ring. A total of 25 kg of charcoal was used. Subsequently 30 kg beech block wood were added and the rest up to the upper flange was completed with briquetted cotton stalks.

The performance of the test

The test was run from July 23, 1984 until July 24, 1984. The entire electrical output was 112 kWh at a total duration of 15 hours.

The test plant used produces normally 20 kW and more when gasifying block wood. When gasifying briquetted cotton stalks the capacity of the plant was found to be 7,5 kW only which is an average value for an operation period of 15 h (112 kWh/15 h approx. 7,5 kW).

Additionally it was observed that the gas composition declined during the test period as indicated in the following table.

Gas Composition

(measured during the execution of the test at determined intervals)

Gas Composition \ Operating hours		1	3	6	10	15
CO	Vol. %	20	18	12	14	14
H_2	Vol. %	8	13	11	13	12
CH_4	Vol. %	0,5	0,5	0,2	0,5	0,5
CO_2	Vol. %	7	10	12	12	11
O_2	Vol. %	0,5	0,5	0,3	0,5	0,5

The calorific value varies between 700 and 900 kcal/m³n or 2950 and 3800 kJ/m³n.

Average gas composition:

CO	=	15 %
H_2	=	10 %
CH_4	=	0,5%
CO_2	=	11%
N_2	=	61,5%

Hu = 750 kcal/m³n or 3143 kJ/m³n.

These results indicate that the gasification properties of the cotton stalks briquettes are very different from those of block wood These differences in conjunction with the down-draft gasification principle applied led to these results showing that constant test values were not achievable during the test period.

The reasons are in detail:

- Physical properties

  The briquetted stalks did not slide into the oxidation and the hearth zone of the gasifier as necessary which led to frequent bridging. By operating the grate shaker and by stoking from the top (with a steel rod Ø 16 mm) the bridging could be destroyed for a short time but reoccurred. The briquetted stalks broke and twisted and got stuck in the hearth zone due to influence of the process conditions.

- Formation of charcoal

  The application of a down-draft gasifier is only feasable with fuel producing lump charcoal forming the gas reduction zone below the hearth zone. However, no lump charcoal was formed from the briquetted cotton stalks. Thus the entire amount of beech retort charcoal which was filled in up to the lower part of the hearth before start-up, was used up. The formed charcoal (picture 3) was very fine grained which was due to the fact that the briquets in the hearth zone disintegrated and therefore were not able to form block coal. A too high part of fines in the charcoal led to an excessively high pressure loss after a short time of operation which led in consequence to the stop of the process.

Filter dust

The filter discharge was 2,2 kg/15 h corresponding to 0,15 kg/h. This relatively high amount of [illegible]arge (e.g. it is 3 times the amount for block wood) is prob[illegible] so due to the high portion of fines in the charcoal bed an[illegible] carbon loss for the process.

The condensate

The condensate from the cooler and water separator was 36 l/15 h corresponding to 2,4 l/h (hydrogen balance).

The dry amount of gas is calculated from Hu_{Gas} of 3143 kJ/m³n (medium value) and $W_{el.}$ of 114 kWh and an assumed efficiency of the engine generator unit of 26% by:

$$V_{G\ tr.} = \frac{W_{el.}}{Hu_{Gas} \times 0{,}26}$$

$$= \frac{114 \times 3600}{3143 \times 0{,}26}$$

$$= 502 \ m^3n$$

or $$= V_{G\ tr.}\ 33{,}5 \ \frac{m^3n}{h}$$

The total fuel consumption m_B was 167 kg for 114 kWh in 15 operating hours; in relation to the above the hourly consumption is:

$$m_B = \frac{167}{15} = 11{,}1 \ \text{kg/h}$$

<u>Pressure and Temperature Values</u>

		according to load
Lower Pressure at generator outlet	mm WS	60 - 130
Differential pressure filter	mm WS	70 - 150
Differential pressure cooler	mm WS	approx. 20
Total lower pressure of the plant	mm WS	140 - 300
Temperature at generator outlet	° C	160 - 280
Temperature at nozzle ring	° C	around 1000 - 1100
Temperature at filter outlet	° C	120 - 140
Temperature at cooler outlet (incl. flushing and fan)	° C	34 - 38
Ambient temperature	° C	22 - 30
Humidity (rel.) of air	%	40 - 50

Water content in the gas

The test showed the amount of condensate collected in the cooler and water separator at 35° C to be 36 l.

Assumption:

The gas cooled to 35° C is saturated with moisture:

φ	= 1	36	g/kg
ρ Gas	=	1,2	kg/m³n
502 x 1,2	=	602,4	kg Gas

The gas still contains 21,7 kg water.

Total amount of water discharged:

$$m_{H_2O} = 36 + 21,7 = 57,7 \text{ kg}$$

Relation between fuel/gas

The following results are computed from the data determined in the test:

- specific fuel consumption per kWh

$$\frac{m_B}{W_{el.}} = \frac{167 \text{ kgB}}{114 \text{ kWh}} = 1,46 \frac{\text{kgB}}{\text{kWh}}$$

- specific gas generation

$$\frac{V_G}{m_B} = \frac{502\ m^3\ Gas}{167\ kg\ B} = 3{,}00\ \frac{m^3\ Gas}{kg\ B}$$

- specific air consumption

Based on the hydrogen relation gas/air it was found:

$$\frac{xN_2\ Gas}{xN_2} \bullet V_{Gas} = \frac{61{,}5}{78} \bullet 502 = 396\ m^3\ air \mathrel{\hat{=}} 26{,}4\ m^3n/h$$

$$\frac{V_L}{m_B} = \frac{396\ m^3\ air}{167\ kg\ B} = 2{,}37\ \frac{m^3\ air}{kg\ B}$$

- specific gas consumption per kWhel

$$\frac{V_{Gas}}{W_{el.}} = \frac{502\ m^3}{114\ kWh} = 4{,}4\ \frac{m^3}{kWh}$$

- gasification efficiency

$$= \frac{\text{specific gas generation} \bullet \text{calorific value (gas)}}{\text{calorific value (fuel)}}$$

Calorific value of the briquetted cotton stalks approx. 17500 kJ/kg.

$$= \frac{3{,}00 \times 3143}{17500} = 0{,}54$$

- efficiency of the complete plant

$$\eta_{total} = \frac{W_{el.} \cdot 3.600}{m_B \cdot Hu_B}$$

$$= \frac{114 \cdot 3.600}{167 \cdot 17.500}$$

$$= 0{,}14$$

Control of the test data by quantity and material balances

1. Calculation of the dry gas volume by means of C-balance

$$V_{G\,tr.} = \frac{m_c \cdot 22{,}414}{12} \quad \frac{1}{x_{CO} + x_{CO_2} + x_{CH_4}}$$

(0,15 + 0,1 + 0,005 = 0,255)

$$\dot{m}_{waf} = \dot{m}_{raw} \; (1 - x_{H_2O} \text{ (raw)} - X\text{-ash})$$

$$\dot{m}_{waf} = 11{,}1 \; (1 - 0{,}12 - 0{,}02)$$

$$\dot{m}_{waf} = 9{,}55 \text{ kg}$$

$$\dot{m}_c = 9{,}55 \cdot 0{,}47$$ C-content: 47 weight %

$$\dot{m}_c = 4{,}49 \text{ kg/h}$$

$$\dot{V}_{G\,tr.} = 32{,}9 \text{ m}^3\text{/h}$$

2. Calculation of the water vapour content in the crude gas by means of hydrogen balance

$$n_{H_2O} = \frac{m_{H,B}}{M\ H_2} + \frac{m_{H_2O,B}}{M_{H_2O}} + \frac{m_{H_2O,\ air}}{M\ H_2O} - (x_{H_2} + 2\ x_{CH_4})\frac{V\ G\ tr.}{22.414}$$

Assumption:

The hydrogen content of cotton stalks is 5,6% by weight of the raw weight (taken from the elementary analysis).

$m_{H,B}$ = 11,1 kg/h • 0,056 = 0,62 kg/h

$m_{H_2O,B}$ = 11,1 kg/h • 0,12 = 1,332 kg/h

$m_{H_2O,\ air}$ = 32,422 kg/h • 0,010 = 0,324 kg/h

n_{H_2O} = 0,24 kmol/h

m_{H_2O} = 4,32 kg H_2O/h

$m_{H_2O} = 4{,}32\ \frac{kg}{h} \cdot 15\ h = 64{,}8$

Resume of Tests

Briquetted cotton stalks are not an appropriate fuel for a down draft gasifier due to the fact that no lump charcoal is being formed as necessary for the process. No constant operating parameters could be achieved during the test period, and the average capacity of the gasification unit was very low in comparison with block wood.

Glossary:

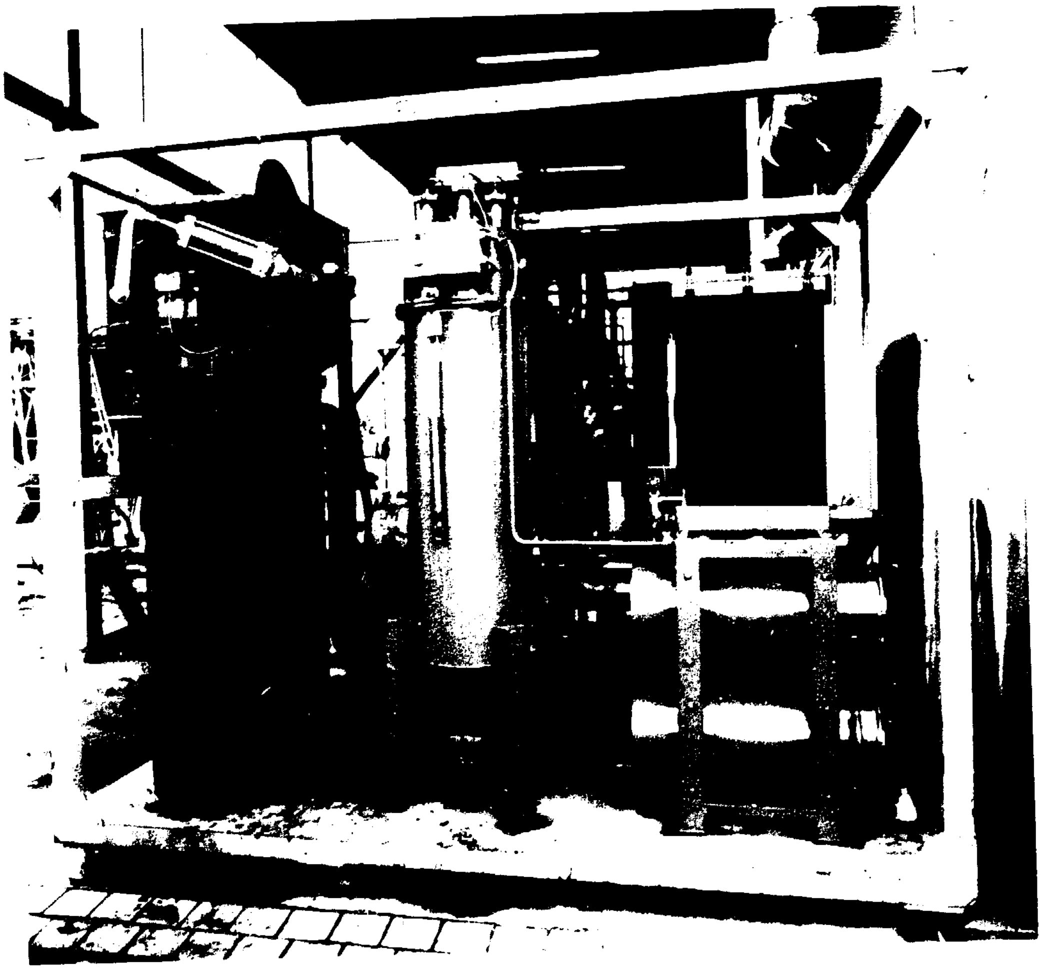
Hu	=	lower calorific value
Wel	=	electric work in kWh
$V_{G\ tr.}$	=	volume of dry gas
m_B	=	mass of fuel
xN_2	=	quantity of nitrogen in the gas
V_L	=	volume of air
m_{waf}	=	mass ash and water free
m_C	=	mass of carbon
n_{H_2O}	=	quantity of mol H_2O
$m_{H,B}$	=	mass of H_2 in the fuel
$m_{H_2O,B}$	=	mass of H_2O in the fuel
M	=	mol
x	=	parts
B	=	fuel

FWAR - Fixed-Bed Gasifier
Test Report

Test start: July 23, 1984	Duration of test: July 23 - July 24, 84
Operating hours: 15	Page-Nr.: 13
Total operating hours: 15	

Test data Block wood gasification:		Dimen- sion		Actual Operating Results
FUEL	Kind	-		Cotton Stalks
	Quantity	kg/h		11,1
Gasification medium	Air, Hearth zone	m^3/h		26,4
	Air, Bottom	m^3/h		
	Total air	m^3/h		26,4
	Quantity/kg Fuel	m^3/kg		2,37
GAS	Quantity	[illegible]/h		32,9
	Quantity/kg Fuel	m^3/kg		3,00
	Calorific value	kJ/m^3		3143
Gas Composition	H_2	Vol.% tr		10
	CO	Vol.% tr		15
	CO_2	Vol.% tr		10
	CH_4	Vol.% tr		0,5
	N_2	Vol.% tr		63,5
	H_2O	Vol.%		14,3
Gasifier Disposal	Quantity	kg/h		
Filter Disposal	Quantity	kg/h		0,15
Gasifier Efficiency	η	%		54
Engine output	electrical output	kW		7,6
Efficiency of the gen-set	$\eta_{el.}$ gen-set	%		ca. 26

Page	Date	Authors
13	03.08.1984	



Picture 1:

Plant GF 4 - K 02

Picture 2: Fuel - Cotton stalks briquetted

Picture 3: Charcoal formed from cotton stalks (very fine grained)

Elementary Analysis from Fresenius Institute for Cotton Stalks from SUDAN

Results:

Drying loss at 105° C 12,0 %

The subsequent tests were conducted with the sample dried at 105° C.

Carbon (C)	47,43 %
Hydrogen (H)	5,64 %
Upper Calorific Value (H_o)	4.490 kcal / kg ≙ 18.800 kJ/kg
Lower Calorific Value (H_u)	4.194 kcal / kg ≙ 17.562 kJ/kg

Annex 17.31
Table 19

Composition of Groundnut Shells (Senegal) by courtesy of Messrs. Omnical

-	Water	W	=	5,7%
-	Ashes	A	=	2,1%
-	Sulphur	S	=	0,1%
-	Carbon	C_2	=	47,9%
-	Hydrogen	H_2	=	5,5%
-	Oxygen + Nitrogen	$O_2 + N_2$	=	38,7%
-	Calorific gross value		=	19.090 kJ/kg
-	Calorific net value		=	17.730 kJ/kg
-	apparent density		=	130 kg/m³

Ash

-	SiO_2	=	28,8%	MnO	=	0,29%
-	MgO	=	9,70%	ZnO	=	0,08%
-	CaO	=	9,50%	CuO	=	0,06%
-	P_2O_2	=	4,35%			
-	Al_2O_2	=	3,70%	Na_2O	=	1,54%
-	Fe_2O_3	=	3,32%	K_2O	=	28,72%

Program arranged for the Experts from Sudan

Wednesday August 17, 1983

Arrival and Accomodation in the hotel.

Thursday August 18, 1983

Briefing at FRITZ WERNER and arrangement of the tests to be conducted. Trip to Bodenfelde, Messrs. Degussa (Deutsche Gold und Silber Scheideanstalt) followed.

Messrs. Degussa is leading in charcoal production using the retort process. The specialists were introduced to the entire production process at Degussa - the charcoal production and the refining of the condensate.

Messrs. Degussa generate the energy required for their factory partially from the wood to be carbonized. In summer when less energy is required internally, the surplus of electricity is fed into the national grid.

Carbonization experiments with cotton stalks were conducted in the laboratory at Degussa. A report on the experiment results is enclosed.

August 23, 1983

Visit to Messrs. Imbert-Energietechnik, Weilerswist near to Cologne

Messrs. Imbert has resumed the technology of the fixed-bed gasifier which was built in the 30ties and 40ties in Germany and Europe. Generally the enterprise manufactures gasifiers of this kind for application in stationary energy generation plants. As fuel for these gasifiers only lump wood of cigarette box size should be applied. At the moment experiments are being made to determine whether briquets can be gasified. However, so far no positive results have been obtained.

Visit to Messrs. Klöckner-Humboldt-DEUTZ in Cologne-Kalk

Messrs. KHD, a major enterprise in steel processing and plant technique, have a department which is concerned with the construction and design of fixed-bed gasifiers. KHD can refer to constructions built in the 30ties which were produced in a small series. The KHD-gasifier is a combination between a downdraft gasifier according to the Imbert principle and an updraft gasifier. The advantage of this unit is that not only lump wood can be gasified but also certain quantities of pellets and briquets.

The gas produced by this type of gasification has a relatively high tar content. Therefore, a costly gas cleaning unit is required to remove the dirt and tar particles from the gas. The special filter for this filter should be constructed so that it can be disposed of in the public sewage. This process is costly and somewhat problematic, thereby limiting the application of this tpye of gasification.

August 24, 1983

Earth Kiln

In Schloßborn/Taunus an earth kiln was inspected. This type of kiln is similar to the installation in South Sudan. The kiln is used in this case as a tourist attraction. The charcoal produced was of very good quality. However, this was due to the fact that only hardwood was carbonised.

August 25, 1983

Visit to Messrs. Schmauss in Morbach/Hunsrück

Schmauss has been operating a saw mill for the last 5 years which generates energy using an updraft gasifier coupled with a gas engine. Dry saw dust is used as fuel. The gasifier in the Schmauss mill operates according to the system of the updraft gasification. The gas produced contains tar and considerable quantities of condensates. Tar as well as condensate are then discharged through a filter which must be cleaned subsequently. The highly-polluted water which is produced during the cleaning process must again be processed in a special sewage plant. The environmental load has prevented the procedure so far from gaining more importance.

Visit to the Buderus Factory in Dietzholztal-Ebersbach

Messrs. Buderus are specialised in the construction of large combustion plants. Buderus was visited because the firm has built boiler plants for Senegal fueled by peanut shells in 1979.

August 31, 1983

Visit to Messrs. ZENO, Norken/Westerwald

ZENO means - Zerkleinerungsmaschinen Norken - shredding machines Norken.

The firm specialised in the manufacture of wood chippers and briquetting machines. The trainees were introduced to units used for the shredding and briquetting of cotton stalks.

September 9, 1983

Visit to University of Gießen / Prof. Schmutterer, Phytopathologist

Prof. Schmutterer is a pest control expert, specialised in cotton plants. Prof. Schmutterer has spent several years in Sudan and is especially aware of the pest control problems involving cotton stalks. The aim of this visit was to clarify whether it is possible to destroy the parasites by briquetting the cotton stalks. Should this prove successful, it will no longer be necessary to burn the stalks which could then be used as domestic fuel.

In continuation of this study it is recommended to contact Prof. Schmutterer on the problem of pest control by means of briquetting.

September 5, 1983

Visit to University München, Dept. Bayerische Landesanstalt für Landtechnik in Weihenstephan, Group Strohenergie, Head of Department: Dr. Strehler

Dr Strehler is a specialist for the conversion of agricultural residues into energy. In his institute in Weihenstephan directive experiments using straw combustion have been performed. At the moment they are in charge of a research program which is to examine the updraft gasifier according to the Schmauss system with straw. These tests are not concluded yet. However, also here the problem to purify the sewage water out of the gas scrubber remains to be solved.

September 6, 1983

Visit to Messrs. MAN, Maschinenfabrik Augsburg-Nürnberg Department New Technology

This department deals predominantly with solar techniques and Dr. Hood was especially interested as he specialises in solar energy.
Both experts believed that there would be definitely possibilities for the application of the solar technique in Sudan. However, their profitability is not advanced enough yet that they could be applied on a large-scale.

Visit to Messrs. Bio-Carbon

Bio-Carbon is a consultant's office promoting the processing method of an American firm for the manufacture of charcoal. The feedstock is heated by partial combustion and condensates are produced. Up until now no plant has been put into operation. The firm is seeking for first orders.

September 8, 1983 to September 17, 1983

The trainees who came to FRITZ WERNER in Geisenheim were given theoretical and practical instruction in the gasification method.
The specialists had the possibility to observe a fixed-bed gasifier in operation, fed with lump wood.
Unfortunately it was not possible to show the FRITZ WERNER fluidised-bed gasifier in operation as it was being re-modeled at the time. This was the reason why no practical training with the fluidised-bed could be carried out during the stay of the trainees.

Companies and Persons contacted during the visit of the experts

1. DEGUSSA
Uslarer Straße
3417 Bodenfelde
Mr. Josef Schreiner and Mr. Siemon

2. Imbert Energietechnik GmbH & Co. KG
Bonner Straße 49
D-5354 Weilerswist
Mr. W.O. Zerbin

3. KHD Humboldt Wedag
5000 Köln 61
Mr. Johannes Ferges
Gasification - Technologic, Dept. IH-NP

4. Schmauss
Felsenstraße 12
5568 Daun
Mr. Schmauss

5. Omnical Kessel (Buderus)
6344 Dietzholztal-Ebersbach
Mr. Ernst N. Etzold
Mr. Eberhard Nickel

6. ZENO
Zerkleinerungsmaschinenbau GmbH
Waldboden
5239 Norken / Westerwald
Mr. R. Krüger

7. GTZ
6236 Eschborn 1 bei Frankfurt/m.
Mr. Holger Liptow

8. University of Gießen
Bio Department
Prof. Schmutterer
Postfach
D-6300 Gießen

9. Landtechnik Weihenstephan
Techn. Universität München
D-8050 Freising
Dr. Arno Stehler

10. MAN
Dachauer Straße 667
Postfach 500 620
D-8000 München 50
Mr. Jörg Siemer
Dr. Gerhard Isenberg

11. Bio-Carbon-Carbonisierungs- und Pyrolysetechnik
Socking 1
D-8254 Isen/Obb.
Mr. Helmut Reger

Annex 17.33
Table 20

GLOSSARY

TOE	=	Tons of oil equivalent = 41.8 x 10^6 Joules
	=	10'000 kcal (1)
atro	=	absolute dry
km^2	=	approx. 238 feddans
ton	=	always metric ton (1'000 kg)
(1)	=	reference
kWh	=	kilowatt hour
kWel	=	kilowatt electric
kWhel	=	kilowatt hour electric
kWth	=	kilowatt thermal
kWhth	=	kilowatt hour thermal
MW	=	megawatt
m^3n	=	normal cu meter
1 feddan	=	0.42 ha
1 ha	=	2.38 feddan

Conversion Factors used: (1)

Energy Source	TOE/ton
Wood	0.43
Charcoal	0.72
Agricultural residues	0.20
Animal wastes	0.25

1 LS	=	1,85.--DM
1 DM	=	0.76 LS
1 US-$	=	2,50.--DM

1 gal imp. of gasoline	=	LS 3.500
1 gal imp. of diesel	=	LS 1.750
1 bag of charcoal (40kg)	=	LS 8.000 at Khartoum

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(3) Current Agricultural Statistics, CAS Vol. I, No. 3, Statistics Section, Department of Agricultural Economics, June 1979.

(4) First Estimations of Areas and Yields of Main Crops for 1982/83 in Comparison with 1981/82, Khartoum 15.11.1982 (arabic)

(5) Sudan Guide, Planning and Management Consultancy, Khartoum 1981

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(7) Sudan National Energy Assessment, Executive Summary, Ministry of Energy and Mining, National Energy Administration Khartoum, October 1982

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(12) The Use of Cotton Stalks for Industrial Purposes, by El Hilu Omer, El Tigani Mohamed El Amin, both Wad Medani, Mohamed Salih A/Rahim, Barakat, 1978/79

(13) Rahad Agricultural Corporation, Annual Agricultural Report Season 1981 / 82

(14) Verwendung überschüssiger Strohabfälle in der BRD, ERNO Raumfahrttechnik GmbH, Bremen 1975

(15) Sudan Gezira Board
Annual Report of Field Crops Economic Surveys
Season: 1980/81
Authors: Abdalls Elamin, Ahmed Elbedawi

(16) Tropical Products Institute of the United Kingdom
Rural Technology Guide 13
The Construction of a transportable charcoal kiln
Author: W.D.J. Whitehead

Literature examined at the Gezira Board archives:

Classification-Nr.	Title
800 - 9	Cost of Production and Yield 1970/71
800 - 10	Crop Cutting and Cost of Production Wheat, Groundnut, Durrah 1968/1969
200 - 75	A report on pulling of cotton stalks
200 - 94	An evaluation of mechanical cotton stalk pulling

Institutes, offices and persons visited or contacted:

1. UNIDO Representation in Khartoum, Sudan - Dr. Harju
   Miss Eimann

2. National Council of Research, Sudan
   Prof. Dr. A.A. El Agib, President
   Dr. Hassan Wardi (Coordinator for the study)
   Dr. Yahia Hassan Hamid
   Miss Igbal Ahmed } Trainees
   Dr. Ahmed Hood }
   Dr. Mohammed Osmann Zahid Ahmed
   Dr. Shommo Shaa El Dien
   Mr. Jayt Jeyasingam (Pulp and paper consultant)

3. National Energy Administration
   Gaafar El Faki Ali, Acting Director

4. University of Khartoum
   Mathew S. Gamser (USAID)
   Prof. Larsen
   Prof. Dr. Yahia Coordinator USAID

5. Barakat Research Station
   Prof. H.E. Omer (Bacteriologist)
   Prof. N. Sharf El Din (Entomologist)
   Prof. Mohammed Bakheit Saad

6. Gezira Board Administration
   Deputy Manager, Abdel Azeim Mohammed Husain
   Director of Agricultural Engineering, Dr. Abdallah Mohammed El Zubeir
   Manager Applied Engineering Dept. Mohammed Mirghani Taha
   Public Relations Manager, Saad Eltaib

7. Rahad Scheme
   Dr. Ahmed Ali Hassan, Director of Agricultural Engineering

8. City of Wad Medani
   Bahaa El Din Beheiri, Mayor

9. Tenants Union of the Gezira Board

10. Youssif El Sadi, Manager El Sanoussi Oil Mill; Abdallah Mahjoub, Manager Taiba Oil Mill } Wad Medani
    Youssif El Sadi
    Manager El Sanoussi Oil Mill
    Abdallah Mahjoub
    Manager Taiba Oil Mill

11. German Technical Cooperation
    Mr. Gerrit F. Ciepluch, Manager
    Dr. Heinz Burgstaller, Plant Protection Project
    Dr. Heinz Räde, Renewable Energy Project

12. Mr. Visser, Euroconsult Office Khartoum

13. Mr. Greiling, Agronomist European Development Fund, Khartoum

14. Mr. Siedler, Commercial Attaché of the F.R.G. Embassy, Khartoum

15. Mr. Avo S. Ismerlian Corporation, Khartoum

16. Beijer Institution , Stockholm
Mr. P.J. Swenningson, Cotton Stalk Project Nicaragua

17. Prof. Dr. H. Schmutterer, Phytopathologist
University of Gießen (F.R.G.)

18. Mr. Rudolf D. Faust, United Nations Expert and Adviser
Mikras Assias 70
Athens 5
Greece

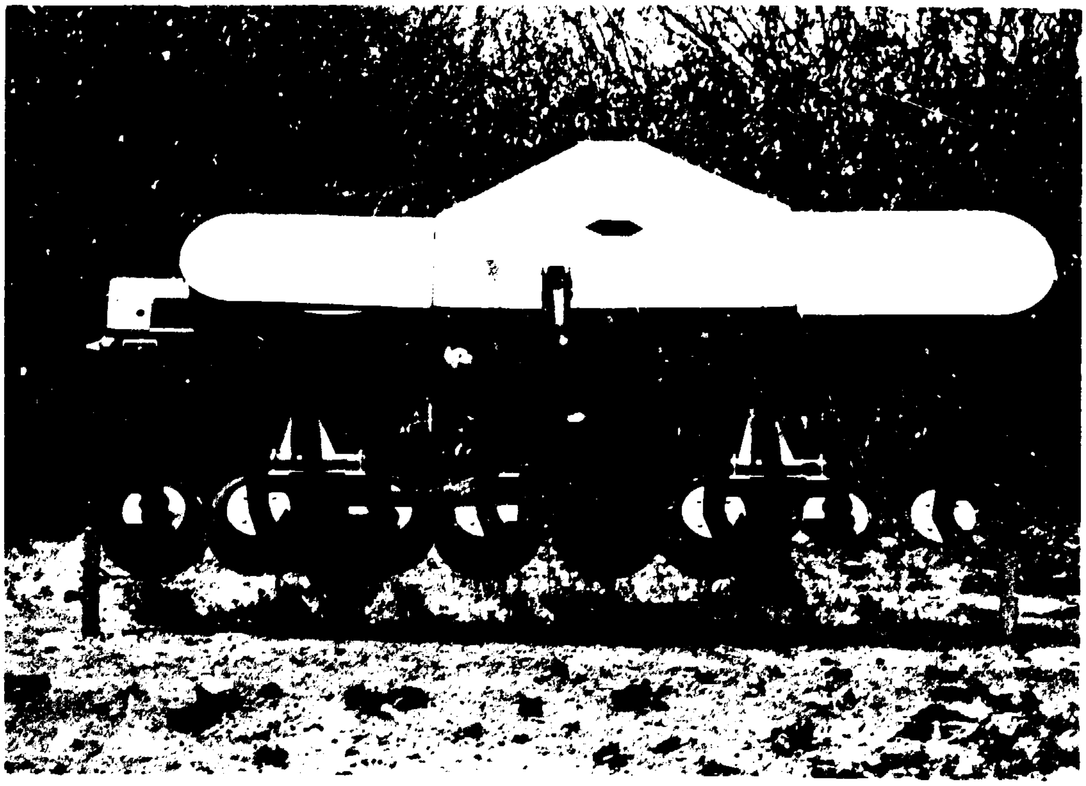
<u>Remarks:</u>

This lists mentions the most important contacts the experts had during the data collection for this report. Many other persons helped to achieve the work. It is the desire of Messrs. Müller, Büchner and Jaster to thank all these persons having supported the team with informations and actions.

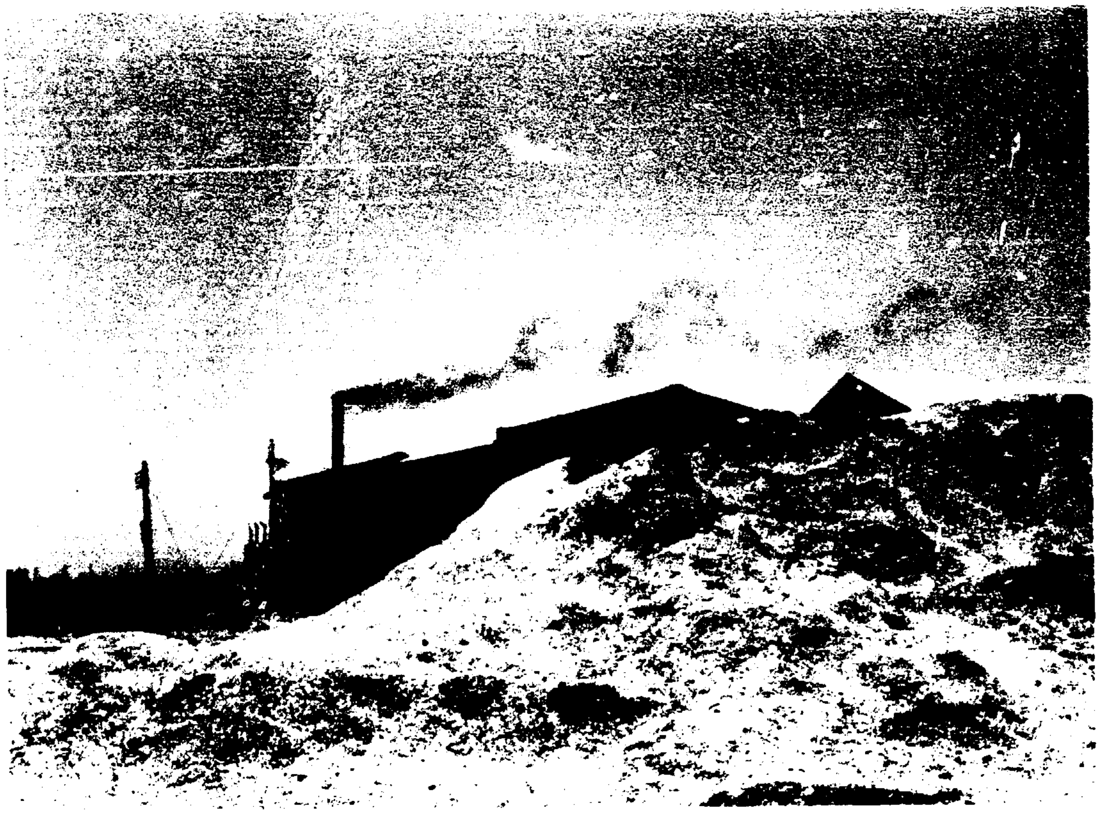
Annex 17.35 - PHOTOGRAPHS -

Cotton stalk pulled by hand after root cutting

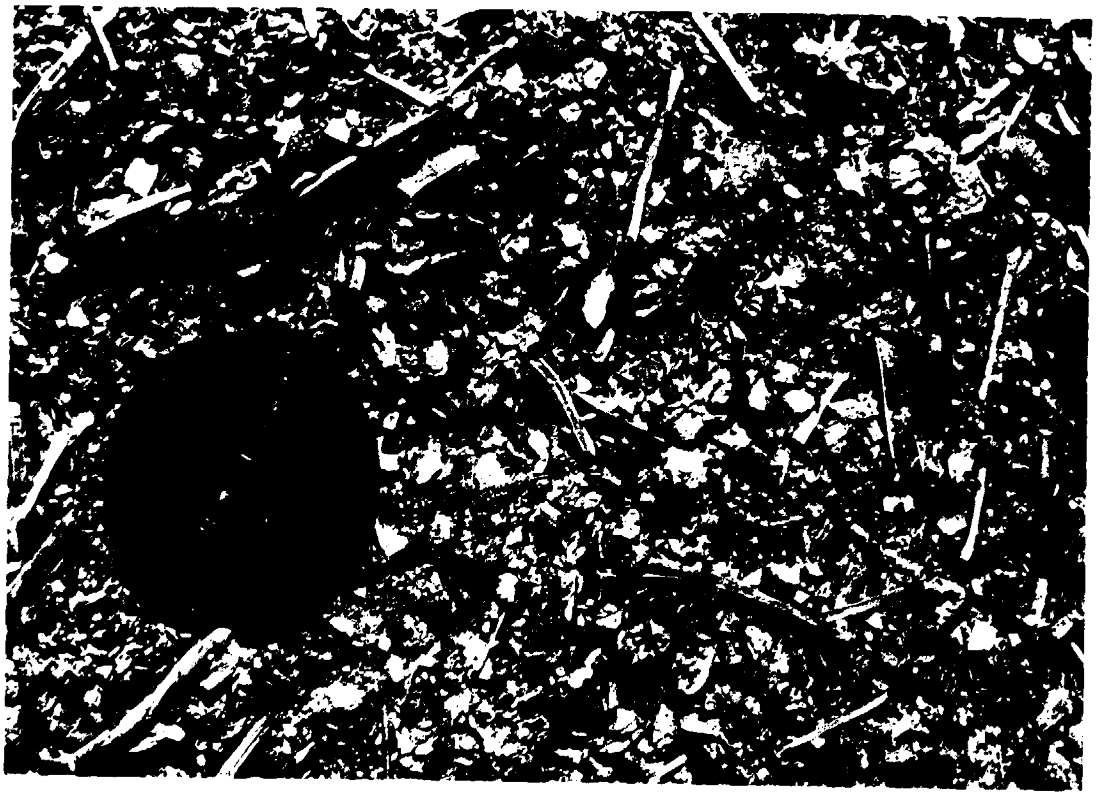
Cotton stalks pulling by hand with the "KAMASHA"



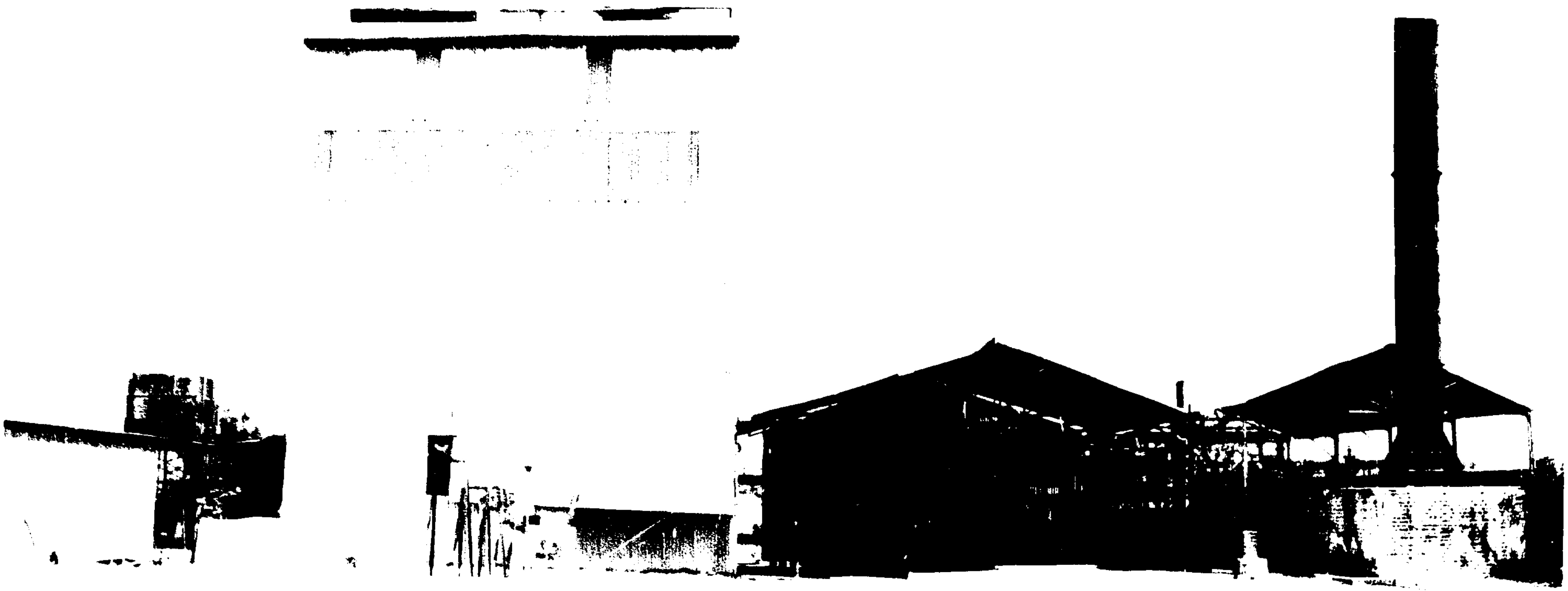
Cotton stalk puller
Prototype developed by the National Institute of Agricultural Engineering in Great-Britain



Oil mill with pile of ground nut shells
Background: Black smoke of shell fired boiler



Ground nut shells

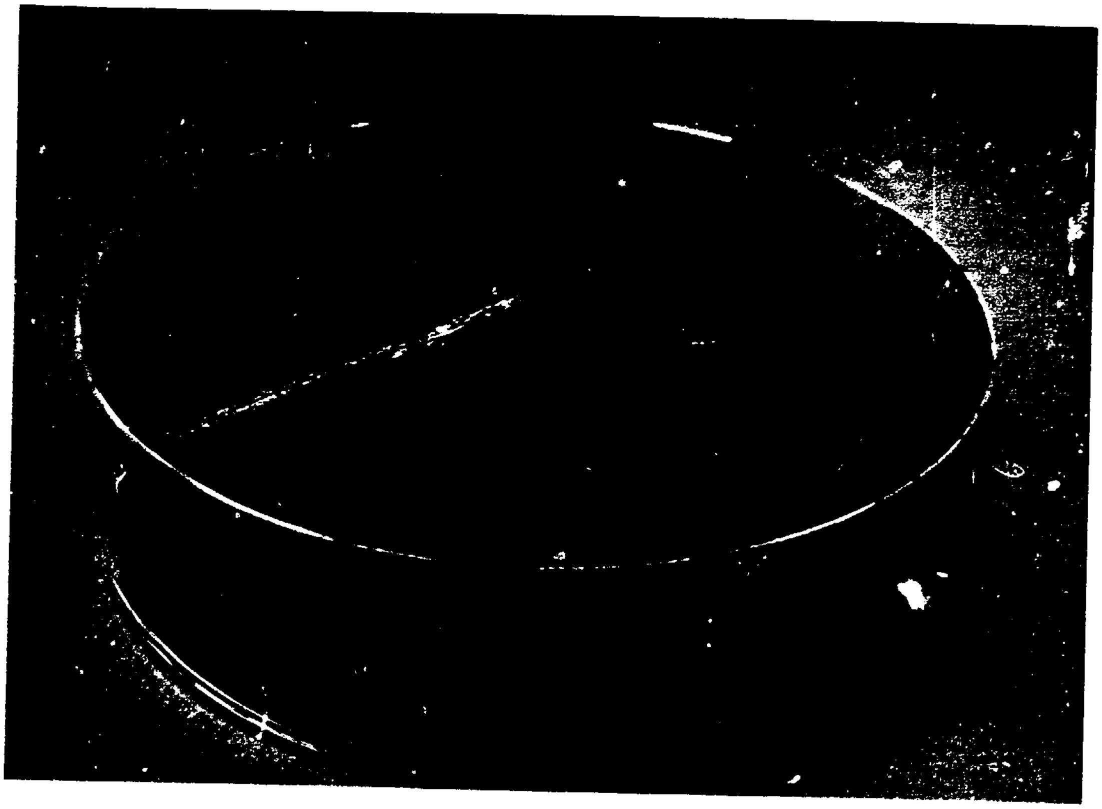


Test station in Barakat erected in the fifties consisting of steam boiler, steam engine and electric generator, chipping and briquetting machine etc.

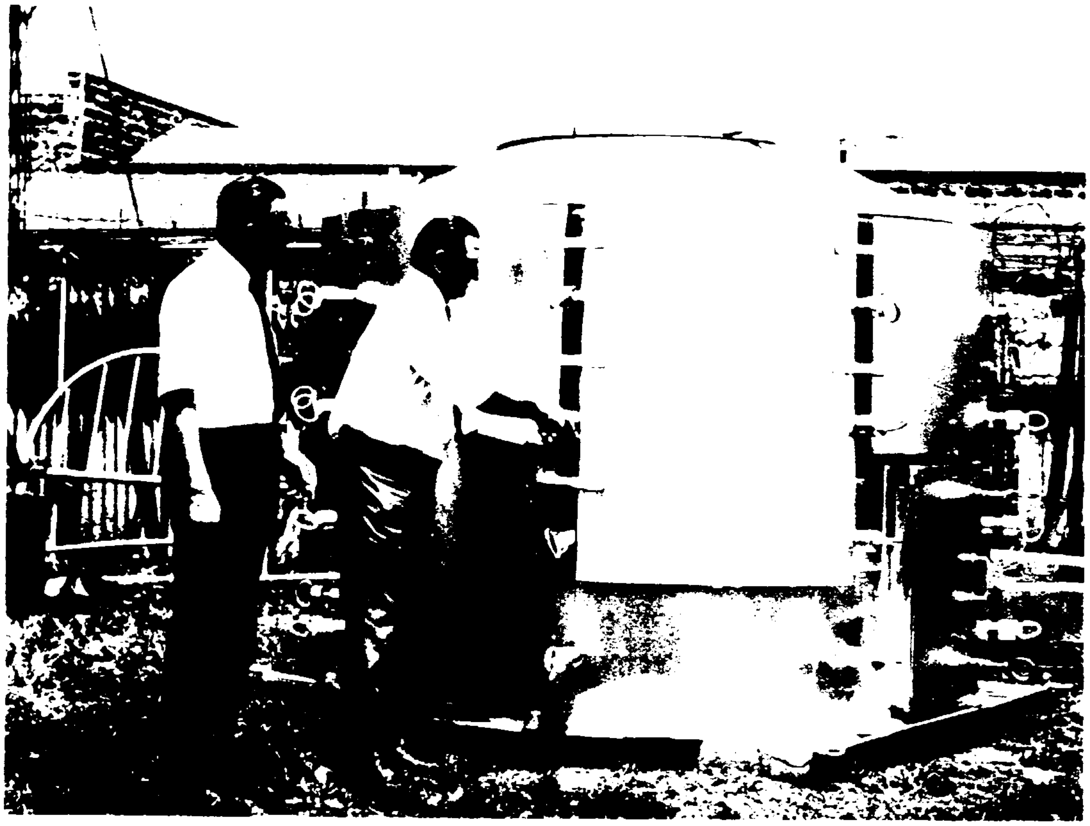
Cotton Stalks prior to crushing and briquetting

Cotton stalks leaving the briquetting press

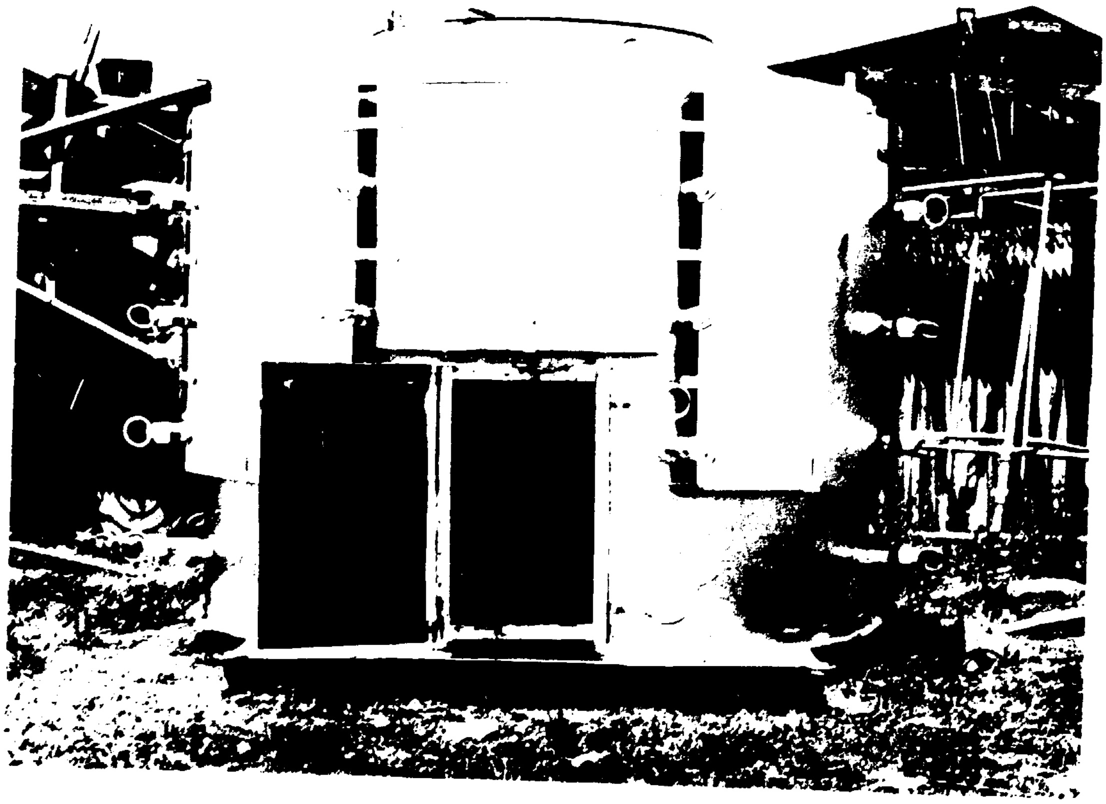
Briquet of cotton stalks with high compaction rate



Charcoal from cotton stalks produced in a laboratory converter



CUSAB Kiln



CUSAB Kiln