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Colofon

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Executive summary

Charcoal production from wood is an important cause of deforestation, one of the most urgent environmental problems of Africa. To date experience with the use of wood charcoal alternatives, produced from feedstocks such as charcoal dust, harvest residues, processing residues and invasive species, has been limited. Its production requires additional techniques, investments and an organisation structure that needs to compete with the existing, usually informally organised charcoal sector.

The project 'Pilots and assessment of alternative feedstocks for charcoal' has resulted in a report and a decision support tool aimed at facilitating the design of an alternative charcoal supply chain. The alternative charcoal tool (ACT) consists of four parts: feedstock selection, market selection, technology selection and production costs determination, and can be found [here](#).

This report presents background information accompanying the ACT, including an overview of alternative charcoal production technologies and a description of three supply chains presented as case studies. The case studies cover the feedstocks charcoal dust, cotton stalks and bamboo and present, in a harmonised manner, information collected from feasibility studies and established business operations, and discuss the collection, production, logistics, costs, sales, marketing and sustainability of alternative charcoal (briquettes). Although almost all data concerns projects and businesses in Africa, in some cases relevant data from elsewhere has been used as well. The main results are summarised below.

Feedstock selection: Biomass has a wide range of forms and characteristics such as composition, moisture content, morphology (shape and size), bulk density etc. that makes a feedstock more or less suitable for alternative charcoal production.

Figure 1 Charcoal production chain of the selected feedstocks

Supply chain	Energy crops	Harvest residues	Processing residues	Charcoal dust
Feedstock production				
Harvest				
Collection				
Transport				
Drying				
Storage				
Carbonization				
Sizing				
Briquetting				
Transport				
Sales				

Furthermore, biomass can be classified as energy crops, harvest residues, processing residues and dust that have different supply chains. See Figure 1. Generally speaking the biomass type with the shortest supply chain will have a logistic advantage over other types of biomass feedstocks as each step in the supply chain represents efforts, money and possible complications. Furthermore,

the biomass classes have some specific sustainability risks. For instance, the use of energy crops and harvest residues could potentially lead to additional extraction of nutrients and carbon from the soil. Processing residues are already extracted from the soil (as integral part of the crop), and usually do not lead to additional extraction of nutrients compared to current practise.

Feedstock availability: Charcoal dust, cotton stalks and bamboo are available in significant quantities across Sub Sahara Africa and find few alternative uses. Therefore, there is a large (technical) potential to produce alternative charcoal from these and other biomass resources. There is some long term experience with the briquetting of charcoal dust, in particular in East Africa (e.g. Kenya). There is no long term experience with carbonisation and briquetting of cotton stalks or bamboo at a commercial scale in Africa.

Feedstock collection: Charcoal dust is available as leftover at (wholesale and retail) charcoal trading sites. Cotton stalks are harvest residues available in the cotton growing fields. Bamboo is available directly from the growing areas (natural stands and -to a little extent- plantations) or, as a processing residue. With the exception of bamboo processing residues, in all cases the resource is dispersed and collection is labour intensive, which is both an opportunity (to generate employment) and a challenge (to organize effectively). To organise the collection of biomass effectively it is recommended to collaborate with women groups, communities or other self-help organisations.

Carbonisation: Charcoal-making from alternative non-wood feedstocks usually involves a carbonisation and a briquetting step using a binder. Four main categories of small-scale and semi-industrial charcoal kilns can be identified: earthen kilns, brick kilns, metal kilns, and semi-industrial retorts. Within each category kilns of different models and capacities are available. Kiln capacities vary from a single drum (200 litres) to several hundred m³ (in case of the Missouri kiln). Portable metal kilns are particularly practical when biomass has to be collected from a wide area, such as e.g. cotton stalks. Brick kilns have a longer lifetime and allow better process control. The Adam retort, a recent development, tries to combine these advantages. The highest and most consistent carbonisation efficiencies can be achieved using (semi-)industrial retorts but due to their high investment costs these are often not affordable in the African context. The morphology of the biomass can also limit the suitability of a certain type of carbonisation kiln. To achieve higher conversion efficiencies and improved environmental performance the implementation of chimneys and of tar and methane recovery facilities is worth investigating.

Briquetting: Briquetting technologies are available in a wide capacity range, from very small to very large and with varying degrees of mechanization and automation. Main categories identified are manual techniques, small-scale electrical techniques and medium-scale electrical techniques. Agglomeration is the main technology used for producing charcoal briquettes from cotton stalks, as they give high quality briquettes, require a relatively low investment, and are therefore suitable for small industrial applications. Since charcoal is a material totally lacking plasticity it needs addition of a sticking or agglomerating material to enable a briquette to be formed. The binder should preferably be combustible. Clay is often used as binder in small-scale applications; starch, molasses and gum Arabic in semi-industrial applications.

Logistics: due to the material already being carbonized, charcoal dust has the shortest and simplest production chain of the three types of biomass feedstock considered. As a result this is normally also one of the most cost-effective options to produce alternative charcoal for energy purposes. This is reflected in the significant number of both small-scale and (semi-)industrial scale initiatives to establish a livelihood or a business from alternative charcoal production using charcoal dust as raw material. The case of Chardust Ltd. in Nairobi is particularly successful and is often used as showcase for replication elsewhere (with varying degrees of success).

Seasonality: the seasonal availability of cotton stalks (4 months/year) and green bamboo (difficult to collect during the wet season) makes year round operation of an alternative charcoal plant based on these fuels difficult to achieve. Long term storage of (raw or carbonized) feedstock is necessary. Alternatively the plant can be operated seasonally as well.

Sustainability: Using an alternative source of biomass, instead of unsustainably harvested wood, involves various environmental advantages (e.g. less forest depletion). However, also alternative feedstocks can have sustainability risks, such as additional extraction of nutrients and carbon from the soil. The use of improved kilns, rather than traditional kilns, with improved carbonization efficiency leads to fewer emissions of greenhouse gas. Equipping the kilns with facilities for tar recovery and the reduction of smoke further reduces environmental impacts. Protection should be provided to prevent workers for the dangers of inhaling dust and to prevent fires. There is a risk of child labour especially in feedstock collection.

Charcoal products: Charcoal dust briquettes are not necessarily a direct substitute for lump charcoal. There is a trade-off between price and performance. Depending on such aspects as the quality of the charcoal feedstock (e.g. ash content, degree of contamination with soil), the binder and the operating pressure applied charcoal briquettes of various quality levels (low, regular, premium) can be produced. Secondary conversion into higher value products (e.g. activated carbon) is possible if a suitable feedstock like bamboo is thoroughly carbonised in a brick kiln.

Business potential: the wood that is used for regular lump charcoal is often not being paid for, but taken for free instead. The market price for charcoal depends to a significant extent on the charcoal transportation costs, which will be high in case of long transport distances. The fact that the wood price and externalities (feedstock depletion, deforestation, greenhouse gas emissions, etc.) are not being factored in the market price of wood charcoal make direct price competition for alternative charcoal a challenge. The main competitive advantage for alternative charcoal may be that it can often be produced closer to urban demand centres, with lower transportation costs associated. To minimise transportation costs the location of the carbonization and briquetting operations need to be selected carefully.

To reduce production costs a (semi-)industrial scale charcoal operation is best run (initially) as a side business, with the main business being capable of absorbing

costs associated with e.g. overheads and the possibility of sharing staff, production and transport facilities. (Owen, 2012) suggest that charcoal briquettes production can only be viable in African countries where charcoal is relatively expensive. He estimates that the minimum wholesale prices would have to be some \$200 per ton (for packaged charcoal). This rules out many African countries as candidate manufacturing sites.

Other viable business opportunities may be to produce charcoal briquettes for the export (barbecue) market, or to produce activated carbon and other higher value charcoal products for the local market using bamboo as feedstock. The first is an established, highly-competitive international business, whereas the second is largely undeveloped in Africa. In the absence of a developed market for industrial (higher-value) charcoal products the use of (bamboo)charcoal as a source of energy cooking fuel may help to get the market started.

Final remarks

Although the experience to date is mixed at best, alternative charcoal briquettes can offer a significant contribution to energy supply in African countries in the longer run, in particular in those markets where wood charcoal prices are somewhat higher.

The role of sustainable charcoal production from alternative feedstocks can be supported by scanning of potential markets across Africa, policies that support charcoal prices reflecting the real costs of wood, optimisation of feedstock collection and storage, technology transfer, the use of carbonisation technology with (further) improved environmental performance, the collaboration with stove initiatives, the generation of income from (voluntary) carbon credits and active support of alternative charcoal businesses.

The Alternative Charcoal Tool (ACT) developed in the frame of the current assignment is a useful instrument especially for potential investors, NGOs and policy makers, recommended for initial assessments of the suitability of a biomass feedstock for charcoal production, technology selection, market selection and to determine production costs.

1 Introduction

1.1 Background

At least 80% of the African population depends on traditional biomass resources such as charcoal and firewood for household energy use. Most charcoal is produced in forests near urban areas, where most charcoal consumption takes place. Charcoal production is an important cause of deforestation, one of the most urgent environmental problems of Africa.

One of the solutions (Vos and Vis 2010) is to promote the use of alternative feedstocks for wood charcoal. Examples are charcoal dust, harvest residues, processing residues and invasive species. So far, the use of wood charcoal alternatives has been limited since its production requires additional techniques, investments and an organization structure that needs to compete with the existing, usually informally organized charcoal sector that requires few investments.

The project 'Pilots and assessment of alternative feedstocks for charcoal' has the objective to determine conditions and strategies to increase the use of the most promising alternative feedstocks to wood charcoal.

The project has resulted in a **decision support tool** in which other supply chains can be designed. The tool can be found [here](#). The alternative charcoal tool (ACT) consists of four parts:

- Feedstock selection
- Market selection
- Technology selection
- Production costs determination.

This report presents accompanying background information, including an overview of alternative charcoal production technologies and a description of three supply chains of alternative charcoal production covering charcoal dust, cotton stalks and bamboo respectively. This allows studying the differences and similarities between different feedstocks in more detail.

1.2 This report

This report has been divided into two parts. Part A presents information on feedstock and technology selection. Part B shows three cases of supply chains in which different alternative feedstocks are applied in different settings.

Part A – feedstock and technology selection

Chapter 2 shows important issues related to feedstock selection. In chapter 3 an overview is presented of alternative carbonisation and briquetting technologies used in African countries, providing background information to the reader who is not familiar with this subject.

Part B – examples of alternative charcoal supply chains

The utilisation of **charcoal dust** is further elaborated in Chapter 4. Since charcoal dust is already carbonised, the supply chain is relatively short, it is expected to be the most viable alternative feedstock to wood charcoal. The availability of charcoal dust is directly linked to current wood charcoal production and is therefore limited. Other alternative feedstocks will be needed to substitute wood charcoal in the long run.

Cotton stalks (chapter 5) are available in large quantities and have no or few alternative uses. Cotton stalks are usually burnt in the fields to avoid cotton pests. A weak point is the relatively long supply chain associated with harvest residues. Also the bulk density is relatively low.

Alternative charcoal production using **bamboo and bamboo residues** is discussed in chapter 6. Bamboo for material and biofuel production forms a new and upcoming market. It is expected that technologies and practices common in Asia will find application in bamboo-rich African countries. Bamboo and bamboo processing residues are very suitable for carbonisation.

Figure 2 Charcoal dust, cotton stalks and bamboo



PART A: FEEDSTOCK AND TECHNOLOGY SELECTION

2 Feedstock selection

Biomass has a wide range of forms and characteristics such as composition, moisture content, bulk density etc. Biomass can be extracted from different supply chains, i.e. as primary (energy) crop, harvest residues, processing residues, etc. A special case is charcoal dust that can be collected as a residue from charcoal production and handling. These biomass characteristics and supply chains (also called biomass classes) determine to a great extent the opportunities of a successful business case. Feedstock selection is therefore considered an essential success factor in the establishment of a competitive charcoal production chain. The main factors identified are described below.

Biomass classification – length of the supply chain

Figure 3 provides a classification of feedstocks based on the length of their supply chain from feedstock to end product. Charcoal dust has the shortest supply chain, only a collection and briquetting step is needed to produce charcoal briquettes. On the contrary, the charcoal production chain based on the growing of dedicated energy crops involves a considerable number of steps. Each step in the supply chain represents efforts, money and possible complications, and this indicator shows that charcoal dust and processing residues have a logistic advantage over other types of feedstocks.

Figure 3: charcoal production chain of the selected feedstocks

Supply chain	Bamboo energy plantation	Harvest residues	Bamboo processing residues	Charcoal dust
Feedstock production				
Harvest				
Collection				
Transport				
Drying				
Storage				
Carbonization				
Sizing				
Briquetting				
Transport				
Sales				

Furthermore, the use of energy crops and harvest residues could potentially lead to additional extraction of nutrients and carbon from the soil. Processing residues are already extracted from the soil (as integral part of the crop), and usually do not lead to additional extraction of nutrients compared to current practise.

Sustainable biomass availability

Feedstock availability is important as it indicates the total potential impact that carbonisation of this feedstock could have. A rough calculation of feedstock availability on a national basis can be made in a straightforward way, based on FAO statistics and residue-to-crop factors. To produce biomass availability data on a regional or local level can be more time consuming.

The share of the feedstock that is currently used for applications such as food, feed, fibre etc. is relevant as well. This type of information is usually available in a more qualitative way. Quantification of the share of biomass that is still available for charcoal production can be more difficult and time consuming. A practical approach to avoid competition with other uses is to check the market price of the residue and to avoid the use of biomass that can be used for food and feed production.

Bulk density

The bulk density of biomass determines how much biomass can be transported in a single load (e.g. truck load). Of course the bulk density of low density feedstocks can be increased using various techniques; however, this requires an extra (logistical) effort, compared to high density feedstocks.

Moisture content

In case the feedstock has a low moisture content, an initial drying step can be avoided. Furthermore, transport of very wet biomass should be avoided, as this contributes to the logistic costs.

Shape and size

The shape and size of biomass is relevant for the composition of the charcoal production chain (see also chapter 3.) If the biomass feedstock has a large size, the charcoal could potentially be sold as 'lump charcoal' without briquetting step, which would reduce production costs. In case the particle size is very small, like a powder, direct carbonisation could be challenging and a briquetting step before carbonisation could be considered. If the feedstock is already converted into charcoal, like in case of charcoal dust, the carbonisation step can be skipped.

State of technology

Before selecting a certain feedstock, it is advisable to check whether experience has been with carbonisation of the feedstock. If no information can be found (on internet or elsewhere) on the use of the specific feedstock and when several other indicators are *negative*: i.e. low bulk density, high moisture content, low availability, harvest residue etc. it is advisable to reconsider alternative charcoal production with the selected feedstock. If the other indicators are *positive*, it is worth to further investigate a possible business case.

Conclusion

The above described how biomass feedstock indicators can be used to evaluate the suitability of a feedstock for alternative charcoal production, covering feedstock availability, sustainability, logistics, and production technology. Especially logistic indicators are crucial, i.e. length of supply chain, bulk density and moisture content. The evaluation of feedstocks is also part of the **decision support tool** that can help to rank the suitability of different feedstocks.

3 Carbonisation & briquetting technologies

3.1 Carbonisation technologies

3.1.1 Introduction

Charcoal is the solid residue remaining when wood species, agro-industrial wastes and other forms of biomass are carbonised or burned under controlled conditions in a confined space such as a kiln. Charcoal-making is the transformation of biomass through the process of slow pyrolysis. The process takes place in four main stages governed by the temperature required in each stage (Seboka 2009):

Stage 1: drying (110-200°C)

Air-dry wood contains 12-15% of adsorbed water; after the first stage all the water is removed. This stage requires heat input, which is provided by burning a fraction of the biomass that would otherwise have been converted into charcoal.

Stage 2: pre-carbonisation stage (170-300°C)

During the pre-carbonisation stage endothermic reactions take place resulting in the production of some pyrolytic liquids such as methanol and acetic acid, and a small amount of non-condensable gases such as carbon monoxide and carbon dioxide.

Stage 3: carbonisation (250-300°C)

In this stage, exothermic reactions take place and the bulk of the light tars and pyrolytic acids produced in the pyrolysis process are released from the biomass.

Stage 4 carbonisation (>300°C)

During this stage, the biomass is transformed into charcoal, characterised by an increase in the fixed carbon content of the charcoal. The charcoal does, however, still contain appreciable amounts of tarry residue, together with the ash of the original biomass.

It is important to notice that the processes in stage 1 and 2 demand heat, while in stage 3 and 4 surplus heat is produced.

The following main types of charcoal kilns and more advanced retorts can be distinguished: earthen kilns, brick kilns, metal kilns, semi-industrial retorts and industrial retorts. They are presented in the next sections (based on (Seboka 2009) (Foley 1986) (FAO 1983) and others).

3.1.2 Earthen kilns

Earth mound kiln

This type of kiln dominates charcoal production in Africa. The biomass is gathered, cut to size, and placed on the ground. The mound or pile of biomass is covered with earth. The earth forms the necessary gas-tight insulating barrier behind which carbonisation can take place without leakage of air, which would allow the charcoal to burn to ash. The kiln is fired and the biomass heats up and begins to pyrolyse. The kiln is mostly sealed, although a few air pockets are initially left open for steam and smoke to escape. As the kiln emissions change colour, the charcoal producer may seal some air pockets. When the production process has ended, the kilns are opened or dug up and the charcoal is removed. The conversion efficiency of this type of kiln is typically about 10-15%.

Improved earth mound kiln (Casamance kiln)

The Casamance kiln was developed in Senegal and is an earth mound kiln equipped with a chimney. This chimney, which can be made of oil drums, allows a better control of air flow. In addition, the hot fumes do not escape completely but are partly redirected into the kiln, which enhances the yield.



Figure 4 Casamance kiln. Source: Energypedia <https://energypedia.info/>

Due to this reverse draft carbonisation is faster and more uniform giving a higher quality of charcoal and efficiency. Disadvantages of this kiln type are that it requires some capital investment for the chimney and it is more difficult to construct.

Earth pit kilns

Earth pit kilns form another way of making charcoal used in many parts of the world. Pit kilns are preferred where the soil is well drained, deep and easy to excavate. The earth is excavated to the required depth, width and length. Wood is heaped into the trench, making provision for air passages. The wood is loaded horizontally into the pit and covered with grass, leaves and then earth to ensure that it is airtight and that it has sufficient thermal insulation. The pit is then left for about 4 days to allow cooling to take place; the complete process takes about 7 days. Charcoal yields from such pits are low (10-15%). Ventilation may be difficult to control and frequently carbonisation is incomplete, producing only low quality charcoal. Furthermore, pit kilns are labour intensive since a pit must be dug into the ground.

Unlike woody biomass, agricultural residues such as cotton stalks, or process residues such as sawdust and coffee husk, cannot be carbonised using earth mounds or pit kilns. Due to their physical characteristics (shape, size and bulk density), such biomass materials tend to flare up and hence other carbonisation technologies with better air control need to be employed.

3.1.3

Brick kilns

Like earthen kilns, brick kilns are stationary kilns. They are suitable for semi-industrial production of charcoal. Brick kilns come in many designs and sizes, and have an efficiency of 25% up to 30%. Types of brick kilns include the Brazilian beehive kiln, the Argentine half-orange kiln, the Japanese Yoshimura and Iwate brick kiln, the European Schwartz kiln and the Missouri kiln.

Figure 5 Beehive kilns in Minas Gerias, Brazil. Source: BTG



Brick kilns have generally a substantial capacity, in the case of the Missouri kiln sometimes as much as hundred m³. The carbonisation time is up to 28 days, which is relatively long. The stationary nature of brick kilns has the disadvantage that the biomass has to be collected and transported to the kiln. An advantage is that tar recovery is possible: (Foley 1986) describes a tar removal method from beehive kilns with a recovery rate of 120 kg tar/tonne charcoal; (Pari, Hendra, and Setiawan 2004) show the collection of wood vinegar in a Yoshimura kiln by leading the pyrolysis smoke through bamboo poles. Brick kilns have a lifetime of up to 10 years; the investment costs are estimated at 500 Euro or more, depending on the type and size of kiln and prices of local materials (bricks, iron, transport costs). These investment costs are modest compared to (semi-)industrial retorts, but are still high for most small business in developing countries.

3.1.4 Metal kilns

The development of demountable metal kilns has been described in detail in (Foley 1986). Early reports on metal kilns date back to the 1890s, and have resulted in robust metal kilns like the Uganda Mark V kiln (1960s) and the TPI kiln (1970s). Furthermore, drum charring units have been developed, made from 200 litre oil drums. Because of the controlled air supply and gas flows during the carbonisation process, metal kilns are able to carbonise all kinds of non-wood materials into charcoal at a reasonably high efficiency of 20-30%. Most metal kilns are transportable, which is very practical in case of biomass that needs to be collected from large areas. The total production cycle of the carbonisation process takes only 2-3 days. The biomass must be cut and/or split to size to fit into the kiln.

Figure 6 the Mark V (left) and TPI metal kiln (right)



If the metal kiln has a bottom plate, the charcoal produced in the process can be recovered without mixture with earth or sand. Metal kilns, if designed to shed water from the cover, can be operated in areas of high rainfall, providing the site has adequate drainage. The capital costs of metal kilns are as low as zero or so for a very simple metal kiln made out of three oil drums without chimney and around 1000 Euro for more advanced kilns, while the lifespan of 2-3 years is relatively short. Nevertheless, since efficiency is high and carbonisation is very quick, metal kilns can be a suitable technology. Recovery of tars in transportable metal kilns is not common, but possible.

3.1.5 Semi-industrial charcoal retorts

Improved Charcoal Production System (Adam-retort)

The Improved Charcoal Production System (ICPS), also called Adam-retort after its German inventor, may be presented as an example of semi-industrial retort technology. The kiln returns the wood gases back to the carbonisation chamber, burns a higher proportion of the tar components and uses the heat for the carbonisation process. Efficiency can be as high as 40 % and noxious emissions are reduced by 70 %. In addition the production cycle is completed within 24 to 30 hours. The retort is suitable for semi-industrial production. The kiln is stationary, indicated investment costs are about 300 to 400 Euro (comparable to brick kilns). The Adam-retort has been introduced in Kenya on a pilot basis. Currently, the kiln is further refined in order to make it portable.

Figure 7 the Improved Charcoal Production System (ICPS) or Adam retort



Continuous Carbonisation System for Biomass (CCS)

The CCS system consists of a large tower (height 7 m, length 3 m) in which the biomass falls in through the chimney and is dried and pre-carbonised while falling through the hot volatiles towards a carbonisation zone in the middle of the tower (an area with limited air supply). The CCS is a viable carbonisation system for light biomass such as coffee hulls, rice husks, shredded biomass and wood chips. Investment costs are approximately 20,000 Euros.

Advanced industrial retorts, applying separate combustion chambers, may achieve efficiencies of up to 40%. Due their high investment costs (at least USD 100,000 for a batch-type twin retort; and several million USD for a large continuous retort) these are not discussed further in this report.

3.1.6 Summary of carbonisation technologies

Table 1 shows an overview of the main characteristics of the main charcoal production technologies. Metal kilns are suitable for many alternative feedstocks, including those with a low bulk density. Stationary brick kilns and retorts have better possibilities for recovery of tars though. Earth kilns are generally not suitable for carbonisation of alternative feedstocks.

Table 1 Overview of main characteristics of carbonisation technologies

Technology	Earth kiln	Brick kiln	Metal kiln	Semi-industrial retort
Kiln models (examples)	Traditional earth mound, Improved earth mound (Casamance), traditional earth pit, improved pit kiln	Brazilian beehive kiln, Argentine half orange kiln, Japanese Yoshimura and Iwate brick kiln, European Schwartz kiln, Missouri kiln etc.	Drum charring unit, Mark V metal kiln, TPI metal kiln	CCS retort, Adam retort
Labour intensity	High	Medium	Medium	Low
Capital intensity	Low	Medium/High	Medium	Medium/High
Mobility	Stationary	Stationary	Portable	Stationary
Lifespan	Pit kilns can be re-used	6-10 years	2-3 years	Few years (Adam retort)
Investment costs (indicative)	Minimal	USD 500 and up	USD 120 (3 drums); USD 1000 (Mark V/TPI)	USD 500 (Adam retort) to 25000 (CCS retort)
Capacity (kiln volume)	Location-specific and very flexible, from as little as 2 m ³ (small kiln) to 35 m ³ or more (large kiln)	Model-specific, e.g. 45 m ³ for the Beehive and hundreds of m ³ for the Missouri kiln	From 0.2 m ³ (single drum) to 7 m ³ (TPI kiln)	2-10 m ³
Carbonisation time	From 1 week (small kiln) to several weeks (large kilns); including cooling time	Can be rather long (21-28 days); shorter for very small kilns	2-3 days	1-2 days
Controlability	Very poor control (somewhat better in Casamance kiln)	Better process control	Better process control	Better process control
Efficiency (yield)	Yields are erratic; typical values 10-15% (small pit kilns); 20% (Casamance kiln)	25-35%	20-30%	30-40%
Recovery of tars and gasses	No	Possible	Possible	Yes
Advantages	-	-	Can be operated throughout the wet season	Adam retort is simple and cheap to construct.
Disadvantages	Unlike woody biomass, residues such as cotton stalks, sawust and coffee husks, cannot be carbonised using earthen kilns due to their physical characteristics (shape, size, bulk density)	In small kilns biomass must be cut and/or split to size to fit into the kiln	Biomass must be cut and/or split to size to fit into the kiln	Limited field experience with Adam retort which is rather innovative

For further reading, several sources can be consulted. The classic '*Charcoal making in developing countries*' (Foley 1986) is still very worthwhile to read. A brief summary of charcoal production technologies, its advantages and disadvantages can be found in (Seboka 2009). Furthermore, other sources like (Pari, Hendra, and Setiawan 2004) present interesting reviews of properties of different charcoal production technologies.

3.2 Briquetting technologies

Depending on the type of biomass that has been carbonised, subsequent sizing (milling) and briquetting may be needed to produce charcoal briquettes. As charcoal is highly abrasive, modern large-capacity briquetting equipment typically used for briquetting of non-carbonised biomass such as hydraulic piston presses and heated or conical die screw extruders are not suitable for briquetting of charcoal (Seboka 2009). Robust technology is called for instead. The main briquetting technologies suitable for producing charcoal briquettes, varying from very small to medium capacity, are introduced below.

3.2.1 Hand presses

Briquetting can be done by hand, using a simple mould and hammering the charcoal dust together. D-Lab of the MIT developed a tool that costs about 2 USD, and can produce 10-12 briquettes per minute (Doe 2009)¹. Hand briquetting of honeycomb briquettes (see section 3.2.5) has been observed as well. There are a considerable number of designs that have been disseminated across rural areas in developing countries lacking electricity supply. Hand briquetting requires only a low investment but is very labour intensive.

3.2.2 Screw extruders

A simple screw extruder, like the one used to mince meat, can be applied to produce charcoal briquettes. (Sugumaran and Seshadri 2010) presents an adjusted meat mincer with electromotor that can produce 10-15 kg briquettes/hour and costs around 300-350 Euro. When or where no electric power is available the technology may be operated manually. Especially when hand-operated the technology is still rather labour intensive.

3.2.3 Agglomerators

Another small-scale briquetting processes applied in several developing countries is the agglomeration technology. The charcoal is milled to powder, binders are added, the components are mixed together, and the mix is then agglomerated. Agglomeration technology involves size enlargement of a nucleus/balls of charcoal formed within a rotating cylinder. Agglomerated charcoal briquettes are produced using a motor-driven agglomerator, the typical nominal capacity of which is 25-50 kg/hour. Agglomerated charcoal briquettes are spherical and typically have diameters between 20-30 mm. The briquettes can be used for household cooking as well as for fuelling industrial furnaces. Agglomerated briquettes are stronger than most other briquette types (Visser 2012), (van Essen 2012).

¹ See www.youtube.com/watch?v=LqI63IEg3MM&feature=related for a demo of this technology

Figure 8 Charcoal briquetting using a tool developed by D-Lab (Doe 2009)



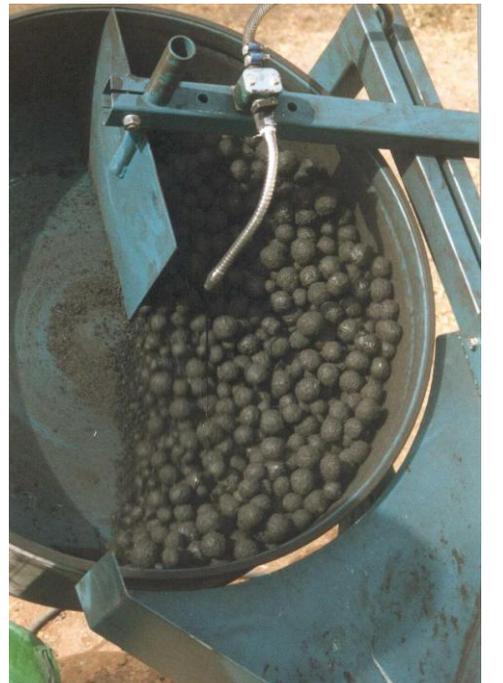
Figure 9 Meat mincer based briquetting machine (Sugumaran and Seshadri 2010)



Figure 10 Roller press used by Chardust Ltd. in Kenya (Chardust Ltd. 2004)



Figure 11 Agglomerator developed by BTG



3.2.4 Roller presses

Roller presses are considered the world standard technology to produce ovoid (pillow-shaped) charcoal briquettes from a variety of biomass types. In a roller press, a mixture of charcoal and binder is fed to the tangential pockets of two rollers to produce briquettes. The smooth production of briquettes using this technology requires high-quality rollers with smooth surfaces on which the briquettes are shaped. The type of roller determines the shape of the briquettes. Currently, roll presses available in developed countries have production capacities of 1 t/hr and more. The 1 tonne/hr capacity press with controlled feeding device costs about € 250,000. Much cheaper roller-type charcoal briquetting machines can be sourced in India and China: (Seboka 2009) indicates that a roller press with a capacity of 1.5 tonne/hr costing € 15,000 can be found in India.

3.2.5 Hydraulic press

The honeycomb briquetting machine is an example of a hydraulic press. By changing the mould of the hydraulic press a different shape of briquette can be produced e.g. hexagonal. The technology is cost-effective and uses simple mechanical and electrical parts to produce uniform, highly-packed briquettes in a uniform mode, suitable for small and medium sizes. Like with agglomeration, milled charcoal and binder material form the base materials.

Figure 12 Honeycomb briquetting press. Source (Wang 2011)



Honeycomb briquettes have excellent burning qualities as they burn from the inside out through small holes so the energy release is gradual and uniform, giving a blue flame. Consumers use small-size beehive briquettes for short time cooking or boiling in order not to waste the briquette; large-size beehive briquettes are used for long-time cooking. The principal drawback of this is that it requires a special stove (beehive stove), which is readily available in Vietnam, China and Thailand, but is less well-known in Africa (Seboka 2009).

3.3 Summary of briquetting technologies

Table 2 presents an overview of the main characteristics of the main charcoal briquetting technologies.

Table 2 Overview of main characteristics of briquetting technologies

Technology	Manual techniques	Small-scale electrical	Medium-scale electrical
Equipment types (examples)	Hand mould, Mould and hammer, Lever extruder, Manual screw extruder	Electrical screw extruder, agglomerator	Piston extruder, roller press (imported)
Labour intensity	Very high	High	Medium to low
Capital intensity	Low	Low to medium	Medium to high
Investment costs (indicative)	From a few USD to 150 USD	Few hundred to a thousand USD	Few thousand USD up to 20,000 USD (equipment sourced in Asia). (Much) higher for equipment imported from OECD countries
Capacity	Low (up to 6 kg/hr)	Few hundred to a thousand kg/day	Up to a few tonnes per day
Binder	Biomass feedstock specific. Often clay	Biomass feedstock specific. In extruder often clay. In agglomerator e.g. molasses	Biomass feedstock specific. Often clay. For premium briquettes higher quality binder is needed
Briquette shape	Various (e.g. sausage or beehive/honeycomb shaped)	Sausage (extruder); spherical (agglomerator)	Uniform highly packed briquettes. Piston press: shape depends on mould used
Briquette quality	Relatively low quality (not waterproof if clay is used)	Medium to high quality (equipment and binder specific)	Medium to high quality (binder specific)
Type of distribution	Selling to neighbours / own community	Selling in a few mixed market outlets	Organised retail network; regular customers
Advantages	Equipment can be produced locally	-	-
Disadvantages	Beehive briquettes require special stove	Local availability of binder for agglomerated briquettes may be limited	Beehive briquettes require special stove

3.4 Binders

Charcoal is a material totally lacking plasticity and hence needs addition of a sticking or agglomerating material to enable a briquette to be formed. The binder should preferably be combustible, though a non-combustible binder effective at low concentrations can be suitable. Below a number of binders are described briefly.

3.4.1 Clay

Clay has the advantage that in many areas it is widely available at practically no cost. (Chardust Ltd. 2004) (p 27) describes that 20 kg water, 7.5 kg clay and 42.5 kg carbonised sawdust was used to produce 50 kg of charcoal briquettes, which means that the end product contains around 15% of clay. Main disadvantage is that clay does not add to the heating value of the briquette; if a large amount of clay is used for briquetting the briquette will ignite and burn poorly or not at all. Furthermore, all clay added to the briquette will turn into ash. On the other hand briquettes with high ash content are reported to burn and glow long, which can be advantageous for specific applications like coffee making.

3.4.2 Starch

The most common binder is starch. About 4-8% (usually 5%) of starch made into paste with hot water is adequate (FAO 1983). Starch sources are commercial starch, rice powder, boiled rice water (rice starch), cassava starch and other materials (Foley 1986) (Seboka 2009) (MCRC 2008). The binder is mixed with water and heated for some time after which it is ready for mixing with the charcoal powder. Starch is preferred as a binder though it is relatively expensive. Because starch is a main food product as well, it is widely available and often promoted as a binder in low-tech carbonisation and briquetting projects (Doe 2009), (Sugumaran and Seshadri 2010).

3.4.3 Gum arabic

Gum arabic, also known as acacia gum, is a natural gum made of hardened sap taken from two species of the acacia tree; *Acacia senegal* and *Acacia seyal*. The gum is harvested commercially from wild trees throughout the Sahel. It is edible, used in syrup drinks like Coca Cola, and other traditional and modern industrial applications. Gum arabic is successfully being applied as binder for charcoal briquettes. Other gum types like gum obtained from *Bauhinia retusa* have been tested with good results as well (Foley 1986) (p 156). Arabic gum as binder does not emit heavy smoke, and no thermal treatment step is needed. Gum can be expensive, but lower grade qualities are expected to be affordable.

3.4.4 Molasses

Molasses is a by-product from the sugar cane industry. For each tonne of briquettes about 20-25% molasses is needed. Each unit of pure molasses is diluted with 2-3 units of water before entering the briquetting process. Briquettes made by molasses burn well, however the briquettes have an unpleasant smell during the initial phases of burning. To avoid this smell, the briquettes can be thermally treated before use, also called "curing", which is in fact a light torrefaction step. Molasses can be used as fodder and for ethanol production as well and needs to be purchased.

In some countries with low alcohol consumption, molasses was a waste product that was being dumped (van Essen 2012). At least it was possible to buy the molasses at a relatively low price (Visser, Vis, and Siemons 2002). Given the increased demand for molasses for fuel ethanol production, it is expected that the molasses prices will rise considerably.

3.4.5 **Wood tar**

Wood tars that arise during the carbonisation process could be recovered and used as a binder for briquetting. The recovery of tars helps to reduce the emissions to the air, but tar recovery technologies are only applied in stationary kilns and retorts. Briquettes made with wood tar require a full carbonisation step to avoid the emission of heavy smoke.

3.4.6 **Pitch**

Pitch is a very viscous liquid that remains after the distillation of wood tar or coal tar. Fossil pitch is used for the briquetting of fossil coal briquettes. Tar and pitch are often used interchangeably. However, pitch is considered more solid while tar is more liquid. Pitch could be used as a binder as well. Like wood tar, it requires re-carbonisation to avoid heavy smoke.

3.4.7 **Summary of binders**

Table 3 shows a summary of the main properties of the different binders. Starch is often used as binder in small scale projects as it is widely available and has good results, but it is also expensive. Highly plastic clays are cheap and suitable providing not more than about 15% is used. Molasses and gum arabic are often used in semi-industrial applications. Tar and pitch from coal distillation or from charcoal retorts have been used for briquettes but they must be carbonised again before use to form a properly bonded briquette. They are of good quality but costly to produce.

Table 3 Overview of properties of main binders

Binder	Clay	Starch	Gum	Molasses	Wood tar/pitch
Percentage of final product	15%	4-8%	<10% ^{a)}	20%	<10% ^{a)}
Price	Low	high	Medium-high	Medium-high	low-medium
Alternative uses	no	Food/feed	Food/feed	Food/feed	Energy
Contributes to calorific value of the briquette	no	yes	yes	yes	yes
Thermal treatment needed to avoid smoke	no	no	no	Preferably	yes
Increases ash content	yes	no	no	Yes	No
Waterproof briquettes	no	no	no	After curing	After curing

^{a)} Estimation BTG

All briquettes using hydrophilic binders (starch, molasses, gum, clay) are not waterproof and will disintegrate when they come into contact with water or stored under humid conditions. Obviously, this is more an issue in the tropical countries than in the Sahel. After thermal treatment the briquettes become water resistant. Thermal treatment also increases the strength of the briquettes, which is relevant especially if long distance transport is needed. However, thermal treatment of briquettes was reported only in cases when it was necessary to avoid unpleasant smoke, like with wood tar/pitch and to a lesser extent with molasses as binders.

PART B: EXAMPLES OF ALTERNATIVE CHARCOAL SUPPLY CHAINS

4 Charcoal dust

4.1 Introduction

Charcoal dust has the shortest supply chain; a briquetting step is all that is needed to produce charcoal dust briquettes. It is therefore regarded as one of the most promising feedstocks for alternative charcoal.

A number of commercial operators in Sub Sahara Africa have recognised the opportunity to salvage dust and to convert it into a commercially viable fuel (indicative production capacity between brackets):

- Chardust Ltd. in Nairobi, Kenya (2,500 tons/year). Has been in the business for over a decade, and employs some 80 people, Chardust Ltd may be the only sustainable charcoal dust operation at this scale in Africa.
- East African Briquettes Company in Tanga, Tanzania. A company based on the Chardust Ltd approach, established with support of Shell Foundation in 2005/2006 (approx. 700 tons/year).
- BRADES company in Saint-Louis, Senegal (approx. 100 tonnes/year).
- A charcoal dust briquetting company in Kigala, Ruanda (currently dormant/mothballed).

In addition, more and more small-scale operator associations are entering into the charcoal dust briquetting business. (Njenga et al, 2013) describes experiences of community self-help groups producing charcoal fuel briquettes from charcoal dust in poorer neighbourhoods of Nairobi for home use and sale.

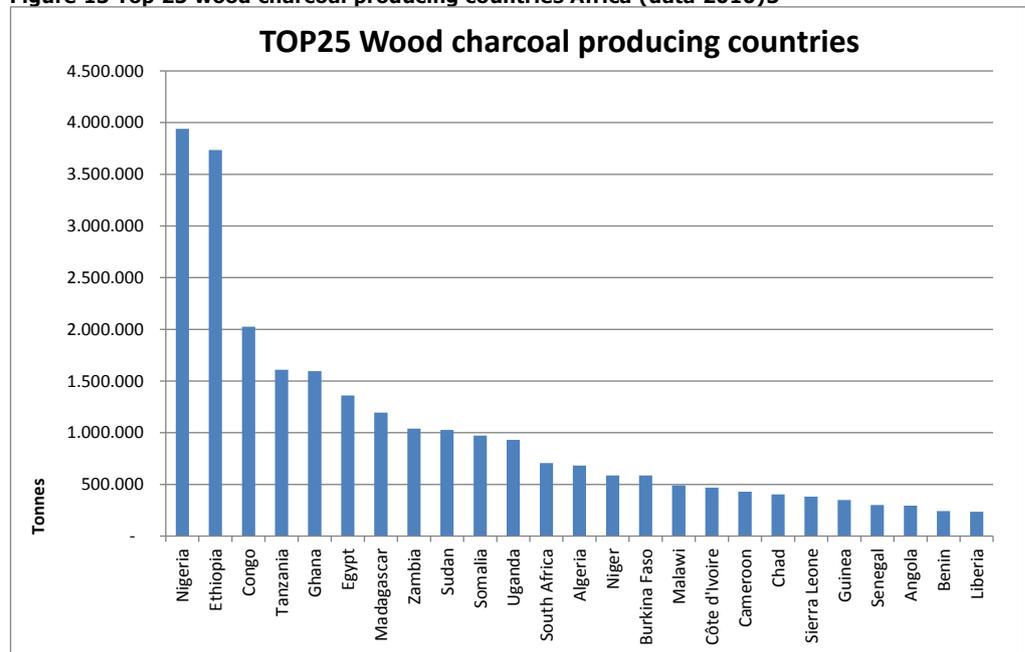
In the next sections the collection, production, logistics, costs, sales, marketing and sustainability of charcoal dust briquetting are addressed, mainly based on information collected from the above mentioned initiatives. In some sections relevant data from beyond Africa, mainly Haiti, has been used.

4.2 Availability of charcoal dust

Due to the fragility of charcoal, excessive handling and transporting of wood charcoal over long distances results in fines and charcoal dust at strategically placed trading sites. This material cannot be used or sold without further processing. In Nairobi 10-12% of the citywide charcoal consumption (>700 ton/day) is discarded as dust (Karstad 2005). According to (Owen 2011) around 10% of Africa's charcoal is thrown away before it reaches the stove, representing a tremendous waste of precious biomass in an industry already criticised for inefficiency and poor environmental practice.

The total production of wood charcoal in Africa is - according to FAOstat - approximately 28 million tonnes (reference year 2010). Figure 13 shows the top 25 wood charcoal producing countries in Africa. Based on a charcoal-to-dust ratio of 5 to 10%, the total amount of charcoal dust available in Africa is 1.4 - 2.8 million tonnes, representing an energy value of 46 - 92 PJ² (under the assumption no charcoal dust is exported outside Africa). These numbers form the theoretical potential of charcoal dust for fuel briquette production.

Figure 13 Top 25 wood charcoal producing countries Africa (data 2010)³



The availability of charcoal dust for energy production is limited by the accessibility of the dust (see section 4.3 for collection of charcoal dust) and alternative uses of charcoal dust. Currently in Africa, biochar as a soil amendment is a concept under development. For example in Arusha (Tanzania) charcoal dust is gathered at urban charcoal markets to improve the fertility of tropical soils. The concept of using charcoal dust as soil improver is, however, only known by a small fraction of farmers and agricultural development workers (Lotter 2010). For that reason it is expected that this market segment has no significant impact on the availability of charcoal dust. It is reported that in Senegal blacksmiths use pieces of broken charcoal lumps (not the dust). In conclusion it is expected that most of the charcoal dust in Africa is still left as waste and not used as a substitute for lump wood charcoal.

² Assumption energy value of charcoal 33,0 MJ/kg (FAO, 1983)

³ FAOstat data on charcoal production is not always reliable. For instance Kenya is not in the Top 25 because according to FAOstat its charcoal production is 17.700 tonnes/year, which is clearly an underestimation.

4.3 Charcoal dust collection

Charcoal dust collection systems are illustrated in three cases, from Kenya, Senegal and Haiti respectively. In each case the challenge is the same i.e. the cost-effective collection of (highly) dispersed low-density material.

Case Kenya

Chardust Ltd., (Nairobi) developed a strong market for charcoal dust briquettes, selling more than 2,500 tons a year with a growing customer base (Owen 2011). Charcoal consumption in Nairobi is estimated at 700 tons per day, yielding approx. 88 tonnes of dust per day (Njenga et al, 2013). Originally Chardust Ltd. relied exclusively on chardust collected from large charcoal wholesale sites, deploying its own second hand lorry (Karstad 2005). To meet its growing feedstock demand, Chardust looked to set-up a carbon collection programme with a view to collect dust from many highly dispersed and poorly accessible small-scale trading sites (see Figure 14.)

Figure 14 Charcoal dust Kibera (from Karstad 2005).



In the programme 'Development Marketplace (DM)' Chardust teamed up with an NGO running a garbage collection programme to encourage Kibera slum dwellers to become 'carbon collectors'. Dust is collected by MUUM⁴ members and brought to 7 collection sites across Kibera (see Figure 15). Each site is equipped with a wooden holding bin that has the same volume as the Chardust lorry. When the bins are full they are emptied by Chardust. Subsequently the MUUM members get paid in cash (see Figure 16). Revenues are shared transparently between dust collectors (73%) and MUUM (27%).

Setting up the carbon collection scheme has proved beneficial for many. Chardust has expanded its feedstock supply base, while avoiding high collection cost. Slum dwellers and others have found a job. After 18 months 250 people were involved in the supply chain, supporting 20 new jobs at Chardust Ltd. One year after DM funding ended, new sites continued to be established in Kibera, sustained by income from dust sales (Karstad 2005).

4 Makina Umoja Usafi na Maendeleo, a Community Based Organisation

Figure 15 Collection sites distributed throughout Kibera (from Karstad 2005).



Figure 16 Dust collection system Chardust and MUUM members (from Karstad 2005).



Dust collected by MUUM members and brought to bin site

Bin filled with dust

Full bins emptied by Chardust and MUUM members paid in cash

Case Senegal

In the city of Saint-Louis in North Senegal (population 160.000), access to charcoal is constrained by cost and scarcity as the city is hundreds of kilometres away from the areas where people are permitted to produce wood charcoal. There is a significant potential resource of charcoal residues in the many existing charcoal yards and storage areas in Saint-Louis (FAO and PISCES 2009). This new fuel could initially replace approximately 28% of the annual charcoal consumption in the city⁵.

To expand the range of available cooking fuels, a Public Private Partnership (PPP) was established between the PERACOD donor programme, a private company established by BRADES (Bureau de Recherche/Action pour le Développement Solidaire) and the forest cooperative CFF (Co-opérative Forestière de Fleuve). The

⁵ Note from the author: in the long run this percentage is expected to be 10%.

partnership aims to convert residues available in the local 'charcoal stockyards' into charcoal briquettes (known as char-briquettes).

A feasibility study was carried out in 2006 to evaluate the availability of charcoal dust and the viability of a charcoal briquettes production plant. Subsequently, PERACOD supported BRADES to install such plant through the public private partnership. For the collection and supply of the charcoal dust in total 26 contracts were signed in an 8 month period. Two people supplying clay and char-briquette retailers and wholesalers (women's grouping and individuals) are directly employed by BRADES. CFF helped in identifying which charcoal retailers could supply charcoal dust (FAO and PISCES 2009).

Case Haiti

Experiences in Haiti show that large amounts of charcoal dust can be collected and processed into marketable fuel briquettes. In the Port of Archaie alone, where charcoal ships dock, constant unloading has left a huge black doom. All over Haiti, even in towns and cities, these mountains of lost dust can be seen. Charcoal dust collectors bring the dust from small-scale trading sites to the processing site of a Haitian briquetting business. The charcoal collectors get paid in cash (Figure 17).

Figure 17 Screenshots from Charcoal Dust video (UNEVOC).



Charcoal dust in Port of Archaie



Charcoal dust in towns and cities



Collection of charcoal dust



Loading charcoal dust



Charcoal collectors payed in cash



Storage before briquetting

4.4 Charcoal production from charcoal dust

Compared to other alternative charcoal feedstocks, charcoal dust has the shortest supply chain as the feedstock has already been carbonised earlier. Thus only a briquetting step is needed to produce charcoal briquettes. The briquetting process can be divided into the following steps (the letters correspond with Figure 18 on page 33):

- **Screening (sieving)**; required to remove stones and other material from the dust (a, b)
- **Drying**; the dust needs to be perfectly dry (c)

- **Sizing (crushing)**; dust is conveyed to the hammer mill, which produces bits of uniform sizes. Next the charcoal dust is crushed and pressed through the perforated metal (d e, f, g).
- **Mixing with binder**; the powder is taken to the mixer, where a binding agent is added (h, i). A worker checks that the mix has the right consistency for moulding.
- **Briquetting**; once binder and dust are properly blended, the mixture is taken to the briquetting machine where the briquettes are produced (j, k).
- **Drying briquettes**; the briquettes are spread out to dry on a netting, which is placed e.g. in a hothouse to speed up the process (l, m).
- **Packaging**; the dried briquettes are packaged in plastic bags and sealed. Neatly packaged, the charcoal briquettes can be sold (n, o, p, q, r).

Different briquetting techniques are applied for charcoal dust. The scale of operation for charcoal dust briquetting varies from small-scale manual briquetting up to (semi-) industrial scale operations with automatic feeding systems. Figure 18 and Figure 19 give an overview of the overall process. On the next pages the most relevant steps are described in more detail to illustrate the different techniques and materials that can be used for charcoal dust fuel briquetting.

Figure 18 Charcoal dust briquetting production process in Haiti (UNEVOC 2006).



Figure 19 Charcoal dust briquetting production process in Goma (pictures from <http://gorillacd.org/2011/09/09/chardust-fireballs/>)



Collect the charcoal dust waste from the 5 major charcoal markets with the help of local employed women.



Bring it to the Virunga National Park facility on the edge of Goma.



The dust is sorted to remove stones, nails, plastic and other objects that can damage the machines.



A Hammermill machine breaks the dust up into powder.



The Fireball machine turns the dust into balls by adding hot water to the mix as it turns and turns.



The balls are laid out on racks to dry for about 4 days, depending on the weather.



And then packed into white nylon bags.



And now they are ready to sell. That's a lot of charcoal that would otherwise go to waste, and burns as well as the original.

Screening (sieving)

Charcoal dust screening to remove stones and other materials is done manually. Two different sieving methods are shown in Figure 20.

Figure 20 Sieving methods for charcoal dust; (above) Chardust, Kenya (below) Haiti.



Chardust Ltd. (Kenya) uses sieving also to separate small charcoal lumps (larger pieces) from fines (powder). The fines are contaminated with soil (clay), which is virtually impossible to remove. For that reason these fines are only used in lower quality briquettes. An advantage is that no additional binder is required.

Sizing (crushing)

For sizing (crushing) of charcoal dust a hammer mill is used to make bits of uniform size. The charcoal dust is feed into the grinding chamber manually or automatically by conveyor belt (See the figure below). The swinging hammers, in the rotating hammer rotor, crush the material, after which it passes through a perforated screen. The particle size of the ground material can be controlled by applying different size of screens. The crushed charcoal dust is sucked by an air blower and conveyed through a pipe into the cyclone separator were it gets separated into thin and more coarse material.

Figure 21 Hammer mill for sizing charcoal dust: (left) manual feeding and (right) automatic feeding



Mixing with binder

Binder is used to strengthen the briquettes. As discussed previously (in Section 3.4), clay is often used as a binder. Charcoal dust that is collected from the ground is often already mixed with parts of clay. Small amounts of clay may be added for the right consistency.

In Saint-Louis (Senegal) clay is collected near the production facility. For 100 ton of charcoal dust briquettes approximately 17 tonnes of clay is required annually. Two workers are employed and the costs of clay extraction and transport amount to some 0.015 USD/kg (FAO and PISCES 2009).

Depending on the final product targeted, Chardust Ltd. (Kenya) uses different kind of binders. For low quality briquettes no additional binder is used. For higher quality briquettes some 3-4% binder is needed (such as molasses, corn starch or gum Arabic). This type of binder is rather expensive (indicative price 0.50 USD/kg).

In the case of Haiti molasses of unrefined sugar cane is used as binder.

Briquetting of charcoal dust

For the briquetting of charcoal dust the full range of techniques as discussed in Section 3.2 is being used, from small scale manual briquetting via semi industrial agglomeration pans to industrial roller presses. Chardust Ltd. uses different techniques in parallel. Depending on such parameters as the mould, the operating pressure and the binder used, the resulting briquettes will have different characteristics and can serve different markets.

- **Manual briquetting;** (Ashden 2012) and (Van Essen, 2012) mention various examples of manually produced charcoal briquettes. Figure 22 shows hand moulds used in Mali for the production of briquettes from waste charcoal dust using molasses as binding agent.

Figure 22 Hand moulds for charcoal dust and molasses binder in Mali



- **Small-scale extrusion;** Chardust Ltd. (Kenya) and BRADES (Senegal) started their businesses using manual extruders, but have both moved on to using motorised systems with a view of increasing capacity and reducing production costs. Chardust first used second-hand meat mincers. BRADES started operations using 4 manual driven rotor presses (capacity 15 kg/hr each) but later quipped these with motorized rotors (see Figure 23).

Figure 23 Briquetting charcoal dust in Saint-Louis (Senegal) using the rotor press.



- **Industrial roller press;** in many places including Haiti and Kenya industrial roller presses are used for briquetting charcoal dust (Figure 16, j). The machine in Haiti can make 700- 1.400 small briquettes per minute. This fairly high capacity justifies the cost of this installation (some 60.000 USD for a second hand unit and around 250.000 USD for a new one (UNEVOC 2006). In Kenya a relatively inexpensive Indian roller press is used (price USD 50.000) (See Figure 24)

Figure 24 Charcoal dust briquetting process with roller press in Kenya (Karstad 2005)



- **Pan agglomerator;** Chardust Ltd. uses pan agglomerators for its premium grade briquettes. Operations are labour intensive (dust and liquid binder are fed manually) and output is relatively low (0.25 t/day). By combining high quality feedstock (relatively clean and clay-free charcoal lumps) and liquid binder high quality briquettes can be produced in a small scale plant. Another advantage of the pan agglomerator is that due to its modular character it is very easy to expand and replicate (see Figure 25). In the case of Chardust Ltd, production of agglomerated briquettes started with 1 ton/week (1 day shift) and has gradually expanded to 5 ton/week (2-3 shifts) (van der Plas 2012). Except agglomeration all work is done manually. Some 16 full-time labourers are employed.

Figure 25 Agglomerator from Chardust (Kenya) for processing charcoal dust into briquettes.



Drying and packaging

Charcoal dust briquettes are spread out on wooden or metal racks to dry in the open air (Wondwossen 2009). In Senegal, charcoal dust briquettes are left to dry for three days (see Figure 26, above). Outdoor drying is, however, problematic during the wet season (Le biocharbon 2009)

Packaging material can be expensive and it is not uncommon to use second material for packing charcoal briquettes. In Senegal recycled paper is used. Two women are employed to produce bags, producing on average 20 bags per hour each. Bags costs 2 cents for the material, or 3.25 cents including labour costs.

Figure 26 Drying methods for charcoal dust briquettes and bags for sale; (above) Saint-Louis, Senegal (middle) Haiti and (below) Chardust, Kenya.



In Haiti the briquettes are dried in a hothouse to speed up the process. Briquettes are dried in one day. After drying the briquettes are packaged and sealed. For the customers convenience a lighter made of cane-pulp, paraffin and wax is enclosed in the bag.

In Figure 26 different drying racks and bags for charcoal dust briquettes are shown.

4.5 Logistics of charcoal dust briquettes

In some cases regular wood charcoal is transported over hundreds of kilometres (e.g. in Saint-Louis, Senegal). This gives charcoal dust briquettes a cost advantage as the raw material can be collected locally from urban and peri-urban markets.

However, it is essential to optimise the logistics for collecting charcoal dust and shipping charcoal briquettes. To service markets beyond Nairobi, Chardust Ltd. sells its premium briquettes to a supermarket chain. Supermarket trucks that carry a wide range of products bring the Chardust briquettes as far as Mombasa and Kilifi on the Kenyan coast and even to Kigali in neighbouring Rwanda. Chardust Ltd. would never be able to organise transport over such long distances cost-effectively (Owen 2011) (Owen 2012).

4.6 Production costs charcoal dust briquettes

The costs of producing charcoal dust briquettes can be split into:

- Investments costs (mill, briquetting equipment, drying and packaging)
- Operational costs such as procurement of raw materials (charcoal dust, binder), transport of raw materials, personnel, energy, etc.

As a rule of thumb, and under the condition that the production facility is located near the raw material and the customer base (close to city markets), the target is to produce at a cost that is equal to, or lower, than the wholesale price of lump charcoal, if the mass domestic market is targeted.

Furthermore the experiences of Chardust Ltd. suggests that starting a new venture has a higher chance of success when it is developed as an add-on to an existing business so that production facilities (land, building, back office staff, etc.) can be shared. An alternative is that donors contribute funding for a startup-period.

Table 4 and Table 5 give an impression of the production costs of charcoal dust briquettes, as determined in the PERACOD feasibility study mentioned before (PERACOD 2006). It concerns a plant in Senegal with an annual output capacity of 100 tonnes based on (manual) rotor press technology. By deploying manually operated equipment, the total investment costs and the annual depreciation can be kept very low. The production costs are calculated at 0.18 Euro per kg of charcoal dust briquettes. It is noted that purchase and transport costs of charcoal dusts make up more than half of the production costs, and that labour is also an important cost item.

To increase the output (from 60 kg to 140 kg per hour) and to reduce the production costs the rotor presses at the charcoal briquettes plant in Senegal were equipped with a motor at a later stage. The change was targeted to lead to a reduction in the production costs to a level under the wholesale prices of wood

charcoal (15 Eurocents per kg). The retail price for charcoal briquettes is 19 cents per kg, considerably less than the retail price for wood charcoal sold in Saint-Louis (30 to 38 cents per kg, depending on the season).

Table 4 Investment costs charcoal dust briquetting system (100 tonnes / year), PERACOD 2006

Investment cost items	Quantity	Unit price (in Euro)	Amount (in Euro)	Duration of live (years)	Depreciation (in Euro)
Briquetting machine	4	90	360	5	72
Mill	1	750	750	10	75
Wheelbarrow	2	38	75	3	25
Drying plant	1	300	300	3	100
Various	1	150	150	1	150
Total investment			1.635	Total	422
				depreciation	

- Historical Exchange Rate CFA Franc (2006) to Euro (2012) 0.0015 (www.oanda.com).

Table 5 Production costs of 100 tons of charcoal dust briquettes per year (PERACOD 2006).

Production cost items	Quantity	Unit price	Total (in Euro)	Production costs Euro per kg
Indirect costs				
Personnel (12 months)	12	450	5,400	0.0521
Depreciation	1	422	422	0.0041
Maintenance (5% of investment)	0,05	1.635	82	0.0008
Subtotal			5,904	
Direct costs				
Purchase charcoal dust	86,400	65	8,424	0.0813
Transport dust	86,400	10	1,296	0.0125
Purchase clay	17,280	10	259	0.0025
Electricity (kWh)	6,480	250	2,430	0.0234
Subtotal			12,409	
Total production costs			18,313	0.1766 / kg

- Historical Exchange Rate CFA Franc (2006) to Euro (2012) 0.0015 (www.oanda.com).
- Operations based on five employees; one in charge of extraction binder, four in charge of briquetting and drying / packaging.
- Salary based on 60.000 FCFA per month (90 Euro / month).

4.7 Sales and marketing of charcoal dust briquettes

The possibility to produce charcoal briquettes with different (performance) characteristics opens up the opportunity to target different market segments. Important market segments, in terms of volume and/or profitability, include:

- the mass domestic market, consisting of (peri-)urban households that use charcoal as (daily) cooking. This is by far the largest market segment;
- business and institutional consumers. This segment includes large consumers such as restaurants, hotels, institutes etc. and in countries where night temperatures drop to say less than 10 °C also poultry farmers and safari camps (using charcoal for space and water heating);
- the urban middle class, using charcoal on an occasional basis for barbecue. This is a small but growing market segment.

The company Chardust Ltd. is addressing each of these three market segments, supplying them with different qualities of charcoal briquettes, as follows (Owen, 2012):

- The business and institutional market is served by **lower grade briquettes**, marketed as Vendors Waste Briquettes and sold in large bags. These briquettes are made as cheaply as possible in bulk from charcoal dust (fines) with some contamination of soil (clay). No binder is added. The high ash content (due to the clay) cause the briquettes to burn slowly, rendering them particularly for slow-release space heating at night time;
- The mass domestic market is served by **regular grade briquettes**, made in roller presses and sold in 4 kg bags. As feedstock screened charcoal waste is used, with minimum contamination. Gum Arabic is used as binder. Briquettes are sold by Chardust Ltd. at prices below the urban wholesale price of charcoal.
- **Premium grade briquettes** targeted at the urban middle class are labelled as Fireballs and sold in fancy packaging in supermarkets. These are made in pan agglomerators from charcoal lumps and a liquid binder (a blend of molasses, corn starch or gum Arabic). This market segment is less price sensitive and fireball briquettes are more expensive than lump charcoal.

Figure 27 shows the different grades of charcoal briquettes marketed by Chardust Ltd., and Table 6 specifies the prices for them.

Figure 27 Different qualities of charcoal briquettes marketed by Chardust Ltd.



Vendors waste briquette (VWB)

- 50 kg, printed white, polypropylene sack
- 35 gm pillow shape
- made from charcoal dust & fines
- no binder
- 3 hr burn
- no smoke, sparks or smell

BBQ charcoal briquette

- 4 kg, 2-ply 80 gm printed brown paper sack
- 35 gm pillow shape
- made from premium charcoal waste selected for quality and purity
- 8% ash
- Bound with gum arabic

Fire Balls

- 4 kg, white cardboard box with carry handles and colour label
- Spherical briquette
- made from premium charcoal waste selected for quality and purity
- Low ash
- Bound with starch & molasses

Table 6 Chardust products and prices (April, 2012). www.chardust.com

Type of briquette	Quantity	Wholesale price (KES)	Wholesale price / kg (KES)	Wholesale price / kg (EURO)
Vendors Waste Briquette	50 kg	700	14	0.125
BBQ charcoal briquette	4 kg	171	43	0.380
Fire Balls	4 kg	254	64	0.565

- Historical Exchange Rate Kenyan Shilling KES (2012) to Euro (2012) 0,0089 (www.oanda.com).
- Figures from www.chardust.com.

The experiences of Chardust Ltd. – and other start-ups in Tanzania, Uganda and Rwanda – suggest that in general charcoal dust briquettes have to compete directly on price with wood charcoal. As a result, the (semi-)industrial production of charcoal dust briquettes can only be viable in African countries where charcoal is relatively expensive. Chardust Ltd. estimates that the minimum wholesale prices would have to be some \$200 per ton (for packaged charcoal). This rules out many African countries as candidate manufacturing sites! On the other hand in areas with high charcoal prices (e.g. Saint-Louis, Senegal) and sufficient charcoal dust there is a good potential for charcoal dust briquetting (Owen 2011).

Smart marketing, innovative packaging and in general good entrepreneurship are further requirements for success.

4.8 Sustainability aspects of charcoal dust briquettes

Briquettes made by recycling charcoal dust substitute regular wood charcoal and thus help to prevent (illegal) cuttings and deforestation. Emissions of tar and methane, associated with wood charcoal production, and of greenhouse gases, associated with long-distance wood charcoal transport, are avoided. As charcoal dust can be sourced locally in urban areas transport-related emissions will be significant lower for chardust briquettes.

With the exception of some small and/or experimental scale use as reducing agent, by blacksmiths, or as biochar, a soil amendment, there are few alternatives to make good uses of charcoal dust

Char dust collection and briquetting generates employment and income and contributes to the development of livelihoods. Charcoal dust collection commonly involves a large number of people including slum dwellers and women's groups. Attention should be paid to prevent child labour, for example by working together with an NGO or a community that is responsible for dust collection.

An important aspect to consider are the working conditions of the employees. A potentially harmful effect is the inhalation of dust. Labours (involved in collection, briquetting and handling) should be instructed and general precautionary measures be taken to avoid inhalation of charcoal dust (e.g. the use of masks with dust filters).

5 Cotton stalks

5.1 Introduction

Cotton stalks are available in large quantities and have no or few alternative uses. Cotton stalks are usually burned in the fields to avoid cotton pests. This makes them a logical candidate for alternative charcoal production. A weak point is the relatively long supply chain associated with harvest residues. Also the bulk density is relatively low. However, considerable experience has been gained with this feedstock.

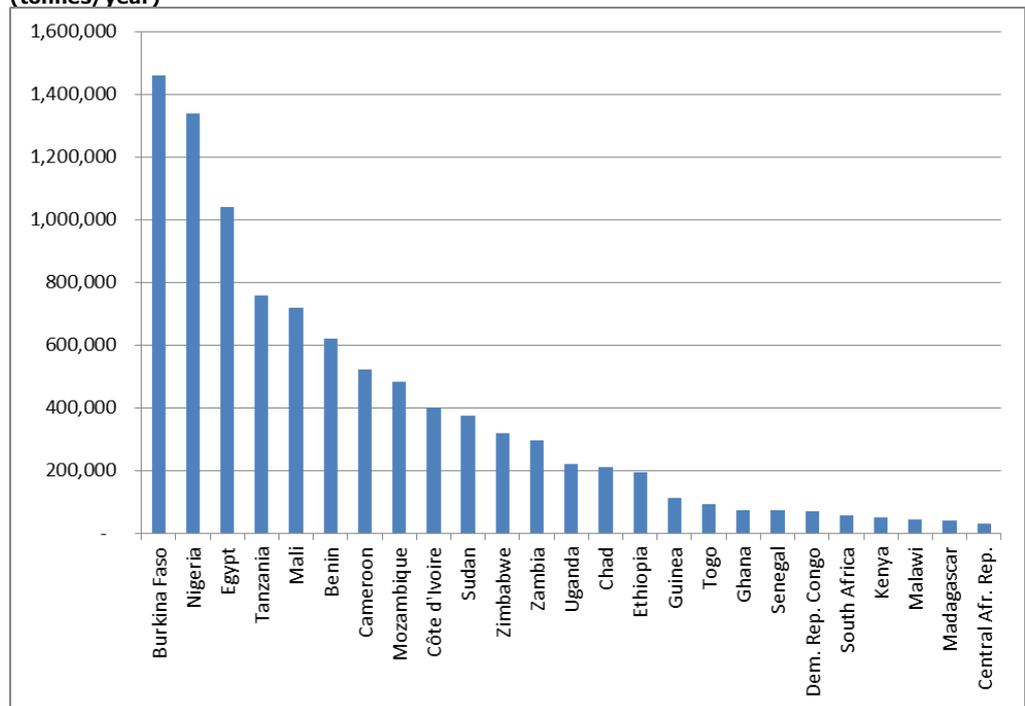
5.2 Availability of cotton stalks

Using FAO statistics on cotton production (reference year 2010), combined with a residue to crop factor of 2.755 (Koopmans and Koppejan 1997), the annual availability of cotton stalks in Africa is calculated at approx. 10 million tonnes, which represents an energy value of 75 PJ alternative charcoal. See Figure 28 for an overview of availability in the top 25 African countries where cotton is grown.

Cotton stalks are not suitable as fodder. Because of the presence of cotton pests, mostly insects, cotton stalks are burned after harvesting. Because they burn fast the stalks are less suitable as fuel for cooking. Effectively there are few if any uses for cotton stalks, and thus almost all stalks are in theory available for carbonisation. If such uses emerge in future these would reduce the quantity of cotton stalks available for charcoal production.

There is however more to availability than just the technical potential. In the next section, the harvesting and collection process is studied. Experience presented in this chapter is primarily based on the work of BTG and Biomass Mali in e.g. Sudan and Mali in the last decades.

Figure 28 Availability (technical potential) of cotton stalks in top 25 African countries (tonnes/year)



5.3 Harvest and collection of cotton stalks

Cotton has a limited harvesting window. For instance, the period for harvesting cotton in the Fanaa district of Mali runs from mid October until early January. By law, all cotton stalks have to be removed and burned before mid May. As an alternative to burning, the cotton stalks can be carbonised. Given the above harvest season, the cotton stalk carbonisation would have to be completed between mid-January and mid- May, a period of four months (Visser, Vis, and Siemons 2002).

Measurements in Sudan (BTG 1991) show that cotton stalk yields vary from 1500 kg/ha at poor sowing and irrigation conditions to 2500 kg/ha at good conditions.

Cotton stalks have to be collected from the fields and brought to the site of the cotton field. There they are broken a few times into smaller pieces such that the stalks fit in the carbonisation kiln.

Both in Sudan and Mali BTG sought to co-operation with parastatal cotton organisations to set up the cotton stalk collection process (Visser, Vis, and Siemons 2002). Biomass Mali established co-operation with a women's organisation (Reuters 2006), see Figure 29.

Figure 29 Collection of cotton stalks to the carbonisation unit. Source (Biomass Mali 2006)



5.4 Charcoal production from cotton stalks

The charcoal production process consists of the following steps:

- Carbonisation (in the field)
 - Breaking the (field dried) cotton stalks into smaller pieces
 - Feeding the stalks in the carbonisation unit (loading)
 - Carbonisation
 - Unloading
 - Packing for transport to the briquetting plant.
- Briquetting (at a central location/factory)
 - Charcoal storage
 - Sizing of charcoal to powder
 - Briquetting
 - Curing.

Carbonisation of cotton stalks

Earth or pit kilns such as traditionally used for wood carbonisation (see Section 3.1) are not suitable to carbonise cotton stalks. Because of the lack of control of air the material would easily flare up and combust. Portable metal kilns are the preferred technology, because:

- Carbonisation is rapid. The total production cycle (including kiln loading, carbonisation, cooling down and kiln unloading) takes only 2-3 days.
- A reasonable efficiency (yield up to 25%) can be achieved,
- Most metal kilns are transportable, which is very practical when biomass has to be collected from large areas.

In Mali and Sudan experience is gained with the carbonisation of cotton stalks using simplified versions of the Mark V and TPI metal kilns, made from three drums and without chimneys. The absence of a chimney leads to a somewhat lower carbonisation efficiency (Foley 1986). Based on earlier work of BTG, (Visser, Vis, and Siemons 2002) a yield of 20% is assumed, a conservative estimate compared to the 25% that is generally assumed to be achievable with metal kilns.

The carbonisation process, illustrated in Figure 30, works as follows. First the cotton stalks need to be sized such that they fit well in the kiln. Next the metal kiln is fed with cotton stalks (approx. 225 kg) and lit. After some time all air pockets are closed and the carbonisation process starts. Carbonisation takes ten to twelve hours. Supervision of the kiln is only required during start-up and the first carbonisation. This means the farmer can perform two carbonisation cycles per day. After carbonisation and cooling down, the kilns are emptied and the carbonised stalks (approx. 45 kg, assuming 20% yield) are collected. Using 125 litre rice bags some 25 kg of charcoal can be packed in each bag. Finally the bags of charcoal are transported to the briquetting plant.

In Mali many farmers are familiar with making wood charcoal. However, every farmer to be involved in cotton stalk carbon production would need to receive instruction how to operate the carbonisation ovens efficiently. (Hood 1998) carried out instruction sessions and reported that at the third instruction day most farmers were able to operate the ovens without help.

Figure 30 Closing the lid of the metal kiln, and starting the fire. Source: (Biomass Mali 2006)



Storage

The carbonised cotton stalks are stored in bags. The amount of carbonised material to be stored and the storage period depend on the briquette production scheme adopted: seasonal (four month operating window) or year round. In the latter case, considerable amounts of carbonised cotton stalks need to be stored for a longer time. Considering the usually hot and relatively dry climate where cotton is produced appropriate storage facilities are required to prevent fire.

Sizing

Sizing of the carbonised cotton stalks takes place in two steps. In the first step, some workers trample on the bag with stalks to crush the carbon into smaller pieces. In the second step, the bag is emptied and the content is conveyed manually to a hammer mill, used to comminute the charcoal pieces further into powder.

Briquetting

In the various projects in Mali and Sudan, a low-cost agglomeration technology, developed by BTG using adapted cement mixers, is employed. This technology works according to the principle of tumble growth granulation. Charcoal powder enters the agglomerator and drops of the liquid binder (molasses, Gum arabic) are fed by a tap, or manually. The initial nucleus of binder and charcoal grows quickly to briquettes by tumbling in the agglomerator. See Figure 31.

Figure 31 The agglomeration and drying process



The agglomerators have an output capacity of 50 kg briquettes per hour each (semi-industrial scale), and it is possible to use multiple agglomerators in parallel. Using 50 kg/hr units, capacity expansion quickly becomes very labour intensive, also from an African perspective (Traore 2010). Another approach to achieve higher capacities is to apply tumble growth granulators such as are used to granulate fertilisers. An alternative option would be to employ pressure briquetting techniques like roller presses. Both the larger agglomerators and the roller presses involve higher investment costs than the simple agglomerators based on concrete mixers.

Drying

After agglomeration, the briquettes need to be dried. Depending on the climate conditions and whether drying on the ground or on special frames is applied, once in a while the briquettes might need to be turned to promote the drying process.

Curing

Briquettes that use molasses as a binder have an unpleasant caramel-like smell during combustion. To avoid this smell, the briquettes can be "cured", which refers to heating them for a little while allowing the fumes to be released in advance. Curing can be considered a (light) torrefaction process. After curing the briquettes need to be cooled. When applying other binders than molasses (e.g. Gum Arabic) the curing step can probably be avoided.

Packing

Finally, briquettes will be bagged. The size and appearance of the bags used depends on the market segment that is targeted. Consumers buying charcoal in very small quantities probably won't get to see the bag, and simple bags would suffice. If the briquettes are to be sold through supermarkets visually attractive packaging should be used.

5.5 Logistics of cotton stalk charcoal briquettes

The supply chain consists of the following steps:

- Collection and transport of cotton stalks or millet stalks to the carbonisation unit.
- Storage of stalks at the carbonisation unit
- Packing of carbonised stalks
- Transport of carbonised stalks to the briquetting unit.
- Storage of briquettes at the briquetting unit
- Transport of briquettes to the market/wholesale area
- Transport of briquettes to sales points for sale to the end users.

The siting of the production plant requires careful attention. The carbonisation of cotton stalks should always take place in the field. The briquetting plant could be located closer to the (urban) markets where the briquettes are sold. However, in view of its low specific density the transport of carbonised stalks is very expensive. Therefore, it makes economic sense to locate the briquetting facility also near the cotton fields. In any business case it is preferable to use cotton fields nearest urban markets, with a view to minimise total transport distance and costs.

As agglomerated briquettes are somewhat friable, and could break during transport and handling, transport via poorly maintained dirt roads should be avoided. Alternatively, the briquettes may be cured, which will make them much stronger and resistant to breakage, or protective packaging may be used.

At the briquetting facility, several internal transport movements have to be made, e.g. bringing agglomerated stalks to the hammer mills, transport of the powder to the agglomerators and transport of briquettes to the drying facility. (van Essen 2012) described the development of a cotton stalk agglomeration facility in Sudan in the 1990s, that had a fair degree of automation with belt conveying of charcoal

powder from hammer mill to the agglomerators. Mechanisation and automation adds to the complexity of the facility, but helps to increase production capacity and reduce specific production costs thus helping to operate the facility in a commercially viable way.

5.6 Production costs of cotton stalk charcoal briquettes

In 2002 BTG completed a feasibility study for a 2000 tonnes briquetting plant in Mali (Visser, Vis, and Siemons 2002). This study is used to illustrate the production costs of a cotton stalks carbonisation and briquetting facility.

Collection and carbonisation

As explained before, cotton stalk collection and carbonisation is done by cotton farmers or women's organisations. They get paid by the weight of supplied carbonised material. In Mali, remuneration was based on what farmers would have earned if they produced wood charcoal, an activity that farmers employ when the work at the fields is done. That price was calculated at F.CFA 12 (€0.02) per kg. Taking into account a small bonus of F.CFA 3 per kg, a price of F.CFA 15 (€0.025) per kg of carbonised stalks was negotiated, or F.CFA 450 (€0.75) per standardised 30 kg bag. One farmer operating two metal kilns can produce 90 kg of charcoal per day, and generate an additional monthly income of F.CFA 40 000 (€ 67).

Briquetting

Table 7 shows what equipment is needed for a 2000 tonnes/year cotton stalks carbonisation and briquetting facility, assuming portable metal kilns and pan agglomerators are used. The investment costs for the equipment were estimated at €114,000; site preparation (water and electricity supply, storage, and building) would add about € 50,000.

Table 7 Equipment required for a 2000 t/yr briquetting facility (Visser, Vis, and Siemons 2002)

Equipment	Capacity	Quantity
Carbonisation ovens (to be placed at farmers' sites)	2 m ³	195
Bags for carbonised cotton stalks (8 month storage)	125 l	35,930
Hammer mills	250 kg/hr	3
Agglomerators	50 kg/hr	14
Drying tables	6 m ²	157
Ovens for thermal treatment	250 kg/hr	3
Small tools (barrows, shovels, buckets)	Various	Various

Table 8 shows the labour force required for the briquetting facility. In total 76 persons are needed. In addition some 100 seasonal workers (farmers) are needed to collect and carbonise cotton stalks. Most of the workforce is needed for transportation of products between the process steps, and for the operation of the process equipment.

Table 8 Labour requirements for the briquetting plant Source: (Visser, Vis, and Siemons 2002)

Function	Task	Number of persons
Worker	On site transportation of raw materials, intermediate products and end products	36 (18 per shift)
Operator	Operation hammer mills, agglomerators and ovens for thermal treatment	32 (16 per shift)
Technician	Maintenance	2 (1 per shift)
Production leader	Production management	2 (1 per shift)
Plant manager		1
Secretary		1
Bookkeeper		1
Driver		1
Total		76

The production costs were estimated at 79 F.CFA/kg (120 Euro/tonne) charcoal (Visser, Vis, and Siemons 2002). Truck transport is available for carrying the carbonised stalks to the factory at an estimated 50 F.CFA/tonne/km (0.083 Euro/tonne/km). The sales price of wood charcoal at that time was estimated at 90 F.CFA/kg (136 Euro/ton), giving only a small margin for profit and reselling. Moreover, the study is based on continuous operation throughout the year, assuming feasible storage of carbonised cotton stalks for up to 8 months. It will be challenging to operate this business without any subsidy or external support.

5.7 Charcoal sales and marketing of cotton stalk charcoal briquettes

Households are the principal buyers of charcoal and therefore the main target group. For instance the charcoal consumption in Bamako (Mali) exceeds 100,000 tonnes/year, showing the large substitution potential of charcoal briquettes. In general, the basic problems associated with setting up and running a viable charcoal briquettes business are economic and social rather than of a technical nature. For example the resistance of consumers to change from familiar lump charcoal must be overcome (Foley 1986).

Acceptation by the end user

In 2001 the CED performed acceptability tests for agglomerated briquettes (Sanogo, Toure, and Diabate 2001) with a view to collect consumers' reactions the consumers towards the product. In total 50 households and 20 representatives from special groups of consumers like laundries and small restaurants were involved in the acceptability tests. Each participant received 25 kg of agglomerated briquettes with molasses as a binder that were not cured (thermally treated). The results are summarised in Table 9, presenting a comparison between cotton stalk briquettes and regular wood charcoal.

Table 9 Summary of results acceptability tests CED. Source: (Sanogo, Toure, and Diabate 2001)

Criteria	Charcoal	Agglo-briquettes	Observations
Presentation	good	good	round shape of briquettes, their homogeneity
Heat	good	good	agglo-briquettes generate the same heat as charcoal
Smoke	little smoke	less than charcoal	however, at the start the agglo-briquettes generate a little smoke that later completely disappears
Fouling	yes	less than charcoal	
Fire hazard	yes	no	charcoal generates a lot of sparks
Lighting	easy	difficult	equivalent in a number of cases
Combustion time	short	long	equivalent in a number of cases
Water resistance	good	bad	non-cured agglo-briquettes disintegrate
Ash	acceptable	much	
Smell of smoke	acceptable	not acceptable	by 20% of households
Time to light	short	long	charcoal fire dies out if not maintained by wind
Use	all purposes	all purposes	because of the ash, the laundries prefer charcoal
Price			Equal or lower than of charcoal (average price proposed by the consumers is 50 F.CFA)

The households, owners of small restaurants and coffee sellers appreciated the briquettes, mainly because of the heat generated and the long combustion time. The smoke that appears after ignition of the agglo-briquettes was regarded unacceptable by 20% of the households. The curing step can help to avoid the smell and also improves the water resistance of the briquettes. The ash content, that is higher than that of wood charcoal, did not lead to negative reactions. The consumers indicated to be willing to pay a price slightly lower or equal to the price of wood charcoal. As indicated earlier, according to (Traore 2010) briquettes with Gum arabic as binder produce a less unpleasant smoke, and these briquettes are accepted without curing step.

Costs and organisation of marketing

A proper marketing campaign can cost a considerable amount of money but is considered necessary to familiarise prospective customers with the charcoal briquettes. It may comprise a promotion campaign and a publicity campaign (Visser, Vis, and Siemons 2002). The publicity campaign could start with a launching day, where leading local organisations involved with household energy are invited. This day will be fully covered by TV, radio and written press. The publicity campaign itself will consist of commercials, sketches, micro programs and broadcastings. The promotion campaign will comprise of the following elements:

- (comparative) cooking demonstrations, in the neighbourhood
- promotional sales of agglo-briquettes at traditional charcoal selling points

- distribution of free (or price reduced) aggro-briquettes to selected prospective customers, e.g. (small) restaurants, coffee-sellers, skewer-sellers etc.

5.8 Sustainability aspects of cotton stalk charcoal briquettes

Sustainability of the feedstock

The use of cotton stalks helps to avoid deforestation, a major issue across Africa. The removal of cotton stalks from the fields does not lead to an additional loss of nutrients; fearing cotton pests, farmers have the habit of burning cotton stalks and generally don't apply the ash of burned cotton stalks in their fields. A small portion of the cotton stalks used for producing charcoal might have otherwise been used directly as household fuel in cotton growing areas.

Carbonisation (in the field)

Metal kilns applied for cotton stalks carbonisation have increased yields that are higher than that of traditional kilns (which are not suitable for cotton stalks). The carbonisation yield in metal kilns can be increased even further when chimneys are installed. This is attractive from both a financial and an environmental perspective but adds to the investment costs.

When transportable metal kilns are employed, the pyrolysis gases and liquid smoke is emitted to the air and not captured. Various possibilities exist to recover and utilise the gases and liquid smoke, but again these measures add to the investment costs and they are commonly implemented in stationary (brick) kilns or retorts (like the Adam retort), rather than in transportable metal kilns. Maybe some cheap type of smoke condensation can be implemented, e.g. by leading the smoke through bamboo pipes.

The collection and sizing of cotton residues involves manual labour with low financial rewards. On the positive side it generates income for a larger number of people. The smoke from the carbonisation process should not be inhaled. Instruction should be provided and general precautionary measures taken to avoid inhalation of smoke.

Briquetting (at the factory)

The most important health issue for the workers is the prevention of inhalation of charcoal dust. Especially those working close to the hammer mills and agglomerators should wear mouth & nose protection. Secondly, loads moved manually should not exceed 60 kg (two sacs at a time using wheelbarrows), as the actions have to be carried out repeatedly. Furthermore, drinking water and showers should be made available, and the use of overalls and helmets or caps should be promoted when necessary.

The most important safety issue is the prevention of fire and dust explosions. All stored and produced materials are flammable, therefore the entire site should be a non-smoking area, with the possible exception of some clearly appointed areas for breaks, away from the production and storage facilities. Near the hammer mills, the ovens for thermal treatment and in the charcoal storage hangars, fire hoses must be available to extinguish accidental fires.

6 Bamboo and bamboo processing residues

6.1 Introduction

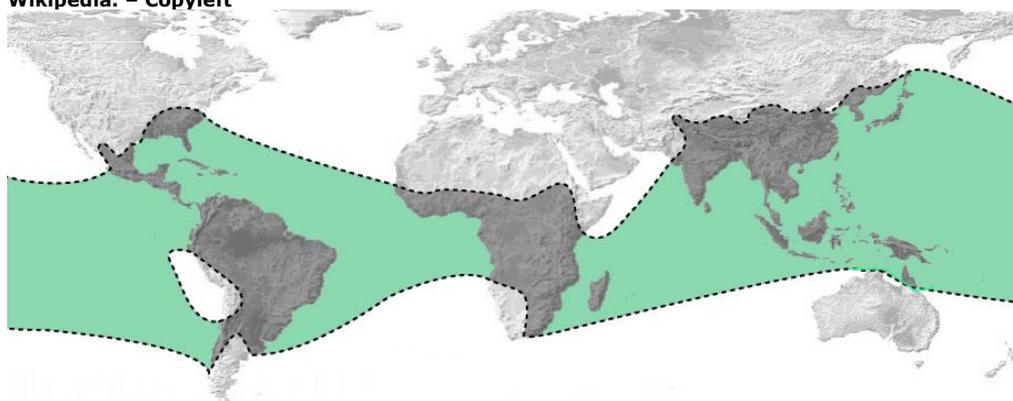
There are various initiatives across Africa to develop bamboo charcoal production. For example Adal Industrial PLC set up a facility to produce charcoal from bamboo processing residues near Addis Ababa (Ethiopia) in 2007. And recently the International Network for Bamboo and Rattan (INBAR) set up bamboo charcoal production pilot sites and technology transfer centres as part of a community-based charcoal project in Ethiopia and Ghana. Most of the experience, however, with bamboo charcoal production is gained in Asia, e.g. in Japan and China and more recently in Vietnam, Thailand and India.

In the next sections the collection, production, logistics, costs, sales, marketing and sustainability of bamboo charcoal are addressed, based on information collected from the above mentioned initiatives.

6.2 Bamboo resource availability

Bamboos are woody grasses that grow in the tropical, subtropical and temperate regions of the world (see Figure 32). There are about 1500 registered uses of bamboo (Bystriakova, Kapos, and Lysenko 2004).

Figure 32 Distribution of bamboo around the world. Source: www.payer.de / Pixeltoo / Wikipedia. – Copyleft



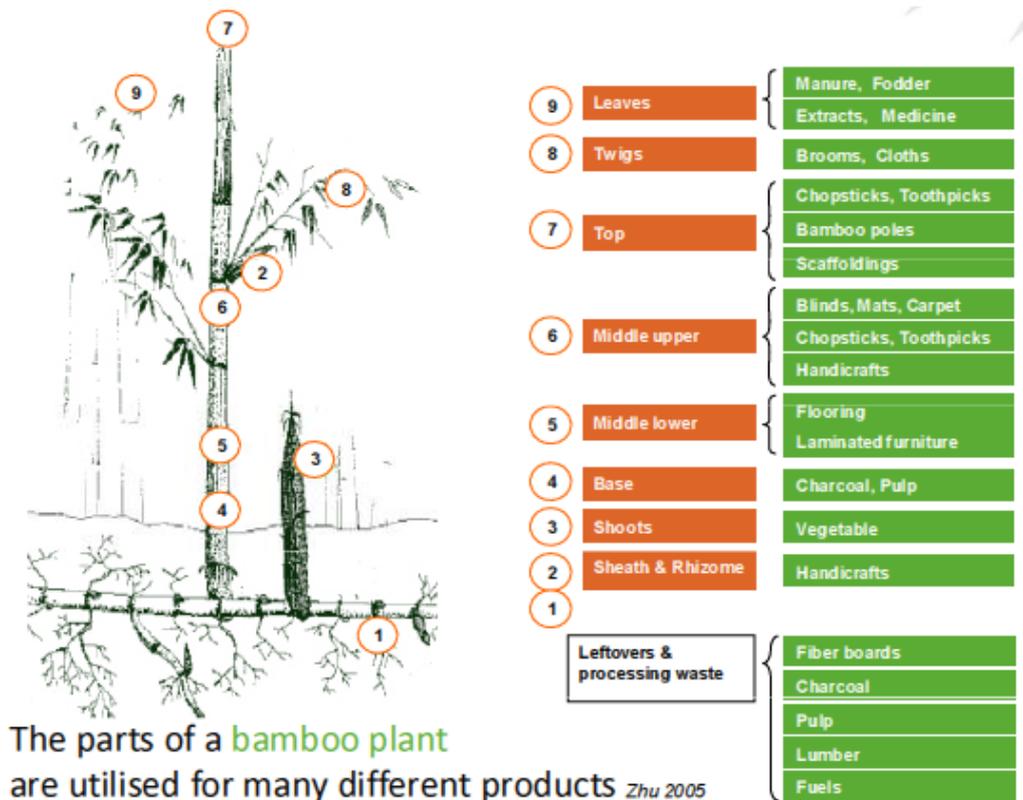
Six countries in mainland Africa (Ethiopia, Kenya, Nigeria, Uganda, Tanzania, and Zimbabwe) reported over 2.7 million ha of bamboo forest, which is equivalent to roughly 4% of the continent's total forest cover. There are some reports on the conversion of bamboo forest to agricultural land and inappropriate management (Lobovikov et al. 2007).

The establishment of bamboo plantations is currently considered in various African countries (e.g. Ethiopia, Kenya, Congo, Mozambique, Congo, and South Africa). At present, bamboo plantations are less common in Africa.

Bamboo has long been considered the poor man's timber and although the potential applications are manifold (see Figure 33) it continues to find little commercial use at present across Africa. Bamboo culms are occasionally harvested and used for fencing and house construction (traditional houses, more recently also for refugee camps). Application as scaffolding material, an established practice in Asia, is less common in Africa.

Bamboo can be used as cooking fuel in a number of ways: without prior carbonisation, as a direct substitute for firewood, or after conversion into charcoal, as a substitute for wood charcoal. Use as firewood substitute is an established practice for some poorer households in rural Africa. The use for the production of (industrial) heat, power, or combined heat and power, for local usage, or for the produce of solid biofuel, for the export market, is being investigated in various African countries (e.g. Namibia, Kenya and Ethiopia).

Figure 33 Potential uses for bamboo



6.3 The bamboo production, harvest and collection process

Bamboo grows remarkably fast, in particular in the rainy season. In Ethiopia it reaches its full height (typically well above 10m) in about four months. The stem (called the culm) reaches its maximum diameter (normally between 5 and 12.5 cm) in these first four months, after which the culm wall thickness gradually increases over a period of about four years. After four years the bamboo is fully grown. After another two years the bamboo is losing part of its flexibility.

Harvesting entails cutting the bamboo and haulage to the point of use. A single man can harvest bamboo culms using a machete and/or a handsaw.

Depending on the terrain where bamboo is growing hauling bamboo culms can be labour-intensive. When distances are short and the surface is flat one or two man can carry (one or several) bamboo culms to the point of use or sale. In the opposite case (long distances; steep terrain) the use of animal traction or machinery is required. When using animals (donkeys or horses), multiple culms can be towed directly or after loading them on a cart (Figure 35). When a cart is used for transport suitable forest roads will need to be available. In the case of long distances a common approach is to establish a collection point, from where onwards transport can take place using motorised transport.

Figure 34 Man hauling bamboo culms (source: <http://www.vivaveracruz.com/blog/?p=2908>)



Figure 35 Horses towing bamboo culms (source: Practical Action)



6.4 Bamboo charcoal production

Bamboo charcoal can be made from bamboo culms or, after optional briquetting, from the waste material of traditional or industrial bamboo processing. The prior briquetting step is needed when the bamboo waste is of different shapes and sizes. The charcoal production process involves the following major steps:

- Raw material preparation
 - Bamboo harvesting
 - Bamboo sizing (cutting and splitting into smaller pieces)
 - Air drying
- Charcoal production

- Stacking (loading) bamboo in carbonisation kilns
- Ignition of the bamboo
- Carbonisation of the bamboo
- Cooling of the produced charcoal
- Extracting the charcoal (and storage of charcoal in sheds)
- Charcoal briquette production
 - Crushing and grinding the charcoal into powder
 - Mixing powder with an appropriate binder
 - Manual or mechanised production of briquettes from charcoal
 - Checking, packing and storage of briquettes in sheds

Raw material preparation

Bamboo culms that are 4-5 years old make the best quality charcoal. The bamboo culm has by then attained its maximum weight, and its moisture and starch levels have lowered. In view of its considerable length (>10 meter) it is necessary to cut the bamboo culm into several pieces. Lengthwise splitting of bamboo is sometimes also applied. Homogeneity of size in a batch will make stacking easier and produce better results. The size of the end-product (charcoal) is related to the size of the bamboo placed in the kiln.

In many applications of bamboo processing, the upper and lower portions of bamboo culms are not used, and are often left behind in the field or discarded at the point of use. These primary residues, as well as the lops and tops of bamboo culms and thicker branches, can be used in charcoal making.

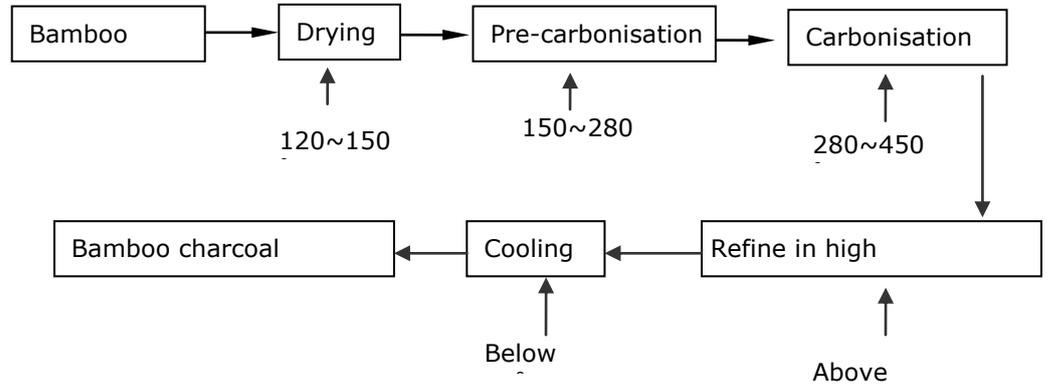
Fresh bamboo has a high moisture content, usually well above the 20-25% considered ideal to get the best carbonisation yields. Therefore fresh bamboo should be left to dry for some time, in particular during rainy periods, when drying will take longer. To dry large quantities of bamboo A-shaped drying frames can be used. For large-scale operations, artificial drying may be considered, in particular when waste heat is available at low costs.

In the case of industrial bamboo processing residues, raw material preparation involves the collection of residues of different shapes and sizes (including bamboo sawdust), and pressing these into bricks. This requires heavy machinery.

Carbonisation of bamboo

The carbonisation process for bamboo is in general not different than that for wood or other types of biomass. A simple flow chart of the process is presented in the figure below.

Figure 36 Bamboo carbonisation process flow chart



For costs considerations, it is best to produce bamboo charcoal close to the raw material source. When bamboo charcoal is made directly from bamboo culms, brick kilns or metal kilns can be used. As discussed in Section 3.1, these kilns are usually relatively small (less than 10 m³). When making bamboo charcoal briquettes from the compacted waste material of industrial bamboo processing, carbonisation retorts (that require electricity for their operation) are also used. Each of the 3 principle kiln types has advantages and disadvantages, and which kiln is preferred depends on the local situation and conditions. In the INBAR project both brick kilns and metal kilns (of different sizes) are piloted. In the Chinese bamboo processing industry retorts are commonly used.

Brick kilns

Bamboo charcoal brick kilns are generally built in wide and open areas of solid soil with convenient traffic and water supply. The kiln can have different shapes and sizes; e.g. Chinese brick kilns have an input capacity of 4-6 tons of bamboo. A common element is the presence of various intakes; in the front for material and elsewhere to observe flame and burning situation and to control the interior temperature (by adjusting their opening). A few samples of brick kilns used for bamboo charcoal production are presented in Figure 37.

Carbonisation in brick kilns is relatively slow and will produce good-quality charcoal with high carbon content and calorific value. Bamboo charcoal produced in this manner may be used as raw material for various higher value added applications, e.g. for the production of activated carbon.

In brick kilns in China the charcoal yield is about 25%-30%. (Jonkhart 2012) reports similar yields for the brick kiln piloted in the INBAR project.

Figure 37 Bamboo charcoal brick kilns in Ethiopia and India



Metal kilns

Bamboo charcoal metal kilns are typically small, to enable easy transportation. Metal kilns are always cylindrical and may be equipped with a chimney. The simplest and cheapest version is known as a drum charring units and can be made from scrap oil barrels. A few samples of metal kilns used for bamboo charcoal production are presented in Figure 38.

Metal kilns are exclusively used when the aim is to produce solid fuel from bamboo. When producing bamboo charcoal for higher value applications metal kilns are less suitable, as the carbonisation process goes much faster than in a brick kiln and is thus harder to control.

Figure 38 Bamboo charcoal metal kilns in Africa (sources: INBAR and Arti-Africa)



Retorts

A retort (also referred to as mechanical furnace) has a body made of thick iron sheet lined with firebricks and coated with heat preservation material. Retorts combine the speed of operation of metal kiln with the quality achieved in brick kilns. They also allow the collection of bamboo vinegar, which in the Far East is a valuable co-product used in e.g. agricultural applications. As their use for carbonising bamboo seems to be limited to China and Japan they are not discussed in more detail here. Samples of retorts are shown in Figure 39.

Figure 39 Bamboo carbonisation retorts in China and Japan (sources: INBAR)



Chris Adam, the developer of the Improved Charcoal Production System (ICPS, see 3.1.5), has indicated that this retort would also be very suitable for bamboo charcoal production. Besides a few incidental tests there is no field experience using the ICPS retorts with bamboo as feedstock yet (Adam, 2012).

Bamboo charcoal briquetting

Carbonised bamboo culms are not commonly used as fuel as such. Due to its shape the bamboo charcoal will burn fast, whereas charcoal is typically appreciated and needed for its slow and long burning. For most uses, further conversion into charcoal briquettes is required.

As described in Section 3.2 many shapes of briquettes can be made, depending on the briquetting method applied and the mould used e.g. ovoid (pillow shaped), hexagonal, spherical, beehive (honeycomb), stick and even cubic.

Spherical balls can be made in agglomeration pans using ground charcoal and a liquid binder. In Kenya spherical balls made of chardust are highly appreciated and sold at a premium (Owen 2012). Beehive (honeycomb) briquette can be produced mechanically as well as manually. Its larger size (a cylinder segment 13 cm in diameter and 8 cm in height) and the presence of longitudinal holes are optimised for use in beehive stoves. Hexagonal and ovoid briquettes can be used in the same charcoal stoves as lump charcoal. Adal Industries in Ethiopia uses a roller press to produce ovoid briquettes.

Figure 40 shows different shapes of briquettes tested at the workshop of the Ethiopian Rural Energy Development and Promotion Centre (EREDPC), local partner of INBAR in the bamboo charcoal demonstration project.

Figure 40 Bamboo charcoal briquettes in Ethiopia (sources: Kasa, 2011 and INBAR)



6.5 Logistics of bamboo briquettes

For fresh bamboo the bamboo charcoal value chain consists of the following steps:

- Bamboo culm harvesting and hauling to the carbonisation unit.
- Bamboo culm drying and sizing
- Bamboo culm carbonisation
- Packing and storage of carbonised bamboo
- Transport of carbonised bamboo to the briquetting unit.
- Bamboo charcoal briquetting
- Packing and storage of bamboo charcoal briquettes
- Transport of charcoal briquettes to collection point of the wholesaler
- Transport of charcoal briquettes to points of sale to final customer

When using bamboo processing residues, rather than fresh bamboo culms, the supply chain has similar elements, however, the order of the individual steps is slightly different⁶.

The siting of the production plant requires careful attention. Carbonisation should ideally take place in the field, close to the bamboo resource base. Briquetting should preferably be carried out close to the (urban) markets where the briquettes are sold. To minimise the number of handling steps it would be convenient to co-locate and integrate the carbonisation and briquetting plants. Furthermore it is important to minimise the number of transport modalities and the total transport distance, as both these elements can contribute heavily to the total supply costs. Another issue to consider is that some briquettes - in particular those made without binder in low pressure machines - are friable, and could break during transport and handling. Transport via dirt roads should be avoided, or more protective packaging should be used. In some cases a physical separation of the carbonisation and briquetting plant may be useful (e.g. when the bamboo stands are far away from charcoal consumer centres, when transport is expensive, or when the quality of the roads is (seasonally) very bad).

⁶ When using bamboo processing residues the supply chain is similar, however, the order of the individual steps is slightly different, in particular when prior briquetting is involved.

In the case of a mechanised briquetting process several internal transport movements have to be made. Conveyor belts can be used for this purpose. In case briquetting is done manually internal transport will usually also be done manually.

6.6 Production costs of bamboo briquettes

The costs of producing bamboo charcoal briquettes can be split into:

- Investments costs (equipment for carbonisation, milling, briquetting, drying and packaging)
- Operational costs such as procurement of raw materials (bamboo culms, binder), transport of raw materials, labour, energy, packaging etc.

A large number of factors impact the bamboo charcoal briquettes production costs. These are discussed in qualitative terms below.

6.6.1 Investment costs bamboo charcoal briquetting

Carbonisation kiln

(Jonkhart 2012) reports that in Ethiopia new metal kilns and brick kilns are available for around € 1000 and € 2000 respectively. According to (Seboka, 2009) the bamboo charcoal production cycle in metal kilns is much faster (1-5 days) than in brick kilns (8-20 days). As a result, with similar production efficiencies (up to 25%) the metal kiln is cheaper to use in terms of cost per kg output, even when taking into account the longer lifetime and larger volume of brick kilns.

Milling and briquetting equipment

For grinding a simple hammer mill can be applied. The price of briquetting equipment depends on the type of technology applied. Simple hand operated tools for briquetting are inexpensive (less than USD 100). An electrical extruder, manual extruder or manual screw press may costs around USD 500-1,000. A roller press from India or China will costs in the order of USD 15,000-20,000.

Drying equipment

To dry small numbers of briquettes these can be spread on a tarpaulin on the ground. For drying larger quantities the use of drying beds or racks is recommended. These can be produced locally e.g. from iron frames and chicken mesh.

Packaging and storage

When packaging is done manually little or no special equipment is needed. To package larger volumes of charcoal the use of machines may be considered. In case of large production volumes there is likely to be need for large (waterproof) storage room too.

6.6.2 Operational costs bamboo charcoal briquetting

Bamboo culms collection, haulage and pretreatment

Although bamboo finds little commercial use at present, and lower quality culms and residues are available at low costs or for free, it is likely these have to be paid for when large volumes are demanded. Labour and simple tools (costing not more than a few dollars) are required to collect the bamboo feedstock. In addition, the cost of hauling bamboo culms from the field to the carbonisation and briquetting plant will need to be paid for. These costs depend on the type of transport (manual, animal traction, motorised vehicles) and the distance involved.

For air or sun drying small volumes of bamboo culms sufficient space is needed. In case larger quantities need to be dried A-frame drying racks, allowing culms to be dried in upright position, may be built and used. Artificial drying would be very expensive and is therefore not considered realistic unless waste heat is available.

Purchase or extraction of binder

A mixture of clay and water can be used as a cheap binder. Starchy binders are much more expensive and can increase the production costs considerably.

Purchase of packaging material

Packaging can also be a significant cost item, in particular when selling briquettes in smaller quantities. A low cost option is the use of second hand polypropylene bags (such as those in which food aid is distributed). Briquettes that are made with clay as binder require more robust packaging than polypropylene bags.

Charcoal briquettes transport costs

The costs of transporting charcoal briquettes depend on the type of transport and the distance involved. Transport costs can be significant, in particular when urban markets are far away from rural production areas.

Labour costs

Labour is needed in each step of the value chain, and therefore labour costs can add up significantly. The amount of labour needed and the specific labour costs depend on the production scale and the degree of mechanisation.

6.6.3 Total production costs bamboo charcoal briquetting

Production costs will be lower when bamboo feedstock is nominally free (as is the case when industrial processing residues are used, or when communities harvest bamboo culms from their own stands), simple technology (including kilns made from recycled metal, plus hand operated briquetting equipment) is used, no external labour is hired, transportation distances are short and no building or other infrastructure has to be established. When labour needs to be hired mechanisation of some processing steps (e.g. briquetting equipment) will make economic sense.

On the other hand production costs will be higher when feedstock has to be procured, imported processing equipment is used, external labour needs to be

hired, briquettes are produced far away from the sales markets, and a dedicated building and other infrastructure needs to be established. When such conditions apply bamboo charcoal production may only be a viable venture when (a) it is run as a side business, with the main business being capable of absorbing costs associated with bamboo procurement; (b) transport and production facilities including some staff can be shared between charcoal briquettes production and the main operation; (c) bamboo charcoal briquettes can be sold at a premium compared to lump charcoal.

For illustration purposes the production cost level at a (semi-)industrial size plant in Asia is presented. For a Chinese carbonisation plant (output 30 ton/month) using retorts the specific production costs are calculated at USD 268 (EUR 206) per ton, with bamboo resources (processing residues) contributing USD 42 (less than 16%) to these costs (Jiang, 2004). For a carbonisation plant of the same size producing tube bamboo charcoal in brick kilns the specific production costs are calculated at USD 573 (about EUR 441) per ton, with biomass resources (fresh bamboo) contributing USD 424 (approx 75%).

6.7 Charcoal sales and marketing of bamboo charcoal briquettes

Charcoal that is made from bamboo can be used for a variety of purposes. In China bamboo charcoal is rarely used as fuel but instead for water and air purification, waste water treatment, and medical uses. Charcoal co-products, such as vinegar, are used for agricultural applications (Jonkhart 2011). Chinese researchers are continuously developing new higher-value applications for bamboo charcoal; an overview of such applications is presented by (Fu and Hunde 2012).

Charcoal briquettes made from bamboo processing residues find a ready export market in e.g. South Korea where it is used as a quality fuel for barbecuing.

In Africa where at present there is little market for these higher value added applications bamboo charcoal can alternatively be used as substitute for wood charcoal. Using bamboo exclusively as a source of energy adds relatively little value to the resource. However, due to the early stages of development of the bamboo sector in Africa the number of higher-valued added applications that can be developed realistically in the short term is limited.

The marketing of bamboo charcoal briquettes is not different from marketing other alternative charcoal briquettes, as discussed in the previous chapters. Important market segments, in terms of volume and/or profitability, may include the mass domestic market, business and institutional consumers (restaurants, hotels, hospital, schools, etc.) and the urban middle class. And in most countries it is rather unlikely that bamboo charcoal briquettes can be sold at a lower price than lump charcoal, which is typically produced by an under-taxed, under-regulated informal sector, which sources its raw material at little or no cost.

Even in the African economic setting there may be some niche market opportunities for a viable bamboo charcoal business, as the following examples from East Africa illustrate:

- In its factory near Addis Abeba, Adal Industrial PLC produces bamboo charcoal briquettes using knots (bamboo processing residues of about 5-15cm length) as feedstock. The briquettes are packed into 5kg bags and sold in various supermarkets in Addis Ababa (Kasa, 2011).
- In the INBAR project in Ethiopia, beehive (honeycomb) briquettes were test marketed and sold together with improved beehive stoves (available for a few dollars) by the piece (approx. 400 gram) at open air markets. Due to the higher fuel efficiency of the stove, less fuel is needed to cook a meal than when lump charcoal and a regular charcoal stove is used.
- Charcoal briquettes that are higher priced but attractively packaged may still find some customers e.g. those willing to pay more for a product that is produced in a sustainable manner. Such environmentally and socially conscious buyers may include individuals as well as institutions (for the latter it may be a part of their company's policy).

It remains to be proven to what extent a viable and sustainable business can be set-up to serve these cooking fuel market niches.

6.8 Sustainability aspects of bamboo charcoal briquettes

6.8.1 Sustainability aspects of bamboo harvesting

Bamboo grows rapidly, also without using irrigation water. The overall quality of a bamboo stand improves and the total culm mass increases with regular removal (thinning) of culms. After harvest the culms will regenerate without replanting. This makes bamboo an ideal feedstock for a wide range of applications.

Due to bamboo finding limited commercial applications, few African farmers manage their bamboo resources properly. As a result, the culm density (number of culms per ha) is far higher than what is needed to maximise the culm diameter and the culm mass. Many over-aged bamboo culms, that have little commercial value, are left standing.

When bamboo is in high demand, bamboo plantations can be established. Apart from producing bamboo (as a substitute for timber) these plantations can be used as carbon sinks. Unlike woody crops bamboo offers the possibility of annual selective harvesting and removal of about 15-20% of the total stock without damaging the environment and stock productivity. In recent years the interest of establishing bamboo plantations for this dual purpose has increased significantly, with initiatives reported in Ethiopia, Kenya, Mozambique, South Africa, and Congo among other places.

Harvesting large quantities of bamboo can be tough, especially at locations where the terrain is steep and/or culms are growing densely. Full grown individual culms can be heavy (more than 20 kg fresh, due to their high moisture content), making their handling and hauling exhaustive. Using animal traction will greatly reduce the burden to humans.

6.8.2 Sustainability aspects of bamboo charcoal briquette production

Producing charcoal in metal or brick kilns from a underutilised biomass resource and with improved yield compared to traditional earth (pit or mound) kilns contributes to reducing CO₂ emissions. Recycling or flaring the pyrolysis gases as can be done in brick kilns and in Chris Adam's ICPS retort greatly reduces methane emissions linked to charcoal production.

Transport is a major component in the bamboo charcoal value chain, both in terms of costs and energy. Fuel consumption and greenhouse gas emissions linked to bamboo charcoal transport can be significant, even higher than for wood charcoal, when using fresh (wet) bamboo as feedstock, hauling it to a central location, away from the harvesting site, and using motorised vehicles for transport. When using bamboo processing residues as feedstock to produce bamboo charcoal at a site close to the consumer market, the costs and energy demand associated with transportation is likely to be much lower compared with lump charcoal.

The conversion of tube bamboo charcoal into charcoal briquettes is not required in the case of lump charcoal. Energy is needed for the briquetting step, with associated greenhouse gas emissions.

Bamboo charcoal has a heating value that is roughly the same as that of lump charcoal. Greenhouse gas emissions (in particular CO₂) related to charcoal combustion are a function of the combustion efficiency, which is higher in improved stoves (commonly used for beehive charcoal briquettes).

7 Conclusions and recommendations

7.1 Conclusions

General: Although the experience to date is mixed at best, alternative charcoal briquettes can offer a significant contribution to energy supply in African countries in the longer run, in particular in those markets where wood charcoal prices are already, or on track of becoming, somewhat higher (and starting to reflect the real costs).

Feedstock availability: Charcoal dust, cotton stalks and bamboo are available in significant quantities across Sub Sahara Africa and find few alternative uses. Therefore, there is a large (technical) potential to produce alternative charcoal from these and other biomass resources. There is some long term experience with the briquetting of charcoal dust, in particular in East Africa (e.g. Kenya). There is no long term experience with carbonisation and briquetting of cotton stalks or bamboo at a commercial scale in Africa.

Feedstock collection: Charcoal dust is available as leftover at (wholesale and retail) charcoal trading sites. Cotton stalks are harvest residues available in the cotton growing fields. Bamboo is available directly from the growing areas (natural stands and -to a little extent- plantations) or, as a processing residue. With the exception of bamboo processing residues, in all cases the resource is dispersed and collection is labour intensive, which is both an opportunity (to generate employment) and a challenge (to organize effectively).

Logistics: due to the material already being carbonized, charcoal dust has the shortest and simplest production chain of the three types of biomass feedstock considered. As a result this is normally also one of the most cost-effective options to produce alternative charcoal for energy purposes. This is reflected in the significant number of both small-scale and (semi-)industrial scale initiatives to establish a livelihood or a business from alternative charcoal production using charcoal dust as raw material. The case of Chardust Ltd. in Nairobi is particularly successful and is often used as showcase for replication elsewhere (with varying degrees of success).

Carbonisation: Over the last few decades a wide range of improved kilns has been developed and tested, to speed up carbonization and to increase carbonization yields. Kiln capacities vary from a single drum (200 litres) to several hundred m³ (in case of the Missouri kiln). Portable metal kilns are particularly practical when biomass has to be collected from a wide area, such as e.g. cotton stalks. Brick kilns have a longer lifetime and allow better process control. The Adam retort, a recent development, tries to combine these advantages. The highest and most consistent carbonisation efficiencies can be achieved using (semi-)industrial retorts but due to their high investment costs these are often not affordable in the African context. The morphology of the biomass can also limit the suitability of a certain type of carbonisation kiln.

Briquetting: Briquetting technologies are available in a wide capacity range, from very small to very large and with varying degrees of mechanization and automation. Agglomeration is the main technology used for producing charcoal briquettes from cotton stalks, as they give high quality briquettes, require a relatively low investment, and are therefore suitable for small industrial applications.

Charcoal products: Charcoal dust briquettes are not necessarily a direct substitute for lump charcoal. There is a trade-off between price and performance. Depending on such aspects as the quality of the charcoal feedstock (e.g. ash content, degree of contamination with soil), the binder and the operating pressure applied charcoal briquettes of various quality levels (low, regular, premium) can be produced. In case bamboo is carbonised in a brick kiln an intermediate charcoal product can be produced that offers potential for secondary conversion into higher value products (e.g. activated carbon).

Marketing: The African market for alternative charcoal briquettes as a possible substitute for lump charcoal or otherwise is largely undeveloped. When introducing charcoal briquettes in the local market substantial marketing efforts including promotional and publicity campaigns, are needed.

Seasonality: the seasonal availability of cotton stalks (4 months/year) and green bamboo (difficult to collect during the wet season) makes year round operation of an alternative charcoal plant based on these fuels difficult to achieve. Long term storage of (raw or carbonized) feedstock is necessary. Alternatively the plant can be operated seasonally as well.

Employment opportunities: an alternative charcoal plant generates a considerable number of jobs, both direct jobs at the factory itself as well as indirect jobs for the collection of raw material.

Sustainability: Using an alternative source of biomass, instead of unsustainably harvested wood, involves various environmental advantages (e.g. less forest depletion). The use of improved kilns, rather than traditional kilns, with improved carbonization efficiency leads to fewer emissions of greenhouse gas. Equipping the kilns with facilities for tar recovery and the reduction of smoke further reduces environmental impacts.

Protection should be provided to prevent workers from the dangers of inhaling dust and to prevent fires. There is a risk of child labour especially in feedstock collection.

Business potential: the wood that is used for regular lump charcoal is often not being paid for, but taken for free instead. The market price for charcoal depends to a significant extent on the charcoal transportation costs, which will be high in case of long transport distances. The fact that the wood price and externalities (feedstock depletion, deforestation, greenhouse gas emissions, etc.) are not being factored in the market price of wood charcoal make direct price competition for alternative charcoal a challenge. The main competitive advantage for alternative charcoal may be that it can often be produced closer to urban demand centres,

with lower transportation costs associated. To minimise transportation costs the location of the carbonization and briquetting operations need to be selected carefully.

To reduce production costs a (semi-)industrial scale charcoal operation is best run (initially) as a side business, with the main business being capable of absorbing costs associated with e.g. overheads and the possibility of sharing staff, production and transport facilities. (Owen, 2012) suggest that charcoal briquettes production can only be viable in African countries where charcoal is relatively expensive. He estimates that the minimum wholesale prices would have to be some \$200 per ton (for packaged charcoal). This rules out many African countries as candidate manufacturing sites.

Other viable business opportunities may be to produce charcoal briquettes for the export (barbecue) market, or to produce activated carbon and other higher value charcoal products for the local market using bamboo as feedstock. The first is an established, highly-competitive international business, whereas the second is largely undeveloped in Africa. In the absence of a developed market for industrial (higher-value) charcoal products the use of (bamboo)charcoal as a source of energy cooking fuel may help to get the market started.

Additional funding: experience to date suggests that it is challenging to establish and operate an alternative charcoal briquetting facility in a competitive way without any external support. Microfinance could be used to set up smaller charcoal businesses. Larger facilities will require commercial loans, possibly in combination with additional (donor) funding.

7.2 Recommendations

Feedstock collection: to organise the collection of biomass effectively it is recommended to collaborate with women groups, communities or other self-help organisations.

Feedstock storage: For feedstock that is only available seasonally, it is recommended to investigate whether storage of (carbonised) feedstock (cotton stalks, fresh bamboo or another type of biomass that needs harvesting) is possible, such that year-round operation of the alternative charcoal plant can be guaranteed. If this is not the case, it should be researched if the plant can be operated only part of the year, creating seasonal labour.

Carbonisation: To achieve higher conversion efficiencies and improved environmental performance the implementation of chimneys and of tar and methane recovery facilities is worth investigating.

Business viability: a business case that seems to offer good prospective is the marketing of charcoal briquettes in combination with improved charcoal stoves. When using improved stoves with higher energy efficiency users will find that less fuel is needed; which is considered maybe the single most important criterion for user appreciation. It is recommend to assess opportunities for collaboration with

stove producers. An additional reason for seeking such collaboration with stove producers is the potential to generate income from (voluntary) carbon credits⁷. Such carbon credits may also help finance the implementation of carbonisation equipment with reduced environmental impact (e.g. kilns with chimneys, or with tar and methane recovery).

⁷ see e.g. the pilot work done by Toyola Energy Limited (TEL) in Ghana

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ANNEX: Introduction ACT - Alternative Charcoal Tool

In order to help select promising alternative feedstocks to be considered for charcoal production a **decision support tool** has been developed in which supply chains can be designed. The tool can be downloaded from [here](#). The alternative charcoal tool (ACT) consists of four parts:

- Feedstock selection
- Market selection
- Technology selection
- Production costs determination.

ACT alternative charcoal tool

Version 1.0

Welcome at the screening tool for eco-friendly charcoal production from alternative feedstocks

At least 80% of the African population depends on traditional biomass resources such as charcoal and firewood for household energy use. Most charcoal is produced in forests near urban areas, where most charcoal consumption takes place. Charcoal production is an important cause of deforestation, one of the most urgent environmental problems of Africa.

One of the solutions is to promote the use of alternative feedstocks for wood charcoal. Examples are charcoal dust, harvest residues, processing residues and invasive species. So far, the use of wood charcoal alternatives has been limited since its production requires additional techniques and investments and need an organization structure that needs to compete with the existing, usually informally organized charcoal sector that requires few investments.

This screening tool gives information and insight in the potential of charcoal production from alternative feedstocks. The screening tool consists of four modules, that cover feedstock, market and technology section and production costs.

Please ACT and select a module

[Module 1: feedstock selection](#)



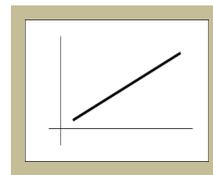
[Module 2: market selection](#)



[Module 3: technology selection](#)



[Module 4: production costs determination](#)



THIS TOOL IS DEVELOPED BY:



THIS TOOL IS SUPPORTED BY:



The ACT has been developed as a decision support system with three categories of potential users in mind:

- Private business (entrepreneurs and investors)
- Governments
- Development NGO's (and donor organisations)

Entrepreneurs and investors can use the tool modules as a quick guidance for assessing business case opportunities. Governments and development NGO's can

use the screening tool as an instrument to support policy-making and for the design and implementation of development programmes and projects.

To maximise the relevance of the screening tool, and to ensure that it produces relevant outcomes for all user groups, a draft version was field tested in two African countries, i.e. Ethiopia and Ghana, where it was presented to and discussed in a series of bilateral meetings with local stakeholders. The suggestions and feedback from these stakeholders and from Agency NL are incorporated in the current (beta-version of the) tool.

The tool has also been presented to selected donor organisations (EU Energy Initiative Partnership Dialogue Facility, EUEI PDF, Deutsche Gesellschaft für Internationale Zusammenarbeit, GIZ and the United Nations Industrial Development Organization, UNIDO) for their feedback.



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