DRAFT REPORT: VERSION 2 (FINAL)

Urban Briquette Making Pilot

Identification of biomass waste-based briquettes making technologies (part 2 of 5)

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Acronyms

CARE2	Capital Access for Renewable Energy Enterprises
CBO	Community Based Organisation
CTCN	Climate Technology Center and Network
DEEP	Developing Energy Enterprises Project
EEP	Energy Environment Partnership
FGD	Focus Group
GKIT	Greening Kenya Initiative Trust
IAC	Indoor Air Concentration
KeBS	Kenya Bureau of Standards
KES	Kenya Shillings
KIRDI	Kenya Industrial Research and Development Institute
KPCU	Kenya Planters Co-operative Union
NAWASSCO	Nakuru Water and Sanitation Services Company Limited
NCCAP	National Climate Change Action Plan
NCSP	Nakuru County Sanitation Programme
NDC	National Designated Contribution
NDE	National Designated Entity
SNV	Netherlands Development Organization
UBPA	Kenya United Briquette Producers Association
VEI	Vitens Evides International
WIRE	Women in Renewable Energy

1 Introduction

1.1 Overview of briquetting technologies

The term "briquette" is a composite term used to identify a wide range of biomass-based fuels that vary in terms of composition, shape, size, energy density and price[1]. This variety is largely determined by the feedstock options and the process of production. Feedstock options used to create briquettes can be classified into four main groups: organic municipal waste, agricultural residue (e.g. coffee husks, sugarcane bagasse, rice husks, macadamia nuts, wheat straws), forestry residue (e.g. sawdust, chips, offcuts) and charcoal dust. Processes of production results in two main classes of briquettes; carbonized and non-carbonized briquettes. Carbonized briquettes are made from biomass that has undergone pyrolysis while non-carbonized briquettes on the other hand are processed directly from biomass sources through various casting and pressing processes also known as compaction or solidification. The raw material is typically compressed under high pressure which releases the lignin in the biomass enabling the binding process that forms the non-carbonized briquettes[2].

Relative to non-carbonized briquettes, carbonized briquettes have a higher calorific value, burn with minimal smoke, contain lower ash content, and cannot be destroyed by insects such as termites[3]. For these reasons, they are preferred for cooking and space heating (e.g. poultry farming). Non-carbonized briquettes are cheaper (per unit mass) and burn longer (up to 6 hours)[4], therefore preferred by industrial and institutional users such as factories, schools, hospitals and prisons. The ability to burn for long reduces the number of times the fuel must be loaded to the boilers thus reducing the cost of energy for end-users. These two briquetting processes are explained under section 2 of this report. In addition to these two main classes of briquettes, there is a third but uncommon class known as semi-carbonized briquettes formed through a process known as torrefaction[5]. These are briquettes whose outer layer (2-4 millimetres) is carbonized while the inner section is non-carbonized. The approach to production includes manual (artisanal), mechanical and electrical processes and varies from micro-scale production (e.g. hand-made briquettes) to large-scale production (e.g. assembly line industrial scale based).

While recognizing the diversity in input material, types of producers, process of production and scale of production, this report will outline the technologies under each of the main steps along the

[1] Ministry of Energy (2019). *Kenya Household Cooking Sector Study: Assessment of the Supply and Demand of Cooking Solutions at the Household Level.* https://www.eedadvisory.com/wp-content/uploads/2019/11/moe-2019-cooking-sector-study-.pdf

[2] Nikolaisen, L.S., and Jensen, P.D. (2013). Biomass feedstocks: categorisation and preparation for combustion and gasification. *Biomass Combustion Science, Technology and Engineering (*pp. 36 -57*)*. Woodhead Publishing Series in Energy. https://doi.org/10.1533/9780857097439.1.36

[3] Hu, J., Lei, T., Wang, Z., Yan, X., Shi, X., Li, Z., He, X., Zhang, Q. (2014). Economic, environmental and social assessment of briquette fuel from agricultural residues in China – A study on flat die briquetting using corn stalk. *Energy 64*, 557 -566.

[4] Key informant Interview

[5] Stepien, P., Pulka, J., Bialowiec, A. (2017). Organic Waste Torrefaction – A Review: Reactor Systems, and the Biochar Properties. Pyrolysis Intechopen http://dx.doi.org/10.5772/67644

production process. The main processes are divided into; i) pre-processing, ii) pyrolysis and carbonization, iii) mixing, iv) binding and compaction and v) drying as shown in Figure 1 below.

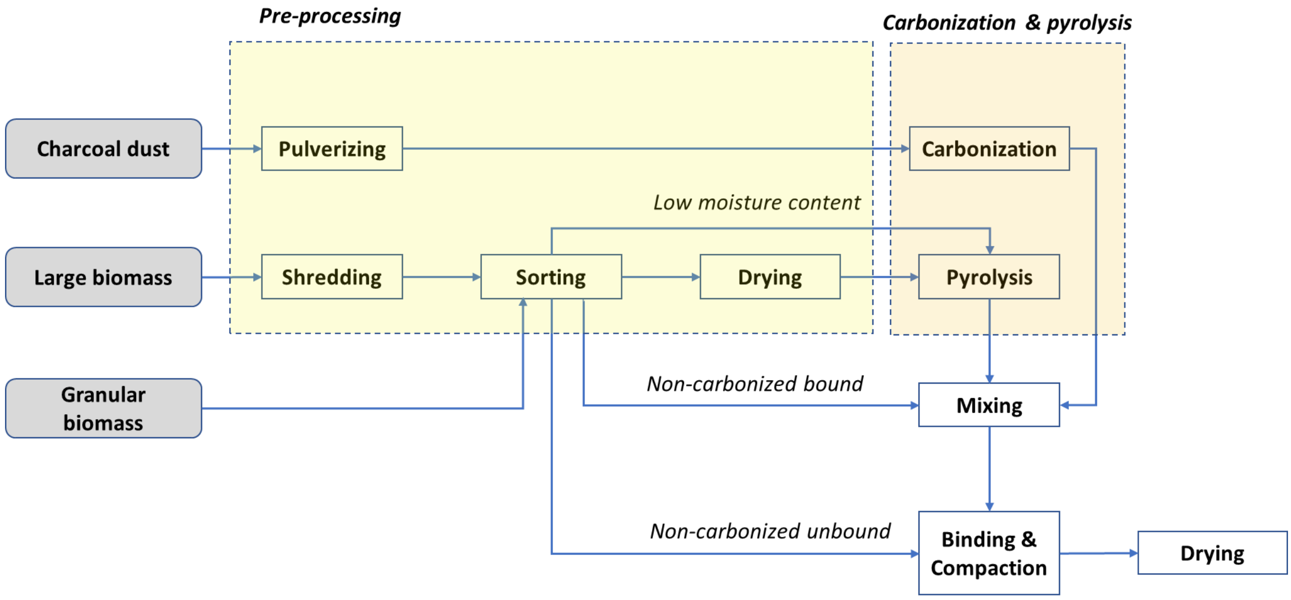

Figure 1: Main step along the production process

1.2 Purpose of this study

Kenya, through its National Designated Entity (NDE), has sought technical assistance from the Climate Technology Centre and Network (CTCN) to support the development of the briquetting sector as part of its objectives under the National Designated Contribution (NDC) and National Climate Change Action Plan (NCCAP). Production of briquettes is viewed as a potential alternative to traditional and unsustainable forms of solid biomass. This evaluation focuses on charcoal dust, sawdust and organic municipal solid waste and their potential as viable feedstock options for briquette production. Based on the *Technical Assistance Response Plan – Terms of Reference* submitted by the NDE, this assignment assesses the briquetting value chain ranging from sourcing of raw materials, production technologies, supply chains to the policy environment in the sector. For each of these tasks, the output is a standalone report. This report is part 2 of a series of 5 reports as shown in Table 1 below and focuses on identification of biomass waste-based briquette making technologies.

Table 1: Series of reports

#	Report	Title
1	Part 1	Review of legal frameworks related to briquette production in Kenya
2	Part 2	Identification of biomass waste-based briquettes making technologies
3	Part 3	Analysis of the supply chain of the briquette making processes
4	Part 4	Development of a training manual
5	Part 5	Inventory of raw materials that can be used for making biomass briquettes

1.3 Approach and methods

Information and data used in this report was collected through literature review and primary data analysis. This was then analysed and synthesised into a unitary report. **Error! Reference source not found.** below summarizes the main approaches and methods used.

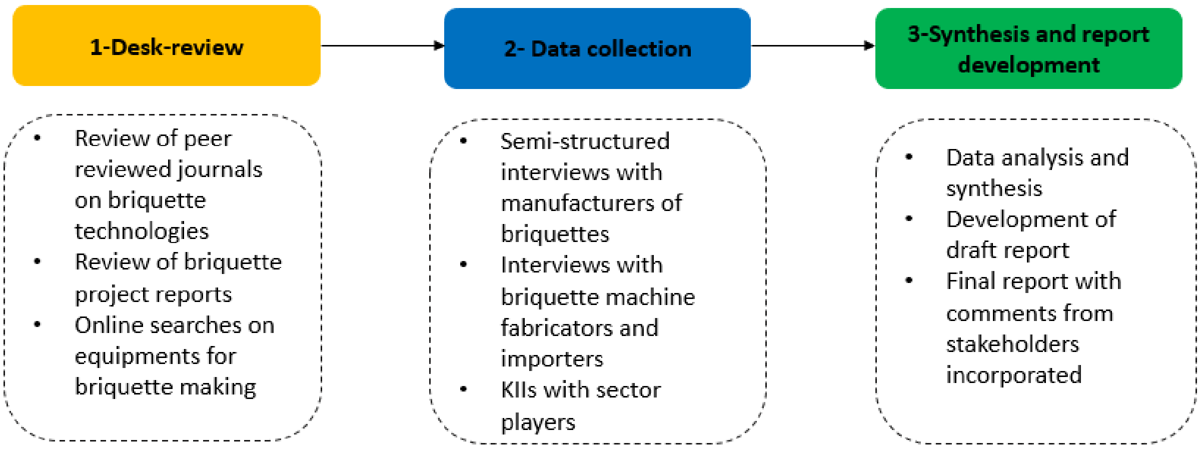

Figure 2: Summary of approach and methodology

i. ***Literature and secondary data review*** included the appraisal of relevant literature on briquetting technologies from peer reviewed journals, grey literature, Government reports and various data depositories. A summary of the main reports published in the recent past is provided in Table 2 below.

Table 2: List of prominent reports

#	Author/Institution	Title	Key findings
1	GVEP (now Energy 4 Impact)	Assessment of the briquette market in Kenya (2013)	- Survey covered 35 briquette entrepreneurs - Categorized the briquetting technologies into handmade, manual machines, locally fabricated electric machines and imported machines - Charcoal dust was the most common type of feedstock (26/35 respondents) - Charcoal was the most preferred fuel compared to briquettes due to quality issues
2	George Ngusale	Briquette Making in Kenya; Nairobi and Peri-Urban Areas (2014)	- Survey covered 18 briquette entrepreneurs - Charcoal dust was the most common feedstock for briquette production - Consumers are the schools, churches, hotels and some households - Barriers identified included; technological challenges (lack of briquetting machines, low quality binders and lack of appropriate feedstock), lack of finance to grow the business, and lack of briquette standards.
3	Mary Njenga	Evaluating Fuel Briquette Technologies and their	- Study of briquette production methods in Nairobi and surroundings

		Implications on Greenhouse Gases and Livelihoods in Kenya (2013)	- A Focus Group Discussion (FGD) with 8 self-help groups and 1 private company was carried out - Additionally, laboratory experiments on ash contents, volatile matter and calorific values for the different types of briquettes were conducted - Fuel briquettes made from charcoal dust and soil as the binder performed the best in terms of combustion and emission qualities - Type of tree species determine the quality of charcoal dust produced during charcoal production - Carbonizing sawdust increased calorific value of the briquette by 40%, reduced Indoor Air Concentration (IAC) of CO by 67% and $P.M_{2.5}$ by 98% - Adopting improved wood production and wood carbonization systems will result in additional cooking fuel supply and reduced Global Warming Potential - Trainings to community groups were recommended to aid in improving the quality of briquettes produced
4	Article on Energy for Sustainable Development- (Mwampamba,T.,Owen.M. and Pighart.M)	Opportunities, challenges and way forward for the charcoal briquette industry in Sub-Saharan Africa (2012)	- Study covered charcoal producers in Kenya, Rwanda, Uganda, and Tanzania - Briquettes have displaced only small volumes of charcoal demand - Main barriers in the sector include; low prices of wood charcoal, fiscal requirements for briquette producers, and supply-driven (versus market-led) approaches to industry development.

ii. ***Primary data collection*** involved conducting interviews with briquette producers, briquette making equipment fabricators and distributors, and a select set of opinion leaders and experts in the sector. From a long list of 60 briquette producers a representative short list of 25 producers was created. This sample included a mix of carbonized and non-carbonized briquette producers; small, medium and large-scale producers; sole entrepreneurs, community-based organizations and limited companies; and a regional representation of producers. Three interviews were held with local fabricators, 1 importer and 1 international manufacturer. A list of the respondents is provided in Annex 2 and Annex 3.

iii. ***Report synthesis*** which focused on aggregating and analysing qualitative and quantitative data to identify the briquette making technologies in Kenya and the challenges in the sector.

1.4 Summary of past initiatives and current producers

Two of the earliest briquette making plants in Kenya were installed in the 1980s with the goal of meeting energy demand for industries and reducing the high dependence on imported oil [6]. The need for self-reliance was driven in part from the lessons and inconvenience of the 1973 global oil crisis[7]. One of the most prominent briquetting plants was set up by the Kenya Planters Co-operative Union (KPCU) in 1981 to supply consumers who depend on charcoal in urban and peri-urban areas

[6] FAO. (1990). *The briquetting of agricultural wastes for fuel; Part 3 Country Reviews*. http://www.fao.org/3/t0275e/T0275E06.htm
[7] Issawi, C. (1978). The 1973 Oil Crisis and After. *Journal of Post Keynesian Economics*, *1*(2), 3–26. https://doi.org/10.1080/01603477.1978.11489099

of Kenya and for export to Saudi Arabia[8]. About 200 tonnes of charcoal a month was produced from 400 tonnes of coffee husk during the earlier years. The project was informed by the various studies that had predicted a shortage in the supply of wood and an increase in rate of deforestation if alternative sources of fuels were not promoted. Between then and now, there have been several initiatives led by development agencies, research institutions, Government departments, non-governmental organizations. Table 3 below provides a summary of key initiatives that have been implemented in Kenya.

[8] FAO (1985). *Unasylva – International journal of the forestry and food industries*. Food and Agriculture Organization of the United Nations, Rome – Italy.

Table 3: Summary of key initiatives promoting briquetting technologies

#	Organization	Name of the initiative	Activities
1.	Energy 4 Impact	- Developing Energy Enterprises Project (DEEP) - Capital Access for Renewable Energy Enterprises (CARE2) Project (2008- present)	- Business and technical advisory services - Market development - Financial linkages to purchase machinery - Improve quality of briquettes through product design - Promote gender diversity and inclusion
2.	Practical Action East Africa	- Briquette Commercialisation Project (2011-2015)	- Technical advisory on the technology - Assistance on setting up the business
3.	Netherlands Development Organization (SNV)	- Improved Charcoaling Technologies and Briquetting using Agricultural Waste (Jan-Sept 2013)	- Technical advisory on the technology - Assistance on setting up the business
4.	Middlesex University, Kenyatta University, Terra Nuova	- Fuel from Waste Network (2010-2012)	- Formed a network of briquette producers - Facilitated knowledge sharing - Create awareness of the technology/best practice
5.	Kenya United Briquette Producers Association (UBPA)	- Supporting the expansion and replication of briquetting businesses in East Africa[9]	- Supporting technical, financial, and policy innovations.
6.	Hivos in partnership with the Greening Kenya Initiative Trust (GKIT)	- The National Biomass Briquette Program (2018-2022)	- Establish standards for production of domestic and industrial briquettes - Support community-based enterprises to create sustainable income while safeguarding the environment
7.	NAWASSCO in partnership with SNV, Umande Trust and Vitens Evides International	- Nakuru County Sanitation Programme (2018)	- Formed a subsidiary company Nawasscoal for producing carbonized briquette from the combination of sawdust and faecal matter collected in Nakuru county
8.	Kenya Bureau of Standards (KeBS)	- Quality assurance	- Development of the briquette standards - Enforcement and monitoring for compliance
9.	Kenya Industrial Research and Development Institute (KIRDI)	- Research and Development	- General research on briquettes - Testing facilities
10.	Jomo Kenyatta University of Agriculture and Technology	- Research and Development	- Research in low cost briquette-making machines
11.	University of Nairobi	- Research and Development	- Testing facility - Research in briquettes
12.	The Kenya Forestry Research Institute (KEFRI)	- Research and Development	- Research on improved carbonization methodologies
13.	Ministry of Energy	- Energy Centers	- Demonstration and training hubs in sustainable energy. - Training and awareness creation of briquetting technology.

[9] The Charcoal Project.(2019). *New Carbonized Briquette Producer Association Created in Kenya*. https://newsite.charcoalproject.org/kenya-briquette-manufacturers-association-to-hold-first-general-meeting-july-23rd/

14.	Energy and Environment Partnership (EEP)	- Research and Funding	- Research into briquette markets - Grant programs

Other organizations that have been active in the sector include; rotary international who partnered with Energy 4 Impact to provide grants for purchasing of briquetting; Green Africa foundation who were involved in trainings and facilitating acquisition of machines for the manufacturers; Legacy Foundation that was involved in the production of the wood press machines and user manuals; Kiva which provides loans to business start-ups including briquette producing enterprises ,and the Green Belt Movement who partnered with AMREF to train manufacturers in Kajiado on briquette production.

Profiles of producers interviewed

Briquette producers can be grouped into sole entrepreneurs, limited companies, and Community Based Organisations (CBO). Out of the 20 interviews carried out, 11 were limited companies and these include Kings Biofuels, Eversafe Limited, Sanivation, Nyalore Impact, Biomass Energy East Africa Limited, White coal industries limited, Bioafriqenergy Limited, Eco Charge, Kencoco, Acacia Innovations, and Wood Heat Energy Limited. Although most of them (12 out of 20) started operations in the last five years, other companies such as Kings Biofuels, Eversafe Limited, Lean Energy and Chardust have been in the market for the last decade. The sector is however dominated by informal and artisanal small-scale producers, who do not: label their products nor supply them in standardized units; belong to a formal or registered association or a production hub, and do not have an online presence making it difficult to exhaustively profile them, their businesses and products. Many of these are opportunistic, resulting in inconsistent production patterns and produce briquettes as a supplementary product.

Out of the 20 respondents, 14 of them have their business registered as a company or a CBO, 11 of the businesses are owned by women and 10 of the businesses are owned by youths (less than 35 years). Fourteen (14) of the businesses are fully operational, 4 are partially operational and 2 had closed their businesses. Details of the businesses interviewed are provided in Figure 3 belowError! R

Figure 3: Profile of the briquette producers interviewed

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The 20 businesses interviewed for this survey employ a total of 332 employees with women being more (55 %) than men (45%). It is also observed that youths are active in the sector with 69% of all employees being youths. Men form a higher proportion of full-time employees (62%) with women working on temporary basis. This might be explained by the fact that most large producers hire temporary workers to help with activities such as sorting of waste, drying of the raw material and briquette drying which are often performed by women. In regard to management, the proportion of men in managerial positions are slightly higher at 51 % compared to women at 48%. It is also observed that more than half of the employees in managerial positions are youths (53%). Further details are provided in the Table 4 below.

Table 4: Employee composition of the 20 producers

#		Men	Women	Youth
1	Total	45%	55%	69%
2	Permanent	62%	38%	68%
3	Temporary	27%	73%	71%

Feedstock and type of briquettes

As discussed above, there are 3 types of briquettes. From the interviews conducted with the briquette producers, all the 3 types were identified in this study. Carbonized briquettes are common among the CBOs and sole proprietors while non-carbonized are mainly produced by limited companies. Only one of business produces semi-carbonized briquettes. A summary of type briquettes per business is provided in the Figure 4 below.

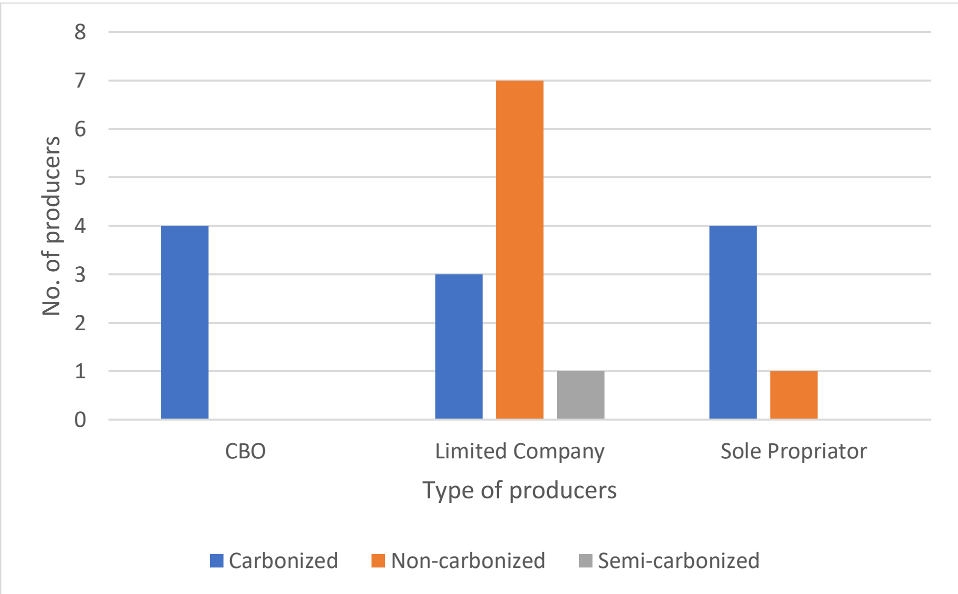

Figure 4: Types of briquettes produced

Macadamia nut shells, sawdust, charcoal dust, baggase, maize cobs and paper waste were identified as the main type of feedstock used by the producers interviewed. Charcoal dust was the most common type of feedstock with 9/20 producers (CBOs and sole proprietors) using it as the main feedstock. This may be explained by the fact that the waste is already carbonized and can be acquired for free or at a cost as low as KES 1 per kilogram making it a desirable raw material for small scale producers. Charcoal dust is also used prominently by producers who target households, small hotels or poultry farmers who require carbonized briquettes. Baggase and sawdust were the most common raw materials for limited companies who produce non- carbonized briquettes. For producers who use more than one type of biomass, the following combinations were identified; sawdust and coffee husks, sawdust and charcoal dust, charcoal dust and macadamia shells, charcoal dust and coconut waste, faecal waste and sawdust.

Production and type of end-users

To estimate the production capacity, the producers were asked to estimate the tonnes of briquettes produced for 2019. The production capacity for 2019 was classified into 3 groups based on quantities produced. Further analysis per group on type of business, type of briquettes produced, and main consumers was carried out and is summarized in Table 5 below. From this analysis it is evident that large quantities of briquettes were produced by limited companies who specialize in non-carbonized briquettes for industrial, institutional and small enterprises such as eateries. Small quantities produced were targeted at households, small enterprises such as eateries and space heating for poultry farmers.

Table 5: Production capacity for 2019[10]

#	Production Range (tonnes/2019)	Type of businesses	Type of briquettes	Main end-users
1	1,000-2,500	Limited Companies (4 companies)	Non-carbonized	- Factories - Public institutions - Small enterprises e.g. Kiosks
2	200-700	Limited Companies (3 companies)	Non-carbonized Carbonized	- Factories - Public Institutions - Households
3	5-100	CBOs (2 CBOs) Sole Proprietors (3 producers) Limited Companies (1 company)	Carbonized Non-carbonized Semi-carbonized	- Households - Small enterprises e.g. Kiosks - Poultry farmers

[10] Note that 25 % of the producers did not provide information on production quantities for 2019

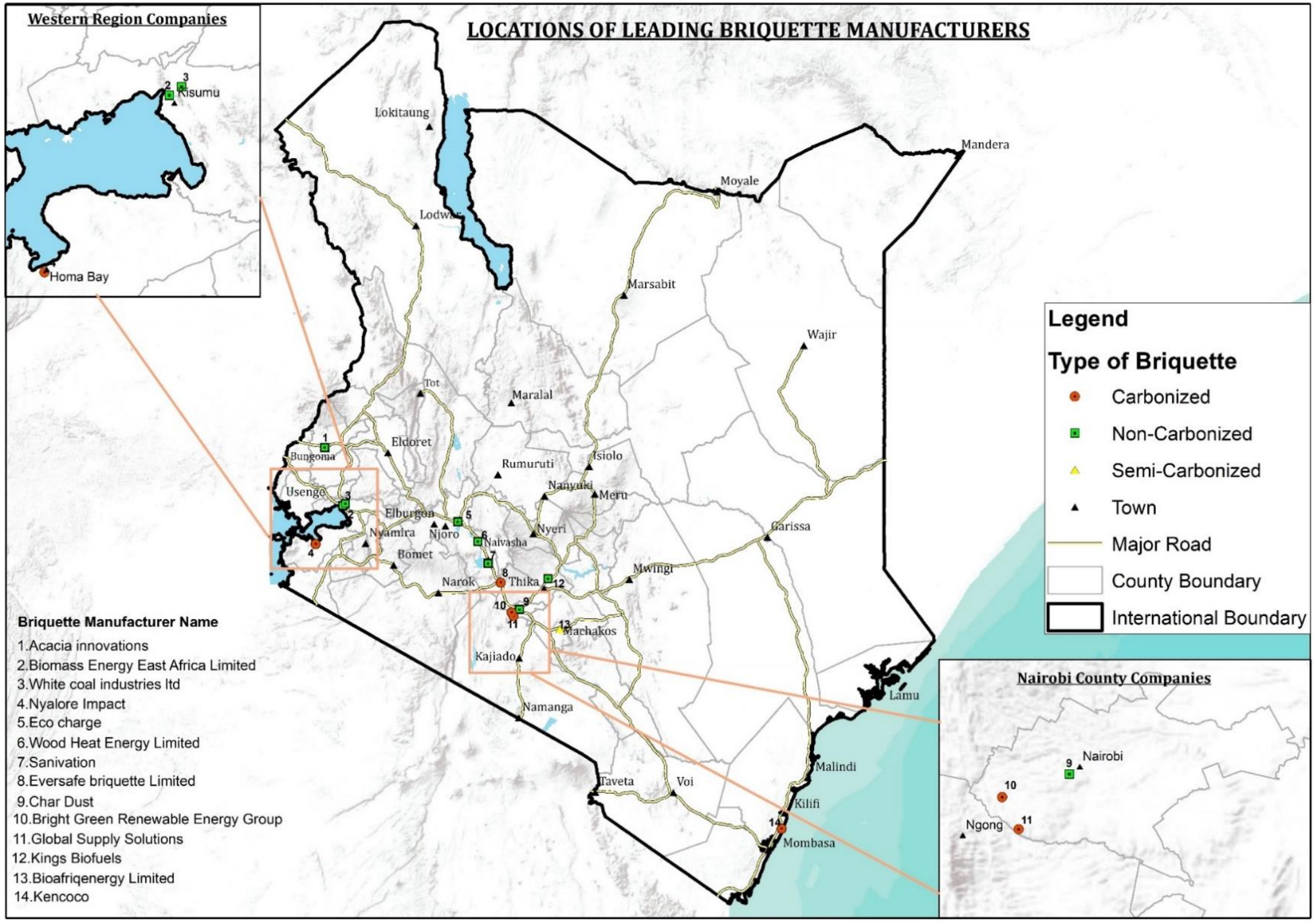

Figure 5: Location of briquette manufacturing companies in Kenya

2 Description of the Processes

2.1 Pre-processing

Producers have to first identify a suitable feedstock. This choice is driven by various factors including proximity to a source, proximity to markets, availability of technology options and cost considerations. The preparation of raw materials includes drying, sorting and separation, shredding, grinding, pulverizing and milling. Factors including type, moisture content and size of the raw material will determine the pre-processing method. For example, to produce high quality non-carbonized briquettes, the moisture content of the raw material must be between 6% and 16%[11]. This is important since compaction will not occur at high moisture content. Sugarcane bagasse may have moisture levels of up to 50% which requires sufficient levels of energy for drying as part of the pre-processing[12]. Other feedstock options including charcoal dust and macadamia nuts start off with low moisture content and may not require any drying[13]. However, the hard outer shell of the macadamia nuts may require crushing or milling to facilitate proper compaction. Paper waste, wheat straws and sugarcane bagasse may require shredding. The drying process includes open air sun drying, use of solar drying where the raw materials are dried in an enclosed structure similar to a greenhouse covered with high density transparent polythene sheet that allows radiation into the room, or the use of blowers and driers powered by electricity or fossil fuel[14]. Sorting or in other cases waste separation is required when the feedstock has high levels of foreign materials and other impurities that may interfere with the briquetting process. Handpicking and use of sieves are the most common methods [15]. Some materials require grinding before the compacting process. This is done through a hammermill driven by either an electrical or a diesel engine[16]. The diesel driven hammermill is much preferred in areas where the electricity grid has not reached or is unreliable.

Collection and processing of centrally located feedstock is preferred although many of the producers have to source from several points which can be tedious and costly. Coffee husks for instance, is sourced from coffee milling companies such as Kofinaf Coffee millers, Central Kenya Coffee Mill Karatina, Thika Coffee Mill; sugarcane bagasse from the sugar factories including Chemelil Sugar Company, Kibos Sugar and Allied Factory and; pineapple waste from pineapple growers and processors such as Delmonte Limited. Sawdust can be sourced from saw millers who are mostly located along the Nakuru-Nairobi Highway, timber yards and furniture workshops. Charcoal dust is mainly collected from charcoal wholesalers in urban areas. Municipal solid waste sources include organic waste (vegetables, legumes, tubers, grains and fruits), bio-degradable paper, plastic and animal residues and waste. Dumpsites such as the Dandora in Nairobi and Kachok in Kisumu are

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[11] Nikolaisen, L.S., and Jensen, P.D. (2013). Biomass feedstocks: categorisation and preparation for combustion and gasification. *Biomass Combustion Science, Technology and Engineering (*pp. 36 -57*)*. Woodhead Publishing Series in Energy. https://doi.org/10.1533/9780857097439.1.36

[12] KCIC (2017). *Sugarcane Bagasse as an Alternative Renewable Energy Solution*. https://www.kenyacic.org/news/sugarcane-bagasse-alternative-renewable-energy-solution

[13] Chardust Ltd., and Spectrum Technical Services (2004). *The Use of Biomass to Fabricate Charcoal Substitutes in Kenya. Feasibility Study; Forming Part of the Shell Foundation-Supported Project on Charcoal Briquetting in Kenya*. Nairobi; Kenya

[14] Rane, M.V., Kata Reddy, S.V., Essow, R.R. (2005). "Energy Efficient Liquid Dessicant-based Dryer". *Applied Thermal Engineering* (pp 5-6).

[15] UN- HABITAT (2014). *Charcoal Briquette Production - A Practical Training Manual*. Nairobi Kenya

[16] Temmerman, M. (2019). *Recycling of Organic Waste for Energy and Smallholder Livelihood in The Gambia; Briquette Production manual - Basic and Advanced Technology*. CTCN

prominent collection points. Collection of municipal waste requires a waste handling permit. Key competitors for organic waste include the manufacture of organic fertilizer and animal feed, especially pig feed.

Briquette producers are commonly located near the source of the raw material. For instance, producers using sugarcane bagasse are mainly in the sugar-belt region of Kenya where the sugar processing companies are located. One of the producers interviewed reported moving his production site from Kiambu County to the Flyover trading centre along the Nakuru-Nairobi highway to be close to the source of sawdust in order to reduce the cost of transportation. Some producers however have to travel long distances to collect the feedstock and can go as far as Uganda (approximately 700 kilometres from the site of production). Purchased feedstock can be obtained through i) competitive tendering processes, ii) direct sourcing or spot purchases and iii) use of brokers.

2.2 Pyrolysis and Carbonization

Carbonization or pyrolysis of the biomass feedstock, which is the conversion of raw materials into carbon in the absence of air, is only done in the production of carbonized briquettes. Pyrolysis involves thermo-chemical decomposition of organic material under high pressure, in high temperature of between 200 °C and 1,500 °C, in the absence of oxygen[17]. The product of the pyrolysis process is carbon residue. Not all raw materials have to go through this process as some like charcoal dust is already carbonized. The general requirement is that raw material must be dried before carbonization, if not, some of the material will have to burn to produce the energy for drying feedstock before carbonization begins. This significantly reduces the amounts of biomass feedstock that is converted into briquettes[18]. High temperatures are a requirement for pyrolysis, but because most of the biomass is both a fuel and the material that is being carbonized, a balance must be maintained between producing heat and releasing carbon material. Hence, air flow must be carefully restricted at the optimum time when the proper temperature is reached. For example, at 270ºC[19] most of the agricultural waste remains unburned (sawdust is 250^{0}C) and can be converted to carbonized briquettes[20]. From the surveys with producers, use of an oil drum remains the most common mode of carbonization. This finding is similar to the briquette study done in Nairobi peri-urban areas by Ngusale (2014)[21] that reported that the affordability of recycled oil drum (KES 1,000), its availability at a local market, portability and low area footprint made it a popular carbonization method. It was observed that the carbonization plants were powered by firewood bringing to question the issue of promoting briquettes as an alternative fuel with the goal of reducing the rate of deforestation in the country.

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[17] Hub pages. (n.d). *How to Make Fuel Briquettes – Charcoal Dust – Carbonization and Pyrolysis of Biomass*. http://ngureco.hubpages.com/hub/How-to-Make-Fuel- Briquettes-Charcoal-Dust-Carbonization-and-Pyrolysis-of-Biomass

[18] Wondwossen Bogale. (2009). *Preparation of Charcoal Using Agricultural Waste*. file:///C:/Users/TBC/Downloads/56314-Article%20Text-95679-1-10-20100708.pdf

[19] Ibid

[20] KII with the briquette manufacturers

[21] Ngusale. (2014). Briquette making in Kenya: Nairobi and Peri-Urban areas. Renewable and Sustainable Energy Reviews (pp 749 - 759)

2.3 Mixing

Binders are a necessity in the manufacturing of carbonized briquettes. They are added to the raw material to enhance bonding and to attain stable briquettes[22]. They are used in instances where high temperatures and high pressure are not achievable which is the case with carbonized briquettes. Non-carbonized briquettes use machines that can densify and bond the materials under high temperatures and pressure and therefore do not require a binder. A good binder is one that is effective in holding the briquette together, has low ash content, burns without smoke and has a high energy out-put[23]. Examples include gum arabica, fine clay, cassava flour, wheat flour, molasses, soaked wastepaper and red soil[24]. Clay, red-soil and waste papers produce smoky briquettes. As such molasses, gum arabica and binders made from cassava and flour are more preferred because of their high calorific value. For this study the most common binder (7 out of 11 businesses using binders) was starch from cassava and maize. One manufacturer reported having settled for gum arabica even though it is more expensive compared to molasses, as it improves the quality of the briquette and consumers preferred the briquettes made from this binder.

2.4 Compaction

The type of material, moisture content, fraction size, pressing temperature and compacting pressure are the key determinants of quality when manufacturing briquette. Compacting is key as it dispels entrapped air which is the main cause for loose briquettes. The latter are of a lower quality and deteriorate while in storage. From literature review, compaction in Kenya is carried out either manually or with compaction machines such as motorized screw press machine, mould-box press machine, wooden press and the ram piston[25]. The ram piston and motorized screw press are fabricated from locally available materials and are therefore, commonly used. For this study we identified 3 briquette machine local fabricators, 1 importer and 1 international manufacturer from Denmark. Imported machines are either from Europe, India or China. Although the machines from Europe are expensive compared to the rest of the machines in the market, it was reported to have several advantages including: high quality, high efficiency, less breakdowns and they can be automated reducing the number of employees required in a production site. Another key determinant of cost of machines is the machine's production capacity per hour with machines of high production capacity being more costly. Most machines are bought directly from fabricators rather than dealers with a typical price range as follows: manual presses for KES 11,400 -11,700, electrical presses for KES 80,000 – 200,000, imported presses with a starting price of KES 10 million and can even be as high as KES 50 million[26,27,28]'. None of the briquette producers interviewed currently use manual presses. Most of them (80%) use electric machines that are either imported

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22 World Agroforestry Center (2016*). A Review on Production, Marketing and Use of Fuel Briquettes*. CGIAR Research Program on Water, Landand Ecosystems (WLE), International Water Management Institute (IWMI)

23 GVEP (2013). *Assessment of the Briquette Market in Kenya*. GVEP International Africa Regional Office, Nairobi Kenya.

24 Ngureco (2011). How to make fuel briquettes – Charcoal Dust Carbonatization and pyrolysis of biomass. https://hubpages.com/technology/How-to-Make-Fuel-Briquettes-Charcoal-Dust-Carbonization-and-Pyrolysis-of-Biomass

25 GVEP 2013. *Assessment of the Briquette Market in Kenya*. GVEP International Africa Regional Office, Nairobi Kenya.

26 Cohen, Y., and Marega, A. (2013). *Assessment of the Briquette Market in Kenya*. GVEP International

27 Ngusale (2014). Briquette making in Kenya: Nairobi and Peri-Urban areas. *Renewable and Sustainable Energy Reviews 40* (pp 749 – 759)

28 Data from this study

(56%) or locally fabricated (44%). The machine sellers reported that most manufacturers consider the cost of technology before quality. As such, they buy the less expensive machines that are of poor quality and are prone to breakdowns and have a high maintenance cost. Four (4) of the producers reported to have purchased the machine on loan while seven (7) bought with their own financing. Local fabricators also reported that most customers buy the machines on loan and may take long to pay or in some cases may not make the full payment of the loan.

When considering the technological issues, the enabling conditions include having numerous options available for different levels of production. However, for large scale production, machinery must be imported, in which a highly qualified technician is needed to adjust machine settings to local conditions and lastly, adjustments or newly designed stoves may be necessary for the efficient briquette combustion[29].

2.5 Drying

This applies to carbonized briquettes. Due to the favourable climatic conditions in Kenya, the sun drying remains the most common means of drying wet briquettes at a temperature of 25◦C which typically takes 3–5 days. This is done by placing the briquettes on drying racks or on laying them gently on the ground. The drying racks can be built to allow stacking of several trays or can be simple from a wire mesh. Other methods adopted include; solar drying, where the wet briquettes or materials are dried in a greenhouse, the drying takes 1–3 days; use of driers (e.g. flash driers) and drying ovens. From the surveys conducted, 10 out of the 13 producers who dry their briquettes use open air method for reducing moisture in their briquettes while one uses a greenhouse and 2 use drying racks. After drying, briquettes are stored at room temperature 20◦C. A comparison between the various methods for drying is provided under chapter 3.

[29] Ibid

3 Description of the Technologies

3.1 Inventory of locally available options

A	**PRE-PROCESSING**		
#	**Technology/ Appliance**	**Description**	**Cost**
i	***SORTING***		
a	Sorting sieves 	These are fabricated by mounting a coffee mesh roll on a rack. The roll is purchased from local stores. This is ideal for when small size raw materials of 2mm are required. Large particles are sorted and then crushed	The coffee roll which is the main component of the sieve is purchased per meter. I Meter- KES 300
b	Hand picking  (www.pixabay.com)	This type of sorting is done manually. No cost of machine and technical skill required. This is used mainly to remove foreign materials from the waste.	The only cost associated with this method is cost on labour.
ii	***SHREDDING***		
a	Electrical shredder 	This is purchased from local stores in Kenya. It is similar to those used for shredding animal feeds. Depending on the size you want to achieve one can adjust the sieve size. For small size particles the sieve sizes are small.	KES: 75,000

iii	***MILLING***		
	Hammer mill 	Imported by Camco Machinery. This is used for crushing or milling raw materials to achieve the desired particle sizes and to reduce the size of the hard-raw materials such as groundnut shells. This is like similar to those used for milling corn to flour. Capacity production Kg/hour ranges from 900-1,000 Kg/hour	Cost ranges from KES 120,000 -450,000

B	**PYROLYSIS AND CARBONIZATION**		
#	Technology/ Appliance	Description	Cost
i	*PYROLYSIS*		
a	Drum-oil carbonizer  (Source Hubpages Link)	Recycled oil drum can be bought from local *jua Kali* markets Load the raw material into the drum and close the lid Place the drum on a three stone open fire and allow to burn in limited air.	KES: 1,000-1500

b	Constructed concrete kiln  (Source Kencoco Limited)	Constructed using available raw materials. The structure has steel on the inside for support and a loading opening. During pyrolysis the holes are closed to make the kiln airtight.	The cost of construction varies. One manufacturer reported to have used KES 150,000 for the construction of the kiln.

C	**MIXING**		
#	Technology/ Appliance	Description	Cost
a	Rotating mixers  (source Nawasscoal)	Available from local fabricators e.g Jaffidian Enterprise Limited. Raw materials are added to the rotating drum from the upper end, heat is introduced in the low side, which forms the countercurrent contacting allowing the materials to mix to form the briquettes. Varying production capacity that can go up to 1,000 Kgs a day	A capacity of 1,000 Kgs per day go for KES 250,000
b	Electrical mixers (Wheel mixer)	Imported through online platforms such as Alibaba. Has spindles that move from side to side to cause mixing of the raw materials	Cost. KES: 120,000- 340,000

			
c	Manual mixing  (Source: Practical Action)	Mostly done by the owner of the business so no labour costs. Used for small scale production.	No cost

D	**COMPACTION**		
#	Technology/ Appliance	Description	Cost
i	*SCREW PRESSES*		
a	Manual screw press	Mechanical co-centric saw dust screw briquetting machine. Fabricated by a local briquetting expert Isaiah Maobe in 2003 It is a manual machine which is ran by peddling. Depending on the effort of the person running the machine it can produce 600 Kgs per day	KES: 450,000

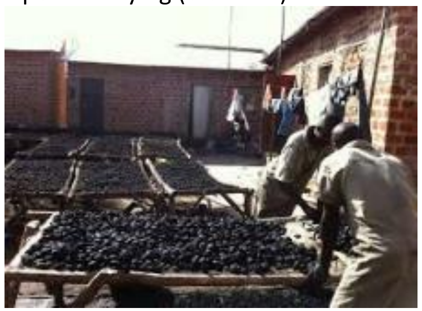
			
b	Motorized screw press  (Source; Kendubay Machinery)	Locally fabricated motorized -screw machine. Local fabricators include Kendubay Machinery, Kejofra Engineering and Benmah Product Company. There are two types the one fitted with a gear and one without. The gear fitted machine improves compatibility of the raw material thus produces higher dense briquettes Run using electricity and production capacity is dependent on the power rating of the machine. A motor of 750 watts can produce up to 7,000 tonnes per day when using charcoal dust as the raw material	Fitted with a gear: KES 85,000 No gear: KES 65,000
c	Mechanical co-centric 	Mechanical co-centric saw dust screw briquetting machine Fabricated by Maobe, 2003 The motor is rated 750 watts and can produce between 4,000-5,000 Kgs per day Ran using electricity	KES: 450,000
ii	*PISTON PRESSES*		

Identification of biomass waste-based briquettes making technologies

a	Hydraulic Briquette Pressing Machine 	Manufactured and distributed in Kenya by C.F. Neilsen Production capacity of 30kg to 1,500 Kgs per hour	500 Kgs per hour capacity is KES 7 million
b	Extruder Briquetting Press 	Manufactured and distributed in Kenya by C.F. Neilsen Production Capacity of 500 Kgs per hour Used to produce household briquettes	KES: 12 million

c	Mechanical briquetting machines 	Manufactured and distributed in Kenya by C.F. Neilsen Different models and production capacity Production can be as high as 7,000 Kgs per hour	Cost ranges from KES 10 Million to 50 Million
iii	*HAND PRESSES*		
a	*Wooden press*  (Source: Local fabricator Isaiah Maobe)	Fabricated locally Production capacity is dependent on man-power it ranges between 100-150 Kgs per day Not popular nowadays as producers have moved towards improved machines	KES:15,000
iv.	*OTHERS*		
a	Agglomerator	The machine is motor-driven, and the common capacity is 25-50 kg/hour. Purchased from local fabricators	KES:450,000

	 (Source Eco-consulting Link)		

E	**DRYING**		
#	Technology/ Appliance	Description	Cost
a	Open air drying (ground) 	Spread the briquettes or raw materials depending on spread sheets on the ground. The number of tonnes that can be dried using this approach is dependent on availability of space.	Labour cost for spreading the briquettes
b	Open air drying (elevated) 	This is done either using drying trays and racks. The manufacturer can acquire the necessary materials (mesh and pools) from local stores and fabricate the rack.	The coffee roll which is the main component of the sieve is purchased per meter. I Meter- KES 300

c	Solar drying (use of greenhouses) 	In solar drying, wet briquettes or materials are dried in an enclosed structure which is a typical greenhouse covered with high density transparent polythene sheet that permits radiation into the room. Various greenhouse installers in Kenya e.g. PEGWA Enterprises and Amiran Drying is fast, can take 1-3 days	Cost is dependent on size of the greenhouse for example; 6M by 12 M - KES 150,000 24M by 12 M- KES 800,000
d	Driers e.g vertical driers 	Imported from Maxton Engineering China The capacity per hour is dependent on the machine power rating A 37 KW drier can dry between 15-20 tonnes of briquettes per hour Applied for large scale production of briquettes	Cost ranges based on power ratings KES 1 million to 10 million

3.2 Comparative analysis

It is critical for a producer to identify the right technology for the briquette production process. The technologies for the different raw materials are usually similar with the main difference being the preparation process employed for the feedstock. For instance, while a hammer mill can be used for crushing both macadamia shells or milling wood chips, availability and reliability of electricity would determine if a manufacturer settles for a diesel-powered hammer mill or an electric mill. This section compares the different technologies available under selected steps of the briquette production process with the aim of comparing the advantages and disadvantages of each technology.

From the discussion on compaction of briquettes, it can be concluded that there are 3 types of technologies for compacting; (i) low pressure which uses manpower to drive the process (hand-made briquettes and manual machines), (ii) medium pressure, and (iii) high pressure technology which is used in production of non-carbonized briquettes.

Low pressure technologies include manual presses which are fabricated locally and do not require complicated skill to operate. These machines are either operated by hand, or foot and include simple single or twin hand and pedestal piston extruders, wooden lever, hand screw, small pipes. The advantage with this technology is that it is low cost and needs the least start-up costs and technical operating skills. The producer can also take care of breakdowns with little guidance from the fabricator. The downside of the technology is that it is only applied for small scale production of briquettes, it's time consuming and exposes the producer to dust and dirt. Production capacity per day are highly dependent on the person running the machine.

Medium pressure compaction machines include screw extruders, agglomerator, roller drums, and hydraulic presses which run on mechanical means. The machines can be fabricated locally. Production capacity can range between 250 Kgs to 5,000 Kgs of briquettes per day for the locally fabricated machines. The technology needs minimum labour and maintenance costs. The main challenge with locally fabricated machines is poor quality. Poorly fabricated machines result in poor quality briquettes and frequent breakdowns which halt production.

High Pressure Compaction machines used in this category include heated-die screw, ram/piston, and hydraulic presses, and all are mechanically driven to compact granular biomass materials into non-carbonized biomass briquettes of different shapes and sizes. These, machines are imported and are suitable for large scale briquettes for factory consumption. Production capacity per hour can be as high as 7,000 Kgs per hour. Although they have high production rate, they are have high initial cost (between KES 10 million to 50 million) ,require skilled manpower, spare parts may not be locally available, and are associated with high electricity bills, maintenance costs, and replacement of worn out machines with new ones compared to the low and medium pressure technologies. Table *6* below provides a comparison between the available technologies under compaction.

Table 6: Comparison of the compacting technologies for briquette production

#	Compacting technologies	Advantages	Disadvantages
1	Low pressure technologies	- Low start up-cost - Minimum technical skills required for operations - The producer can easily take care of the breakdowns	- Low volume production - Variable quality - Requires high manpower
2	Medium pressure technologies (e.g. screw extruders, agglomerator, roller drums, and hydraulic presses)	- Technology is locally available - Spare parts can be sourced locally - Higher production volumes compared to low pressure technologies - Higher quality compared to the low-pressure technologies - Minimum labour is required	- Local machines are of poor quality and are therefore prone to breakdowns - Require electricity to run - Compared to low pressure technologies the cost is higher (cost ranges between KES 65,000-500,000)
3	High pressure technologies (heated-die screw, ram/piston, and hydraulic presses)	- High production volumes - Less labour is required as most work is automated	- High initial cost (between KES 10 million to 50 million), - Requires skilled manpower, - Spare parts may not be locally available, - High electricity costs and maintenance cost compared to medium and low-cost technologies

The low and medium pressure compacting technologies requires the use of binders and drying of briquettes. Comparing the different binders available in the market, gum arabica and molasses have better burning qualities from clay, red-soil and waste papers which produce smoky briquettes. In addition to quality, availability, cost and alternative use of the binder are key factors to consider when selecting a binder. In some instances, quality supersedes the cost of the binder. For example, one manufacturer based in Naivasha reported that they use gum arabica which is costlier than molasses because of its high quality. The high cost of gum arabica is due to the fact that it has to be transported from Northern Kenya. One manufacturer in Kilifi reported having to switch binders from cassava to imported non-edible corn starch due to complaints from locals on the use of 'food' for briquette manufacturing.

As discussed, drying of briquettes can either be through open air drying (use of racks or spread on the ground), use of driers, greenhouses and ovens. Open air drying requires space to spread the briquettes out, while use of driers, the cost of purchase and operating auxiliary requirements such as electricity are inhibitive. Use of ovens requires an external source of thermal energy such as firewood which comes at a cost. Relying on the sun for drying of briquettes may halt production during the rainy seasons if an alternative drying method is not available. A producer can have more than one type of drier and utilize it on a need basis. The different drying methods are compared in Table 7 below.

Table 7:Comparison of the drying methods

#	Drying technologies	Advantages	Disadvantages
1	Open air drying	- Low initial cost. Drying racks can easily be fabricated at site and spreading the briquettes on the ground requires no equipment (3-5 days)	- Requires space to spread out the waste - Depends on climatic conditions with production coming to a stop during the rainy days - Require a larger work-force
2	Driers	- Takes less time to dry (1 hour) - smaller work-force required	- Requires high initial cost - Electricity bills for running of the machines or diesel costs - Associated with maintenance cost
3	Solar drying through greenhouse	- Convenient for waste with high moisture content e.g. sludge - Less days required for drying (1-3 days)	- High initial cost - Space for setting up the green house
4	Oven	- The briquette takes less time to dry (2- 6 hours)	- High cost compared to open air drying - An external source of heat is required e.g. firewood

3.3 Case studies

3.3.1 Nawasscoal – Utilizing municipal waste

Nawasscoal Company is a subsidiary of the Nakuru Water and Sanitation Services Company Limited (NAWASSCO), that produces briquettes from a combination of faecal matter, sawdust and molasses as a binder[30] . It was formed as part of the Nakuru County Sanitation Programme (NCSP) whose main objective was to demonstrate a commercially viable sanitation value chain that would benefit the peri- urban communities in the low- income areas of Nakuru. It was co-funded by the European Union and implemented by NAWASSCO in collaboration with Umande Trust, Vitens Evides International (VEI), SNV Netherlands Development Organization, Egerton University and University of Nairobi.

Human waste, which is the main raw material used to produce the briquettes, is acquired from the NAWASSCO treatment plant. Availability of the feedstock is not a challenge as the plant collects 2,000 cubic meters of sludge every day and only utilizes 100 cubic meters per day[31]. About 98 % of the sludge composition is water and 2% is biosolids as such the first step is dewatering. This is achieved using drying beds greenhouses where the sludge is left to dry for 2-3 weeks. The sludge is further dried through solar driers to achieve a moisture content of about 20% which is the required moisture content for carbonization. The dry sludge is then carbonized at a temperature of 400°C. The carbonization process also acts to sanitize and sterilize the sludge through flaring /the harmful gases, killing the pathogens and removing the bad oduor. The second raw material is sawdust. Sawdust is

[30] Nakuru County Sanitation Programme (2018). *Sanitation Value Chains: Unlocking Opportunities in Sanitation*. https://nawasscoal.co.ke/nawasscoal_uplds/2020/06/2018-ncspbooklet-selectedpublicationsjournalcontributions.pdf

[31] Figures presented in this case study were provided in the Key Informant Interview with Nawasscoal

collected from the different saw millers in Nakuru County. It is prepared by removing the foreign materials through hand picking. The raw material has a moisture content of 40% and is sun dried to 20%.

The next step is milling of the two raw materials to achieve fine particles. This is done using a hammer mill. The two are then mixed in equal proportion and fed into a rotating drum machine and molasses is (binding agent) added as a binder to form ball shaped briquettes of 2.5 cm in diameter. The briquettes are then dried using drying racks in greenhouses for 3-4 days. The dry briquettes are weighed and packed in bags of 2kg, 5kg, 10kg and 25kg. These are sold either directly from the company or indirectly through their stockists (six in Nakuru, two in Nairobi and one in Kisii). The cost per Kg is currently at KES 30. The company produces 15 tonnes of briquettes per month. The briquettes have gone through a series of test including; ash content, calorific value, moisture content and test on presence of pathogens. **Error! Reference source not found.** below shows a summary of t he process.

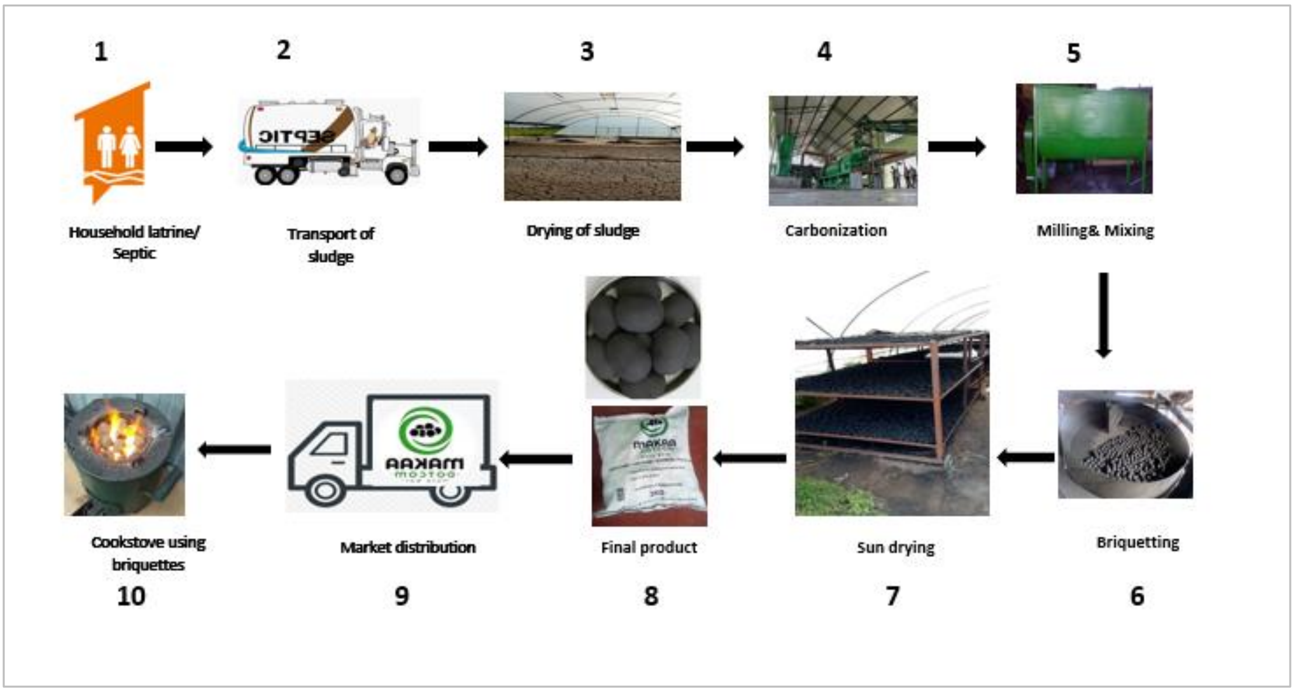


Figure 6: Summary of the briquette production process

One of the challenges faced by the company is people's perception in using briquettes made from human waste for cooking. Most communities considered this a taboo. However, with the community trying out the briquettes and ascertaining that they do not smell, and that they burn longer than charcoal, they have been more receptive of the briquettes. Having the KEBs label of quality also helped in regaining consumer confidence. The other challenge faced at the commencement of the project was the absence of laws on handling of faecal matter in the production of the briquettes. The project partners were able to lobby the Nakuru County Assembly to develop a public health bill that stipulates how to handle human waste. The company is aiming to scale production to 10 tonnes per day through the purchase of high capacity briquetting machines.

One of the challenges reported by some of the manufacturers is constrained feedstock. Bans on logging and charcoal production and the seasonality of coffee for instance are factors that contribute to limited raw materials. Faecal waste provides an alternative feedstock which is available in large quantities and at all times and with the right technologies can be utilized to produce briquettes. This case study by Nawasscoal demonstrates the potential of such waste as a possible raw material in the process of briquette making.

3.3.2 Josa Green Technologies

Josa Green technologies Limited is an energy solution enterprise based in Wakiso District in Uganda which is 10 Kms from Kampala. It was founded in 2014 with the aim of providing a range of energy products and services such as energy saving cook stoves for both institutions and household, briquettes, biogas digesters, ovens, brooding kit etc. They produce carbonized briquettes from charcoal dust, agricultural waste, wood cuts and organic waste. The raw material is carbonized from source. They identified women groups and individuals who collect waste and carbonize it before selling to briquette producers. Clay is added to the mixture of raw materials as a filler and cassava starch as a binder. Once the waste is in the factory, it is sorted using a sieve, the large particles crushed using a crusher, the raw materials mixed in the right proportions and compacted with an automatic honeycomb using a press machine. In addition to the automatic electric briquetting machines they have a manual press that is used when there are power outages. The following methods are employed in drying the briquettes; use of dryers, ovens powered by briquettes and sun drying.

Stick Briquettes – mainly for HH and small enterprises

Honeycomb Briquettes – mainly for Institutions

Figure 7:Types of briquettes produced by Josa Green Technologies

Their business model has evolved with time as they better understand the market. At the start their target market was households. However, they quickly realized that since the honeycomb briquettes require custom made stoves to burn efficiently, and these stoves are expensive, low income households could not afford them. They started to produce stick briquettes which can burn on any type of stove. They also increased their customer base to include institutions, small hotels and roadside kiosks and poultry farmers. They deliver the briquettes to institutions at a cost and also have 8 outlets in Kampala that end-users can purchase the products from. In terms of volumes sold, institutions and briquettes for productive use are their largest customers base. The main challenge currently experienced is market saturation from large scale producers who are purchasing all the feedstock. In years to come the small-scale producers will be kicked out of the market.

For the sustainability of briquette making businesses there is need to diversify the consumer base. Josa Greens Technologies started out by targeting household end-users but quickly realized that uptake of the fuel was low. While still addressing the low uptake of the fuel by households they changed their business model to incorporate institutions, small hotels and roadside *kiosks* and poultry farmers to avoid being thrown out of business. Another key lesson from Josa Green Technologies is the introduction of a group of actors in the supply chain who not only collect the waste but carbonize it before selling it to the producer. This could potentially reduce the start-up costs of briquette producing businesses by removing the cost of carbonization equipments for carbonized briquettes. It can also be a source of employment for youths and women.

3.4 Gender and the briquetting

The findings of this study show that the proportion of women in briquette making is relatively high. Similar conclusions were made in a study by GVEP international on the assessment of briquette production in Kenya [32]. In this study, business ownership was disaggregated between women, men, youths and group ownership. Out of the 20 manufacturers interviewed, 11 of the businesses were owned and managed by women (7 limited companies, 3 sole proprietors and 1 Community Based Organization), while half of the businesses are owned and managed by youths[33]. It is also noted that more than half of the women owned businesses (a total of 7) were formally registered. Two of the women briquette manufacturers have been in the business for the last ten years. Most of the businesses owned by women operate throughout the year (8/11) and partial operations are due to limited demand from the market and raw materials. In terms of the machines used for briquetting, only 3 out of the 11 interviewed were making handmade briquettes, the rest use electric machines. No men were found to be using hand pressing for briquetting. This may be interpreted to mean that although we have a considerable number of briquette businesses that are owned by women and with large and medium scale producers, we still have a portion of them who run informal businesses and using poor technologies for briquetting.

All briquette businesses had more youths as full time (at 69%) employees. Additionally, there are some women and youth-owned businesses where they are the only worker. Out of the 332 employees across the 20 businesses interviewed women are more (at 55 %) than men (at 45%). Although we have women spread across the different activities of briquette making, more of them were casual workers (73%) involved in drying of the briquettes and sorting of waste. One manufacturer said that the women are keen on picking out the foreign materials. Opinions towards women in briquetting are varied across the different manufacturers. One female respondent observed that if the women run the briquetting machine the breakages are minimum. She explained that women were keen on ensuring that the raw material is well sorted thus objects such as nails do not end up in the machine leading to un-screwing of the machine. Another respondent reported that in one instance he hired female workers to aid in the activities in the briquetting process but did not stay for long. He explained that the lifting of loads was prohibitive to the women. Another explained that although the business could not hire women for the manual activities in the briquetting process the people in charge of fund-rising and marketing of the briquettes were woman.

[32] Cohen, Y., and Marega, A. (2013). *Assessment of the Briquette Market in Kenya*. GVEP International, Africa Regional Office.

[33] A person below who is 35 years and below

The study finds that there are great business opportunities for women and youths to generate income through briquette making; women can be catalysts for change agents and not just users of different energy technologies; and there is need to leverage women groups and other social institutions to scale the briquetting business.

4 Options to promote uptake of technologies

4.1 Aggregation of informal supply

The briquette sector is characterized by small scale producers who are opportunistic and are scattered across the country. This makes it hard to coordinate their activities to ensure production of quality briquettes. To effectively provide services to these enterprises requires a form of pooling. One approach to aggregate small producers into central production hubs could be modelled around the use of energy centers that are to be established in every county. This can be through formation of co-operatives or associations. Co-operatives have found application in various sectors of the economy with agriculture being the leading sector. Through co-operatives, small scale farmers in Kenya who form the majority of producers have been able to eliminate middlemen and fetch better prices for their produce. Further, regulating quality of products becomes easy as it becomes the responsibility of the organization to ensure their products meet the required standard.

Research indicates that co-operatives are instrumental in reducing business failure. Nembhard, in his research on benefits and impacts on cooperatives in the United States reports that co-operatives have lower failure rates that traditional corporations and small businesses[34]. From the assessment, only 10% of co-operatives fail after the first year compared to 60-80% of the traditional businesses. The high survival rate of co-operatives has been attributed to the high number of people required in starting a cooperative and support from the community where they are established. From this briquette study, it was evident that businesses in the briquette sector are quite short-lived with 60% (12 out of 20) businesses interviewed formed within the past 5 years.

Co-operatives also have the additional advantage of addressing market failures including access to finance. The structure of co-operatives positions them well to receive different funding types such as grants and loans, which are not readily available for independent businesses. Other benefits of aggregation would include better bargaining power, low cost of production due to increased scale, improved marketing strategy including packaging and branding, accumulation of assets and human capital.

4.2 Promote local manufacturing

Despite the efforts underway to improve the quality of briquettes produced in the county, one of the main impediments is the availability of appropriate briquetting equipment. Briquette producers reported encountering low or absence of local technological capacity to fabricate densification equipment especially for non-carbonized briquettes. Of the four commonly used densifying equipment, that is, agglomerator, screw extruder, pillow briquettor and ram/piston press, only the screw extruder and the agglomerator are locally manufactured. The ram/piston press and pillow briquettors are imported from China or India[35]. Ultimately, the cost of importation is prohibitive making it difficult for emerging briquettes producers to be able to procure quality machines. Addressing these challenges would be through promoting local production. This can be anchored on the Big Four Agenda which is keen on transforming the manufacturing sector in Kenya.

[34] Nembhard, J.G. (2014). The benefits and impacts of cooperatives. *Grassroots Economic Organizing (GEO) Newsletter*, *2*.

[35] Mwampamba T.H., Owen M. and Pigaht M. (2013). Opportunities, challenges and way forward for the charcoal briquettes industry in Sub-Saharan Africa. *Energy for Sustainable Development 17* 158 – 170.

According to the Agenda, government is keen on increasing access to finance through increasing loan guarantees to SMEs and also incentivizing commercial banks to provide low interest loans for manufacturing industries. With increased access to cheap capital (in the case of reduced interest rates) manufacturing companies are able to increase their production capacities hence lowering the cost of the final consumers thus creating demand.

Additional support to the sector can be unlocking innovation through financing research and development spearheaded by the government in partnership with private sector. This initiative is key in addressing the rising concerns by briquette producers such as high rates of wear and tear of locally manufactured machines as compared to imported machinery which drive up the cost of operation and maintenance.

4.3 Access to finance

Setting up a briquette making business is a capital-intensive venture. The purchase of briquette making equipment and maintenance, testing and labelling of the briquettes, marketing the briquettes, acquiring a premise and purchasing of the feedstock are activities along the landscape of briquette businesses that are expensive. Depending on the scale of production, and with the assumption that the business will have to use a type of machine for briquetting, the initial cost of setting up can range from KES 500,000 to KES 50,000,000[36]. While most large-scale producers have access to different forms of finance including loans and grants, it remains a hurdle when it comes to small scale producers. These entrepreneurs are often not able to meet the requirements for financing including collateral in the case of debts or to meet the conditions stipulated in other forms of grants for example, in one a case was required to use cleaner modes of transport (EVs) instead of conventional engine drives. Further, for debt, there is need to demonstrate constant cashflow which is an indicator of the firm's capacity to repay the loan in time. In the case of businesses operating on credit models (especially those serving institutions), this becomes unattainable as their cashflows remain erratic and is hard to track over time. As is with start-ups, these enterprises require patient capital (such as concessional loans and grants) before breaking even. These can be advanced through varied forms such as Results Based Schemes (RBF). For example, under component 2 of the Kenya Off-Grid Solar Access Project (KOSAP), the government is providing subsidies scheme through an RBF mechanism to promote uptake of improved biomass stoves. Similar strategies can be implemented for uptake of alternative fuels such as briquettes. As businesses mature, they can tap into other sources of financing including debt and venture capital.

The second layer of limitation in access to finance is lack of skills in writing fundable proposals for grant funding. While producers have an understanding and experience in the technical aspects of briquette production, lack of capacity in writing bankable proposals was reported as a hurdle for small scale producers. Trainings offered to businesses such as one conducted by E4I under the Women in Renewable Energy (WIRE) program are a good starting point to help businesses develop good business plans which they can use to seek funding. Instead of isolated projects, different players in the sector with similar programs can collaborate to equip entrepreneurs with requisite skills in financial modelling, pitching business ideas, grant application and general fundraising.

[36] Key informant with a briquette technology expert and data from the surveys

4.4 Linking suppliers to markets

This study indicates that women and youth are majority of entrepreneurs (sole proprietors) engaged in production of briquettes in the country. These businesses are however characterized by use of low technologies which significantly affects the quality of briquettes and their uptake. Gender quotas in the market for briquettes can play a double role in ensuring inclusivity of the sector and promoting uptake of more mechanized technologies. This builds up on the recommendation for government to provide a directive requiring at least 10% of institutions to use briquettes for their thermal applications. Gender quotas would then be applied in the procurement process where for example, 30% of the 10% to be supplied to the institutions would be sourced from women/youth owned businesses or women/youth groups. Such directives address barriers such as lack of market which is a prevailing challenge for such producers. In order to meet to the required production, these enterprises will require to increase their production capacity hence necessitating automation of processes where possible to increase efficiency, maintain quality and lower the production costs. This in return will lead to increased uptake of mechanized technologies.

ANNEXES

ANNEX 1: IMAGES OF TYPES OF BRIQUETTES

Non-carbonized Carbonized Semi-carbonized

Figure 9:The three types of briquettes images from Pixabay and manufacturers

Figure 8: Industrial briquettes (large in size and can burn for long and at times irregular in shape) images from Josa Green Technologies, Ever Green and Pixabay

Figure 10:Household and small enterprise briquettes (small size that can fit into charcoal stoves) images provided by a briquette producing expert Isaiah Maobe and Pixabay

ANNEX 2: LIST OF BRIQUETTE MANUFACTURERS INTERVIEWED

#	Name of Business	Location	Name of Respondent	Gender
1.	Imarisha Kenya	Nyeri	David Nderitu	Male
2.	Mwaki Mutheu	Kitui	Patrick Vaati	Male
3.	Kiangure Springs environment innitiative	Tetu-Wamagana-Nyeri-Gathuthi	Joram Mathenge	Male
4.	Biomass Energy East Africa Limited	Kisumu	Rose Maiyo	Female
5.	Loyce Auma	Nairobi	Loyce Auma	Female
6.	African Solutions	Kisii Town	Elias	Female
7.	Eco charge	Nakuru	Mary Nyambura	Female
8.	Nerea Akinyi	Kisumu ndogo Nairobi, Kibera	Nereah Akinyi	Female
9.	Kings Biofuels	Kenol-Thika	Francis Akamu	Male
10.	Wood Heat Energy Limited	Fly- over along the Nakuru highway	Isaiah Maobe	Male
11.	Janet Adhiambo	Kibra	Janet Adhiambo	Female
12.	Eversafe briquette Limited	Mai Mahiu Naivasha	Lydia Waithera	Female
13.	Titus Kinoti	Njiru Nairobi	Titus kinoti	Male
14.	Kencoco	Kikambala Kilifi	Said Twahir	Male
15.	Sanivation	Naivasha	Dickson Ochieng	Male
16.	Roda Auma	Kibira	Rodha Auma	Female
17.	Nyalore Impact	Homa Bay Town	Dorothy Otieno	Female
18.	Bioafriqenergy Limited	Machakos	Doreen Achieng	Female
19.	White coal industries ltd	Kisumu kibos road	Anonymous	Anonymous
20.	Acacia Innovations	Bungoma	Elana Laichena	Female

ANNEX 3: LIST OF BRIQUETTE MACHINE FABRICATORS AND DISTRIBUTORS

#	Name of company	Type of Business	Name of respondent	Contacts	Gender
1.	Kejofra Engineering	Local Fabricators	Martin Maina	0741 077384	Male
2.	Benmah Product Company	Local Fabricators	Benson Mahogo	0722 237869	Male
3.	Kendubay Machinery Service	Local Fabricators	Mr. Victor	0798 990468	Male
4.	Camco Machinery	Importer/distributor	Mr.Osiemo	0714 255499	Male
5.	CF Neilsen	Manufacturer/distributor	Thomas Nyabera	020 4440293	Male