BIOMASS BRIQUETTING IN SUDAN:

A FEASIBILITY STUDY

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Executive Summary

Generally, biomass can be defined as renewable organic materials that contains energy in a chemical form that can be converted to fuel. It includes the residues from agricultural operations, food processing, forest residues, municipal solid wastes and energy plantations. The use of biomass residues and wastes (for chemical and energy production) was first seriously investigated during the oil embargo of the 1970s.

In recent years the use of biomass as a source of energy became of great interest world-wide because of its environmental advantages. The use of biomass for energy production, biofuels, has been increasingly proposed as a substitute for fossil fuels. Biomass can also offer an immediate solution for the reduction of the CO2 content in the atmosphere. It has three other main advantages: firstly its availability can be nearly unlimited, secondly it is locally produced and thirdly the fact that it can be used essentially without damage to the environment. In addition to its positive global effect by comparison with other sources of energy, it presents no risk of major accidents, as nuclear and oil energy do.

Due to their heterogeneous nature, biomass materials possess inherently low bulk densities, and thus, it is difficult to efficiently handle large quantities of most feed stocks. Therefore, large expenses are incurred during material handling (transportation, storage, etc.). Very often, of all the factors considered, transportation presents the second highest cost, next to capital recovery. It was also noted that transportation costs of field residues will increase with the increasing size of a conversion facility. In order to combat the negative handling aspects of bulk biomass, densification is often required. The process of compaction of residues into a product of higher bulk density than the original raw material is known as densification or briquetting. Densification has aroused a great deal of interest in developing countries all over the world in recent years as a technique of beneficiation of residues for utilization as energy source.

The advantages and benefits of biomass densification are:

- It improves the handling characteristics, reduces transportation cost, enhances its volumetric calorific value, and produces a uniform, clean, stable fuel, or an input for further refining processes. Although briquetting of biomass does not add to its heat value, briquettes are easier to transport and store. Briquettes are six to ten times denser than loose biomass, burn more efficiently, and create less pollution.
- Normally the bulk density of loose biomass is in the range of 0.05-0.02 g/cm3 and can be densified to briquettes of density 1.1-1.4 g/cm3. Densifying biomass feed stocks improves the process of feeding the fuel into co-fired power plants (e.g. coal). Also, the combustion of dense granulated and uniformly sized biomass can be controlled more precisely than loose, low bulk density biomass and thus reduce emissions.
- Biomass briquetting provides additional income to farmers, creates jobs and possibly rural development - it can serve social and economic functions as well.

Biomass densification represents a set of technologies (ranging from very simple to very complex) for the conversion of biomass residues into a convenient fuel. The technology is also known as briquetting or agglomeration. Depending on the types of equipment used, it could be categorized into five main types:

- Piston press densification

- Screw press densification
- Roll press densification
- Pelletizing
- Low pressure or manual presses

Early introduction of biomass densification in Asia, particularly India and Thailand, was primarily through private sector endeavors. Such ventures showed limited success because of:

- Mismatch of technology, raw material supply and prospective markets,
- Technical difficulties and the lack of knowledge to adapt the technology to suit local conditions,
- Excessive operating costs (mainly electricity and maintenance),
- Lack of focal points for the accumulation and exchange of experiences in briquette production in conjunction with advances in briquetting technology.

Collaboration, coordination, joint research, involvement of the private sector and donor support resulted in overcoming the constraints and barriers. The design and manufacture of briquetting machines appears to have evolved and been adapted to suit local conditions in different countries. India and China take the lead in the manufacture of briquetting equipment, particularly the ram and die technology. It was also realized, at early stages, that briquettes are best suited as an industrial fuel. The marketing constraints were addressed through directing briquettes to industrial and institutional uses as substitute for solid industrial fuels, particularly coal. The use of briquettes in the domestic sector proved unrealistic due to the relatively low price of fuelwood and the need for specially designed stoves for briquettes.

The two common types of briquetting presses employed in Asia are heated-die screw press and piston press. It appears that heated-die screw press technology is preferred in most East and Southeast Asian countries while the piston press is dominant in India. The most common raw materials used in biomass densification in Asia are: sawdust, rice husk, coffee husk, tamarind seeds, tobacco stems, coir pith and spice waste. However, successful endeavors, mainly using heated-die screw, were obtained using sawdust and rice husk. Sawdust is practically the only raw material used for producing briquettes, which are subsequently carbonized; it is the dominant raw material in Malaysia, Philippines, Thailand and Korea. On the other hand rice husk is the only raw material used in Bangladesh.

Apart from Bangladesh and Thailand, the use of biomass briquettes as domestic cooking fuel is rather limited in Asia. The main end use of biomass briquettes, particularly in India, is for industrial applications – industrial process heat generation and institutional kitchens, where the fuel has a competitive price with coal. The government environmental policy – to reduce coal utilization, regulations and incentives are the main deriving vectors for widespread use of biomass briquettes in India. Many biomass briquetting factories are funded through the Clean Development Mechanism, CDM.

In Bangladesh, rice husk briquettes are used as domestic cooking fuel as well as in restaurants. The use of briquettes in humanitarian settings is only reported in Thailand, where the Government banned refugees' access to forests surrounding the camps. The briquetting industry flourished due to contracts for supply of briquettes to refugee camps.

The history of biomass briquetting in Africa dates back to late 1970s and early 1980s, when it was realized that high dependence on fuelwood for domestic consumption was the main contributory factor to deforestation and desertification. Policy decisions were the driving forces behind the push, and biomass briquettes were mainly intended for domestic consumption as substitute for firewood and charcoal. The raw materials most commonly briquetted in Africa are coffee husks and groundnut shells; sawdust and cotton stalks are also used to a limited extent.

Unlike in Asia, the feature of briquetting programs in Africa was largely one of single projects in various countries which have usually not been successful. Unlike India and Thailand, no African country has developed anything resembling a briquetting industry with several plants based upon the same technology. In addition there was and is still no collaboration or coordination in Africa on research and development and other issues pertaining to the development of a briquetting industry.

Although briquetting projects in Africa received high donor funding and policy support, four reasons seem to explain the failure of briquetting projects in Africa:

- Inappropriate or miss-specified expensive machinery was ordered
- Poor planning in re: availability and supply of raw materials – free supply of raw materials was assumed
- The low local prices of firewood and charcoal inhibited the marketing of briquettes
- Poor marketing – there is a clear failure to market the briquettes in the domestic sector. Other existing markets do exists, but were not sufficiently considered
- Little involvement of the private sector
- High expectations, short project life spans and early withdrawal of donor as well as government financial support

In recent years, the introduction of small-scale low pressure briquetting is spreading in Africa, particularly in East Africa. However, the level of production is so low that anticipated impacts are negligible.

In Sudan, biomass briquetting witnessed a boom during 1980s and early 1990s. The domestic sector – the largest consumer of fuelwood - was the targeted end user of biomass briquettes. The main objective was to stem environmental degradation (desertification) caused by deforestation. Briquettes were manufactured using agricultural wastes such cotton stalks, groundnut shells and bagasse. Similar to the situation in other African countries, the fact that briquettes were marketed against low priced fuelwood, raw material availability, finance and management were the main reasons behind failure of biomass briquetting projects in Sudan.

The availability of agricultural residues for briquetting in Sudan looks uncertain, either because the residues have other traditional uses or are inaccessible. Lessons learned from past Sudanese experience with biomass briquetting showed that if an agricultural residue is available, then its collection, transportation and storage constitute the main cost barrier making fuel briquettes uncompetitive with cheap firewood and charcoal.

Forest residues and wild grasses could be potentially generated in Southern Sudan. However, under the present post-conflict situation in Southern Sudan there is no data available or the resource areas are inaccessible. The use of grasses to treat contaminated water in the oil fields is another potential for biomass briquetting. However, further investigation is recommended to assess the available resources, land area devoted to grasses and the intentions of petroleum companies.

The meager forest resources of Darfur, particularly around major cities and towns, are undergoing rapid depletion. The conflict forced over two million rural inhabitants to concentrated

IDP camps located around the major towns, and the demand for firewood increased tremendously. Deforestation in Darfur and particularly around the main towns is a key contributing factor to further degradation of the fragile environment of Darfur. If the current population pressures on meager forest resources continues and energy use patterns do not change, satisfying future demands will pose a major environmental problem, because of the contribution to deforestation, land degradation and erosion.

The potential availability of alternative fuels in terms of agricultural and forest residues are very low in Darfur. Due to war and insecurity, agricultural production has been drastically reduced. In addition, the main residue, millet stalk, has a traditional use as a predominant building material in Darfur.

Mesquite presents a huge potential resource for biomass briquetting in Eastern Sudan. The Mesquite eradication policy concentrates on material uprooting and burning. Mesquite wood is salvaged in terms of firewood and charcoal, while tree branches are burnt to ashes on the fields.

As a natural resource Mesquite could sustainably be managed and economically exploited – via briquetting – while appropriate measures are taken to avoid the invasion of agricultural lands by Mesquite. Briquetting of biomass thus carries tremendous scope and potential in converting Mesquite into a more usable form of fuel.

Seeing the high potential of Mesquite resources in the Red Sea state, and particularly in the Khor Baraka area, its exploitation for briquetting looks attractive. The environmental and economic benefits of Mesquite briquetting are considerable, mainly in terms of rural development. The Khor Baraka area lacks any sort of development. However, the lack of infrastructure (water and electricity) may demand extra investment. In addition, considering the high transportation cost in Sudan, the transport of briquettes over 2,000 km to deliver it to IDP camps in Darfur looks rather impracticable from a financial point of view. Under such circumstances, other alternative fuels, like LPG, look more feasible.

All organizations funding or providing humanitarian assistance to IDP camps in Darfur have concerns and interest in finding an alternative cooking fuel. Some NGOs are presently testing the introduction of LPG in El Fasher IDP camps, while another is sponsoring an alternative fuel study.

Biomass briquettes are not known in Darfur. However, IDPs are susceptible to accepting a switch to an alternative fuel if it suits their cooking habits and preferences. There is no evidence that present models of fuel-efficient stoves (FES) in use in IDP camps will be suitable for burning biomass briquettes. Under such circumstances briquette acceptability tests are highly recommended before embarking on large scale dissemination. The NGOs presently implementing FES programs have accumulated experience in FES dissemination.

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Acronyms

AIT	Asian Institute of Technology
BDT	Bangladesh Currency
CDM	Clean Development Mechanism
CHP	Combined Heat and Power
CPA	Comprehensive peace Agreement
DANIDA	Danish Development Assistance
GDEA	General Directorate for Energy Affairs
DGIS	Dutch Development Cooperation
D-JAM	Darfur Joint Assessment Mission
ERI	Energy Research Institute
FAO	Food and Agriculture Organization of the United Nations
FNC	Forests National Corporation
GOSS	Government of Southern Sudan
GTZ	German Development organization
IDP	Internally Displaced Person
IREDA	Indian Renewable Energy Development Agency Limited
MSW	Municipal Solid Waste
NGO	None Governmental Organization
R&D	Research and Development
SAG	Sustainable Action Group
SDG	Sudanese Pound
SPLA	Sudan people Liberation Army
ToR	Terms of Reference
UNAMID	United Nations African Mission in Darfur
UNEP	United Nations Environment program
UNDP	United Nations Development Program
UNOCHA	United Nations organization for the Coordination of Humanitarian Assistance
UNIDO	United Nations Industrial Development Organization
UNSO	United Nations Sahelian Organization

1. Introduction

During the last four decades Greater Darfur was severely hard hit by repetitive droughts and famines (Fouad Ibrahim). These environmental incidents have caused massive population movements from the north to the south, within the region, and to other parts of the country, mainly central Sudan. At each drought recurrence the population loses almost all its wealth, mainly livestock, and undergoes very difficult and degraded livelihood situations. The population movements engendered some localized conflicts between displaced and hosting communities.

Traditional subsistence agriculture and animal herding are the dominant economic activities of Darfur inhabitants. Food insecurity and fodder shortages result from rainfall fluctuations from year to year, and combine with low agricultural productivity and production. The successive droughts and desertification have created unstable living conditions in the region. In combination with the absence of any development projects, the region is considered among the poorest areas of the Sudan.

The successive droughts have had significant negative impacts on the environment, natural resources and on the population's livelihoods. The phenomenon of desertification is spreading at great speed, moving southwards. People have resorted to using large farming areas in order to maintain subsistence agriculture, while animal herders tended to move further southwards and stay there for longer periods. Also as a consequence of desertification, more and more of the sedentary population migrated to the cities and towns and rural areas in the different parts of the country. Taking into consideration the high population growth rate (3.6%), the hinterland geography of the Darfur region, and lack of infrastructure and social services, huge development efforts are badly needed in order to maintain a decent quality of life, improve livelihoods and put the Darfur region on the first rung of economic development.

The difficult conditions prevailing in the Darfur region noted above prompted the start of the civil war in February 2003, between the Government of Sudan and rebel groups. The war caused massive displacement of rural inhabitants, who have been subjected to severe atrocities and violence. As a result, hundreds of villages have been burned, people killed, and their property (livestock, food, furniture, and farms) looted and damaged. The sedentary rural populations in the three Darfur States, were forced to flee their villages and become internally displaced (over 2 million people in over one hundred IDP camps and over 500,000 people in rural villages and the urban areas) – Figure 1.1. More than 200,000 Darfuris took refuge across the border in Chad. The IDP camps in Darfur are mainly located around the major capital towns and other major towns, namely: El Fashir, El Geneina, Nyala, Kaas, Kutum, Kabkabiya, and Mornay. In general, about one half of the total population, or 3.45 million people (including host communities), have been directly affected by the conflict, through violence, displacement and degraded livelihoods.

A high demand for firewood can lead to environmental degradation in areas that host IDPs, as supplies of dead wood are progressively exhausted and live trees cut in an uncontrolled manner. Cutting trees for fuel often tends to be the most prominent of the environmental impacts associated with IDP/refugee camps and settlements. In areas already suffering from firewood scarcity, the IDPs have to spend significant amounts of time, money, and labour securing meagre amounts of fuel to meet their cooking energy needs. In some instances they may be exposed to physical risk in the process [Darfur Joint Assessment Mission]. Use of energy by IDPs is therefore an important issue to consider from several perspectives, not only environmental, but also social, economic and protection-related.

Sudan has a long experience with refugee camps in Eastern Sudan. The failure to supply or provide for adequate cooking energy for IDPs has resulted in excessive depletion of the forest cover within the camps' environs and even further afield. The impact on the environment and particularly the ecosystem has been very severe. Similar trends are now repeating themselves in Darfur, where nearly over 2 million IDPs are present in camps around the major cities and towns.

It is; therefore, felt that urgent effective interventions are needed, not only to ensure fuel supplies but also to lay the foundation for the rehabilitation of the degraded areas. Several alternative measures are available. The guiding principles are to give communities alternative technologies that are culturally acceptable and/or familiar. The more replicable, appropriate, cost effective, locally available, easy to make, environment friendly and culturally fitting is the technology, the higher its chance of success.

At present several NGOs are presently engaged in disseminating improved woodstoves in Darfur, particularly in IDP camps as part of their humanitarian interventions [UNOCHA-El Fasher, Darfur Fuel Efficient Stoves Working Group]. However, with firewood becoming scarce, women have to search increasingly further away from the camps. This exposes them to a greater risk of harassment, loss of property or even sexual violence. UNAMID patrols (now completely stopped) were not successful in addressing women's protection issues, in part because the distance and travel time for the patrols is so great that most women cannot participate. In addition, due to some accidents, participants lost confidence in UNAMID's effectiveness in protecting them. Furthermore, five years in to the conflict and the presence of the camps, the firewood is now becoming out of reach after constant cutting, pushing access further and further away. It is clear that now more than ever, alternative fuels need to be found. Even with effective patrols, the wood will likely soon be too far away or too scarce to reach in nearly all areas of Darfur.

Densification of agricultural residues and wood waste into fuel briquettes can provide a relatively high-quality alternative source of fuel, especially where fuelwood resources are scarce. Within the above context, USAID and the Women's Refugee Commission requested the consultant to carry out a study (see ToR in Annex I) to evaluate the potential and study the feasibility of the manufacture and use of biomass briquettes in Sudan. The ultimate goal is to consider the delivery of biomass briquettes to Darfur for use as substitute cooking fuel to replace firewood in the IDP camps.

2. Methodology

Goals

The aim of the study is to evaluate and study the feasibility of the manufacture and use of biomass briquettes in Sudan.

Desk Research

To accomplish the goals the consultant undertook desk reviews of biomass briquettes programs previously and currently used in humanitarian, development and emergency contexts worldwide.

Field Visits

The consultant conducted field visits to Southern Sudan (Juba), Eastern Sudan and Darfur. In Juba the consultant had meetings with responsible persons at the Ministry of Agriculture and Forests. In Eastern Sudan the consultant visited Red Sea and Kassala states where he met with concerned NGOs operational in the two states as well as had meetings with Forest National Corporation (FNC) authorities. In Darfur the consultant visited El Fasher, Nyala and Kass. The IDP camps visited were Al Salam and Abu Shauk in El Fasher, Kalma in Nyala and Kass IDP camps. The purpose of the visits was to undertake interviews with Darfur based government officials; UN and NGO staff; IDP camp management officials and other relevant individuals and agencies to evaluate the potential for distribution and large scale use of biomass briquettes in IDP settings in Darfur.

The itinerary of the visits and persons met is presented in Annex II.

Focus Groups

Focus group discussions were organized with groups of women and men in Al Salam, Abu Shauk, Kalma and Kass IDP camps. The groups included women (users of firewood, users of LPG and users of Kerosene), men, and community leaders (Umdas and Sheiks). The discussions were intended to sense the awareness of IDPs about alternative cooking fuels, particularly biomass briquettes; learn of any previous experiences they have had with biomass briquettes; understand their opinions on the use of briquettes, specific cooking preferences, needs and techniques (time, temperature, flexibility, etc.), local staple foods, etc.

Meetings

In addition to the Focus Groups, meetings were held with key partners. In particular, meetings were organized with FNC, the United Nations Food and Agricultural Organization (FAO) and NGOs with fuel-efficient stove (FES) programs in the IDP camps. In Nyala, a three hour meeting was organized by FAO grouping all organizations with environmental concerns, including government, UN and NGO organizations.

3. Literature Review of Biomass Densification Technologies and Projects

3.1. Introduction

In developing countries biomass is the most important source of energy for the three-quarters of the world's population who live in them. In some countries it provides over 90 percent of total energy consumption. The use of biomass is mostly in its traditional forms in inefficient stoves, mainly for meeting domestic energy needs, namely cooking and heating. Fuelwood (firewood and charcoal) supply is based on non-sustainable harvest from forest resources. Heavy reliance on non-sustainable fuelwood with consequent deforestation has lead to cooking fuel scarcity in many developing countries, particularly in Sub-Saharan Africa. Increased deforestation has enhanced desert encroachment and has contributed to environmental degradation witnessed in terms of climate change manifestations.

The energy crisis of the early 1970s and 1980s, and later the climate change phenomenon, have prompted a growing awareness of the detrimental environmental consequences resulting from greenhouse gas emissions, and have consequently reinforced the importance of renewable energy technologies (RETs), particularly biomass, as an energy source in developed and developing countries. Biomass energy is undergoing a revival of interest and new technological advances are showing that it is capable of becoming more efficient and competitive (David Hall). In this context, biomass appears to be an attractive energy resource because it is a domestic and environmentally sound renewable fuel (Ehab Abd El Aziz El Seaidy, 2004).The use of biomass residues and wastes as an energy source can meet the requirement of fostering sustainable development, due to their numerous positive environmental and social impacts, including improvement of degraded lands, creation of employment opportunities and raised living standards for poor communities in developing countries (UNDP-Clean Energy for Development).

Generally, biomass can be defined as renewable organic materials that contain energy in a chemical form that can be converted to fuel. It includes the residues from agricultural operations, food processing, forest residues, municipal solid wastes and energy plantations. The use of biomass residues and wastes (for chemical and energy production) was first seriously investigated during the oil embargo of the 1970s. When oil prices dropped after the embargo, biomass residue lost its competitiveness with fossil fuel (Matsumura et al. 2005).

In recent years the use of biomass as a source of energy became of great interest world-wide because of its environmental advantages. The use of biomass for energy production (biofuels) has been increasingly proposed as a substitute for fossil fuels. Biomass can also offer an immediate solution for the reduction of the CO2 content in the atmosphere. It has three other main advantages: firstly its availability can be nearly unlimited; secondly it is locally produced; and thirdly the fact that it can be used essentially without damage to the environment. In addition to its positive global effect by comparison with other sources of energy, it presents no risk of major accidents, as nuclear and oil energy do (Ehab).

Due to their heterogeneous nature, biomass materials possess inherently low bulk densities, and thus, it is difficult to efficiently handle large quantities of most feed stocks. Therefore, large expenses are incurred during material handling (transportation, storage, etc.). A detailed study by Kumar and co-workers (2003) examined the cost to produce biomass power from direct combustion in western Canada. Of all the factors considered, transportation had the second highest cost (next to capital recovery) when the biomass power plant was at full capacity (year 3). It was also noted that transportation costs will increase with increasing power plant size. In order to combat the negative handling aspects of bulk biomass, densification is often required.

A variety of technologies can convert solid biomass into cleaner, more convenient energy forms such as gases, liquids and electricity. The economic use of biomass residues and wastes implies the development of cost-effective, save, and sustainable feedstock supply technologies. These technologies should address the following inherent characteristics of biomass residues and wastes: (a) low bulk density, (b) variable and often high moisture content, (c) combustibility, (d) affinity to spoilage and infestation (e) geographically dispersed and varied material, (f) seasonal variations in yield and maturity, (g) a short window of opportunity for harvest and demands on labor and machines that often conflict with main crop (grain), and finally (i) local regulations that put limits on store size and transportation loads [Shahab Sokhansanj].

The above uneven and troublesome characteristics of biomass residues could be overcome by means of compaction of the residues into high density and regular shapes. The process of compaction of residues into products of higher bulk density than the original raw material is known as densification. Densification has stimulated a great deal of interest in developing countries all over the world in recent years as a technique of beneficiation of residues for utilization as an energy source (Animesh Dutta). Table 3.1 shows the advantages and disadvantages of biomass densification.

Table 3.1: Advantages and disadvantages of biomass densification process

Advantages	Disadvantages
- The process increases the net calorific value of the material per unit volume - End product is easy to transport and store - The fuel produce is uniform in size and quality - Helps solve the problem of residue disposal - Helps to reduce deforestation by providing a substitute for fuelwood - The process reduce/eliminates the possibility of spontaneous combustion of waste - The process reduces biodegradation of residues	- High investment cost and energy consumption input to the process - Undesirable combustion characteristics often observed e.g., poor ignitability, smoking, etc. - Tendency of briquettes to loosen when exposed to water or even high humidity weather

3.2. Biomass Feed-stocks for Densification

Biomass residues and by products are available in abundance at:

- Agro-processing centers (rice husks, bagasse, molasses, coconut shells, groundnut shells, maize cobs, potato waste, coffee waste)

- Farms (rice straw, cotton stalks, jute sticks)
- Forests (bark, chips, shavings, sawdust, thinning and logging wastes)
- Municipal waste (city refuse, sewage).

Additional sources of biomass are produced from energy crop plantations, where fast growing grass and tree species are specifically grown for energy purposes. In some locations (southern Sudan) where climatic conditions are favorable, wild grasses could be an important source of biomass.

The total volume of residues from agriculture and forestry can be very large as they form a major part of the total crop. Thus rice and wheat crops contain about 1.75 tons of straw per ton of cereal grain whilst the stalks of cotton plants may amount to 3.5 tons per ton of cotton. Maize cobs are about one third of the weight of the maize grain whilst the shells of groundnuts are about half the weight of the nut itself (Soren & Mike Prior – Summary Report).

Based on the above residue production figures, the estimated annual production of rice husk, for example, in India, may be as much as 15 – 20 million tons and in Sudan there are one million tons of cotton stalk and 2.7 million tons of groundnut shells. Such volumes are significant compared with the total fuel use in these countries and suggest that residues could have s significant impact on fuel use. In practice, however, these residue availability figures have proven to be misleading. Only a fraction of reported figures on material availability can be considered as available for fuel briquetting, governed by several factors which will vary from crop to crop and country to country (Soren).

Agricultural residues may have several alternative and traditional uses (animal feed, building material, soil maintenance, energy source, etc.). Such alternative uses might be more valuable than fuel briquetting. For example in Darfur, millet stalk is the predominant thatching material in the rural areas.

Agro-processing residues, for example bagasse and to some extent groundnut shells, may already have a more convenient use as fuel. In the sugar industry bagasse is principally used for generating heat and power. In other circumstances the agricultural residues are important sources of domestic fuel. For example cotton stalk is an important domestic fuel in the rural areas of central Sudan.

Generally field crop residues have an inherent characteristic of being spatially scattered. The production areas may as well be located in remote areas - mechanized farming in Sudan. Under such circumstances the cost of collection and transportation to central processing points may be prohibitive. Forest residues are also classified under this category.

The production of residues is seasonal and depends on multiple factors, like irrigation patterns (irrigated or rain-fed), farming practices/operations, rainfall variation, weather conditions and other agricultural inputs. Generalized production figures for the most common agricultural residues is reported in the literature (Table 3.2) but are only useful for preliminary assessments of potential resource availability. Site specific investigation and field measurements are often of great importance in order to ascertain resource availability and avoid risks. For example failure of rain-fed crops is very common in tropical areas. In Sudan it happened that a briquetting factory based on rain-fed groundnut cultivation remained idle for a complete season due to crop failure.

The volume of residues which are available as a resource for a briquetting project needs to be evaluated, taking into consideration the factors noted above, rather than using global figures based upon crop production statistics.

Table 3.2: Residues to Crop Ratios for some selected crops.

Crop	Residue	Residue production (tones/tone of crop)
Rice	Straw	1.2 – 2.9
Wheat	Straw	1.0 – 1.8
Sorghum	Stalk	0.9 – 4.9
Millet	Stalk	2.0 – 3.7
Barley	Straw	1.1 – 1.8
Oats	Straw	0.9 – 1.8

Based on the above factors, agro-processing residues are more attractive for briquetting due to their inherent concentration at specific locations, which eliminates availability uncertainties and transport costs. On the other hand, farm residues are very often widely scattered on the fields and their beneficiation implies additional costs in terms of harvest, collection and transport.

The seasonal availability and sometimes regulations (in case of cotton stalk in Sudan) make feed-stocks only available during very short periods of time. The raw material has to be collected, transported and stored in order to ensure plant operation for a long period otherwise the business might not be financially feasible. Depending on a specific site's weather conditions, certain feed-stocks may necessitate certain storage conditions in order to avoid degradation or rotting. In conclusion, the raw material or feed-stock for briquette production must be selected carefully.

3.3. Biomass Densification process

The major reason for biomass residue briquetting is in most cases to increase the bulk density of a given material. A more general term for this process is thus densification. Under such a heading, one could include a vast variety of processes, from baling of straw, through a string of processes using increasing pressure and/or binding agents, to the high pressure processes such as piston briquettors and pellet machines. (Soren-Summary)

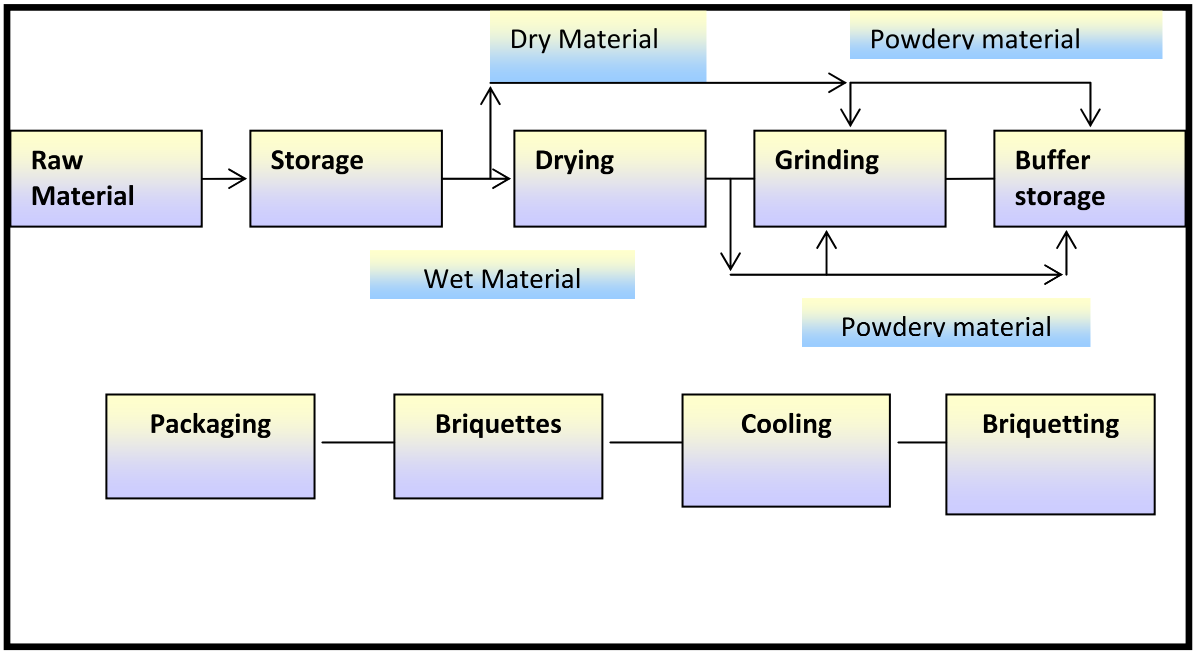
Briquetting is the process of densification of biomass to produce homogeneous, uniformly sized solid pieces of high bulk density which can be conveniently used as a fuel. The densification of the biomass can be achieved by any one of the following methods: (i) Pyrolysed densification using a binder, (ii) Direct densification of biomass using binders and (iii) Binder-less briquetting.

Depending upon the type of biomass, three processes are generally required involving the following steps, Figure 3.1 (Biomass briquettes Tech & practices, Grover):

A. Sieving - Drying - Preheating - Densification - Cooling - Packing
B. Sieving - Crushing - Preheating - Densification - Cooling - Packing
C. Drying - Crushing - Preheating - Densification - Cooling - Packing

When sawdust is used, process A is adopted. Process B is for agro- and mill residues which are normally dry. These materials are coffee husk, rice husk, groundnut shells etc. Process C is for materials like bagasse, coir pith (which needs sieving), mustard and other cereal stalks.

Figure 3.1: Flow diagram of briquette production process



3.4. Biomass Densification/Briquetting Technologies

The production of a compacted solid out of loose granular material on an industrial scale is a nineteenth century technique first used to make a solid fuel out of peat. It has since become a widespread technology in many fields, for example animal feedstuffs, fertilizers and iron-making. Fuel briquetting of peat and, particularly, brown coal is still practiced on a large scale (Soren-Summary).

The application of briquetting to biomass residues from agriculture or forestry is of later origin, being used on a widespread scale in USA during the depression, 1930s, and in central European countries suffering from fuel shortages during the Second World War. The briquetting of wood wastes using screw presses was pioneered in the late 1940s in Japan as a wood substitute. In the era of cheap oil in the 1950s and 1960s, biomass fuel briquetting was little used but it revived again after 1974 when there was a general search for alternative fuels for oil (Soren- Summary).

Historically, biomass briquetting technology has been developed in two distinct directions. Europe and the United States have pursued and perfected the reciprocating ram/piston press while Japan has independently invented and developed the screw press technology. Although both technologies have their merits and demerits, it is universally accepted that the screw pressed briquettes are far superior to the ram pressed solid briquettes in terms of their storability and combustibility. Japanese machines are now being manufactured in Europe under licensing agreement but no information has been reported about the manufacturing of European machines in Japan.

Worldwide, both technologies are being used for briquetting of sawdust and locally available agro-residues. Although the importance of biomass briquettes as a substitute fuel for wood, coal and lignite is well recognized, the numerous failures of briquetting machines in almost all developing countries have inhibited their extensive exploitation. (Biomass briquetting technology and practices)

Biomass densification represents a set of technologies for the conversion of biomass residues into a convenient fuel. The technology is also known as briquetting or agglomeration. Based on operating conditions it could be classified into two categories:

- Hot and high pressure densification
- Cold and low pressure densification

Based on mode of operation it falls into two categories:

- Batch densification
- Continuous densification

Depending on the types of equipment used, it could be categorized into five main types:

- Piston press densification
- Screw press densification
- Roll press densification
- Pelletizing
- Low pressure or manual presses

On the basis of compaction pressure, the densification technologies can be divided into (FAO, Field document No. 46):

- High pressure compaction
- Medium pressure compaction with a heating device
- Low pressure compaction with a binder

High compaction technology or binder less technology consists of the piston press, the screw press and pelletizing. The relative merits and demerits of each technology are briefly described below.

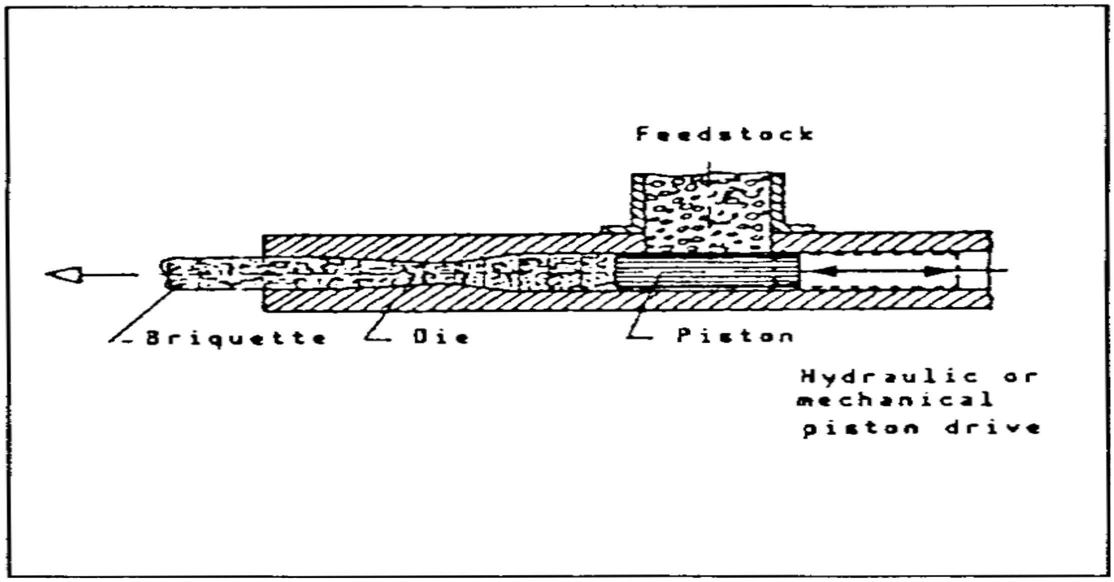
In all these compaction techniques, solid particles are the starting point. The first two techniques use raw biomass materials, while the last two techniques could be used for both raw and carbonized biomass materials. Low pressure compaction includes manually operated briquetting presses of different types, like Nichant and Legacy.

Depending on the type of equipment used, densified biomass can be categorized into two main types: briquettes and pellets. Briquettes are of relatively large sizes, typically 5 - 6 cm in diameter and 30 - 40 cm in length. Pellets are small in size, about 1 cm in diameter and 2 cm in length. Because of small and uniform size, pellets are particularly suitable for automatic auger-fed combustion systems.

3.4.1. Piston Presses

There are two types of piston press, Figure 3.2, the die and punch technology; and 2) hydraulic press.

Figure 3.2: principle of piston press



In the die and punch technology, which is also known as ram and die technology, biomass is punched into a die by a reciprocating ram with a very high pressure thereby compressing the mass to obtain a compacted product. The standard size of the briquette produced using this machine is 60 mm, diameter. The power required by a machine of capacity 700 kg/hr is 25 kW. The ram moves approximately 270 times per minute in this process. The main merits and demerits of this technology are:

- There is less relative motion between the ram and the biomass and hence the wear of the ram is considerably less. However, wear and tear of the die is greater
- It is the most cost-effective technology currently offered by the Indian market
- Some operational experience has now been gained using these machines
- The moisture content in the raw material should be less than 12% for best results using this machine
- The quality of the briquettes goes down with an increase in production for the same power
- Carbonization of the outer layer is not possible. Briquettes produced are somewhat brittle
- Piston blockage and wear and tear are the common problems

The hydraulic press process consists of first compacting the biomass in the vertical direction and then again in the horizontal direction. The standard briquette weight is 5 kg and its dimensions are: 450 mm x 160 mm x 80 mm. The power required is 37 kW for 1800 kg/h of briquetting. This technology can accept raw material with moisture content up to 22%. The process of oil hydraulics allows a speed of 7 cycles/minute (cpm) against 270 cpm for the die and punch process. The slowness of operation helps to reduce the wear rate of the parts.

Further, the relative movement of the material within the die is only for a limited length. The wear and tear of the machine will be lower than those currently available machines in the Indian market. The merits/demerits of this technology are as follows:

- This technology can be used to compress any type of agro waste
- Raw material with moisture content up to 22% can be briquetted
- The power consumption is less compared to existing contemporary technologies
- The output of the machine is uniform
- The wear and tear of equipment will be less
- The cost of the machine is high

The ram and die densification technique helped developing countries and has been adapted all over the world due to its advantages. Briquettes have high specific density (1200 Kg/m3) and bulk density (800 Kg/m3) compared to 60 to 180 Kg/m3 of loose biomass. Compared to fire wood or loose biomass, briquettes give much higher boiler efficiency because of low moisture and higher density. In India the briquetting machine capacity ranges from 500-2000 kg/hr.

Piston presses work best with dry (15% moisture content maximum) cellulose material which is fed into a compression chamber. A reciprocating piston then forces the material through a tapered die to form a long briquette. Typically flywheel drive machines produce between 300 and 500kg of briquettes per hour while hydraulic machines can produce up to 2000kg/hour.

While it may be possible to achieve the claimed service lives of between 500 and 1000 hours using relatively clean material such as sawdust, use of agricultural wastes containing high levels of silica (sand) will reduce operating hours considerably. The initial cost of this type of machine is high and the briquettes are prone to breaking. (Andrew Russel-BP)

3.4.2. Screw Presses

There are basically two types of screw presses:
- Conical Screw press
- Screw press with heated die

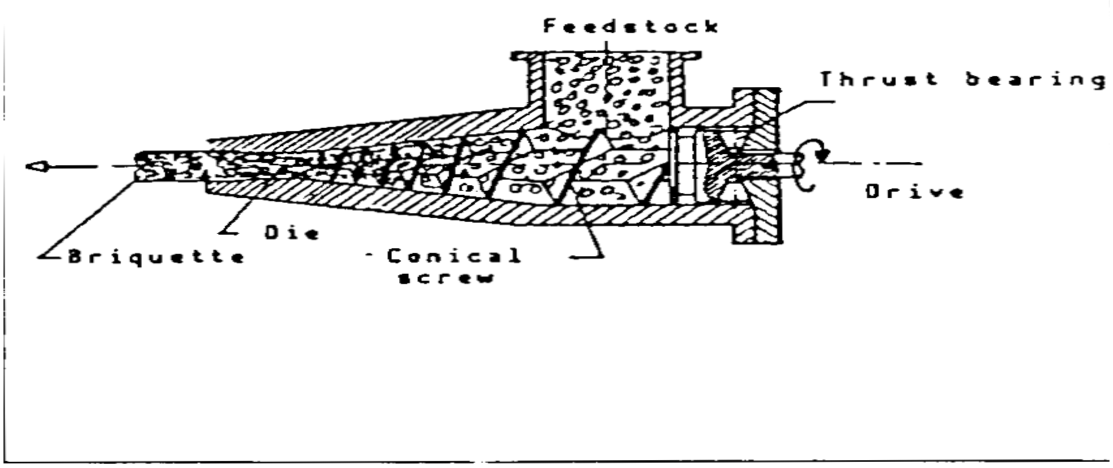
The compaction ratio of screw presses ranges from 2.5:1 to 6:1 or even more (Reed et al. 1978 quoted in Moral 1999, p.369). In this process, Figure 3.3, the biomass is extruded continuously by one or more screws through a taper die which is heated externally to reduce the friction. Here also, due to the application of high pressures, the temperature rises fluidizing the lignin present in the biomass which acts as a binder. The outer surface of the briquettes obtained through this process is carbonized and has a hole in the centre which promotes better combustion. Standard size of the briquette is 60 mm diameter. The main merits and demerits of this technology are shown in Table 3.3.

Table 3.3: Merits and demerits of screw press

Merits	Demerits
- The output from the machine is continuous and not in strokes, and is also uniform in size. - The bulk density is higher (1500	- The power consumed by this equipment is high compared to the piston press. - The wear rate of the screw is very

kg/m³ against 1200 kg/m³ for the die and punch technology). - The outer surface of the briquette is carbonized facilitating easy ignition and combustion and also provides an impervious layer for protection against moisture ingress. - The central core of the briquette is hollow which provides a passage for supplying the air necessary for combustion. - The machine runs very smoothly with no shock loads. - The machine is very light due to the absence of reciprocating parts and flywheel. - There is no alternate suction and pressurization of machine thereby reducing the possibility of dust collection in the machine.	high. - There is a limitation on the raw material that can be compacted.

Figure 3.3: principle of screw extruder/press



3.4.3. Comparison between Screw and Piston presses

Table 3.4 shows a technical comparison between the piston and screw presses, which are the biomass densification technologies widely in use worldwide. In the piston press the wear of the contact parts e.g., the ram and die is less compared to the wear of the screw and die in a screw extruder press. The power consumption in the former is less than that of the latter. But in terms of briquette quality and production procedure the screw press is definitely superior to the piston press technology. The central hole incorporated into the briquettes produced by a screw extruder helps to achieve uniform and effiicent combustion and, also, these briquettes can be carbonized. The main problem with a screw feeder is that its form and pitch is designed to suit a particular particle size, so if this alters the screw is susceptible to jam.

Table 3.4: Comparison between screw extruder and piston press

	Piston press	Screw extruder
Optimum moisture content of raw material	10 – 15%	8 – 9 %
Wear of contact parts	Low in case of ram and die	High in case of screw
Output from the machine	In strokes	Continuous
Power consumption	50 kwh/tonne	60 kwh/tonne
Density of briquette	1 – 1.2 gm/cm³	1 – 1.4 gm/cm³
Maintenance	High	Low
Combustion performance of briquettes	Inclined to crumble on grate, smoky	Burns well with minimum smoke
Carbonization to charcoal	Not possible	Possible
Suitability in gasifiers	Not suitable	Suitable
Homogeneity of briquettes	Non-homogeneous	Homogeneous
Particle size	Variable	Particular particle size
Cost	High	Less than piston press

Source: P.D. Grover, S.K. Mishra and J.S. Clancy, Development of an appropriate bio briquette

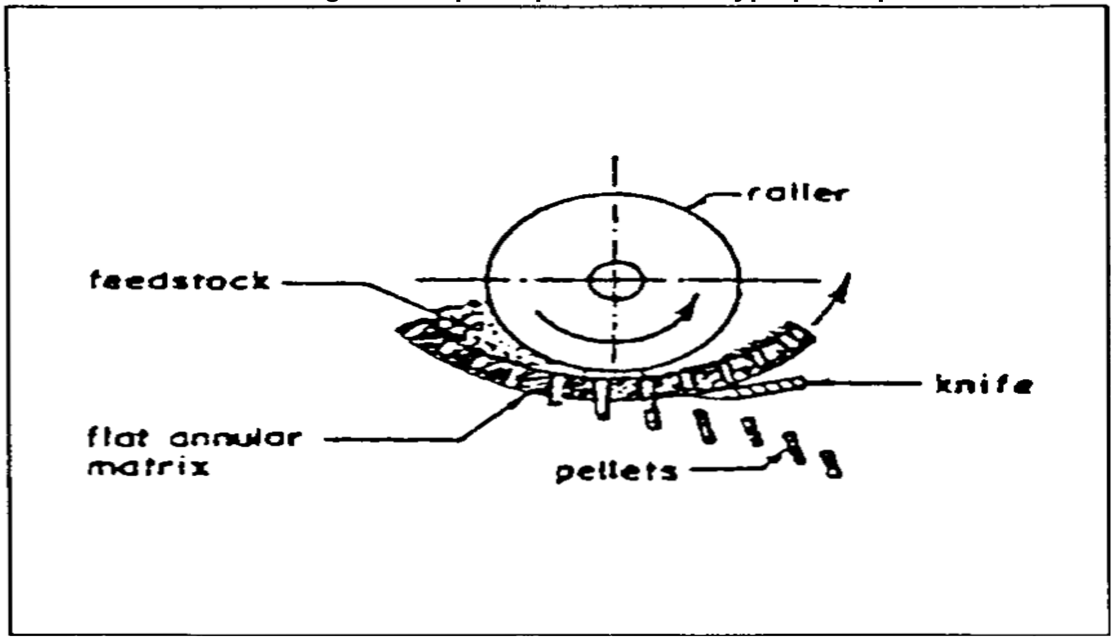
3.4.4. Pelletizing

Pelletizing is closely related to briquetting except that it uses smaller dies (approximately 30 mm) so that the smaller products are called pellets. The pelletizer has a number of dies arranged as holes bored on a thick steel disk or ring and the material is forced into the dies by means of two or three rollers. The two main types of pellet presses are: flat/disk and ring types. Other types of pelletizing machines include the Punch press and the Cog-Wheel pelletizer. (Dutta)

The flat die type (Figure 3.4) features a circular perforated disk on which two or more rollers rotate. The ring die press features a rotating perforated ring on which rollers press onto the inner perimeter. Large capacity pelletizers are available in the range of 200 kg/h to 30 ton/h thus; pellets press capacity is not restricted by density of the raw material as in the case of piston or screw presses. Power consumption falls within the range of 15 – 40 kWh/ton.

Pelletizers produce cylindrical briquettes between 5mm and 30mm in diameter and of variable length. They have good mechanical strength and combustion characteristics. Pellets are suitable as a fuel for industrial applications where automatic feeding is required. Typically pelletizers can produce up to 1000 kg of pellets per hour but initially require high capital investment and have high energy input requirements.

Figure 3.4: principle of flat die type pellet press

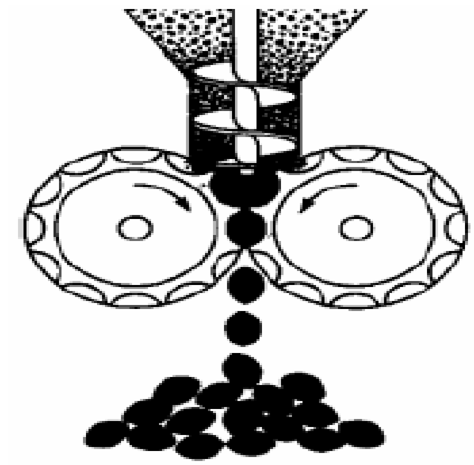


The pellet machines are highly regarded in Europe and North America because they require the least amount of input power per Kg of briquette output. They have high capacity and can produce up to 8 tons per hour. These machines have highly engineered ring dies and rollers that require specialized machines for re-surfacing when they have worn out. The briquette diameters are smaller than for the piston press which would change the way the briquettes burn. (Rwanda Feasibility study-ITC).

3.4.5. Roller Press

In a briquetting roller press, the feedstock falls in between two rollers, Figure 3.5, rotating in opposite directions and is compacted into pillow-shaped briquettes. Briquetting biomass usually requires a binder. Very often this type of machine is used for briquetting carbonized biomass to produce charcoal briquettes.

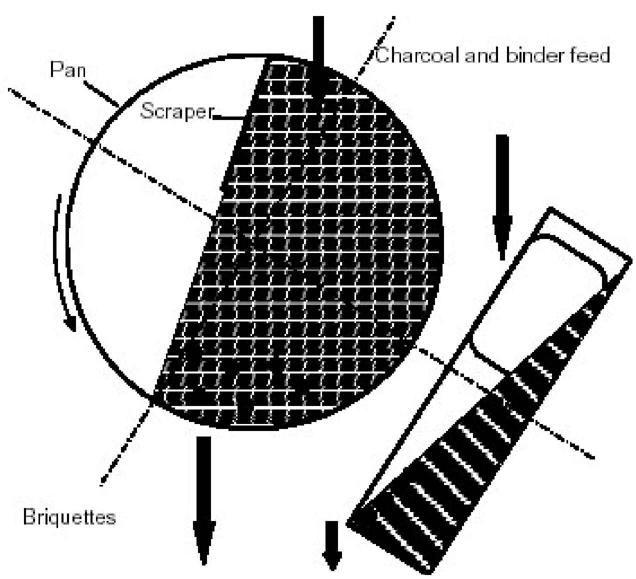
Figure 3.5: Principle scheme of roll press with a force feeder (screw)



3.4.6. Agglomeration

Agglomeration is a well known technology used by the fodder, pharmaceutical and metallurgical industries. It is mainly composed of a rotating pan/drum, Figure 3.6, into which feedstock powder and a binder is continuously fed. The generated centrifugal force and the binder work together to produce spherically shaped briquettes. The main biomass raw material used for agglomeration is charcoal powder**.**

Figure 3.6: principle of drum agglomerator



3.4.7. Manual Presses and Low pressure Briquetting

There are different types of manual presses used for briquetting biomass feed stocks. They are specifically designed for the purpose or adapted from existing implements used for other purposes. Manual clay brick making presses are a good example. They are used both for raw biomass feedstock or charcoal. The use of a binder is imperative. Figures 3.7 to 3.11 show typical examples of manual presses in use in different countries. The common inherent characteristics of manual presses are: very cheap implement/equipment; low production capacity; demand intensive labor; and use of binders. The raw material is basically partially decomposed plant and old newspaper, or namely "throw away materials" (Briquette press, Legacy).

The main advantages of low-pressure briquetting are low capital costs, low operating costs and low levels of skill required to operate the technology.

Low-pressure techniques are particularly suitable for briquetting green plant waste such as coir or bagasse (sugar-cane residue). The wet material is shaped under low pressure in simple block presses or extrusion presses. The resulting briquette has a higher density than the original material but still requires drying before it can be used, as shown in Figure 4.10. The dried briquette has little mechanical strength and crumbles easily.

Binders can be added to this process to improve mechanical strength and also allow dry materials to be briquetted. Binders such as molasses and vegetable starch (from maize, cassava etc.) add to the calorific value of the briquette. Materials such as clay, ash and cement can be used as a binder but they inhibit combustion, producing more ash and smoke.

Many different materials can be used for briquette making, for example agricultural residues like ground nut shells, straw, tree leaves, grass, rice and maize husks and banana leaves. It is also possible to use already processed materials such as paper, saw dust and charcoal fines. Although some materials burn better than others, the selection of raw material is usually most dependent on what is easily available in the surrounding areas of where the briquettes are made. Of course a briquette can consist of a blend between many different raw materials. (Biomass briquettes in Malawi)

The inflammability is not the only thing that matters when the raw material is being selected. Another important characteristic is its ability to bond together when compressed. For these reasons fiber-rich materials are good. When these materials are soaked in water and partly decomposed, the fibers in the material are able to create strong bonds. The calorific value of a basic paper/sawdust briquette will be around 15 MJ/kg. This value will of course differ depending on the selection of raw materials. It can be compared to firewood that is around 16 MJ/kg (dependent on moisture content) and charcoal around 30 MJ/kg (CEEDS). These values should not be confused with the energy gained from the briquette when burned in different stoves.

Figure 3.7: Briquetting mould for production of Beehive briquette

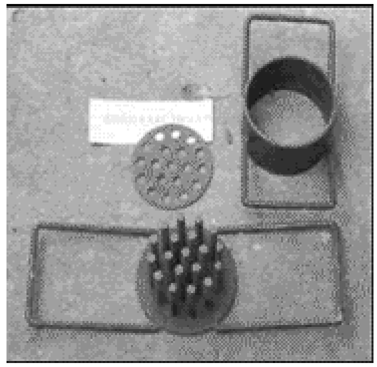


Figure 3.8: pedal press

Figure 3.9: Manual for brick shaped briquettes

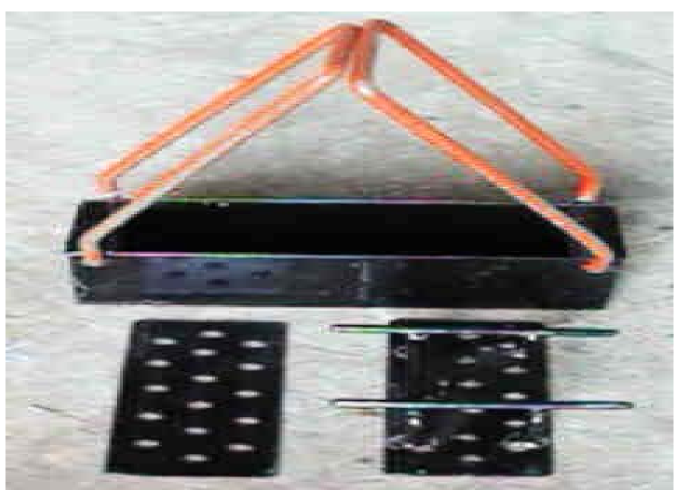


Figure 3.10: Legacy press

Figure 3.11: Manually biomass briquettes

3.4.8. Energy Required for Biomass Densification

Energy is needed to transform waste materials into a handy fuel. The amount and type of energy used has a large impact on the economic viability of the technology. Present technologies have caused many people to preconceive the idea that densification costs more energy than it produces. Although this is a misconception, it calls for consideration. At present a Taiwanese screw extruder will consume 13 kWh of electricity in producing 100 kg of sawdust briquettes per hour. This implies a ratio between input and output of 3% (1 kg of briquette = 15 MJ). When accounting for end use efficiencies this ratio increases to 9%. (Efficiency for electric cooking = 90%, cooking on briquettes = 30%). Although these figures appear acceptable, the need for improvement of excessive energy consumption was mentioned by all entrepreneurs in Thailand. Energy makes up a considerable part (25%) of the cost price of briquettes in Thailand. (A4. Energy Consumption Twente)

Energy input constitutes a sizable fraction of densified biomass production cost. Biomass densification systems require energy for the two main processes normally involved: a) fuel preparation, i.e., drying and size reduction (for example, rice husk obtained from the mills can be normally densified without drying and needs no size reduction. On the other hand, if the raw material needs both size reduction and drying, the amount of energy needed for fuel preparation may be significant); and b) the densification process itself. Table 3.5 shows a comparison of energy consumption by different briquetting presses using different feedstocks.

Table 3.5: Comparison of energy consumption (kWh/ton) of Conical Screw, Heated Die Cylindrical Screw, Pelletizing and Piston Presses

	Conical Screw Press	**Heated Die Screw Press**	**Pelletizing press**	**Piston press**
Values given by manufacturers	45 – 55 (1)	60	10 - 25	35 - 150
		12 - 29	175	10
			30 - 50	19 - 33
			10 - 60	21 -38
				63 – 100
				65 – 90
				50 – 70
				45 – 60
				50
		100 – 200 (1)		
Actual values		110 – 170 (3)	300 (1)	53 (3)
	84 – 128 (1)	150 – 220 (2)	37 (3)	80 (2)

Source: Dutta
Note: (1) Wood materials; (2) Agricultural residues; (3) Agro-industrial residues

3.4.9. Factors Affecting Densification

The properties of the biomass materials that are important to densification process are (FAO 46, Dutta):

- Flow ability and cohesiveness (lubricants and binders can impart these characteristics for compaction)
- Particle size (too fine a particle means higher cohesion, causing poor flow)
- Surface forces (important to agglomeration for strength)
- Adhesiveness
- Hardness (too hard a particle leads to difficulties in agglomeration)
- Particle size distribution (sufficient fines needed to cement larger particles together for a stronger unit)

Other factors that greatly influence the densification process and determine briquette quality are:

Temperature and pressure

- It was found that the compression strength of densified biomass depended on the temperature at which densification was carried out
- Maximum strength was achieved at a temperature around 220°C
- It was also found that at a given applied pressure, higher density of the product was obtained at higher temperature

- It is reported that for pellets produced in a laboratory scale device in the temperature range 130°C to 170°C, both strength and moisture stability increase with increasing press temperature

Moisture Content:

- Moisture content has an important role to play as it facilitates heat transfer.
- Too high moisture causes steam formation and could result into an explosion.
- Suitable moisture content could be of 8-12%

Drying:

- Depends on factors like initial moisture content, particle size, types of densifier, throughput

Particle Size and Size reduction:

- The finer the particle size, the easier is the compaction process
- Fine particles give a larger surface area for bonding
- It should be less that 25% of the densified product
- Could be done by means of a hammer mill
- Wood or straw may require chopping before hammer mill.

Although biomass densification technology is well developed, biomass residue preparation and densification equipment are very sensitive to the specific characteristics of raw materials. The physical and chemical properties of biomass feed-stocks vary greatly, even for the same material originating from different sites. Advanced study of the raw material characteristics is crucial for the proper design of process equipment. The failure of several briquetting projects (either technically or financially) in developing countries during 1980s was mainly due to mismatching equipment to suit the specific characteristics of raw materials.

For example, bagasse has proven to be an excellent feed-stock for briquettes. However, it has to be dried to remove most of the 50 – 60% moisture it contains when it leaves the sugar mill. Moisture levels of 15 – 20% are needed for briquette production. Because of this drawback it is still unclear whether or not bagasse briquettes have any economic potential. (Biomass as a Fuel in developing countries)

4. Review of Biomass Briquetting Programs

In the late 1970s and early 1980s densification aroused a great deal of interest worldwide as a technique of beneficiation of residues for utilization as an energy source. As a result, biomass briquetting emerged in developing countries and consequently several projects were initiated by different donors. The diversity of experiences with biomass technologies is described in the following sections on a regional aggregation basis, mainly: Europe and North America; Asia; and Africa. Densified biomass is mostly in the form of briquettes in developing counties and in the form of pellets in developed countries. (Bhattacharya, Power point)

4.1 Biomass Briquetting in Europe and North America

Although biomass densification technology was long developed in Europe and North America, we can only trace late developments when climate change concerns created revival in biomass energy as the best alternative to fossil fuels. In order to meet their obligations towards the Kyoto Protocol, developed countries heavily invested in R&D and enacted policy and regulatory measures encouraging public and private institutions to switch from fossil to biofuels, in particular densified biomass. In a period of ten years, biomass densification emerged as a new industry providing alternative fuels, investment and employment opportunities in Europe and North America.

Densified biomass used in the developed countries appears to be mostly in the form of pellets. Use of biomass pellets for heat applications, particularly space heating, is well established in USA and Europe. (Commercialization, Battacharya). The small, consistent size of pellets lends itself to automatic feeding into domestic and industrial process heat applications.

Densified biomass is acquiring increasing importance because of the growing domestic and industrial applications for heating, combined heat and power (CHP), and electricity generation in many countries. In countries such as Austria, Denmark, the Netherlands and Sweden, for example, it is becoming a major industry with pellets traded internationally. In Austria, the production of pellets in 2002 was 150,000 tons, but with the rapid expansion of small-scale pellets heating systems it is expected to reach 0.9 Mt/year by 2010. Europe-wide this potential has been estimated at around 200 Mt/year, and is increasing continuously because advances in technology allow the densification of biomass to be more competitive, driven by high demand. The demand is for both domestic (space heating) and industrial units in many developed countries but also in many developing countries, particularly China. Thus it is expected that this market will expand rapidly and become an internationally widely traded commodity despite the growing importance of wood chips due to their lower price. (Frank Rosillo-Calle et al –Biomass Assessment Handbook)

ACCENT reported on the level of biomass pellets produced in Europe and North America in 2005, Table 4.1. The spread in popularity of biomass-derived fuels is entirely due to the huge environmental and local economic benefits. These have been made possible by advances in technology and higher fossil fuel prices resulting from increasing levels of taxation on Carbon Emissions.

Table 4.1: Estimated production of pellets by country in 2005, from plants larger than 5,000 t/y

Country	Production (000 ton/year)	Additional information
Sweden	1,365	2 more 130,000 t/y each, 15 producing over 30,000 t/y
Canada	1.000	5 plants over 80,000 t, several plants in the range 200,000 t range
Russia	758	Two 100,000 t plants, seven over 30,000 t/y
USA	600	
Denmark	535	One 280,000 t plant and two over 80,000 t
Finland	460	Six plants over 30,000 t

Austria	409	Four plants over 30,000 t, three in 80,000 – 100,000 range
Germany	388	Six plants over 30,000 t
Poland	356	One 100,000 t plant and three over 30,000 t
Estonia	345	Three plants over 80,000 t
Latvia	340	One 100,000 t plant, and four over 30,000 t
Italy	169	Estimated three over 30,000 t, many small plants
Norway	138	One plant over 30,000 t
Lithuania	110	One 60,000 t plant
UK	110	Two 50,000 t plants
Netherlands	100	One 100,000 t plant
Slovenia	90	Two 40,000 t plants
Spain	70	One 40,000 t plant
France	62	
Switzerland	60	One plant over 35,000 t
Slovakia		

Source: ACCENT

4.2 Biomass Densification in Asia

Bhattacharya (in Biomass energy and densification) reported that two common types of briquetting presses employed in developing countries are heated-die screw press and piston press. It appears that heated-die screw press technology was invented in Japan in mid 1940s. The technology has spread to most of its neighboring and nearby countries, particularly Korea, China, Vietnam, Thailand, Malaysia, Philippines, Bangladesh, etc. where heated-die screw press briquetting machines are used almost exclusively. Also, the design of screw briquetting machines appears to have evolved and been adapted to suit local condition in different countries.

The high demand for charcoal in Japan was mainly behind the transfer of biomass densification technology (screw extruder) to other Asian countries. The starting raw material was basically sawdust. The extruded briquettes are easily carbonized giving a product very similar but of superior quality to lump wood charcoal. High quality produce was essentially export oriented. However, some limited local use of charcoal briquettes was found with the street food venders.

The most common raw materials used in biomass densification in Asia are: sawdust, rice husk, coffee husk, tamarind seeds, tobacco stems, coir pith and spice waste. However, successful endeavors, mainly using heated-die screw were obtained using sawdust and rice husk. Sawdust is practically the only raw material used for producing briquettes, which are subsequently carbonized; it is the dominant raw material in Malaysia, Philippines, Thailand and Korea. On the other hand rice husk is the only raw material used in Bangladesh.

The piston press technology is the dominant biomass briquetting technology in India, where it is locally made. Compared to piston press machines, heated-die screw press machines have smaller capacity but produce stronger and denser briquettes. It was concluded that screw press technology is therefore more suitable if the briquettes are to be carbonized to obtain briquetted charcoal.

Briquettes made from a mixture of pulverized coal, biomass and slaked lime has been introduced by Japanese company in two Asian countries, China and Indonesia. The briquettes, called coal-biomass briquettes are produced by using a roll press. It is claimed that the use of the desulfurized agent (slaked lime) and biomass results in cleaner combustion of the briquettes in stoves and less ash compared with coal or coal briquettes (Battacharya).

Piston press briquetting machines use a wide range of pulverized materials. In India, these include sawdust, groundnut shells, coffee husk, sugar cane bagassse, cotton stalk, sun flower stalks, spent coffee waste etc.

The technology Development Group - University of Twente, reports that early introduction of biomass densification in Asia, particularly India and Thailand, was primarily through private sector endeavors. Such ventures showed limited success because of:

- Mismatch of technology, raw material supply and prospective markets
- Technical difficulties and the lack of knowledge to adapt the technology to suit local conditions
- Excessive operating costs (mainly electricity and maintenance)
- Lack of focal points for the accumulation and exchange of experiences in briquette production in conjunction with advances in briquetting technology.

In order to overcome the above technical drawbacks, two projects were launched in Asia:

- Biomass Densification Research Project, which was jointly implemented by the two named universities and two private sector companies (Solar Sciences Consultancy Pvt. Ltd, and DENSI-TECH)
- Renewable Energy Technologies in Asia: A Regional Research and Dissemination Program, 1997 – 2004.

The first project was sponsored by the Netherlands Development Cooperation and was implemented by two universities (University of Twente – the Netherlands and The Indian Institute of Technology – New Delhi) and two private sector companies (Solar Sciences Consultancy Pvt. Ltd (India), and DENSI-TECH (Grover, the Netherlands).

The project concentrated on local adaptation of a rather high capacity (750 kg/h) screw press machine for the purpose of large scale commercialization. The main reasons identified for the failure of biomass briquetting (both piston and screw presses) was the high power requirement to form stable, high density briquettes. This high pressure amounts to high electrical energy consumption and high wear rate of machine parts. The following results were achieved (Grover – Biomass Briquetting practices):

- Studied the behavior and established standard procedure for the briquetting of each biomass raw material because of changing physico-chemical characteristics of different biomass or even for the same biomass grown under different agro-climatic conditions
- Binder less densified briquetting is possible only at elevated temperatures of 250-300 Cº under high pressure. This high temperature is basically attained by conversion of mechanical friction into heat energy
- Preheating the feed material entails a drop in resistance to briquetting and consequently results in: (a) reduced pressure required for briquetting, resulting in reduction in power consumption; (b) reduced frictional forces leading to a reduction of wear to contact parts,

particularly the rotating screw; and (c) reduced resistance to flow leading to an enhanced rate of production
- Biomass preheating system was designed, experimented and optimized. Flue gas from the heater could use for drying the biomass raw material
- Guidelines for undertaking feasibility study for a commercial scale briquetting system using the above results was produced
- The project induced the interest of financial institutions to provide credit for the biomass densification entrepreneurs.

The second project involved thirteen organizations from six countries (Bangladesh, Cambodia, Lao PDR, Nepal, the Philippines and Vietnam) and three renewable energy technologies, among others: biomass briquetting. The project was sponsored by the Swedish International Development Co-operation Agency (SIDA) and coordinated by the Asian Institute of Technology in Thailand (Bhattacharya, Dissemination of Renewable Energy in Developing Countries: Experiences of a Regional Project in Asia). The program activities included adaptive research, demonstration of biomass briquetting technology, dissemination of outcomes to stakeholders and capacity building. (Bhattacharya, Capacity Building for Renewable Energy Technologies in Selected Developing Countries of Asia)

The project studied the status of biomass briquetting technology in participating countries and concluded that: In heated die screw press briquetting machines, the screw is prone to wear caused by the abrasive behavior of biomass. The wear of the screw results in significant operating costs. This demands regular attention of the plant owner. The high electrical energy consumption by the briquetting process was another area of concern, which limits the widespread use of the technology. (Bhattacharya – Dissemination of renewable energy Technologies)

The objective of research on biomass briquetting was to eliminate or reduce these technical and operational problems, and to adapt the technology to individual countries according to the type and quality of raw materials available locally. The briquetting machine employed in the technology packages of RETs in Asia program are of the single extrusion heated-die screw-press type. Heated-die screw press briquetting was selected as a popular densification method suitable for small-scale operations in developing countries. Table 4.2, shows the technical specification of the machine.

Table 4.2: Technical specification of the heated-die screw press developed by the Regional Energy Technology program

<table>
<tr><th>General Specifications</th><th>Screw</th></tr>
<tr><td rowspan="3">Induction Motor:
20 hp/1450 rpm; 380V / 50 Hz
Screw speed: 320 rpm
Die – heater: Briquette fired metal stove (AIT design)
Production rate: 80 kg/h
Raw material: rice husk
Electricity consumption: 0.13 kwh/kg
Power transmission: Pulleys & V-belts
Main shaft: Bright steel round rod
Machine bed: Mild steel "C" channel</td><td>Total length: 450 mm
Outer diameter: 55 mm
Material: Mild steel round rod</td></tr>
<tr><td>Die</td></tr>
<tr><td>Length: 300 mm
External diameter: 97 mm
Internal diameter: 55 mm
Tapered length: 75 mm
No. of grooves: 8
Material: Cast iron
Weight: 6 kg</td></tr>
</table>

Length: 1600 mm Width: 500 Height: 1165 mm (excluding motor)	Bearings: type N 6312 & N 6311

Source: S. C. Bhattacharya – technology packages

The main outputs of the adaptive research undertaken by the project are:

- The die electric heater (which consumes 25% of electricity consumption during briquetting) is replaced by a biomass stove fired by briquettes. Die temperature is maintained at 300 – 320 Cº.
- Pre-heating biomass before extrusion reduces briquetting energy consumption and also extends the life of the briquetting screw.
- The hot flue gas from the die-heating stove of the briquetting machine is used for pre-heating the raw material (90 – 130 Cº), rice husk. The optimum moisture content for smooth operation of the briquetting machine is 7 – 8%.
- A smoke removal system is incorporated to the system to eliminate or reduce smoke generation during the briquetting process.
- Energy consumption is considerably reduced when other raw materials are mixed with rice husk (rice husk and sawdust, at 1:1 ratio by volume) in comparison with pure rice husk as raw material.
- Development of hard-facing techniques, for the screw, in Bangladesh has improved the performance of heated-die screw press briquetting machine considerably.
- Briquette Gasifier systems were designed and experimented for process heat applications including a domestic-type gasifier stove for cooking needs that burns the briquettes. The later has a heating power of 3.6 kw and a water boiling efficiency of 22%.
- The briquetting machine was designed, tested and demonstrated in each of the program countries

The main objective of the two projects was to address the barriers that impeded the widespread commercialization of biomass densification technology, namely: capacity building, involvement of the private sector, coordination and exchange of experiences.

India

About 70 biomass briquetting machines were installed in India by 1995; since then briquetting has been gaining acceptance slowly but steadily (UK-India). By 2007 the number of briquetting plants increased to 250. As the technology is locally mastered and economically viable, the number is increasing annually.

Two biomass briquetting technologies dominate the Indian market: the ram and die machine and the screw machine. These two machines use different processes to densify sawdust and agricultural waste, and the end products also have different densities and shapes. The two types of machines are locally manufactured. A third kind of press, the hydraulic press has not been used in India and is considered unsuitable for Indian raw materials (Naidu 1995).

The most common raw materials for heated-die screw-press briquetting machines are saw dust and rice husk. Heated-die screw-press briquetting machines are also available commercially; the number of machines of this type installed so far is about 60. One manufacturer offers preheated biomass briquetting systems.

Ram and die briquetting machines use a wide range of pulverized raw materials; in India, these include saw dust, ground nut shell, coffee husk sugar cane bagasse, cotton stalks, sun flower stalks, spent coffee waste etc. Peanut shell and cotton stalk appear to be the most important raw materials in use. The capacity of piston presses normally lies in the range 400 - 2000 kg/hr (Vempathy, 2002); the number of machines of this type installed so far is about 150.

The briquettes produced by a screw press have some advantages over those produced using the ram and die press, such as better combustion due to the centre hole and carbonized outer layer. However, there are some disadvantages of the screw press viz., higher operating power, maintenance costs and low production capacity. Because of these disadvantages, the screw press has not been particularly successful in India.

The potential of biomass briquetting in India was estimated at 61,000 MW, while the estimated employment generation by the industry is about 15.52 million and the farmers earn about $ 6 per ton of farm residues. The end use of briquettes is mainly for replacing coal substitution in industrial process heat applications (steam generation, melting metals, space heating, brick kilns, tea curing, etc) and power generation through gasification of biomass briquettes. Being derived from renewable resources, the briquette has superior qualities as well as environmental benefits in comparison with coal, Table 4.3. The Indian Government promotes the commercialization of the technology through financial assistance. IREDA support for briquetting in the form of loans since its inception till March 2001 was INR 174 million (47 INR ~ I US$). The largest plant financed by IREDA has a capacity of 12.2 tons per hour. With assistance of USAID, three briquetting plants have been set in Rajastyan state of India. These plants use mustard stalk as the raw material and have combined capacity of about 45,000 tons per year; 12-14 briquetting factories with a capacity to produce 200,000 tons per year are being planned (Farm Waste Utilization – Singh**).**

Table 4.3: Comparison Coal and biomass characteristics

Fuel	**Density g/cm³**	**Calorific value Kcal/kg**	**Ash content (%)**
Coal	1.3	3,800 – 5,300	20 - 40
Biomass briquettes from:			
Sawdust	1.1	4,600	0.7
Groundnut shell	1.05	4,750	2.0
Rice husk	1.3	3,700	18.0
Sawdust-cotton stalk	1.12	4,300	8.0

Source (Farm Waste Utilization – Singh)

The use of biomass briquettes for cooking in the household sector is rather limited, in India. On the other hand it has widespread use in institutional kitchens (hotels, canteens and restaurants). Institutional stoves for burning the briquettes were developed and commercialized.

Following the production process, Figure 3.1, the economics of biomass briquetting in India was reported by Dutta, Table 4.4 and 4.5. It is worth to mention that in India commercial biomass briquetting projects are now liable for CDM funding (CDM Project on Briquettes Manufacturing).

Table 4.4: Values of different heads for economic analysis of biomass briquetting factory in India

No.	Head (unit)	Value (Rs)
1	Initial cost of machine	12,000,000
2	Life (yr)	10
3	Annual use time (h)	960
4	Interest on cost (%)	15
5	Depreciation (%)	10
6	Junk value (%)	10
7	Annual repair and maintenance	5% of initial cost of machine
8	Labor required	4
9	Labor rate (Rs/h)	15
10	Average machine capacity (t/h)	1
11	Fuel consumption (kwh)	9
12	Fuel cost (Rs/kwh)	4.68 (commercial charges)
13	Oil and lubricant charges	20% of fuel cost
14	Working capital	12,000,000

Table 4.5: Economic analysis for biomass briquetting factory

Item	Value (Rs)
Fixed costs	429,000
Variable costs	1,298,035.2
TOTAL COST/YEAR	1,727,035.2
Revenue:	
1- Returns from 960 ton of briquettes at Rs 3.0 per kg	2,880, 000
2- Net returns (assuming 5% losses during storage)	2,736,000
3- TOTAL REVENUE per year	2,736,000
4- Total costs incurred per year	1,727,035.2
5- Net profit per year (3 – 4)	1,008,657.2
6- Total initial cost	1,825,000
7- Payback period	6 months

A remarkable achievement of the Indian biomass briquetting industry is the Sanjha Chulha institutional stove, Figure 4.1, developed by Nishant Bioenergy private Limited. It is specially designed to cater for institutional-scale cooking using biomass briquettes (A Burning Concern – India). In 2005, Nishant Bioenergy won a prestigious Ashden Climate Care award for this innovative stove project.

Figure 4.1: An installed Sanjha Chulha stove – the chimney removes smoke from the kitchen

Bangladesh

Rice husk densification technology was introduced in Bangladesh around 1990 by a private entrepreneur. Later the technology was adapted into a few other places. The machines were locally manufactured. The technology appears to have been developed by the local entrepreneurs without any support from the government or donor agencies (Moral et al. (1999). Rice husk is preferred over other raw materials (sawdust, wheat straw, and groundnut shell) for briquetting because it is centrally available and does not require any pretreatment operations (grinding, drying, etc.)

The comprehensive study conducted by M. Ahiduzzman, 2006, revealed that in Bangladesh briquetting technology has found remarkable acceptance over the last few years. Briquetting technology is being commercially developed, and briquettes are recognized as an alternative for fuelwood. Based on rice husk availability in the country (7.0 million tons per year) there is potential for about 15,000 biomass densification machines. At present, over 1000 briquetting machines (900 heated-die screw presses) appear to be operating in the country. The densification technology is a semi-matured technology in Bangladesh and it is located in certain areas of the country.

The level of expansion of biomass densification technology is affected by several factors like raw material availability, performance of the technology available, income generation activities through the technology, socio-economic conditions of the consumer groups, consumption patterns, market channels of the densified biofuel and impact on the environment, etc.

Tea stalls, street food sellers, restaurants (Figure 4.2) and poor households (Figure 4.3), are users of rice husk briquettes in some urban areas of the country. The main reason for this shift is that firewood is becoming scarce and briquettes are smokeless and provide a higher temperature more quickly than coal and/or wood. The households which cannot avail themselves of a gas grid connection are using rice husk briquette fuel.

Figure 4.2: The use of densified rice briquettes in sweetmeat shop

Source: Ahiduzzaman

Figure 4.3: Showing the use of rice husk briquette fuel in household cooking

Source: Ahiduzzaman

In view of the large amounts of husk produced with the Bangladesh rice crop and the expanding use of this material for densification, M. Ahiduzzaman conducted a comprehensive study on the technical, socio-economical and environmental aspects of biomass densification in Mymensingh District. The following Table 4.6 summarizes the outputs of the study.

Table 4.6: Technical, socio-economical and environmental aspects of biomass densification in Bangladesh

Project	**Entrepreneurial rice husk briquetting units**
Location	Mymensingh District, Bangladesh
Traditional Cooking and local staple food	Rice boiling
Raw biomass material	Rice husk
Ownership of briquetting units	Rice mill owners and private entrepreneurs
Total cost of rice briquetting unit (one screw press)	Figure 4.4
Production capacity	80 - 120 kg/hr
Energy Consumption and cost	174.35 Kwh/ton (electric motor + electric heater); 699.0 BDT/ton
	230.76 Kwh/ton (electric motor + kerosene burner for heating); 882.29 BDT/ton
Production cost per kg briquette	Figure 4.4

Payback period	1.52 years
Biomass feedstock and reason for selection	Rice husk production in Bangladesh is about 7 million tons (of which 838,106 is in Mymensingh region in 2004/05 season), growing annually by 2.57% and only used in parboiling in rice mills. Production is well-distributed across the country with Mymensingh region taking the lead. Excess rice husk is estimated at 2.59 million tons/year available for briquetting.
Manufacturing technique & capacity	Heated-die screw press, 75 – 150 kg/h
Product characteristics	Bulk density: 0.83 ton/m³ Apparent density: 1.22 ton/m³ Calorific value: 14.2 – 17.5 MJ/kg, Table 4.7 and Figure 4.5
Employment by the briquetting units	2.4 man-days per ton
Marketing channels and employment	Whole sale and retailers
Production cost	Fixed costs: 185 BDT/ton Running cost: 2102 – 2646 BDT/ton Total production cost: 2250 – 3000 BDT/ton Details of running costs: - 59% Rice husk cost - 31% electricity cost - 2 % Screw cost - 1% Die barrel cost - 1% Die heater cost - 6% Wage, Figure 4.4
Market margin	2.4 – 12.7%, Figure 4.4
Marketing channels	To consumers (71%) and traders (both whole sale and retailers) (29%)
Briquettes end users & share of consumption	13% Households 23% Tea & and street food stalls 64% Restaurants
Stoves for burning the briquettes	- Commercial sector: Improved grate stove, Figure 4.2 - Households: Portable mudstove, Figures 4.2 and 4.3
Product acceptance by end users	Very good (Table 4.8)
Briquettes consumption by end users, Figure ----	1- Households: 2.5 kg/day (lowest) 2- Tea stall: 16 kg/day 3- Street food stall: 12 kg/day 4- Restaurant: 114 kg/day (highest)
Socio-economic impact of briquettes use	1- Time saving: - Household: 11.8 man-day/year - Tea stall: 16.1 man-day/year - Street food: 24.2 man-day/year 2- Employment: 3.73 man-day/ton (Table 4.9)

- One man-day equal eight hours work

The study reported that energy consumption per ton of output briquettes, depending on heating system (electricity or kerosene) varied greatly from one producer to another within the range of 121 – 243 kwh/ton, with an average value of 183 kwh/ton output briquette.

The consumers of densified biofuel reported that on an average 1 kg of densified rice husk briquette could provide same service of 1.63 kg of wood fuel**.**

Table 4.7: Some physical properties of densified rice husk in Bangladesh

Bulk density of raw material (husk), kg/m^3	117.0
Bulk density of densified fuel , kg/m^3	825.4
Apparent density of densified fuel, kg/m^3	1219.0
Bulk compaction ratio	7.01
Nominal length of briquette, cm	60 to 100
Nominal diameter, cm	5.6 to 6
Inner hole diameter, cm	1.8 to 2.4

Table 4.8: Consumers view of the advantage of densified fuel over wood

Benefit of densified fuel over wood	**Number of respondents**			**Percentage (%)**		**Remarks**
	Agree	**Dis-agree**	**No response**	**Agree**	**Dis-agree**	
No smoke	6	15	11	19	47	Densified briquettes give more heat than wood. Other work can be done during cooking because there is less need for constant fire manage-ment after fire has burned for a long time. Densified briquettes are dry whereas; woodfuel is moist
Less smoke than woodfuel	22	3	7	69	9	
Easy to catch fire	24	5	3	75	16	
Cook feels comfortable	24	4	4	75	13	
Easy to use	19	3	10	59	9	
Available	22		10	69	0	
Uniform quality of fuel	21	1	10	66	3	
Reliable during cooking	18	2	12	56	6	
People does not feel irritation of eyes during cooking	20		12	63	6	
Easy fire management	19	2	11	59	6	
Total respondents						32

Figure 4.4: Pattern of production cost, revenue and market margin among rice husk briquette producers in Bangladesh

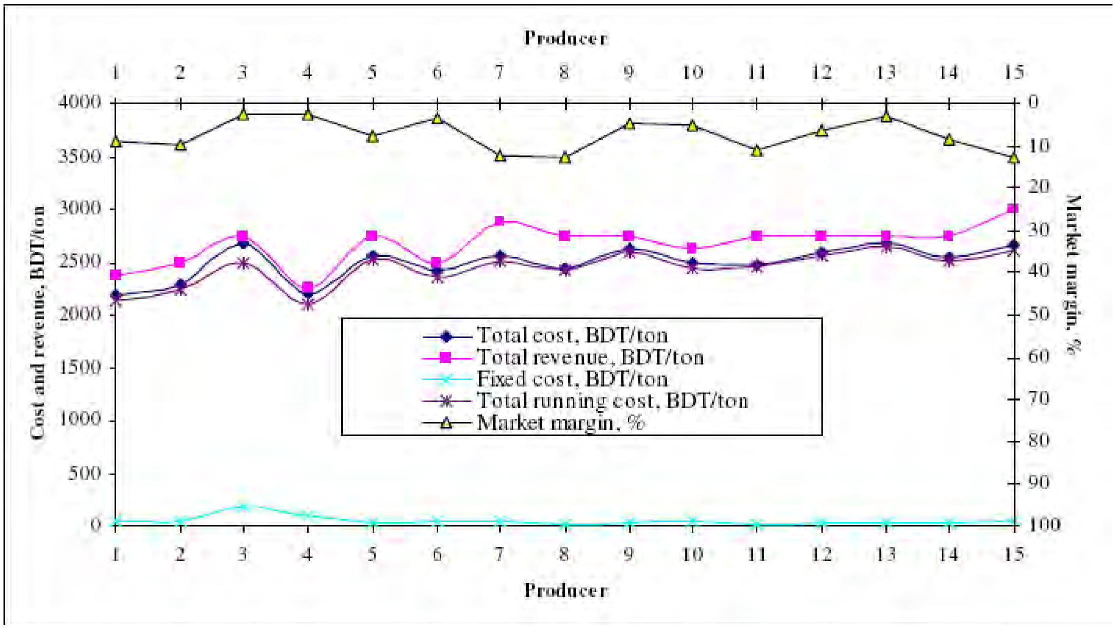


Table 4.9: calculation of employment generated in densified fuel production and marketing processes

Process	Employment
A) Raw Material collection	
Man-hr/ton	6
Man-day/ton	0.75
B) Briquette production process	
Average production capacity, ton/hr	0.09367
Average working persons per machine	1.8
Man-hr/ton	19.22
Man-day/ton	2.4
C) Transportation	
Capacity, ton/truck	10
Persons working	4
Time require, hr	5
Man-hr/ton	2
Man-day/ton	0.25
D) Trading	
Average sales in town	18.02
Labor employed in different shops, person	6
Man-day/ton	0.33
Total employment, man-day/ton product	3.73

Figure 4.5: A typical rice husk briquetting factory in Bangladesh

Thailand

Preecha Kiatgrajai et al (1991) and Bhattacharya (1988) reported on the status of biomass briquetting activities in Thailand that started during the late 1970s. During the period 1978 -1983 when there was dramatic increases in commercial energy prices, biomass briquettes appeared to be an attractive alternative fuel. First screw presses were imported from Taiwan. By 1990 there were 5 manufacturers of biomass briquetting machines (Densification of Biomass in Thailand). Four types of biomass briquettes were produced in Thailand: rice husk; uncarbonized sawdust; carbonized sawdust (biocoal); and green fuel. While sawdust and rice husk were centrally available, production of green fuel demanded more labor and time, starting from collecting raw material, chopping, mixing, densification and finally drying for 7 days. Commercial briquetting is limited to two raw materials, i.e. rice husk and sawdust. By 1990, there were 24 biomass briquetting plants in the country with 76 machines. Only 17 plants were operational. Besides the technological problems, the market demand for the product, supply of raw materials and quality and price of substitute fuels were the main reason behind business shutdown.

The main markets for the briquettes were export of carbonized briquettes and refugee camps in northern Thailand. The household sector and street food vendors were found to consume a small share of the product. The green fuel was produced specifically for military camps and prisons. The study by Preecha et al (1991) concluded that besides the fuel supply to refugee camps, the biomass briquetting has little chance to survive due to high competition and tendency of urban households to switch to modern fuels, eg: LPG and electricity. The carbonized briquette industry could survive if technology is further developed towards reduction of production cost. While other biomass residues have other alternative uses, sawdust will continue to be the raw material available for the biomass briquetting industry.

Bhattacharya reported that the Ministry of Interior issued a policy preventing eight refugee camps, with a total population of 133,000, in northern Thailand from access to forests for provision of their cooking fuel needs. Biomass briquettes were introduced as a substitute fuel and had become an important fuel for household cooking within the camps. This provided a regular market for the biomass briquetting plants that allowed them to survive. The amount of briquettes provided for each refugee was 7 – 8.5 kg per month.

During the period 1997 -2001 the Asian Institute of Technology conducted intensive applied research and demonstration to improve the biomass briquetting technology (heated die screw) in some Asian countries, including Thailand. Although the project achieved remarkable improvements in the technology (reduction of energy consumption and prolongation of die life), the impact on biomass briquetting industry in Thailand was not reported.

China

Battacharya reported on the status of biomass briquetting China, indicating that the technology of biomass densification by means of screw presses is mature, while piston press briquetting machines are also being developed presently.

The capacity of screw press briquetting machines is about 100-120 kg/hr. The raw materials commonly used for briquetting are rice husk, sawdust and agricultural residues. Currently, there are about 600 briquetting machines operating in China. About half of biomass briquettes produced is directly used as boiler fuel as substitute of coal, the other half is used to make charcoal.

Sri Lanka

In Sri Lanka, a commercial heated-die screw-press briquetting machine was adopted by the Ceylon Tobacco Company Limited (CTCL) for producing coir dust briquettes in the early 1980s (Sepalage, 1985). Although the technical feasibility of briquetting coir dust was demonstrated by CTCL and the coir dust briquettes could be used as fuel for curing of tobacco leaves, briquetted biomass was not found to be commercially viable. The main reason behind this was the very low price of fuelwood, partly because of trees felled in a large hydroelectric clearance (Soren-Summary). However, a renewed interest in briquetting technology appears to be emerging in recent years (Adhikarnayake, 1996), mainly directed towards the possible usage of the large volumes of coir dust resulting from the coconut plantations industry. A technique has been developed which compresses coir dust with lime at low pressure.

4.3. Biomass densification in Africa

The history of biomass briquetting in Africa is largely one of single projects in various countries which have usually not been successful. Unlike India, Brazil and Thailand, no African country has developed anything resembling a briquetting industry with several plants based upon the same technology. The raw materials most commonly briquetted in Africa are coffee husks and groundnut shells; sawdust and cotton stalks are also used to a limited extent. A 4000 ton per year pilot cotton stalk briquetting plant was established in Eritrea in 2000, but no information is found about its performance.

Erickson 1987 and Soren (1990) reported that there is considerable similarity between biomass plants in Africa (Table 4.10): they are all one-off units. There have been three kinds of initiatives behind African biomass briquetting plants:

First: Some private industrial plants have been set up briquetting operations, either to feed their own boilers or to make a commercial fuel out of in-house residues. There are examples of this in Gambia, Kenya and Malawi, though the Gambian plant, based upon pelletizing machine, was defunct whilst the Malawian plants, based on wood wastes, did not operate at full capacity. Two other plants of this kind are in Kenya, both based upon coffee residues which are transported to the factories concerned and then densified. In both cases, the object of the exercise is to convert the waste into a form which can be efficiently handled in wood burning boilers.

Second: There have been a number of projects largely financed by development agencies. There have been at least seven such projects located in Zimbabwe, Tanzania, Uganda, Kenya, Sudan, Rwanda, Niger, The Gambia and Senegal, though not all of these are still functional. The types of residue used include coffee husks, papyrus, cotton stalks, wood waste and groundnut shells. Four new plants were in the process of construction in Ethiopia based upon coffee husk, cotton stalk, bagasse, wheat straw and maize straw. In 2003, the author visited two briquetting plants based on bagasse and cotton stalks and both were completely closed down.

Third: a third category of small-scale biomass briquetting projects are implemented by NGOs with the participation of local communities, mainly in Eastern Africa. The communities are trained to produce briquettes using manual presses with the primary objective of satisfying their fuel needs and possibly generating some income. However, the impact of such small projects is rather localized.

During their survey of biomass briquetting plants in East Africa, Soren et al (1989) reported a significant number of outright failures in the African plants and others whose operations have been marred by problems. It was difficult to find a single agency-funded briquetting project which has been commissioned and operates fully satisfactorily. Four reasons seem to explain this failure:

1: Inappropriate or mis-specified machinery was ordered. In some cases the entire plant seems completely inappropriate. This is particularly true of the use of pellet presses. But, in most cases, the equipment suffers because its feed components or peripheral equipment were undersized relative to the needs of the densification process. Most European plant manufacturers make machines which run using wood waste. Bulkier agro-residues invariably require larger feed components and they may also require other changes to the machine setting. Although manufacturers claim competence in all residues, some of this is largely theoretical and the great distances involved preclude any large-scale feedback testing before the equipment specification is finished. This is typically the case of the cotton stalks and bagasse briquetting plants installed in Sudan and Ethiopia.

As briquetting equipment demand regular maintenance, the training of local technicians and the provision and/or local manufacture of spares were often underestimated. In addition, the commissioning period during which the manufacturer technician was present, was very short to enable such training.

2: The second reason for project failure is poor planning. The availability and regular supply of residues was not properly studied. This occurred in the case of two groundnut shell projects in West Africa and a third one in Sudan. In the latter case, a failure of the rainy season resulted in complete shutdown of the plant.

3: The low local prices of firewood and charcoal inhibited the marketing of briquettes. The residues were often assumed to be freely available, while in reality the owners demanded payments once the briquetting factories started. This is typically the case with cotton stalks in Sudan. Originally the farmers uproot, collect and burn the stalks. The project assumed and arranged with the farmers to collect to have access to cotton stalks at agreed collection points, before burning it. Once the carbonization/briquetting factory started, the farmers abstained from uprooting and collecting the stalks. The project incurred additional unplanned cost of uprooting and collecting cotton stalks.

In most African countries fuelwood is harvested on a non-sustainable basis and the market price of fuelwood is far below the sustainable (or replacement cost) value of fuelwood. For reasons of demonstration and piloting briquettes are very often sold at subsidized prices below that of fuelwood. Very often briquetting projects are shut down whenever the donor support is terminated. There is no clear policy support to continue subsidizing the briquettes.

4: There is a clear failure to market the briquettes, even if markets do exists. For example in Ethiopia, there is a clear market in the capital, Addis Ababa, where even the leaves of Eucalyptus has a market, but even so, the established briquetting projects could not penetrate that market. The problem is most often connected to the institutional setup of the briquetting plants. Very often the briquetting plant is attached to a much larger enterprise or government institutions where staff lacks incentives and motivation to undertake an awareness-raising campaign.

For many briquetting plants the market outlets were ill defined at the project conception stage. Most direct briquetting plants targeted the household sector as a potential market for briquettes. However, it later discovered that briquettes are unacceptable due to ignition difficulties and smoke generation causing indoor pollution. In addition, normal household stoves proved not suitable for burning the briquettes. The development of a special stove for burning the briquettes proved to be a complicated task beyond the capacity of product promoters. By the time the briquetting plants turned to market toward the industrial users (industrial boilers, brick and lime kilns, bakeries and hotels) the project has already come to an end.

Soren, 1987 concluded that "the history of briquetting in Africa has not been good. Out of the twenty or so plants identified, only about half a dozen operate in anything like a continuous fashion and only two or three approach any commercial viability. The failure of plants is not dissimilar to that in India and Thailand, where initial enthusiasm led to a harsh awakening for many plants. However, unlike these plants, it has been more than unfavorable external conditions which has led to the demise of many Africa plants. Many have been victims of poor project planning and implementation. This is a surprising situation given the total inexperience in project planning possessed by Indian and Thai entrepreneurs compared with the wealth of such experience of UN development agencies."

Table 4.10: Some of biomass briquetting projects in different African countries

Country	Type of briquetting Machine	Raw material	Targeted Consumers	Remarks
Ghana	Screw press	Sawdust	Household	As briquettes required especial stove – not available as well as price competition with cheap firewood and charcoal. However, product was admired by bricks makers and

				bakers – demand outstripped supply, but plant closed down (5 years) due to operational inefficiencies – 30% idle of working day – problem supply of dry sawdust, poor management regarding marketing and management.
Gambia, 1982 Two plants	Piston press	Groundnut shells	Household	Marketing problem – relatively cheap and abundant wood. High emission of acrid smoke on burning on traditional stoves and briquettes disintegration. Design of special stove solved the smoke problem, but low market. Efforts to shift to industrial market were not successful. Plants closed down.
Malawi, 1981	Screw press	Sawdust	Household	Plant closed down – briquette price cannot compete with cheap wood
Zimbabwe, 1984	Pelletizing plant	Groundnut shell	Household	Successful in technical terms, Product was difficult to sell except as low-cost industrial fuel substituting coal. Plant converted to produce animal feed
Zambia, 1987	Pelletizing plant	Sunflower husk	Industry	Inconsistent product quality – extensive boiler modification. Plant closed down
Rwanda, 1984	-	Papyrus	Household	Technical problems, but product was marketable to households
Rwanda, 2001	Piston press	Sawdust, coffee husk	Institutional	Very successful. Feasibility study undertaken to expand

				factory and use MSW
Ethiopia, 1985 (private)	Low pressure Piston	Sawdust (60%) + coffee parchment and cotton seed husk	Services sector (hotels)	Imported expensive binder was main handicap
Ethiopia, 1987 (WB0	Piston press- several factories	Cotton stalk, bagsse, coffee husk, maize cobs and wheat straw	Household	Plants faced with technical problems as well market competition with cheap firewood and charcoal. All closed down
Tanzania,	Screw press	Sawdust	Household	Initially the briquettes were to be carbonized for domestic use. Failure market penetration the product (direct briquettes) was instead sold at low price to local institutions.
Sudan, 1988, UNDP	Piston press	Groundnut shell	Household	Product rejected by household due to excessive smoke. Design of special stove was not successful. Use in lime kilns was successful but high transport cost hindered marketing. Plant closed for financial viability.
Sudan, 1988, UNDP	Semi-mobile Piston press	Cotton stalk	Household	Technical problems. Different processing parts did not match the material. Plant moved to other sites to use groundnut shells, but marketing was a problem.
Sudan, UNHCR, 1987	TERSTARAM presses, Low pressure	Rotted bagasse and Molasses as binder	Refugee households	Product was not accepted by households, but used prison kitchen and later found market in brick kilns. Plant

				closed down with dismantling of refugee camps –Return.
Sudan, 1989, DGIS	Carbonization +agglomeration	Cotton stalk	Households	There was some success, however plant closed down mainly due to material supply and management problems
Kenya, 1983	Piston, screw presses, Pelletizing plant + screw press for charcoal	Coffee husk	Industrial boiler, and households	Both products cannot compete with cheap firewood and charcoal prices

In addition to conventional binder less briquetting, low-pressure cold briquetting using binder has also been tried in some places. Most noteworthy among these is the carbonization-briquetting process, in which biomass is first carbonized and the resulting charcoal is briquetted using a suitable binder. The process has been tried for cotton stalks in Sudan and coffee husks and bagasse in Kenya. Briquetting of bagasse using molasses as binder has been reported to have had limited success in Sudan.

Another low-pressure binder less briquetting process involves mixing pulverized, chopped and decomposed biomass with water into a pulp. The pulp is pressed inside a perforated pipe to get 4-inch diameter cakes, which are sun-dried to get briquettes (Stanley, 2002). The basic press is made on site and the product is normally of lower density compared with conventional briquettes. A non-profit organization, Legacy Foundation, is currently involved in disseminating the technology in different African countries.

The main generalization that can be made about briquetting in Africa is that it has often proved difficult to sell briquettes against the competitive price of wood or charcoal. The primary marketing problem for briquettes in Africa is their high price relative to wood and charcoal. It is not clear whether this poor competitiveness arises mainly from the very high capital cost of the plants or the low price of wood; probably the balance between the two varies between countries. In Kenya, the main problem is undoubtedly the fact that wood prices remain low, apparently well under 1 US$/GJ in heat terms. At such prices, virtually no alternative fuel can be justified except on long-term strategic grounds. At the other extreme, the prices quoted above for Ethiopia seem to have a very heavy capital cost component. Thus the annualized capital charge for cotton-stalk briquettes was calculated to be 34 US$/ton out of a total ex-factory production cost of 82 US$/ton.

The target market usually aimed for in African briquetting projects has been households burning either wood or charcoal. As noted above, the choice of this market has been largely conditioned by initial policy perceptions rather than any actual consideration of the markets for which briquettes are suitable. However, only very small quantities of briquettes ever appear to have been sold to households. It is notable that the only truly commercial operations which have been identified, those in Ethiopia and Ghana, sold their products to "middle-class" hotels burning firewood or to brick kilns.

A final, optimistic conclusion to what is an otherwise often depressing review of African briquetting: it seems that briquettes of all types can find a market niche when they are produced regularly enough at prices not too far out of line with the competition. It may be that the easiest area to exploit is the substitution of wood in small boilers in hotels, institutions and small industry. However, there is some evidence that briquettes can be acceptable in households without the use of special stoves provided the consumer has sufficient time to work out the best use of the briquettes.

Gambia

In 1989 Keith Bennett reported on the situation of groundnut shell briquetting in Gambia that, "In 1982 a groundnut shell briquetting plant was installed in the GPMB (Gambia Produce Marketing Board) factory at Kaur (200 km up the River Gambia from Banjul) aiming to substitute wood and charcoal use in the urban areas of the country. The plant, financed by DANIDA, operated by GPMB and supplied by DGSMI, now stands idle and some five years later it is clear that the new fuel has had little impact on domestic fuel users. Over this period sales have been low, and briquettes have only managed to retain a small market amongst higher income groups who have access to private transport and can therefore collect briquettes directly from the GPMB depot near Banjul. The packing, local distribution and marketing of briquettes has not proved to be very attractive economic proposition with relatively cheap and abundant wood available throughout the urban areas. Also, during the original campaign to popularize the briquettes, users had the expectation that briquettes were the 'new charcoal.' This certainly caused disappointments to people who tried briquettes with their traditional coal pots and were dismayed with volumes of acrid smoke issuing from their kitchens."

Although a dual fuel improved stove for burning both firewood and briquettes and became available in the market, however, GPMB lost interest of producing briquettes. For such a large company like GPMB, briquetting is a small-scale side activity and it therefore devoted little attention to the project. In the meantime, some brickmakers became interested in using the briquettes, but even so GPMB did not react positively and preferred direct selling of loose groundnut shells.

The above situation was complicated by a strong private initiative to utilize GPMB's loose shells at Kaur. BELGAMIL (Belgium-Gambian Industries Ltd.) has installed a new briquetting plant and associated equipment just 100 meters from the DANIDA plant outside GPMB's factory gates. The company had a commitment from the government and GPMB for the supply of loose shells, although the price and actual tonnage have yet to be specified. The arrangement would clearly suit GPMB, who stand to profit from the sale of loose shells that were previously a disposal problem. Briquettes produced by BELGAMIL were claimed to have 40% higher density compared to GPMB briquettes and can be carbonized to produce charcoal.

Kenya

Several biomass briquetting projects were implemented in Kenya. The main raw material was coffee husk and both direct briquetting and carbonization/briquetting were tried on a commercial basis. Due to the high cost of biomass briquettes compared with cheap firewood, none of the plants was able to continue production. In recent years Chardust established a carbonization/briquetting plant based on bagasse. It seems Chardust is successful in marketing its charcoal briquettes. However, the main market is within the services sector and not households.

In order to produce cheap biomass briquettes for the household sector, the general trend nowadays in Africa is towards low pressure or manual briquetting. The Legacy Foundation is taking the lead in promoting the technology in Africa. Multiple small local NGOs are trained on the technology. Production is mainly based on women's groups to produce their family needs and excess briquettes could be sold to generate income.

The production of biomass fuel briquettes has thus been pursued in the following manner: compacting local organic materials (such as sawdust, leaves, and paper waste). The fuel will be made cheaper and with less impact to the environment, and will provide another income-generating opportunity for local community-based organizations. It will give families an affordable alternative to wood charcoal for daily cooking. Figure 4.6 show the type of biomass briquettes produced using the Legacy production process/press. The technology widely disseminated in Africa, particularly in East Africa (Kenya, Uganda and Tanzania).

Figure 4.6: Low pressure biomass briquettes produced by Legacy process/press

Source: Kenya study tour

Malawi

The UNDP-Malawi Biomass Briquette Efficiency, Marketing and Training Pilot Project (BBEMTP) was implemented between 1992 and 1997. The objective was to provide extension services and training so that women could learn how to make briquettes for their own use and for sale to others. The project targeted women as beneficiaries, with a few officers from government, donor agencies and NGOs as facilitators.

The project was implemented in three pilot districts: Mchinji, Lilongwe and Mangochi. The biomass briquette press used in the project was developed in the United States by the Forestry Products Research laboratories of the University of Washington and was adapted by the Malawi

Industrial Research and Technology Development Centre in collaboration with Stanlinks, the project implementer.

An evaluation of the pilot project was undertaken in 2000 in order to assess the usefulness of the adapted briquette press, and to consider the appropriateness and business feasibility of briquette making as an alternative source of household energy and additional income. The project, being the first of its kind in Malawi, provided useful information on the potential of briquette production for income and energy. The evaluation identified project design weaknesses and lack of market development strategies as factors that contributed to the low field and market penetration of the briquette technology.

This earlier project was initially designed to meet the needs of both household energy and income generation. During implementation, however, there was no marketing strategy to promote sales of the briquettes for use outside the producer households. Moreover, potential customers in the rural areas chosen for the pilot project could still obtain wood without cost, but would have to pay for the briquettes. Sales, therefore, were low and briquette making did not generate much additional income for the targeted women and their households.

Beyond problems relating to the selection of project locations and lack of marketing mechanisms, the project also encountered difficulties related to poor trainee selection, differing expectations between service providers and trainees about the purpose of the training, the low social status attached to biomass briquettes, and a weak entrepreneurship culture among women in Malawi. Although nearly 200 women entrepreneurs were trained, over 80 per cent of them have abandoned the technology.

Benefiting from experience gained and lessons learned from the UNDP briquetting project, another biomass briquette program was initiated by the Nkhomano Development Centre, NGO, following a 1996 study conducted in Blantyre City which revealed critical deforestation of the Ndirande mountain forest reserve due to fuelwood gathering and timber pole harvesting. The project was designed to address deforestation by providing alternative sources of energy, thereby reducing people's dependence on charcoal for fuel and allowing for regeneration of the Ndirande mountain reserve. It was also expected to allow women involved to earn incomes and promote waste management through recycling of paper, sawdust and other waste materials.

The Ndirande Nkhuni programme was designed to avoid the sorts of difficulties encountered by the UNDP-funded project. It has incorporated lessons from the prior experience in refining implementation and management strategies. Table 4.11 shows the main lessons identified in the UNDP-funded project and how they have been addressed in the Ndirande Nkhuni project.

Table 4.11: Comparison of the UNDP-funded biomass briquette project and the Ndirande Nkhuni programme

Lessons/gaps	UNDP funded project (1992-1997)	Ndirande Nkhuni project
Needs assessment	No evidence that a needs assessment was done	A participatory needs assessment was done and women identified lack of energy sources as a problem
Project site selection	Project sites located in rural areas where	Located in urban poor locations (squatter areas)

	fuelwood was not a crisis yet, but scarce income was the main problem	where both lack of income and energy are problems
Trainee selection and group formation	Project selected existing women's groups formed with the sole objective of income generation	Self selected women groups with dual objectives of raising income and obtaining energy
Additional burdens on women	Project targeted rural women who were already overwhelmed with individual household and community chores	Urban women were targeted who have fewer labor-intensive activities than rural women
Market orientation	No cohesive and comprehensive marketing strategy	Market development is a comprehensive component of the project
Policy environment	No government policy on renewable energy sources	Government sustainable renewable energy sources strategy is in place
Technical barriers	Follow-up and monitoring was weak due to varied expectations from trainees and extension workers	Strong monitoring component
Unclear expectations	Project team expected women to use briquettes for household use, women expected also sales	Realistic expectations about the use and income potentials
Stakeholder participation	Women only targeted as beneficiaries	Women participate in project design and needs identification
Donor involvement	UNDP only	Multiple involvement

The project's approach involved the stakeholders in analyzing the merits and demerits of each energy source in order to promote acceptance and usage of the biomass briquettes. The women also were involved in designing project activities. The committees worked with the women to plan how they were going to implement and sustain their project, while the project officer facilitated the process.

The private sector has also been involved. For example, the wood products manufacturing industry is ensuring that women have access to sawdust, a major raw material in the production of briquettes. While initially these companies were giving away the sawdust, they are now charging an affordable price of MK 0.50 per 50 kg bag of sawdust. Other private companies provide waste paper, another ingredient in the briquette production process. Table 4.12 presents more details about the project.

Table 4.12: Particularities of the Ndirande Nkhuni Biomass briquetting program - Malawi

Project	**Ndirande Nkhhuni Biomass Briquetting Program**
Location	Blantyre city, Malawi

Main staple food	Nsima (thick porridge)
Raw biomass material	Waste paper, sawdust, and agricultural residues
Ownership of briquetting units	21 Women's Groups, of 10 women each (from low-income squatter areas of Blantyre city)
Total cost of briquetting equipment	NA, but simple and locally made manual wooden press
Production capacity, per woman	300 – 400 briquettes per day
Energy Consumption and cost	Transport of raw materials
	Muscle power for raw material preparation and briquette production
Production cost per one briquette	2 $ cents
Pay-back period	NA
Biomass feedstock and reason for selection	- Waste paper is city waste product, its collection and disposal costs considerable expenditure - Sawdust is a by-product of wood industry in the city - Agricultural residues freely available at close by farms
Manufacturing technique & capacity	Manual wooden presses
Product characteristics	NA
Employment by the briquetting units	270 women and school children involved in product marketing (after school hours)
Marketing channels and employment	Briquette kiosks in open produce markets in four townships in the city where the women regularly distribute briquettes.
Production cost	-
Market margin	50 % of selling price
Briquettes end users & share of consumption	100% Households
Stoves for burning the briquettes	Charcoal stoves
Product acceptance by end users	Very good
Briquettes consumption by end users	1- Households: 2.5 kg/day (lowest) 2- Tea stall: 16 kg/day 3- Street food stall: 12 kg/day 4- Restaurant: 114 kg/day (highest)
Socio-economic impact of briquettes use	- Time saving: no more collection of firewood - Employment: 270 Women in 3 townships, each receiving $ 5.3 – 6.6 per week - Additional for the wood industry 0.66 $ cent per sack of 50 kg sawdust - Clean city and reduced expenditure on garbage collection and transport

Evaluation	2000, CEEDS, Biomass Briquette Extension, Production and Marketing 2006, Olle Faxälv and lof Nyström, Biomass Briquettes in Malawi

5. Experience with Biomass Briquetting in Sudan

The first national energy assessment of Sudan, 1981, revealed the fact that Sudan was highly dependent on biomass energy, constituting 87% of total energy consumption. More than 90% of biomass energy was consumed by the domestic sector. The country was facing a severe process of deforestation, environmental degradation and desertification. If the trends continued, the meager forest resources would be depleted by the year 2000. On the other hand, the energy assessment provided data on huge untapped biomass resources in terms of agricultural residues.

The first national energy plan, 1983, based on first energy assessment data, raised great concern about biomass energy consumption and recommended policies and programs for addressing the situation. A political decision was made to make use of agricultural residues to substitute fuelwood use in the household sector. The political decision was enthusiastically supported by donors (UNDP/UNSO, UNIDO, FAO, UNHCR, GTZ and DGIS) and several highly ambitious projects were launched as early as 1985. The targeted agricultural residues were cotton stalk, groundnut shells and bagasse. Four projects were started, Table 5.1.

Table 5.1: Biomass residues energy conversion projects

Project	**Location**	**Raw material**	**Donor**	**Implementing organization**
Briquetting of cotton stalk	Gezira scheme	Cotton stalk	UNSO/UNDP	GDEA - Ministry of energy and Mining
Fuel Briquette Project	Al Nuhoud, N. Kordofan state	Groundnut shells	UNSO/UNDP	GDEA – Ministry of Energy and Mining
Carbonization/Briquetting of cotton stalk	Rahad Agr. scheme	Cotton stalk	UNIDO/DGIS	Energy Research Institute
Small scale Carbonization of cotton stalk	Gezira Agr. Scheme	Cotton stalk	GTZ	Energy Research Institute
Bagasse blocks	New Halfa Sugar factory	Bagasse and molasses	UNHCR, FAO	FNC and , Ministry of Interior – Refugee Department

After four years of experimentation, demonstrations, some household acceptability tests and feasibility studies it was decided, in 1987, to establish five pilot factories producing briquettes, charcoal briquettes and bagasse blocks in the country. In addition, by 1992 some of the projects were replicated by the private sector, in particular carbonization/briquetting of cotton stalk (one factory at New Halfa Scheme) and the bagasse blocks (three production units at Al Geneid, Sinnar and Asalaya sugar factories).

Unfortunately with the high enthusiasm, the project designers, consultants and implementers over sighted and underestimated important factors, namely:

1- Agricultural residues are abundantly available, but only seasonally – only three months for cotton stalk as phytosanitary law prohibit its storage
2- Residues were assumed freely available, particularly cotton stalks
3- Harvest, collection and transport costs of cotton stalk were underestimated
4- Trees in the forests had zero value and royalties levied by FNC did not match the actual stumpage value of firewood and charcoal – no measure was taken to increase fuelwood prices
5- Briquettes required special household stove, which was initially not considered by the projects
6- Charcoal briquettes produced using molasses as a binder cannot be handled during the rainy season – period during which charcoal price is highest during the year
7- Energy change dynamics were neglected – energy ladder
8- It was assumed that briquettes had to be sold at lower prices than firewood and charcoal – gave consumers an indication of lower fuel quality

Marketing of cotton stalk charcoal briquettes was to some extent successful. However, the early transfer of the pilot plant factory to the partner organization, in 1990, led to early collapse of the business. The plant was closed down in 1992 due to several problems mainly in terms of planning, management, finance, availability of cotton stalks at reasonable distances from the factory and marketing. The partner organization was a joint venture company between Rahad Agricultural Corporation and the Farmers Union. The latter was supposed to ensure free availability of cotton stalks, as farmers were supposed to uproot, collect and burn cotton stalk by the end of June. Once the factory started operation and charcoal briquettes were seen in the market, the next season the farmers objected paying for the uprooting and collection of cotton stalks. The company had to pay an additional cost for cotton stalks, and combined with the increased collection distance, the business turned out to be unfeasible.

The carbonization/briquetting of cotton stalks was replicated in the New Halfa Scheme by an NGO, which purposely established a private company to implement the project. All the equipment was locally manufactured. In addition to charcoal briquette marketing problems, the availability of cotton stalks, harvest and collection presented the main constraints for the smooth running of the factory. Although a weed plant growing along the water canals was identified and used as substitute for cotton stalk, the factory witnessed additional planning and management problems that led it to close down in 1993.

The fuel briquette project was a joint pilot project between UNSO and the GDEA – Ministry of Energy and Mining. The main objective of the project was to examine the feasibility of producing fuel briquettes from groundnut shells, cotton stalks and other agricultural wastes on a national basis. The direct briquetting of cotton stalk through the Gezira scheme faced several technical problems, mainly mismatching of some equipment components with the flow characteristics of cotton stalk. The mobility of huge equipment, Figure 5.1, within the cotton fields was another problem. The plant was transferred to an oil mill site near Khartoum where groundnut shells were abundantly available, but later returned back to Gezira.

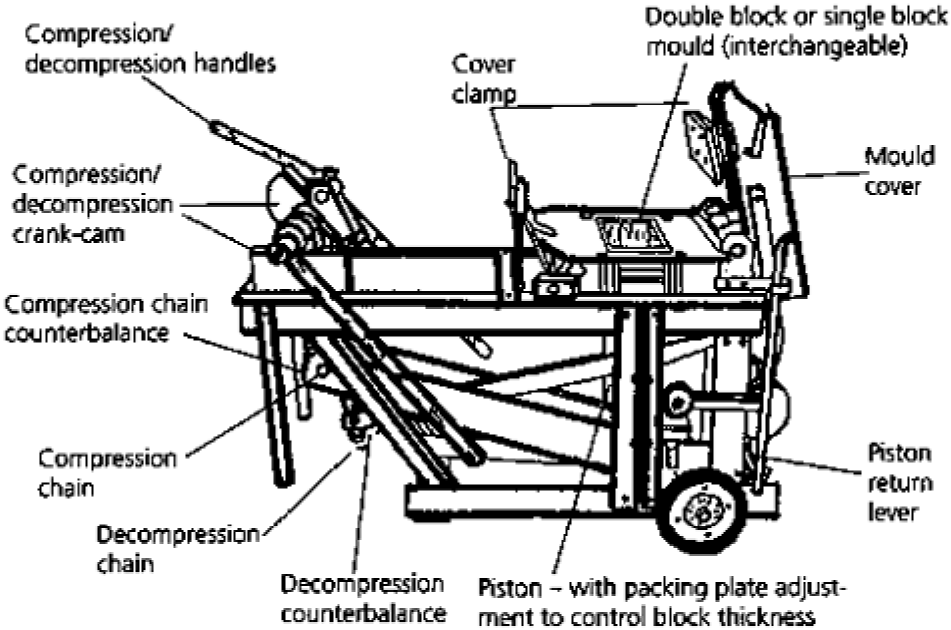
The groundnut shell briquetting plant at Al Nuhoud performed reasonably well. However, the high sand content of groundnut shells caused excessive wearing of the piston head and die. Frequent replacements, every 90 hours, lead to frequent shut downs and resulted in low production capacity (one ton per hour instead of 1.5). Another problem was the inconsistency of groundnut shell supply. The plant was idle for one year due to failure of the rainy season and the resulting lack of groundnut production. The sale price of groundnut shell briquettes was fixed at 20% less than the prevailing price of firewood – meaning the plant was operating at a loss of about 19% of the production cost.

The marketing of cotton stalk and groundnut shell briquettes to the household sector was a complete failure. The use of briquettes for domestic purposes demanded a special stove which was underestimated at the project conception stage. In addition groundnut shell briquettes emit acrid smoke on burning on traditional stoves. Alternative use of briquettes in small scale industries was rather successful, but the high transport cost hindered further scaling up.

Figure 5.1: Mobile piston press briquetting machine, Gezira (Sudan)

The bagasse block, Figure 5.2, was initially conceived to provide cooking fuel for refugees in Eastern Sudan. A refugee cooperative was formed for operating the factory at New Halfa sugar factory. Bagasse blocks proved unsuitable as a household fuel (difficult to ignite and smoke emission). An alternative use was thought in the brickmaking industry. Experimental work showed that bagasse blocks could replace 80% of firewood in the brickmaking industry. This important finding encouraged the private sector to install other production units at three different factories. However, as markets and profits were overestimated, the new units did not continue for a long time, as transport cost always made bagasse blocks more expensive than firewood. However, the original unit at New Halfa continued production until 1999, when refugees returned home.

Figure 5.2: Terteram block-making press



Generally all briquetting projects in Sudan were heavily dependent on donor funding. They were all closed down by 1992, when donor funding terminated due to the economic boycotting of Sudan. An evaluation conducted in 1992 (The Ministry of Energy and Mining) for the two direct briquetting plants showed that the factories were operating at a financial loss. Both factories were closed down. An attempt to sell the briquetting factories to private sector was not successful.

In conclusion, at the time (1980s and 1990s), the potential for briquetting loose low-density agricultural residues into a more usable form of fuel was enormous. However, projects set up in the late 1980s and early 1990s often failed due to high capital, high maintenance and operational costs, and the failure to take into account the other uses and possible costs of the residues available. Although technical problems were relatively easy to overcome, the briquetting factories were closed down mainly due to product marketing constraints. Apart from social acceptability, the production cost of briquettes relative to low prices of firewood and charcoal did not allow for fair market competition.

Before setting up a biomass briquetting production facility it is important, therefore, to understand the nature and availability of the residue, the fuel market in which the briquettes are going to compete, and the type of technology being considered in terms of maintenance, operation and energy requirements.

6. Availability of Biomass Materials for Briquetting in Sudan

6.1. Agricultural residues

Apart from the large-scale agricultural schemes, agricultural production in Sudan is primarily subsistence agriculture, practiced under three main farming systems: irrigated, mechanized rain fed, and traditional rain fed. Of these, traditional rain fed agriculture is the most widely practiced and perhaps the most vulnerable to crop failure.

Based on cultivated areas and crop productivity, the Second National Energy Assessment reported on quantities of agricultural residues available, country wide, for energy conversion, Table 6.1. The figures were actually misleading as the availability of residues was not further analyzed. Similar issues were apparent during the 1980s when several biomass briquetting factories were established based on exaggerated residue availability estimates produced by the First National Energy Assessment, 1981. Crop production in Sudan is either irrigated or rain-fed. Irrigated crops include cotton, sorghum and groundnut are mainly produced in the central plains, where the main agricultural schemes (Gezira, Rahad, White and Blue Niles schemes) are located along the two rivers (Blue Nile and White Nile). Rain-fed cultivation or traditional agriculture includes the rest of the country. However, large area cultivation of crops is mainly within the mechanized farming in Gadaref, Sinnar and Blue Nile states, where sorghum and sesame are the main produce. Large scale rain-fed cultivation of groundnut is mainly practiced on the sandy plains of Kurdofan.

The estimation of availability of crop residues for energy conversion has to account for other factors like traditional uses of residues; location; consistency of production; accessibility; harvest; and transport cost. Apart from cotton stalks and groundnut shells, the other residues have traditional uses as animal fodder or building materials or the material is classified as inaccessible because it is on mechanized farms. In addition, in the last 15 years the production of cotton drastically decreased due to government policy favoring wheat production and the decline in international market. The estimates of cotton stalk availability are based on the regulations imposed by the phytosanitary law. According to law, farmers have to uproot cotton stalks, collect and burn it on the field before the end of June. No storage of cotton stalks is allowed. However, practically these regulations are not applicable anymore as cotton stalks are collected and stored by farmers and others for use as cooking fuel.

Table 6.1: Available agricultural residues for energy conversion, 2000

Type of residue	Quantity (000) tons
Cotton stalk	373
Sorghum stalk	7821
Wheat straw	776
Millet stalk	1121
Groundnut shells	1393
Sesame stalk	2120
Bagasse	327
Total	13931 or 4.458 million toe

Source: Second National Energy Assessment, Ministry of Energy, 2001

Groundnut shell is centrally available at oil mills and decortications plants. In earlier days it was only used as in fuel in traditional boilers providing processed heat for the oil mills. In recent years new uses were developed for the material, mainly as fodder and as an additive in brickmaking. In addition, the rain-fed production of groundnut is quite variable from year to another, depending on the success of rainy season.

Bagasse is to some extent the only agro processing residue available for energy conversion. However, the Kenana sugar company does not produce any excess bagasse – all is absorbed in the power generation system. Other sugar companies like New Halfa, Geneid and Sinnar produce excess bagasse. There are some newly developed uses of bagasse as fodder and additive in brickmaking, but the quantities used are rather small. Asalaya Sugar factory has recently installed a cogeneration system, 13 MW, for the utilization of its excess bagasse. The Sugar Corporation, which owns the four public sugar factories, has plans to replicate the Asalaya power cogeneration system to other factories.

6.2. Forest Residues

Forests are under great stress in Sudan. In the 1950s, forests constituted about 36% of the total area of Sudan (90,000,000 km²). Today, most of this forest land has been depleted to meet the demands for fuelwood, timber and agriculture. According to FAO, in the 1980s the size of forests was estimated at only 20% of the total area of the Sudan. Recently, it was estimated at just 15% (National Forest Inventory, 1998). At present, the annual consumption rate of woody forest products far exceeds the allowable cut. The consumption is approximately 16 million cubic meters annually while the allowable cut is approximately 11 million cubic meters. There are now vast areas completely bare of forest cover except for isolated, scattered natural forests remaining outside forest reserves.

Forested areas are inversely proportional to population density, as 68% of Sudan's forests are in the South where just 15% of the population lives, and only 15% of the Northern states area is forested (as of 1998), where the remainder of the population lives.

Sudan depends mainly on the forestry sector as energy source; as it contributes a total of 4.11 million T.O.E representing 70.8% of energy supplies in the country (FNC, 1995).

Sudan's forest tree vegetation cover was estimated at 40% of the total area in 1901, at 36% in 1958 (Harrison and Jackson 1958), and decreased to 19% in 1990 as estimated by the FAO. It decreased further to 13.7% according to the recent surveys (Abdelnour and Abelmagid, 1997).

Man has been the most powerful and persistent factor causing the deforestation and disturbance of Sudan's natural ecosystems. The main human activities that are threatening the tree species and endangering some of them are unregulated cutting for timber and fuelwood, clearing of forestland for agriculture, overgrazing of livestock, burning and civil wars.

The National Forest Inventory, 1998, showed the annual allowable cut stock in Northern Sudan is only 11.7 million cubic meters, Table 6.2, far beyond the annual consumption. In year 2000 the annual deforestation rate was calculated as 0.589 million ha (0.8% total forested area and UNEP report, 2007, estimated the annual deforestation at 1% of the total country area.

Table 6.2: Total volume of all woods vegetation and annual allowable cut in the Inventoried area

Sector	Total volume of all woody vegetation, (000) m³	Annual allowable cut, increment, (000) m³
River Nile	672	47.04

Eastern	3234	226.4
Central*	29,531	2,067.8
Kordufan	44,218.8	3,095.3
Darfur	89,096.8	6,236.8
Total	166,752.6	11,672.7

Source: National Forest Inventory, 1998

- Khartoum, Gezira, Sennar, Blue Nile and White Nile states

The following Table 6.3 shows the extent of Forest and other Wooded Land for the years 1990, 2000 and 2005.

Table 6.3: Forest cover 1990-2005

	Surface (1000 ha)		
	1990	**2000**	**2005**
Forest	76 381	70 491	67 546
Other Wooded Land		54 153	
Other Land	161 219	112 956	170 054
.. Of which with tree cover			
Inland water bodies	12 981	12 981	12 981
Total	250 581	250 581	250 581

Source: FRA 2005

After the Comprehensive Peace Agreement (CPA), FNC practically became almost two independent administrative units. The federal FNC is mainly responsible for forest resources in Northern Sudan. FNC has several sawmills in Northern Sudan, mainly in Sinnar and Darfur states. However, due to civil war in Darfur only the sawmills in Sinnar state are presently under control and operational, namely: Suki Sawmill; Wad El Naial Sawmill; Sawlail portable Sawmill; and Hawata Sawmill. The timber is supplied from *Acacia Nilotica* forest reserves along the Blue Nile River. The saw mills produce considerable wood wastes and sawdust. The byproducts from sawmills (wood and sawdust) are consumed by the brickmaking industry along the Blue Nile. In addition the sawdust is mainly absorbed by the fishing industry as an insulating material in cooling containers. No surplus wood or sawdust is available for further processing.

Sawmills in Southern Kordofan are not yet recovered or rehabilitated. Under post war conditions many constraints (accessibility in terms of landmines and poor roads) are yet to be removed. In Darfur FNC is almost totally paralyzed and has no access to forest areas, which are either under the control of rebel movements or militias. However, recent reports revealed forest resources in Darfur are heavily damaged by illegal cutting and fire hazards during the past five years, Table 6.4.

Table 6.4: Extent of destruction of FNC forest reserves during the conflict years: examples from South and West Darfur

FNC Reserve	Estimated percentage loss
A) South Darfur	

Kunduwa Forest, Nyala	100%
Gareida	50%
Kass	20%
Tullus	Heavy, although figure unavailable
B) West Darfur	
Murtagellow, Jebel Marra	100%
Golol, Jebel Marra	100%
Kayangat, El Geneina	100%
Sisi	100%
Western Kaja	100%
El Geneina green belt	50%
Mornei	50%
Nyertete, Jebel Marra	20%

On the other hand, the number of sawmills operating in the main towns of Darfur is known to have increased substantially, Table 6.5. The wood waste from sawmills is sold as firewood, while the sawdust is collected by the brickmaking industry. Investigations in Nyala, El Fasher and Kass revealed that sawmills are of a small-scale nature and the amount of sawdust produced does not constitute large enough volumes for further processing into briquettes.

Table 6.5: Increase in sawmills and carpentry in Darfur after start of civil war, 2003

Period	**Nyala**		**El Geneina**		**El Fasher**		**Zalingei**	
	sawmills	**Carpentry workshops**	**sawmills**	**Carpentry workshops**	**sawmills**	**Carpentry workshops**	**sawmills**	**Carpentry workshops**
Pre-conflict	10 - 13	NA	10	65	3	10	3	NA
2008	30	NA	17	120	15	30	21 (including ID camps)	17

In Southern Sudan the situation is similar to that in South Kordofan. As indicated in UNEP's post conflict environmental assessment, the FNC in Southern Sudan has not yet complete hand on the forest resources. There are large Teak plantations, particularly in Yei County, Table 6.6, and other reserved forest areas in Southern Sudan. During the civil war of the teak plantations were subject to uncontrolled felling and export to Uganda. The entire process was managed on the black market by foreign-owned companies and royalties from the timber went to the SPLA.

With the end of the conflict and the establishment of GOSS, the Ministry of Agriculture and Forests ordered a review and evaluation of commercial logging activities. The contracts were annulled and logging banned in both teak plantations and natural forests.

Table 6.6: Teak plantations in Yei County, Southern Sudan

Name of the forest reserve	**Size in hectares**

Loka	918
Kagelu	1,045
Kajiko North	750
Kajiko South	90
Korobe	50
Mumory	30
Yei Council	2

During the consultant's field visit to Juba, it was made clear by the forest authorities that the practice of illegal felling and sawmilling is still continuing due to the inaccessibility of areas by the FNC. However, the Central Equatoria state forest department indicated that there is a plan to rehabilitate five forest reserves under its control, namely: Terekaka; Mangala; Jabur (north and south); and Jebel lado. The rehabilitation plan of 2009, includes: complete clear felling; planting/coppicing; and charcoal production. Residues from these operations could be available for briquetting. The forest reserve of Jebel Lado will be turned into a mechanized farming project (for food security) and accordingly the amount of generated biomass residues will be enormous. In addition GOSS has an ambitious infrastructure program, mainly road construction, and vast forest areas will be cleared to open pathways for road construction. Huge amounts of biomass waste will be generated. However, the remoteness of the areas hinders the exploitation of the resource.

6.3. Mesquite

Prosopis, known as Mesquite in Sudan, is a perennial woody plant, characterized by a strong root system, and with the ability to grow under a wide range of environmental conditions. *Prosopis* is fast growing, salt-tolerant and drought-resistant trees that can grow in areas receiving as little as 50 mm of rainfall per year. *Prosopis* is the only tree able to yield 2.5 tons of wood/ha/year where nothing else can grow. On saline soils in India this can rise to 12 tons.

Mesquite was first introduced into Sudan in 1917 and later on (1970s and 1980s) widely disseminated for the purpose of addressing the problems of Sudan's arid and semi-arid areas, summarized as: fuelwood production; pods for fodder; soil stabilization; and as a means for stopping the desertification process. However, as its spreading and growth are extremely difficult to control, *Prosopis* negatively affects Sudan's agriculture productivity. Therefore Sudan has to spend huge amounts of money, every year, in order to control its fast and wide spreading into agricultural lands and irrigation canals. By year 2005 the estimated land area invaded by Mesquite was 1,551,000 ha, table 6.7. The benefits and drawbacks of Mesquite tree are presented in Table 6.8.

Table 6.7: Areas invaded by mesquite in some states in Sudan, 2005

State and location	Area (ha) 1996	Area (ha) 2005	Hazard classification
Gash Delta	4200	500000	High
Halfa	9044	242000	+High
Tokar Delta	140560	650000	High
Red Sea	20860	50000	Low
Gedarif	2100		Low
Khartoum	5111	13000	Medium

River Nile	3360	28000	Low
Norhern State			
White Nile	11008	60000	None
Gezera	8000	8000	Medium
Kordofan	1260		None
darfur	294		None
Sennar	420		None
Total	206,217	1,551,000	

Source: Dr. Talaat Defalla

Table 6.8: Benefits and drawbacks of Mesquite tree in Kassala area

Benefits of Mesquite	**Problems caused by Mesquite**
- Timber used for building	-Compete with other plants for water and space
- Pods and leaves used as forage	-Cause paralysis for livestock, particularly donkeys, when continuously eaten in large quantities
- Shade	-Cleaning mesquite from farms is very expensive
- Firewood and Wood for charcoal making	-Injuries caused by mesquite thorns believed to be difficult to heal

Source: PA-Sudan, May 2006, Baseline Survey for the Project, "Increasing Resilience to Poverty of Rural Communities in Kassala State".

There is great controversy surrounding the Mesquite tree. When unmanaged, it often colonizes disturbed, eroded and over-grazed lands, forming dense, impenetrable thickets, Figure 6.1. Thickets of *Prosopis* have become established in grazing lands, crop lands and along river courses, alarming pastoralists, farmers and conservationists. There is concern about the impacts of the tree on the biodiversity of native plants and on the amount of water in dryland streams. The *Prosopis* tree has been declared as a noxious weed in many countries, including Argentina, Australia, South Africa, Pakistan and Sudan. On the other hand, *Prosopis* has proved useful in restoring degraded and saline lands, stopping sand movement, stabilizing sand dunes and producing a variety of useful products for the local populations. *Prosopis* has great potentials as a source of fuelwood, timber, honey and animal forage. In eastern Sudan, the only source for firewood, charcoal, and building wood is Mesquite wood, Figures 6.1, 6.2 and 6.3.

Figure 6.1: Clearing mesquite in the Tokar delta, Red Sea state

Source: UNEP

Figure 6.2: Charcoal production from Mesquite using improved metal kilns, Kassala state

Source: Practical Action

Figure 6.3: Traditional Charcoal production using earth-mound kiln, Kassala state

Source: Practical Action

Similar to other countries where Mesquite have been introduced, Sudan declared Mesquite as a noxious weed and launched a national program for its eradication (on 26 February 1995, a presidential decree for its eradication was issued). Several eradication methods were tested, including mechanical (uprooting and burning) and chemical (touch-down herbicides). Although experimentally the chemical method proved more effective, it was not used in the field. The mechanical method (uprooting and burning) is applied widely, but in the absence of other control methods (better management of the resource) Mesquite thickets re-appear after a short period of time, particularly in humid areas (irrigated agricultural schemes and water courses). The example of New Halfa Agricultural scheme demonstrates the high cost and non-effectiveness of mechanical method for Mesquite eradication.

The main reasons for introducing different species of the genus *Prosopis* around the world have been combating desertification and promotion of a fast-growing fuelwood and fodder species that thrives in harsh arid and semi-arid conditions. The phenomenon of Mesquite land domination has become a worldwide (Africa, Latin America and Asia) concern posing similar problems as encountered in Sudan. The FAO has created an international network for the purpose of researching solutions to problems posed by the Mesquite land domination phenomenon. Contrary to the Sudan case, where the Government declared a policy aiming at Mesquite eradication, the international trend endeavors towards sustainable Mesquite resource management and economic exploitation for the benefit of the environment and livelihoods of populations in the rural areas. Besides being a basic source of energy for the rural population, Mesquite honey, timber, charcoal and fuel briquettes are now becoming commercial products worldwide. For example, in India Mesquite shrubs are sustainably harvested and used as fuel for power generation. In Namibia, land domination by shrubs, very similar to Mesquite, have occupied vast areas of land, however, the solution adopted is clearing the agricultural land, while exploiting the rest of the resource by sustainable management using it as fuel in power generation stations.

In India, work on converting *Prosopis* into valuable resources has concluded: (1) that *Prosopis juliflora* can be a very valuable resource for the drylands; (2) that efforts to completely eradicate *Prosopis juliflora* are overly expensive and likely to be ineffective; and, (3) that *Prosopis juliflora*, when managed, can be a very valuable source of commercial products and livelihoods in the drylands. Experiences from India are particularly instructive. *Prosopis* is acknowledged as an important source of fuelwood and an income source for low-income earners in Tamil Nadu. Its value for reclaiming degraded saline soils has also been widely acknowledged. Most importantly, its value for woodfuel, charcoal, timber, furniture construction, animal feed, human food, and medicinal products has been documented and increasingly exploited. The Planning Commission of India's Action Plan for Greening India identifies *Prosopis juliflora* as one of the most promising agro-forestry options for problematic and saline soils. Other regions of the world have much to learn from these experiences.

6.4. Eradication versus Sustainable Resource Management

Mesquite was introduced in Eastern Sudan to stop the desert encroachment and combat desertification. The forestry department considers it an alternative energy source as it can spread and regenerate quickly due to its physiological and morphological characteristics, which give it an advantage over other species in terms of growth, spread and regeneration. Because of these characteristics, the Mesquite tree has spread widely, covering large areas of arable and pasturelands to the extent that it endangered the existence of other trees and pasture plants because of its high competitiveness in absorbing soil moisture and nutrients compared to other types of vegetation. As such, farmers as well as pastoralists regard it as a noxious tree. Some researchers have identified the harmful impacts of the tree in the following:

- Difficulty of getting rid of it;
- It depletes the underground water resources due to its extensive and deep root system, which reach up to 6 meters;
- It is strong competitor for range plants and trees and limits biodiversity;
- It leads to paralysis of animals in cases of excessive feeding.

The author has visited many areas dominated by Mesquite both in Sudan and abroad, the last one being Khor Baraka in Red Sea state. It is the author's own belief that Mesquite can only be cleared from agricultural land and through the development of mechanisms and bylaws that make farmers committed to keeping farmlands clear. However, in many cases land tenure issues combined with the country's general agricultural policies and produce prices have in combination made farmers neglect their lands, while seeking income opportunities in other activities.

There has been for decades an accumulation of Mesquite seeds in the areas dominated by the plant, which can stay at full germination capacity for several years to come. Whenever favorable conditions exist, more plant shoots will appear. Under such circumstances it seems rather logical to consider the sustainable use of the resource instead of trying to reverse the situation to that prevailing before the Mesquite domination. All of the Mesquite eradication methods that have so far been tried, although some are very effective, have shown that the main challenge resides in getting rid of seeds in the soil. An effective eradication method will involve close supervision of the land during moist periods and immediate pulling out of plant shoots. However, such a practice could only be implemented on a limited land area, like cultivated areas.

In many places and Khor Baraka alike, Mesquite has become the main source of livestock feed and livelihoods for the population in the area. Charcoal production and sale contributes up to 50% of household incomes in most parts of rural Red Sea State and its production always been seen as a coping mechanism, but with the near collapse of pastoralism, charcoal production has become a way of life for most households, i.e. a livelihood strategy. Mesquite has invaded all potential agricultural waterways and deltas in Tokar and rural Port Sudan.

In some villages around Kassala the farmers have turned their land into Mesquite forests while keeping close guard on it. In this way they are able to sell building poles, firewood, charcoal and animal fodder. Mesquite has become the main source of livelihoods for rural inhabitants in Kassala , and as such it would be extremely difficult to suggest total Mesquite eradication to these populations.

6.5. Estimation of Mesquite resources

The total area covered by Mesquite in Sudan was estimated at 1,551,000 hectares, while in Eastern Sudan alone (Gash, Tokar, Red Sea and Hafla) in year 2005, Mesquite coverage was estimated to be about 1.4 million hectares. In about ten years (1996 – 2005) the total area covered by Mesquite increased 6.5 times. In Eastern Sudan, during the same period the area increased by more than seven times. In Kassala state it was estimated that Mesquite is spreading at a rate of 483 hectares per year. In Khor Baraka the area covered by Mesquite extends over 130 km along the water course from the delta to the Eritrean border. A survey conducted by FNC, 2006, in the Nile State showed that about 42 small-scale agricultural schemes are menaced by mesquite invasion. The area covered by Mesqiute was estimated at 12,080 hectares.

The mesquite eradication plan succeeded in clearing Mesquite in the New Halfa scheme in 2006. However, Mesquite is now regenerating from seeds stuck in the ground. It is hoped that the local bylaws developed by the agricultural authorities in the area for the purposes of controlling Mesquite will reduce the re-invasion of agricultural land. Other Mesquite clearing/eradication plans are occurring in Gash delta and Khor Baraka delta. Mesquite eradication for the Nile state is planned to start soon. However, it needs sometime before a Mesquite eradication strategy (complete plant uprooting) can be judged to be successful. Indications are that Mesquite can be eradicated only from cultivated land with intensive farmers' awareness and strict follow-up and monitoring by farmers. On fallow and marginal lands, the Mesquite shrub will continue dominating the land and spreading further.

The invasion of agricultural land by Mesquite is considered to be the main drawback of the tree. On the one hand, reports have recognized the usefulness and benefits of the plant as a livelihoods source for the rural population, for building material, as a source of energy (firewood and charcoal), for sand dune and movement fixation and rehabilitation of degraded land. On the other hand, no efforts were made to quantify the Mesquite resource in Sudan. A study on the socio-economic and environmental management aspects of Mesquite in Kassala state estimated that about 16 sacks (one sack = 35 kg) of charcoal could be produced from 0.42 hectare of mesquite thicket. This is equivalent to about 2.8 tons of wood (estimated efficiency of an earth-mound charcoal kiln is 20%). As the Mesquite tree is bushy, only about 40 – 50% its wood could converted into charcoal using traditional earth-mound kilns. The rest of the tree (branches) is considered waste. Based on these estimates, one hectare of Mesquite thicket could produce about 5.6 tons of dry biomass material. The total biomass resource of Mesquite in Eastern Sudan could estimated at about 7.8 million tons of dry biomass.

6.6. Bamboo and Grasses

Grasses may be classified into six main groups: grazing and forage grasses, turf grasses, ornamental grasses, cereals, sugar cane, and woody grasses. Grasses may be either *annual* or *perennial*. Annual grasses die at the end of the growing season, and new seed must be planted at the beginning of the next season. Perennial grasses live through the winter/dry season, however, and grow again each year. Bamboo is considered a woody grass species rather than a tree.

Bamboo is the world's strongest and fastest growing woody plant. In parts of Kenya, the giant bamboo *(Dendrocalamus giganteus)* grows 20 metres high with a diameter of 0.2 metres in one year. The world record holder for growth is the species *Phyllostachys edulis*, whose shoots can grow as much as 121 cm in 24 hours. There are more than 1200 species of bamboo worldwide, with most growing in tropical and semi-tropical climates, such as are found throughout Africa. Bamboo matures in just three years, and can be harvested thereafter every second year for up to 120 years.

Although bamboo is well known for its uses in buildings and furniture, particularly in Asia and Africa, in recent years research is ongoing in many parts of the world to consider bamboo as an energy crop.

Most research on grass as a dedicated energy crop has focused on reed canary grass, switchgrass, and giant miscanthus. As perennials, all three require less energy and financial investment – once established -- than annual row crops. In North America research on energy crop horticulture has produced amazing results on productivity and large investments are under consideration to produce pellets that find uses in domestic/industrial heating, ethanol production as well as power generation.

In Sudan, bamboo and grasses grow wildly in high rainfall areas in southeast, south and southwest Sudan, Figure 6.4. They constitute important building materials both in rural and urban areas. Bamboo and grass harvesting and weaving constitute an important livelihoods activity during the dry season for a considerable proportion of rural population. Transport to urban areas and trade on the products is another employment opportunity generated, Figure 6.5.

In Darfur Bamboo and grasses (Buruni (*Hyparrhenia spp.*) and Marhabeib (*Cymbopogon spp*, which are used for thatching huts and making mats) grow in the southwestern part along the borders with Chad and Central African Republic. There is no data or information land area or resource potential. However, FNC Nyala claimed that during the past five years demand for bamboo as a building material has increased tremendously. Besides its use by host communities, humanitarian organizations are heavily dependent on bamboo for shelter for the IDPs. In consultation with organizations concerned with environmental protection and conservation in Nyala, the issue of bamboo was raised. It is recommended that bamboo resources in Darfur need management, while the residues could be used to produce fuel briquettes. However, the bamboo resource area is presently inaccessible.

Figure 6.4: Wild grass in eastern equatorial, Torit area

Figure 6.5: Bamboo trade in Nyala market

In Southern Sudan grasses are locally used as building materials both in urban and rural areas. In areas closer to Northern Sudan, grass harvesting and reed weaving constitute an important livelihoods activity for the population, particularly in Upper Nile State. Again no information is available on the resource.

In recent years, with the advent of petroleum exploration and production in Sudan, the issue of waste water disposal has become an important concern. As a result of pressure on petroleum companies to address environmental protection and conservation concerns, some efforts are ongoing to find radical solutions for waste water disposal. Among other ideas, bioremediation was tested, Figure 6.6. After five years of experimentation in Helig oil field, grass (reed) was chosen as the most effective option for treating contaminated water. The treated water is used for irrigating tree plantations. Bioremediation of contaminated water and tree planting is now under way, and scaling up to other oil fields in the country, Figure 6.7. Other grass species, mainly bamboo, are also under experimentation. There is no plan on the potential use of reed grass and no information is available on potential resource volume.

Figure 6.6: Experimental reed bed for the treatment of produced water at Heglig

Figure 6.7: Reed grass plantation at an oil field in Sudan

In conclusion, bamboo and grasses constitute considerable biomass resources for the production of fuel briquettes in Darfur and Southern Sudan. However, there is a lack of information on the resource potential. In addition, most of the resource areas are presently considered inaccessible due to insecurity in Darfur and a lack of logistical services and landmines in the South.

6.7. Municipal Solid Wastes

With the high rate of urbanization in Sudan, large quantities of municipal solid waste, MSW, is generated in the major cities and towns. Collection and disposal of MSW and accompanying environmental damage has become a concern for the municipalities in Sudan. There plans for better organization of collection, recycling and landfill disposal. However, only the municipality of El Gadaref town was able to establish proper land filling of MSW, which generates gas supplied to power generation stations. In other towns the MSW is still collected and disposed of using traditional methods.

MSW constitutes of over 60% biomass materials that could be used for producing fuel briquettes. Examples from elsewhere in Africa (Rwanda) show that good organization of MSW collection and sorting could generate employment opportunities and income. It could reduce municipalities' expenditure; make cities much cleaner and promote better environmental hygiene.

The beneficiation of MSW demands data and information on quantities produced, composition and present practices of collection, disposal and recycling. Such information is presently lacking for Sudan. However, informal collection of recycled materials (mainly metals and plastics) does exist at the disposal terminals.

6.8. Conclusion

The availability of agricultural residues for briquetting looks uncertain: either the residues have other traditional uses or are inaccessible. Lessons learned from past Sudanese experience with biomass briquetting showed that if an agricultural residue is available, then its collection, transportation and storage constitute the main cost barriers, making fuel briquettes uncompetitive with cheap firewood and charcoal.

Forest biomass residues and wild grasses could potentially be generated in Southern Sudan. However, under the present post conflict situation in Southern Sudan there is no data available or the resource areas are inaccessible. The use of grasses to treat contaminated water in the oil fields is another potential for biomass briquetting. However, further investigation is recommended to assess the available resources, land area devoted to grasses and the intention of petroleum companies.

Mesquite presents a huge potential resource for biomass briquetting in Eastern Sudan. The current Mesquite eradication policy concentrates only on material uprooting and burning. Mesquite wood is salvaged in terms of firewood and charcoal, while tree branches are burnt to ashes on the fields.

As a natural resource, Mesquite could be sustainably managed and economically exploited for briquette production, while appropriate measures are taken to avoid the invasion of agricultural lands by Mesquite.

7. Feasibility of Biomass Briquette Production from Mesquite

7.1. Site Selection and availability of Mesquite

Table 6.7 (chapter 6) shows the areas covered by Mesquite in Sudan. The largest area is in Eastern Sudan, mainly 650,000 ha in the Tokar area (Red Sea state), 500,000 ha in the Gash Delta and 242,000 in the New Halfa scheme in Kassala state, Table 7.1

Table 7.1: Areas invaded by mesquite in some in eastern Sudan, 2005

State and location	Area (ha) 1996	Area (ha) 2005	Hazard classification
Gash Delta	4200	500000	High
Halfa	9044	242000	+High
Tokar Delta	140560	650000	High
Red Sea	20860	50000	Low
Gedarif	2100		Low

The Mesquite eradication program was already implemented in the New Halfa scheme during 2005/2006, and a considerable area has been cleared in the Gash Delta by an IFAD project currently catering for the rehabilitation of the Gash Delta agricultural scheme. The Tokar Delta scheme is currently planning for Mesquite eradication, but only on cultivated areas. However, the Mesquite has invaded vast areas extending over 130 km along the river (Khor Baraka) from the Delta to the Eritrean border. The eradication effort will only cover a small portion of the total area (Delta Tokor scheme) invaded by Mesquite.

The populations outside the Tokar Delta scheme traditionally practice a nomadic lifestyle, but due to successive droughts, during the last three decades they settled in hamlets along Khor Baraka. Besides keeping small livestock herds, the populations practice small-scale cultivation (flood irrigation) along Khor Baraka. However, in recent years the Mesquite invaded all cultivated areas. Agricultural land clearing efforts made by Oxfam did not prove to be very successful. Nowadays, charcoal production from Mesquite has become almost the sole livelihood opportunity for the majority of populations of the Khor Baraka area. Charcoal produced in Khor Baraka supplies urban markets in Red Sea state, Central Sudan and Khartoum.

Mesquite is a thorny shrub/tree that grows to about 3 m but can reach 15 m. It has a main single stem and a spreading canopy, but it is also a smaller, multi-stemmed tree with branches dropping to the ground. Traditional charcoal production in an earth-mound kiln only makes use of the main stems (up to 5 cm in diameter) of the Mesquite tree, while the branches are left as waste (Figure 7.1). Thorny Mesquite branches left over on the field are considered a nuisance for both people and livestock. The briquetting of Mesquite will convert the whole tree into a valuable product – briquettes.

Figure 7.1: Mesquite branches left over from charcoal making are either burnt into ashes or left on the field

Charcoal production from Mesquite is the main livelihoods activity for the population in Tokar Delta and Khor Baraka areas, particularly in drought years. In addition, taxes on charcoal constitute the main revenue source for the Tokor Locality. In a meeting with the authorities in Tokor Locality, it was made clear that they consider Mesquite to be a valuable natural resource that has to be better utilized. Taxes on charcoal are an important revenue source for the Locality. Apart from clearing Mesquite from agricultural land, they consider the present Mesquite exploitation practices as disorganized and wasteful. The locality is actually looking for investors that could better utilize the Mesquite resource and ensure a regular income and revenue for both the population and the Locality.

The Mesquite resource is available in two distinct areas:

- Tokor Delta agricultural scheme, mainly around Tokor town
- Along Khor Baraka – extending for 130 km towards the Eritrean border

There is an eradication plan for Mesquite within the Tokor Delta agricultural scheme. Outside the scheme, the Mesquite is mainly exploited by the local population for charcoal production. Briquetting could be considered as a salvage operation in the Tokor Delta scheme. Under such a circumstance, an agreement is needed with the Mesquite clearing company to avail the material for the briquetting factory. The present practice of Mesquite clearing only makes use of lump wood in charcoal production, while the remaining bushes are burnt on the field.

Access to Mesquite along Khor Baraka will be through consultation with FNC, Tokor Locality and the local population living in hamlets along Khor Baraka and presently dependent on charcoal making from Mesquite as their main form of livelihood.

7.2. Sustainability of the Mesquite Supply

The vast area, over 650,000 ha, invaded by Mesquite in the Khor Baraka area assures the availability of feedstock for production of fuel briquettes. The challenge for sustainable supply of feedstock resides in the harvest, collection and transport of raw materials to the processing plant. The Mesquite eradication policy implemented by FNC implies complete uprooting of trees and no answer is given in interviewing FNC authorities on whether this only applies to agricultural lands or to whatever land area is dominated by Mesquite, as it is the first time FNC has hears of such an investment idea. However, FNC agrees that the Mesquite eradication policy should only be applicable to cultivated areas. Otherwise it has to be considered as a valuable natural resource with environmental benefits, such as protection against build up of sand dunes. In this area, Mesquite could become a crop rather than a noxious weed. The briquette production technique will convert the whole Mesquite vegetation into briquettes. In this way, valuable crop land is left for cultivation and in other areas the regulated and sustainable use of Mesquite will not leave the land barren and vulnerable for desertification.

The Mesquite uprooting process looks quite expensive, though the briquetting plant could depend on recuperation (in a salvage operation) of trees after they have been uprooted by another entity. Such a system will not assure a sustainable and consistent supply of feedstock to the briquetting plant.

On the other hand, after harvesting, Mesquite trees must be chipped before they are transported to the briquetting plant. In combination, the harvesting, collection, chipping and transport is a process that demands investment in heavy equipment: regular raw material supply is the crucial component of the biomass briquetting process. The issue is whether the briquetting plant will undertake such an operation or contract another organization/entrepreneur for the supply of feedstock. It is generally recommended that raw material supply to the briquetting factory should not be part of the investment; otherwise the management will be distracted from its specific function of plant management. In addition it implies additional investment that might be beyond the capacity of plant sponsor.

Depending on the specific country situation, the price for the feedstock delivered to the briquetting plant varies greatly. In India (depending on the local price of coal) the recommended feedstock price is about US$ 8 to 10/ton. In the US, the recommended price is around US$ 25/ton of delivered wood chips.

7.3. Briquetting Equipment

The pellet press is excluded from consideration for Sudan because it is an advanced technology that demands high investment, high capacity per single machine and a high level of maintenance skills. The economic operation of a pellet press demands a production of at least 15,000 tons of pellets per year. In addition, pellets are mainly directed for industrial uses and not for domestic cooking purposes. The small size of pellets allows for use of automatic feeding system to the boiler.

There are three alternative briquetting machines, namely:

- Screw press
- Hydraulic press
- Piston press

The screw press produces the best quality briquettes. However, its production capacity range is between 250 kg/hr to 750 kg/hr. The machine consumes large amounts of energy per ton (60 to 75 kwh) of produced briquettes and demands frequent maintenance of the screw and die. The research conducted in Asian countries (India and Thailand) has demonstrated that by preheating the feedstock (250 Cº) and hard facing the screw, the energy consumption and wearing of the component is considerably reduced. In addition, experience from the Asian countries show that the low production capacity of the screw press makes it more suitable for small scale entrepreneurs with relevant mechanical skills to operate and maintain the equipment. The screw press option is discarded for the above reasons.

The hydraulic press produces a much lower briquette quality relative to other two options. The piston press, based on a flywheel mechanism, operates slowly. It is very robust and has a reputation for having a long working life. The machine is easily maintained and although the piston and die wear, out they are easy to repair. Energy consumption is high (50 Kwh/ton), but less than for the screw press. The piston press is by far the most commonly used briquetting machine and is the cheapest of all the presses to purchase and install. Its output ranges from 450 kg/hr to 2,200 kg/hr. The piston press is recommended for this project because of its superior strength and it produces a briquette quality best suited for domestic use.

7.4. Ancillary Equipment

The configuration of various equipments and machinery required in a briquetting process depend largely on the type of raw materials used for briquetting.

In order to produce good quality briquettes, feed preparation is very important. Feed parameters include: particle size; moisture content; and temperature. Particle size and shape are of great importance for densification. It is generally agreed that biomass material of 6 – 8 mm in size with 10 - 20% powdery component (< 4 mesh) gives the best results.

The percentage of moisture in the feed biomass for the briquetting press is also a very critical parameter. In general it has been found that when the feed moisture content is 8 -10%, the briquette will have 6-8% moisture content. At this moisture content, the briquettes are strong and free of cracks and the briquetting process is smooth. But when the moisture content is more than 10%, the briquettes are poor and weak and the briquetting operation is erratic. Excess steam is produced at higher moisture contents, leading to the blockage of incoming feed from the hopper, and sometimes it shoots out of the briquettes from the die. Therefore, it is necessary to maintain optimum moisture content of about 12% for the piston press. Although the climatic conditions in the Tokor area are favorable for sun drying, the moisture content of the feed material will go up and down depending upon the ambient humidity and temperature. Therefore it is recommended that the proposed briquetting plant be fitted with dryers.

It is now almost standard practice in biomass briquetting plants to pre-heat the feedstock material prior to briquetting. This provides a number of important advantages. Heating the material helps to release the lignum, a glue type substance from within the cellulose cells of the biomass. During briquetting, the lignum is normally released because of the pressure and the frictional heat in the die. By pre-releasing the lignum, it acts more like a lubricant and reduces the power requirement and wear on the piston and die surfaces. The overall effect of pre-heating improves production and increases profitability because the production rate is increased and maintenance costs on the piston and die are lower (Table 7.2).

Pre-heaters work from small furnaces heating oil which is pumped through a pipe that surrounds the incoming material as it is fed into the compaction chamber. The furnaces are usually fired from a small amount of waste briquettes.

Table 7.2: Increase in production rate of briquettes with pre-heating (90 Cº) on machines with standard capacity of 400 kg/hr

Raw material	(Kg/hr)*	% increase
Rice husk (ground)	480 - 540	35
Groundnut shells (ground)	480	20
Coffee husk (ground)	600 – 700	75
• For sawdust, the screw life increased from 17 to 44 hours		

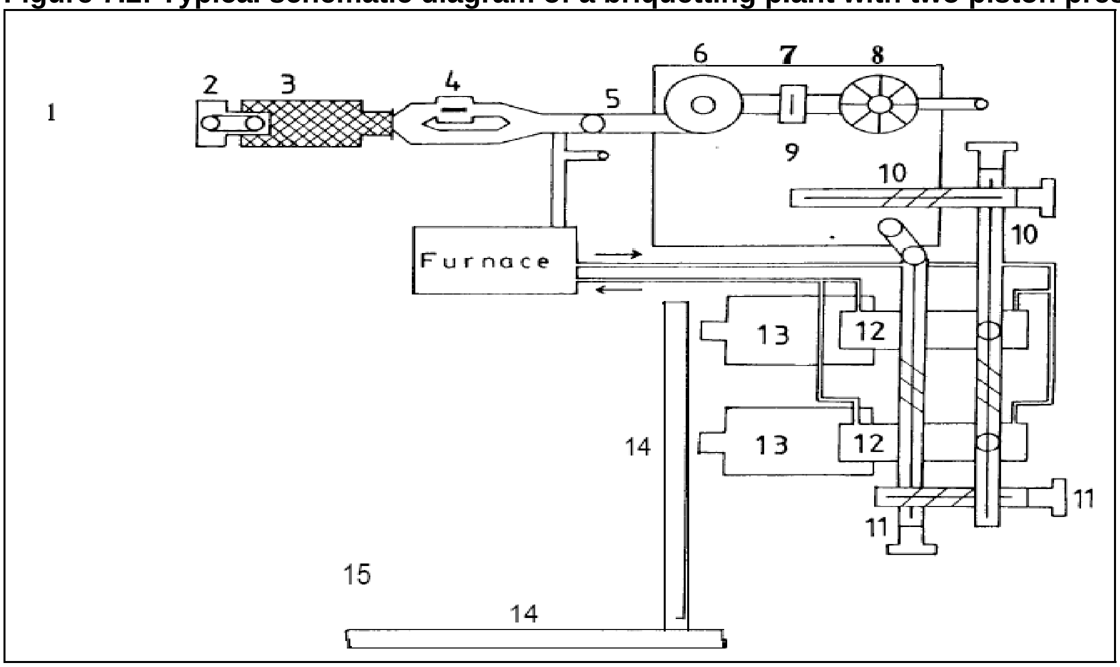
Source: Pete Young and Ismail Khennas

Another factor to consider is removal of smoke and fumes. When the briquettes exit the machine they have temperatures that can be well over 300 Cº. The outer skin of the briquette can even be partially charred and the briquettes are always accompanied by smoke. It is therefore important that a hood with an extractor fan is fitted over the cooling racks to remove the smoke for the safety of the workers and to improve their general working environment.

7.5. Briquetting Plant Setup

The components of a typical briquetting plant can be divided into three groups: a) pre-processing equipment; b) material handling equipment; and c) briquetting press. Pre-processing equipment includes cutter/clipper drying equipment (flash dryer, hot air-generator, pneumatic fans, cyclone separator and drying column) and a hammer mill grinder. Material handling equipment includes screw conveyors, a pneumatic conveying system and a holding bin. A briquetting press (or a number of presses) is the main machine used in briquette production. A schematic diagram of the plant and machinery set-up of a briquetting plant for typical biomass briquetting using a piston is shown in Figure 7.2 or alternatively Figure 7.3.

Figure 7.2: Typical schematic diagram of a briquetting plant with two piston presses



Source: P.D. Grover and S.K. Mishra, 1996, Biomass briquetting: Technology and Practices, FAO

Description of plant components:

1 - Raw material supply: the Mesquite chips for briquetting should be kept in storage bins or in bays under shelters that are fully protected from rain and run off. The shelters should be well ventilated to allow any moisture in the raw material to evaporate. The chips can either be delivered manually at the start of the briquetting process or by automatic feeders typically used in the grain and cereal industry.

2 - Inclined screw or elevator: the residues can either be lifted automatically or manually into the hammer mill.

3 - Vibrating screen: a screen or simple mesh should be fitted over the hammer mill to trap any foreign matter such as over size residues, stones or metals.

4 - Hammer mill: reduces the particle size to 6 to 8 mm.

5 to 8 - Dryer Set-up: to assist the control of the moisture content of the raw material, a dryer is essential.

9 - Intermediate storage bin: the raw material can be held in a storage bin after leaving the dryer. At least 4 hours of production capacity should be held in storage in case of a short breakdown.

10 - Main feed screw: this screw distributes the material in the storage bin to the machines. The supply should be at least 15% greater than production to ensure that none of the machines are starved of material.

11 - Return feed: the excess material not required by the machines is returned to the Intermediate storage bin.

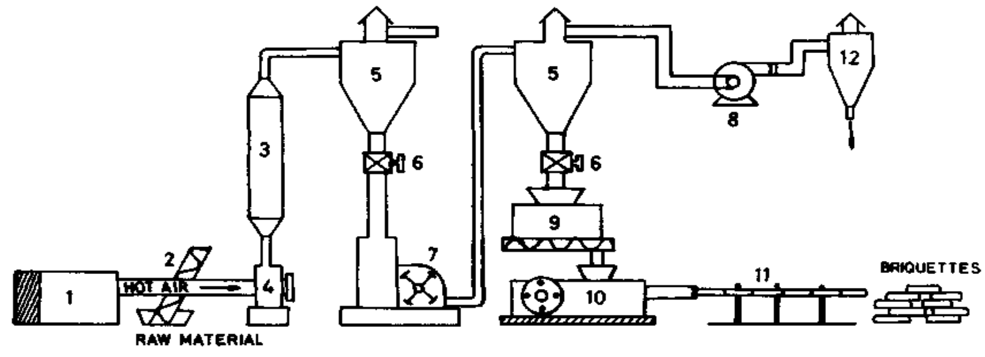
12 - Pre-heater and Furnace: the feed material is dropped into a chamber that pre-heats the material. The temperature should be adjustable from 90 to 200 C depending upon the type and moisture content of the material.

13 - Briquetting machines: the auxiliary equipment can be sized and matched to supply any number of machines, though more than 4 machines may mean that the feed screws become unnecessarily complicated.

14 - Cooling racks: the briquettes are hot after they leave the presses. A system of conveyors needs to be arranged so that the briquettes have time to cool down prior to storage and packing.

15 - Ventilation hoods. the smoke and fumes coming off the hot briquettes should be extracted to the outside of the plant buildings via ducts and hoods closely fitted over the cooling racks.

Figure 7.3: Schematic diagram of the plant and machinery set-up of a briquetting unit using one briquetting press



7.6. Briquetting Plant Capacity and Cost

With the huge Mesquite resource in the Tokor area (7.8 million dry tons), if a rotation period of three years is applied, one could anticipate any briquetting plant size. However, for practical purposes (given generally poor manufacturing conditions in developing countries such as Sudan), it is usually advised to have several moderately sized piston presses in one briquetting plant. In India, the 750 kg/hr piston press is recommended. The briquetting plant will be composed of three piston presses each of 750 kg/hr production capacity. If the plant is operated for two shifts a day for 300 days per year, the yearly production of briquettes would be 18,800 tons. If we consider maintenance hours and other unanticipated periods of operation disruption, then one can easily assume a capacity utilization of 80%, leading to annual production of about 15,000 tons of briquettes per year.

The literature survey of briquetting equipment prices showed great variation between machinery origins as well as between manufacturers. However, the cost of North American and European briquetting equipment is very high compared to that from India and Brazil. Table 7.3 shows the capital cost of briquetting units in India, while Table 7.4 shows the capital cost of similar briquetting units in Europe. For a similar production capacity the European briquetting equipment is about 70% more expensive than that of Indian origin.

Table 7.3: Capital cost of briquetting units for various briquette production capacities in India (1997 prices)

Briquette production capacity (kg/hr)	Capital Cost of briquetting units (US$)* Stalky or wooden material (1997 prices)	
	Dry	Wet
250	18,930	26,014
500	25,320	32,030
750	33,708	40,802
1000	45,500	56,195
1500	59,570	81,360

2250	81,640	92,335

Source: Arun K. Tripahthi et al, A techno-economic Evaluation of Biomass Briquetting in India.

Table 7.4: capital cost of briquetting units for various briquette production capacities in Europe (2006 prices)

Capacity of the Machine (kg/hr)	Average price of briquette press, €	Average price of other equipment, €	Total investment, €
225	50,168	7,525	57,693
500	70,396	10,559	80,955
800	96,128	14,419	110,548
1200	117,990	17,699	135,689
1400	124,360	18,654	143,014
2200	139,300	20,895	160,195

Source: ACCENT, 2006, Acceleration of the Cost-Competitive Biomass Use for Energy Purposes in the Western Balkan countries FP6-2002-INCO-WBC/SSA-3

Other costs involved in establishing the briquetting factory involve:

- Buildings (plant building, offices, workshop, warehouse, concrete slab for storing raw material and site development)
- Water and electricity supply
- Workshop facility and equipment
- Vehicles

8. Potential Impacts of large-scale biomass briquetting

8.1. Socio-Economic Impacts

Apart from the Tokor agricultural scheme, there is no other development project in the Tokor locality. The agricultural scheme dates back to the colonial era and was specifically designed for cotton production. At the time, a special railway and port were established for the export of the produce (cotton). After independence, the scheme witnessed gradual deterioration and additional crops were introduced. The Tokor agricultural scheme was the granary of the Red Sea state. In current times, the scheme suffers from sand movement, clogging of irrigation canals and Mesquite invasion. Such incidences have negative drawbacks on the local economy and particularly the population's livelihoods. Besides the farmers, pastoralists and nomads benefit greatly from the scheme, particularly during the dry season and drought periods. At present most farmers have lost their cultivated land – it is either covered by sand, has no irrigation or has been invaded by Mesquite. In addition, Mesquite has invaded the grazing areas, and combined with successive droughts, pastoralists and nomads have lost their livestock herds and have resorted to charcoal making from Mesquite as a basic livelihoods activity.

Revenue sources for the Tokor Locality are drastically reduced by the loss of agricultural production. In addition, the year 2008 witnessed a shortage of rainfall on the Eritrean highlands, and consequently the Khor Baraka river did not flow. The whole area is under a drought period

– no agricultural production or grazing pasture for livestock. The main income source for the Tokor Locality and the population is now therefore charcoal from Mesquite.

Under the above circumstances, the sustainable management and exploitation of Mesquite will realize strong social and economic benefits, among others:

- Mesquite will no longer be considered as a nuisance, but a valuable resource
- A considerable number of the inhabitants of the Khor Baraka area will find permanent and casual employment in Mesquite harvesting, collection and employment within the briquetting plant
- FNC, which is responsible of Mesquite eradication and replacement with other drought resistant tree species, will save considerable resources. Instead Mesquite will be a permanent source of revenue for FNC
- Tokor Locality will get a sustainable revenue
- Briquetting of Mesquite will reduce the clearing cost of agricultural land
- Inhabitants of the Khor Baraka will regain their agricultural land, presently dominated by Mesquite
- Rural development and creation of entrepreneurial services based on Mesquite harvesting, collection and transport, will arise
- Briquetting is anticipated to provide social services which are badly needed by the location population

8.2. Environmental Impact

Briquettes are intended to replace firewood consumption in the Darfur IDP camps.

Experience from elsewhere (Bangladesh), showed that the energy density of rice husk briquettes is greater than firewood and accordingly, one kg of briquettes is required to replace 1.63 kg of firewood. Based on identification of an appropriate, efficient stove for burning briquettes, any quantities of briquettes delivered to the Darfur IDP camps will replace firewood at a rate equivalent to about 1.6 times the weight of briquettes. Presently, the firewood use in IDP camps is a significant contributor to environmental degradation in Darfur. The environmental impact of firewood replacement in Darfur will be quite significant.

Sand movement and dust storms are inherent features of the Tokor area. Mesquite was specifically introduced in the Tokor area to form shelter belts aimed at stopping sand dune movement that was menacing agricultural land and Tokor town. Mismanagement of Mesquite proliferation, combined with overgrazing of indigenous tree species, fuelwood production and successive droughts, have lead to the invasion of vast areas of land by Mesquite. Generally, in Red Sea state and particularly in the Tokor area, Mesquite is growing on degraded land that is highly denuded of indigenous tree species. The sustainable harvest of Mesquite as a feedstock to the briquetting factory will contribute to maintaining the established tree cover, therefore conserving the degraded lands. In contrast, the Mesquite eradication policy calls for complete replacement of Mesquite by indigenous tree species. However, such replacement has only so far been used successfully in an experiment on irrigated and moist land areas. With the arid and semi-arid conditions of the Red Sea state, and with the continuous decrease in rainfall, it seems doubtful that indigenous tree species will compete with the fast growing and drought resistant features of Mesquite.

9. Project Implementation

9.1. Organizational Aspects

The Sudanese experience with biomass briquetting was very short and was long ago. In addition, the experience and skills developed were mainly with the public institutions – Ministry of Energy and the Energy Research Institute. After 20 years, the trained personnel might no longer even be available. Private sector involvement in direct biomass briquetting was very limited or almost non-existent. Any new effort to establish biomass briquetting in Sudan has to consider organizational setup and capacity building, particularly in the area of training engineers on plant operation and equipment maintenance.

Another area of crucial importance is Mesquite harvesting, collection, chipping and delivery to the briquetting plant. Although it is assumed that the briquetting plant would contract raw material supply to another entity, private sector experience in this area is only limited to Mesquite clearing using mechanical methods. Whatever contractor is selected for raw material supply will need capacity building to undertake such operations.

The Mesquite resource is the ownership of Forest National Corporation, FNC, while the plant will be located in Tokor Locality – Red Sea State. Under such circumstances, FNC, the owner of the feedstock (Mesquite), is considered a crucial partner and possibly a shareholder in the new investment venture. The participation of FNC in the new venture will guarantee the sustainable management of the resource. The FNC has an investment department which has expressed interest in and a willingness to consider and further study the sustainable management and exploitation of the Mesquite resource. The idea was very attractive to FNC as Mesquite eradication is a policy decision which has never been thoughtfully and thoroughly discussed in Sudan.

The participation of the private sector in the new venture demands some efforts. So far the private sector is accustomed to traditional methods of wood harvesting, charcoal making and trade. The Sudanese private sector has never been exposed to biomass briquetting.

9.2. Infrastructure and Services

The plant would be located in a rural area where there is a weak road network (only Tokor town is connected by paved road to Port Sudan), no power grid or water network system. The briquetting plant would have to establish its own power generation station and water supply system. Such additional investments would require a considerable additional investment.

9.3. Product Transport to Darfur

Transportation of briquettes from Tokor to Darfur would cover a long distance that would take a significant amount of time. As railway transport is neither regular nor reliable, all transport systems in Sudan are entirely dependent on roads. There is a paved road network that goes from Tokar to Al Nuhoud (in North Kurdofan) and from there, only seasonal roads are used to reach Darfur. The distance from Tokor to Darfur is over 2000 km (Table 9.1). However, from Khartoum Darfur there is no definite pathway as each truck driver or a group can choose their itinerary. However, for security reasons most drivers prefer following the security convoy, which starts at fixed points somewhere in Kurdofan.

Table 9.1: Distances, transport cost and itinerary from Tokor to Darfur

	Distance, km	Nature of road	Transport cost US$/25 tons	
Tokor – Port Sudan	200	Paved road	Tokor – Khartoum, 25 tons	1,345
Port Sudan - Khartoum	900	Paved road	Khartoum – El Fasher, 25 tons	5,830
Khartoum – Al Nuhood	About 1100 km	Paved road	Khartoum – Nyala, 25 tons	6,278
Al Nuhood – Al Fasher/Nyala		Seasonal	Tokor – El Fasher, 25 tons	6,278
			Tokor - Nyala	6,726
Average transport cost (Tokor - Darfur), is about US$ 250 per ton				
Exchange rate: 1 US$ = 2.23 SDG (Feb. 2009)				

9.4. The use of Biomass briquettes as a Cooking Fuel in Darfuri IDP Camps

Cooking fuel supply to the large numbers of IDPs, over 2 million, in large camps located around major towns in Darfur, has had in a negative environmental impact on tree cover around the towns. Since 2004, the supply of cooking fuel to IDP camps became a real concern to the government, NGOs, Donors and environmentalists. Cooking fuel is not part of relief services provided to IDPs, and fuel collection by IDPs has greatly contributed to environmental degradation around the towns. In addition, the issue is further complicated by insecurity that very often involves harassment, gender-based violence (GBV), loss of property and even loss of life. Cooking fuel supply to IDP camps has become a multifaceted problem.

So far, efforts undertaken to address the negative environmental impact and GBV issue have involved several interventions, but mainly the dissemination of fuel-efficient stoves (FES). However, it has become evident that FES interventions (Figures 9.1 to 9.4) alone cannot address such a complicated problem. Addressing cooking fuel needs in IDP camps in Darfur demands an integrated solution in terms of FES, alternative fuels and creation of new fuel resources. One NGO is presently testing the introduction of liquefied petroleum gas (LPG) and kerosene use in Abu Shouk and Al Salam IDP camps in El Fasher. Another NGO has sponsored a study on potential alternative fuels for IDP camps in Darfur. Other NGOs have tested the use of solar cookers, but they have not been successful. The idea of an integrated approach seems more appropriate for addressing the cooking fuel issue.

Figure 9.1: Improved mudstove

Figure 9.2: AVI3 stove

Source: USAID, 2008, FES Programs in IDP Settings – Summary Evaluation Report, Darfur, Sudan

Figure 9.3: Tara stove

Figure 9.4: Six-brick stove

Source: USAID, 2008, FES Programs in IDP Settings – Summary Evaluation Report, Darfur, Sudan

Interviews and meetings with stakeholders (government authorities, NGOs and UN organizations) in Darfur confirmed the idea of introducing fuel briquettes as a replacement for firewood. However, the question commonly raised was: "Where is the raw material for the production of fuel briquettes?" The war and accompanying situation of insecurity in Darfur have largely reduced agricultural production. In addition, the main crop that produces residues in Darfur is millet, but the stalk has an essential use as a building material. Other resources mentioned include grasses and bamboo, which are available in the southwestern part of Darfur along the borders with Chad and Central African Republic. However, the resources are not quantified and accessibility is hindered by the situation of insecurity.

Cooking stoves presently in use in IDP camps include the 3-stone fire and the FES introduced by NGOs. The FES used most commonly by IDP households is the mud stove. However, for the time being it is not clear whether briquettes are appropriate to use on the improved mud stoves commonly used in Darfuri IDP camps. Otherwise, the program has to consider the development of a special stove for burning the briquettes. Lessons learned from the Fuel Briquette Development project showed that groundnut shell and cotton stalk briquettes could not properly burn on traditional cooking stoves in Sudan. However, project endeavors to develop a special household stove for burning the briquettes were not successful. Instead the use of briquettes was directed towards use in traditional industries (bakeries and lime kilns).

NGOs in Darfur have an accumulated experience in FES production and dissemination. If the situation necessitated the development of a special FES for the use of briquettes, then its dissemination among the IDPs would likely not face many constraints.

The main staple food in the IDP camps is *asida* (a porridge made of either of millet, sorghum and wheat flour or a combination). The meal times are usually early in the morning and in the evening. During the day, most household members are out, searching for livelihoods opportunities. Some meals can be cooked on any stove using any available fuel. However, cooking *asida* demands vigorous stirring and accordingly requires robust stoves that withstand the stress from stirring. Usually the 3-stone fire is well suited for the activity. Other preferences for cooking fuel in Darfuri IDP camps include: the time of cooking, ease of use, cleanliness and convenience. Solar cookers were rejected by IDPs for reasons of long cooking time, unsuitability for cooking *asida* and inconvenience.

Fuel briquettes are not well known in Sudan. They have only been briefly tested as a cooking fuel in central parts of Sudan during the late 1980s. Accordingly, no household interviewed in Darfur had ever heard of fuel briquettes. It will be a new fuel in Darfur. During interviews with women and men as well as with community leaders, no one seems to have an idea about what fuel briquettes are. Even when the consultant presented some fuel briquette samples, interviewees questioned whether and how they could be used instead of firewood or charcoal. Alternatively, the consultant conducted some demonstrations on the production of charcoal briquettes using charcoal dust and clay as a binder (Figure 9.5). None of the attendees believed that the briquettes would burn similar to charcoal. When a demonstration was carried on a charcoal stove, participants were astonished. An interviewee making tea was very happy, as she could save a large sum of money that would otherwise be spent on the purchase of charcoal. Charcoal dust/fines are usually considered to be waste and are thrown away. At central markets (*Zaribas*) in the urban areas, there are heaps of charcoal dust accumulated over the years. However, the resource volume is not to the level to support an organized briquette production facility. It could, however, help poor households produce their cooking fuel needs while endeavoring to generate an income from it.

Figure 9.5: Charcoal dust agglomerates demonstration at Abu Shouk camp

In conclusion, NGOs, donors and IDPs alike are eager to find a solution to the firewood dilemma in Darfuri IDP camps. Recently, the technical and programmatic evaluations of FES programs conducted by USAID and UNEP/ProAct showed that FES programs implemented in Darfuri IDP camps have produced some positive impacts, but not to the levels originally claimed by FES promoters. Therefore, the need for alternative fuels to complement the reduction of firewood consumption was highly recommended.

IDPs are susceptible to accepting alternative cooking fuels as long as it meets their cooking demand, habits, cooks quickly, is convenient and, above all, is freely distributed.

10. Conclusions and Recommendations

Generally, biomass can be defined as renewable organic materials that contain energy in a chemical form that can be converted to fuel. It includes the residues from agricultural operations, food processing, forest residues, municipal solid wastes and energy plantations. The use of biomass residues and wastes (for chemical and energy production) was first seriously investigated during the oil embargo of the 1970s.

In recent years, the use of biomass as a source of energy became of great interest world-wide because of its environmental advantages. The use of biomass for energy production (biofuels) has been increasingly proposed as a substitute for fossil fuels. Biomass can also offer an immediate solution for the reduction of the CO2 content in the atmosphere. It has three other main advantages: firstly its availability can be nearly unlimited, secondly it is locally produced and thirdly it can be used essentially without damage to the environment. In addition to its positive global effect in comparison with other sources of energy, it presents no risk of major accidents, as do nuclear and oil energy.

Due to their heterogeneous nature, biomass materials possess inherently low bulk densities, and thus it is difficult to efficiently handle large quantities of most feed stocks. Therefore, large expenses are incurred during material handling (transportation, storage, etc.).

Agro-processing residues, for example bagasse and to some extent groundnut shells, may already have a more convenient use as fuel. In the sugar industry, bagasse is principally used for processes generating heat and power. In other circumstances the agricultural residues are important sources of domestic fuel. For example, cotton stalk is an important domestic fuel in the rural areas of central Sudan.

Generally field crop residues have an inherent characteristic of being spatially scattered. The production areas may as well be located in remote areas, such as mechanized farms in Sudan. Under such circumstances the cost of collection and transportation to central processing points may be prohibitive. Forest residues are also classified under this category.

A variety of technologies can convert solid biomass into cleaner, more convenient energy forms such as briquettes, gases, liquids and electricity. The economic use of biomass residues and wastes implies the development of cost-effective, safe and sustainable feedstock supply technologies. These technologies should address the following inherent characteristics of biomass residues and wastes: (a) low bulk density, (b) variable and often high moisture content, (c) combustibility, (d) affinity to spoilage and infestation (e) geographically dispersed and varied material, (f) seasonal variations in yield and maturity, (g) a short window of opportunity for harvest and demands on labor and machines that often conflict with the main crops (grain), and finally (i) local regulations that put limits on storage size and transportation loads.

Biomass densification represents a set of technologies for the conversion of biomass residues into a convenient fuel. The technology is also known as briquetting or agglomeration. Depending on the types of equipment used, it can be categorized into five main types:

- Piston press densification
- Screw press densification
- Roll press densification
- Pelletizing
- Low pressure or manual presses

In North America and Europe, environment and climate change concerns have created a revival of interest in biomass energy as a possible alternative to fossil fuels. In order to meet their obligations towards the Kyoto Protocol, developed countries have heavily invested in research and development and have enacted policy and regulatory measures encouraging public and private institutions to switch from fossil fuels to biofuels, in particular densified biomass. Densified biomass used in developed countries appears to be mostly in the form of pellets. Use of biomass pellets for heat applications, particularly space heating, is well established in the US and Europe. The small, consistent size of pellets lends itself to automatic feeding into domestic and industrial burners and furnaces.

Densified biomass is acquiring increasing importance because of the growing domestic and industrial applications for heating, combined heat and power (CHP) and electricity generation in many countries. In countries such as Austria, Denmark, the Netherlands and Sweden, for example, it is becoming a major industry, with pellets traded internationally.

Early introduction of biomass densification in Asia, particularly India and Thailand, was primarily through private sector endeavors. Such ventures showed limited success because of:

- Mismatch of technology, raw material supply and prospective markets
- Technical difficulties and the lack of knowledge to adapt the technology to suit local conditions
- Excessive operating costs (mainly electricity and maintenance)
- Lack of a focal point for the accumulation and exchange of experiences in briquette production in conjunction with advances in briquetting technology.

In order to overcome the above technical drawbacks, two projects were launched in Asia:

- Biomass Densification Research Project, which was jointly implemented by two universities and two private sector companies (Solar Sciences Consultancy Pvt. Ltd, and DENSI-TECH)
- Renewable Energy Technologies in Asia: A Regional Research and Dissemination Program 1997 – 2004, implemented and coordinated by AIT.

The most common raw materials used in biomass densification in Asia are: sawdust, rice husks, coffee husks, tamarind seeds, tobacco stems, coir pith and spice waste. However, successful endeavors, mainly using the heated-die screw press were obtained using sawdust and rice husk. Sawdust is practically the only raw material used for producing briquettes, which are subsequently carbonized; it is the dominant raw material in Malaysia, Philippines, Thailand and Korea. On the other hand, rice husk is the only raw material used in Bangladesh.

The two common types of briquetting presses employed in Asia are heated-die screw press and piston press. It appears that heated-die screw press technology is preferred in most Asian countries while the piston press is dominant in India. The Screw press technology has spread from Japan to most of its neighboring and nearby countries, particularly Korea, China, Vietnam, Thailand, Malaysia, Philippines, Bangladesh, etc. where heated-die screw press briquetting machines are used almost exclusively. The design and manufacture of briquetting machines appears to have evolved and been adapted to suit local conditions in different countries. India and China take the lead in the manufacture of briquetting equipment, particularly the ram and die technology.

Apart from Bangladesh and Thailand, the use of biomass briquettes as domestic cooking fuel is rather limited in Asia. The main end use of biomass briquettes, particularly in India, is for industrial applications – industrial processes of heat generation and institutional kitchens, where the fuel has a competitive price with coal. The government environmental policy – to reduce coal utilization, regulations and incentives are the main deriving vectors for widespread use of biomass briquettes in India. Many biomass briquetting factories are funded through the Clean Development Mechanism, CDM.

In Bangladesh, rice husk briquettes are used as a domestic cooking fuel as well as in restaurants. The use of briquettes in humanitarian settings is only reported in Thailand, where the Government banned refugees' access to forests surrounding the camps (and therefore to firewood). The briquetting industry flourished due to contracts for supply of briquettes to refugee camps.

The history of biomass briquetting in Africa is largely one of single projects in various countries which have usually not been successful. Unlike India and Thailand, no African country has developed anything resembling a briquetting industry with several plants based upon the same technology. The raw materials most commonly briquetted in Africa are coffee husks and groundnut shells; sawdust and cotton stalks are also used to a limited extent. Four reasons seem to explain this failure:

- Inappropriate or mis-specified machinery was ordered
- Poor planning – raw material availability and supply
- The low local prices of firewood and charcoal inhibited the marketing of briquettes
- Poor marketing – there is a clear failure to market the briquettes, even if markets do exists

However, in recent years the introduction of small-scale low pressure briquetting is spreading in Africa, particularly in East Africa.

In Sudan, biomass briquetting witnessed a boom during 1980s and early 1990s. The domestic sector – the largest consumer of fuelwood - was the main targeted end user of biomass briquettes. The briquetting programs received policy support as well as donor funding. However, similar to other African countries, briquettes were marketed against low priced fuelwood, and lack of raw material availability, finance and poor management contributed to the failure of biomass briquetting projects in Sudan.

The availability of agricultural residues for briquetting in Sudan is uncertain: either the residues have other traditional uses or are inaccessible. Lessons learned from past Sudanese experience with biomass briquetting showed that if an agricultural residue is available, then its collection, transportation and storage constitute the main cost barriers, making fuel briquettes uncompetitive with cheap firewood and charcoal.

Forest residues and wild grasses could be potentially generated in Southern Sudan. However, under the present post conflict situation in Southern Sudan, there is no data available or the resource areas are inaccessible. The use of grasses to treat contaminated water in the oil fields is another potential for biomass briquetting. However, further investigation is recommended to assess the available resource, the amount of land area devoted to grasses and the intentions of petroleum companies.

Mesquite presents a huge potential resource for biomass briquetting in Eastern Sudan. The current Mesquite eradication policy concentrates only on material uprooting and burning. Mesquite wood is salvaged for firewood and charcoal, while tree branches are burnt to ashes on the fields.

As a natural resource, Mesquite could be sustainably managed and economically exploited -- via briquetting -- while appropriate measures are taken to avoid the invasion of agricultural lands by Mesquite.

Seeing the high potential of the Mesquite resource in Red Sea state and particularly in the Khor Baraka area, its exploitation for briquetting looks attractive. The environmental and economic benefits of Mesquite briquetting are considerable, mainly in terms of rural development (the Khor Baraka area lacks any sort of development). However, the lack of infrastructure (water and electricity) may demand add additional investments.

All organizations funding or providing humanitarian assistance to IDPs in Darfur have concerns about and an interest in finding an alternative cooking fuel. Some NGOs are presently testing the introduction of LPG in El Fasher IDP camps, while another has sponsored an alternative fuel study. Deforestation in Dafur and particularly around the main towns is a main contributing factor to further degradation of the fragile environment of Darfur.

Biomass briquettes are not known in Darfur. However, IDPs are susceptible to accepting a switch to an alternative fuel if it suits their cooking habits and preferences for an alternative fuel. There is no evidence that present FES in use in IDP camps will be suitable for burning biomass briquettes. Under such circumstances, a briquette acceptability test is highly recommended before embarking on large scale dissemination. The NGOs presently implementing FES programs have accumulated experience in FES dissemination.

The high potential of the Mesquite resource in the Red Sea state looks encouraging for further pursuing the development of biomass briquetting in Sudan. However, the lack of infrastructure in the Tokar area and the high transport costs from the Red Sea to Darfur will make the fuel price when delivered to Darfur very expensive compared to other alternative fuels like LPG.

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Annex I:

TERMS OF REFERENCE
Briquette Feasibility Study Consultant: Sudan

Background
The Women's Refugee Commission is an advocacy and expert resource organization working on behalf of refugee and displaced women, children and adolescents around the world. The Commission, based in New York, conducts research, documents findings, provides technical assistance and undertakes advocacy. One key focus of the Women's Refugee Commission's work since 2005 has been on ensuring safe access by displaced women and girls to appropriate cooking fuel.

The Fuel and Firewood Initiative
The Women's Refugee Commission's Fuel and Firewood Initiative is a comprehensive project supporting the physical integrity and protection of displaced women and girls from violence during fuel collection by fomenting the development, use and eventual institutionalization by the humanitarian community of a coordinated fuel strategy during all phases of refugee and IDP crises. The Fuel and Firewood Initiative is also working with a variety of partners to investigate options for safer access to cooking fuel, including alternatives to firewood.

One of the regions most impacted by the lack of safe access to firewood and alternative cooking fuels is the Darfur region of Sudan. Hundreds of thousands of displaced women and girls are directly affected by the risks associated with firewood collection on a daily basis. In addition, tens of thousands more Darfuri men, women and children are affected by the effects of indoor air pollution. The environmental impact of firewood collection by concentrated displaced populations throughout Darfur has only begun to be studied, but there is little question it has been devastating and will continue to impact the whole region for decades to come.[1]

Despite these widespread negative impacts, however, very few alternatives to firewood as a cooking fuel have been tested in the region. The majority of fuel-related interventions have involved reducing the amount of firewood consumed, rather than replacing firewood altogether.

Non-charcoal biomass briquettes have been tested and used as a cooking fuel in various humanitarian, development and emergency settings worldwide, including but not limited to: Nepal, Thailand, India, Bangladesh, Tanzania, Malawi, Kenya and elsewhere. Many different types of biomass have been used, including rice husks, forest or agricultural waste or residue, charcoal ash and other biomass ingredients. By and large, most biomass briquette programs have been undertaken at a local level, using locally-available biomass ingredients and local production techniques. Moreover, evaluations of briquetting programs have typically not compared diverse types of briquettes and production techniques. As such, the larger implications of biomass briquetting, and the potential for large-scale manufacture and use of biomass briquettes in humanitarian and emergency settings, have not yet been thoroughly studied.

Though Darfur is an arid region with little excess biomass materials available for large-scale briquette production, the environment in South Sudan is more conducive to agricultural and/or biomass production. It *may* therefore be possible to use excess biomass materials available in

South Sudan for the manufacture and use of briquettes in Darfur. ***Thus, the current project aims to evaluate and study the feasibility of the manufacture and use of biomass briquettes in Sudan.***

Project Goal

In order to provide an empirical and evidence basis for the potential larger-scale use of biomass briquettes in Sudan, the Women's Commission seek a short-term Consultant to undertake an evaluation of the use of biomass briquettes in humanitarian, development and emergency contexts globally, and an accompanying Feasibility Study on the potential manufacture and use of biomass briquettes in Sudan.

Project Outputs

The consultant will:

- Conduct a literature review and desk study of biomass briquette programs previously and currently used in humanitarian, development and emergency contexts worldwide. Consultant will share findings. Timeframe for literature review and desk study will be about two weeks. This will include collecting information on:

    - project locations, inception, management and funding;
    - traditional cooking techniques and local staple foods in project location;
    - total project cost and total per briquette or per kg cost;
    - biomass ingredient(s) used and reasons for their selection;
    - production/manufacturing techniques used and materials required for production (presses; kilns, etc.);
    - project and production staff and training and/or distribution methodology;
    - acceptance of/opinions on briquettes from end users, including re: duration of briquettes during cooking; amount of/temperature of heat produced; amount of smoke produced, etc.;
    - duration of project and reasons for discontinuation where applicable;
    - any project evaluations or reports; and
    - interviews with project staff and end users where possible

- Undertake field work in Sudan to investigate the potential for manufacture and use of biomass briquettes. The field work in Sudan will last four weeks and will include:

    - interviews of Khartoum and Juba-based officials from the Department of Forestry; NGOs and UN agencies; university staff; agronomists; foresters; and other charcoal or biomass briquette manufacturers;
    - an overview of the suitable vegetation and production skills, capacity and machinery available in South or East Sudan for the large-scale manufacture of briquettes;
    - an overview of the potential scale of production of briquettes in South or East Sudan (including its impact on the type of technology selected; cost; necessary skills training; amount of electricity or other power source potentially needed, etc.);
    - potential impact of large-scale biomass briquette manufacture on the local and regional economy and environment;

  - an overview of transportation options and cost for shipping briquettes from South or East Sudan to Darfur;
  - interviews with Darfur-based government officials; UN and NGOs staff; IDP camp management officials and other relevant individuals and agencies re: potential for distribution and large-scale use of biomass briquettes in IDP settings in Darfur;
  - interviews with local government officials, local and national NGO staff re: the types of stoves that would be needed for use of biomass briquettes; the availability of such stoves locally and/or availability of sufficient materials and production skills locally; and
  - interviews and focus group discussions with potential end users re: any previous experiences they may have had with biomass briquettes; their opinions on the use of briquettes; specific cooking preferences, needs and techniques (time, temperature, flexibility, etc.); local staple foods, etc.

- Write a report including key findings and recommendations on the manufacture and use of biomass briquettes in Sudan. The recommendations of the report will be focused on which type of briquette/briquette technology(ies) may warrant further research for potential manufacture and use in Sudan. A secondary review may then been suggested to examine social soundness issues in more depth (including the effect of the use of briquettes in IDP settings on relations with host communities; the impact of use on the environment; and effect of use of biomass briquettes in household settings (indoor air pollution, etc.)). The timeframe to write the report should take approximately two weeks.

Conclusion

Although various options for cooking fuel have been developed and used in various humanitarian and rural development context globally, few such options have been sufficiently tested for use in Sudan. The protection, health and environmental consequences of not addressing the need for alternatives to firewood are great. The current feasibility study will assist the larger humanitarian community in understanding the options available to them for responding to and preventing further risk.

Annex II: Timeline of Site Visits and Activities

A) Visit to Red Sea state

Date	Site and activity
20/09/2008	Travel to Portsudan
21/09/2008	Meeting with OXFAM staff
25/09/2008	Travel to Tokor and Khor Baraka, Meeting with Tokor meeting with Locality authorities
25 - 26 /09/2008	Meetings with charcoal makers in Khor Baraka area
28/09/2008	Meeting with stakeholders at OXFAM

B) Visit to Southern Sudan, Juba

Date	Site and activity
18/10/2008	Travel to Juba, meeting with IRC - Juba
20/10/2008	Meeting with IRC - Juba
21/10/2008	Juba University, Meeting with Prof. ----
22/10/2008	Ministry of Agriculture and Forests: Meeting Mr. --------
23/10/2008	Ministry of Agriculture and Forests: Meeting with Mr. Justin Sebit, Plantation Manager, Kagulo Central Equatoria state Forest Department: Meeting Mr. ------, and mr. Justin John , Manager of Tandilo plantation
24/10/2008	Ministry of Agriculture and Forests: Meeting with Mr. Bullen Kenyi, Deputy Forest Director FAO: meeting with Mr. -----
24/10/2008	Central Equatoria state Forest Department: Meeting Mr. Issac Lado, Director general Central Equatoria Forests
25/10/2008	Travel to Khartoum

C) Visit to Kassala State

Date	Site and activity
08/11/2008	Travel to Kassala
09/11/2008	Meeting with practical Action staff
10 – 14/11/2008	Working with charcoal makers in Deblewet area
12/11/2008	Meeting with FNC Kassala
15/11/2008	Travel to Khartoum

D) Visit to Darfur

Date	Site and Activity
A) El Fasher (from 20 to 30 November 2008)	

20/11/2008	Travel to El fasher
23/11/2008	- Al Salam IDP camp - FGD with men group - Al Salam IDP camp – FGD with women group - Al Salam IDP camp – FGD with women group –Users of and/or received Kerosene wick stoves - Al Salam IDP camp – casual interviews with women at a water point - Al Salam IDP camp – Casual interview with Sheiks group at Chief Umda house - Al Salam IDP camp – FGD with women group – Users of LPG
24/11/2008	- Al Salam IDP camp – FGD with Community leaders, Umdas - Al Salam IDP camp – FGD with women group - Al Salam IDP camp market – interview with firewood retailers - Meeting with Practical Action and Women Associations Network
25/11/2008	- Abu Shauk IDP camp – interviews with firewood and charcoal traders in Abu Shauk central market - Abu Shauk IDP camp – FGD women group, OXFAM Women Health Committee in Abu Shauk - Abu Shauk IDP camp – FGD with Sheeiks
26/11/2008	- Abu Shauk IDP camp – Interviews with women working at OXFAM center in Abu Shauk - Abu Shauk IDP camp – FGD with women group - Abu Shauk IDP camp – FGD with women group, users of LPG - Abu Shauk IDP camp – FGD with Umdas
27/11/2008	El Fasher – Meeting with FNC director El Fasher – Meeting with FAO director Al Fasher – Meeting with OXFAM USA and SAG Al Fasher – Meeting with Rural El Fasher Development Network Al Fasher – Meeting with CHF
B) Nyala (from 30 November 2008 to December 4, 2008)	
30/11/2008	Nyala- Meeting with OXFAM livelihood Darfur Coordinator Nyala- Meeting with OXFAM – Nyala livelihood program staff Nyala – Meeting with FAO
01/12/2008	- Kalma camp – Interview with men - Kalma camp – FGD with women group - Kalma camp – FGD with women group, Firewood Committee - Kalma camp – FGD with men group
02/12/2008	Nyala – Meeting with OXFAM area manager Kalma – meeting with representative of Umdas
03/12/2008	- Nyala – Stakeholders meeting
C) Kass (from 20 to 24 December, 2008), 18 Dec. – Khartoum - Nyala	
21/12/2008	- Kass – meeting with OXFAM area manager - Kass – meeting with OXFAM livelihood program team

	- Kass – FGD with women group at Al Beitary camp - Kass – FGD with Community leaders at Al beitary camp - Kass - Interview with firewood collectors, donkey cart
22/12/2008	- Kass – Meeting with FNC - Kass – FGD with women group at Gemeiza camp - Kass – FGD with women group - Kass – Interview with firewood retailers - Kass – Interview with firewood collector, donkey cart
23/12/2008	- Kass – FGD with Community leaders, Sheiks - Kass – Meeting with CHF - Kass – meeting with CARE
24/12/2008	- Return to Nyala

E) Meetings in Khartoum, mainly at FNC

- Dr. Talaat, Mesquit program manager
- Mr. Abdelhamid Adam Hamid, Head of Investment Department