Low-Cost Production of Charcoal Briquettes from Organic Waste

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ABSTRACT

In many regions of the developing and emerging markets, proper management (disposal or recycling) of organic waste represents a significant and continued challenge. Bio-digestion, composting, and other waste-to-energy technologies represent possible solutions to this problem, however due to technological, infrastructural, and logistical reasons these technologies have not hit the required scale to tackle the significant volume of organic waste generated in urban areas. With lack of infrastructure or technology for proper composting or recycling, organic waste represents little to no monetary value for waste picker cooperatives who operate and serve as de-facto waste collectors from urban households.

This paper explores the technology, implementation, and possible commercialization of charcoal briquettes derived from organic waste through thermal treatments in emerging markets. Given the lack of formal and centralized waste management system in emerging markets, we present a low-cost thermal treatment system to produce charcoal briquettes derived from organic waste.

Our project and subsequent experiments take place in both the rural and urban areas of Kenya. We first explored the market in early 2012, interviewing 17 waste picker cooperatives and 5 charcoal producers. Subsequently we conducted our first test in rural area of Rumuruti, Kenya where we successfully demonstrated the use of our low-cost kiln design for the production of charcoal briquettes using agricultural waste. This process has now been scaled to 50 kilns in the community. In urban areas, specifically Kibera, Nairobi, Kenya we partnered with waste picker cooperatives to conducted trials with urban waste. Different methods of briquette-making and binding have been quantitatively tested for carbon monoxide and particulate emissions, and we demonstrated that there are viable methods to make briquettes that are within the safety standards.

After one year of field study and operations (establishment of organic waste derived charcoal briquettes), we have demonstrated the technical viability of such an operation. However, challenges persist in the standardization and commercialization of organic-waste derived charcoal briquettes. We present a hypothesis on the commercialization strategy and possible business model that can be utilized by enterprises looking to venture into commercial scale operations.

Keywords: organic waste, recycling, charcoal briquettes

INTRODUCTION

Proper organic waste management remains, despite various technological advances, a significant challenge in many developing nations. In these locations, where formal and centralized waste collection and treatment services are often unavailable, the entire organic waste value chain needs to be considered and evaluated for the feasibility of any given treatment technology, in addition to the viability of the technology itself.

For treating organic waste, the most immediate solutions that come to mind are composting and biodigestion. While these techniques have met with some success, and are being implemented at various scales in countries such as India (see Ambulkar and Shekdar, 2004), the main challenges are that (1) those techniques are generally only suitable for source-separated and homogeneous organic waste, and (2) the treatment process is often quite sensitive to variations in the characteristics of the waste feedstock (for example, see Klimiuk *et al.*, 2010). Therefore, for organic waste treatment from the commercial perspective, it is often difficult to achieve a consistent biogas or fertilizer output. Furthermore, once the gas or fertilizer is produced, both packaging and distribution are non-trivial issues to consider, and may not be feasible where transportation cost is overwhelming. On the other hand there do exist waste-to-energy (WTE) projects, however to be economically viable such projects are often only implemented at a very large scale, and are not an option for smaller locales. In India, for example, despite the extensive implementation of different biodigestion, composting, and WTE technologies to treat organic waste, currently 90.7% of the country's organic waste is not being managed at all (Annepu, 2012).

Therefore, as a potentially complementary technique to address organic waste management, we have been investigating the possibility of small-scale conversion of organic waste into charcoal briquettes through thermal treatment (pyrolysis or carbonization) in the emerging markets. Given the lack of formal, centralized waste management system in many countries, our scope is on creating and implementing low-cost, decentralized thermal treatment systems that at the same time have a commercialization and dissemination potential. In this paper, we will use Kenya as a case study. We first describe the technologies involved, the testing/validation of the briquettes for emission safety, followed by an analysis on the likely path to commercialization of such technologies.

For Kenya, there are three sources of main energy: wood fuel, petroleum and electricity, accounting for 70%, 21%, and 9% of total energy use respectively. 82% of the urban households have reported to use charcoal as the primary source of fuel with 34% of households in rural areas. A city like Nairobi consumes 700 tons/day of charcoal (Njenga, 2012). Kenya is also rich in its forest area with 1.7M hectares of forests. Continued reliance on wood-based charcoal has led to deforestation at an alarming rate. Additionally, proper organic waste management continues to be a challenge in urban and rural areas of the country.

For the purposes of our study, Kenya represented the near-perfect environment for us to investigate the feasibility and viability of an organic waste driven charcoal briquette production.

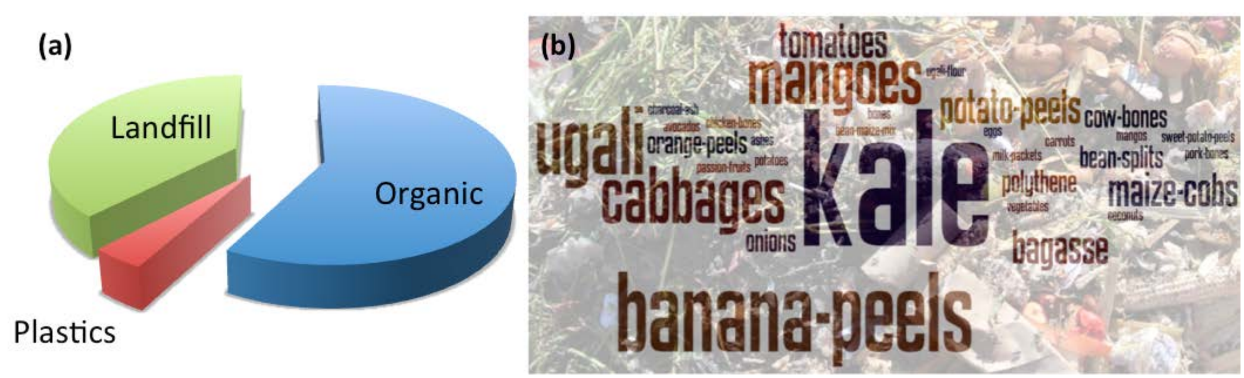

Fig. 1. Results from a waste audit in 2012 in the Kibera slum, Nairobi, Kenya. (a) The composition of typical waste, given by weight fraction, of randomly selected bags from two separate waste-picker cooperatives. (b) A word cloud representing the most common types of organic waste, from an interview with 17 waste-pickers.

TECHNOLOGY

There are three main types of low-cost carbonization kilns that were developed and implemented in the course of the project. The first type, which we will call the open-drum kiln design, was developed by D-Lab at Massachusetts Institute of Technology, and is an open-source technology whose description and use is well-documented online (D-Lab, 2013). We introduced this design in Rumuruti, Kenya, where it was tested for 12 months. However, we found limited use for the design in an urban environment owing to excessive smoke emissions during the carbonization process. In response to this limitation, we developed a second version of the carbonization kiln, which we will call the top-lit kiln design, with reduced smoke emissions during the carbonization process. In this design, there are three components of the kiln: the main kiln, the adapter, and the chimney. We describe each in detail below.

Materials: Obtain two 200-liter oil drums that have sealed bottom and top. Check the drum body so that there are no holes/leaks. One of these two drums will become the main drum, while the other one can be cut in half and made into two separate adapters. In addition, also locate a smaller oil drum with an open end (bottom) and a closed end (top) to serve as the chimney element.

Main kiln: To manufacture the main kiln, cut the top of the 200-liter oil drum open, and open about 20-30 small holes about 5 cm in diameter evenly throughout the bottom of the kiln. Find a metal sheet/cover that can seal the kiln tightly over the top when necessary. This is shown in Fig. 2 (a).

Adapter: To manufacture the adapter, cut the other 200-liter oil drum longitudinally into halves. Each half will have an open end (bottom) and a closed end (top). Cut the bottom (open) edge of the kiln into about 10 pairs of alternating ridges/grooves, as shown in Fig. 2 (b). Next, cut the top (closed) end of the adapter into an opening through which smoke can be directed, as in Fig. 2 (c). Make sure that the opening is smaller enough to fit completely into the chimney piece (to be described below).

Chimney: To manufacture the chimney, cut the top (closed) end of the smaller oil drum into an opening similar to what is shown in Fig. 2 (c).

Operating the kiln: Make sure that the ground is even, then elevate the kiln on three rocks about 5 cm above the ground. Load the biomass in alternating easy-to-light and difficult-to-light layers. Make sure that both the bottommost and the topmost layers are easy to light on fire. Once the kiln is filled, evenly light the top of the kiln on fire. Once the fire has spread throughout the kiln, as seen in Fig. 2(d), cover the main kiln with the adapter, followed by the chimney, as shown in Fig. 2(e) and (f). After about 15-20 minutes, the combusting layer (where the heat is located) should migrate from the topmost layer of biomass to the bottommost layer, at which point it is necessary to cover the kiln completely by applying the lid at the top, removing the stones at the bottom, and sealing all possible cracks with sand, as seen in Fig. 2(g). The kiln is then left to cool for 1-2 hours until it is safe to touch the exterior, or if in a hurry, the kiln can be cooled by applying water to it. After the kiln has cooled, the charred biomass, shown in Fig. 2(h), can be harvested, ground to fine powder, and briquetted using a press and/or a binding agent.

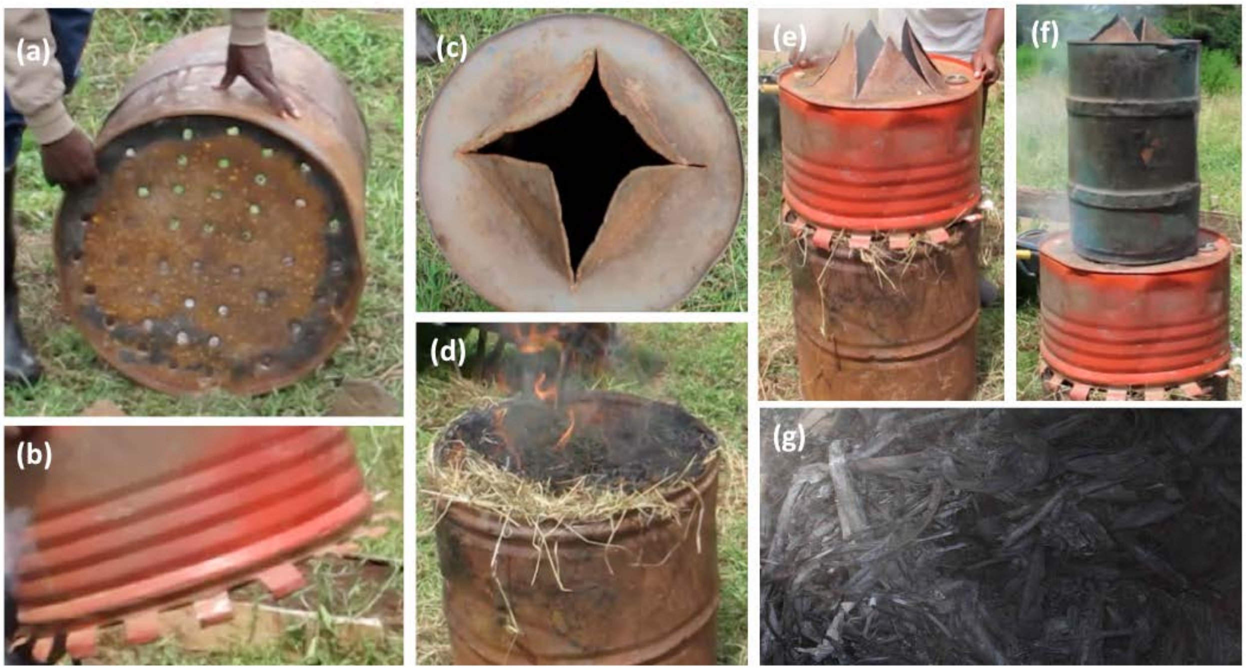

Fig. 2. Carbonization process using the top-lit kiln design. (a) The main kiln has an open top and many small holes at the bottom. The adapter has an alternatingly ridged/grooved bottom (b) as well as a star-shaped opening at the top (c). To operate the kiln, first set the biomass on fire from the top (d), and once the fire has spread all around, cover the main kiln with the adapter (e), immediately followed by the chimney (f). After about 20 minutes of pyrolysis followed by about 1-2 hours of cooling, charred biomass is recovered (g).

The second top-lit kiln design was subsequently introduced both in rural Rumuruti as well as urban Nairobi, Kenya. Both designs are meant for low-cost production (less than US$30 apiece), with minimal requirements needed for both production and maintenance (e.g. no welding). Both rural farmers and urban waste-pickers have been successfully trained to operate the kilns safely.

SAFETY VALIDATION

Combusting solid fuel may carry some health risks, especially so because from our interviews, we found more than 70% of Kenyan households cook indoors. The major risks include acute carbon monoxide poisoning (which is a known issue for wood charcoal), as well as chronic respiratory illnesses from particulate emissions. Therefore, it is of utmost importance for us to verify the health safety of the briquettes.

Methodology

There were two versions of the experimental set-up: laboratory and in-the-field. The laboratory set-up used the state-of-the-art instruments with high sensitivity: Bacharach ECA450 Combustion Efficient and Environmental Analyzer for carbon monoxide measurements, and TSI DustTrak II Aerosol Monitor 8530 for total suspended particle (TSP) measurements. These instruments were installed in a controlled combustion chamber illustrated in Fig. 3 below (Banzaert, 2013).

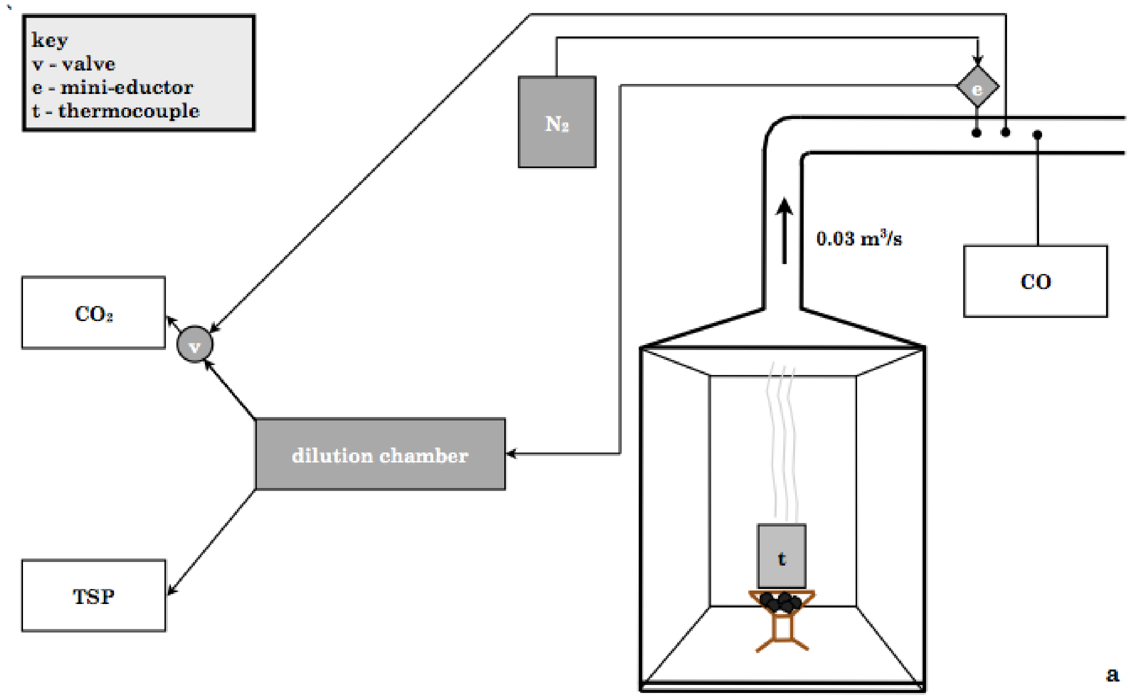

Fig. 3. Experimental set-up of the laboratory-grade combustion chamber for testing particulate and carbon monoxide emissions from the briquettes (reproduced from Banzaert, 2013).

However, these machines were not portable, and were unable to measure combustion emissions as the briquettes were being used for cooking in actual Kenyan households. In order to perform these in-the-field measurements, we needed equipment needed to be portable and robust. For this purpose, we used the UCB Particle Monitor (UC Berkeley, Berkeley, CA), and for carbon monoxide datalogging, we used the EL-USB-CO Carbon Monoxide Data Logger (Lascar, Erie, PA). As illustrated in Fig. 4 below, we were able to verify that the readouts from the in-the-field instruments have a good correspondence with those from the state-of-the-art instruments.

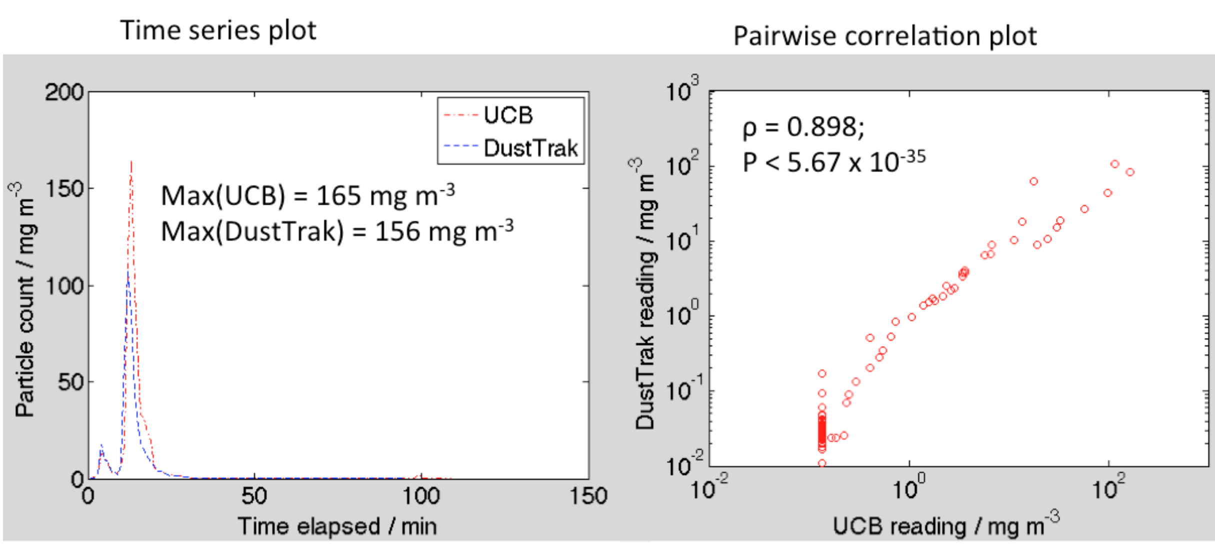

Fig. 4. Correspondence between measurement readouts of UCB Particle Monitor (which we employed in actual Kenyan households to test for briquette emissions) and of TSI DustTrak II Aerosol Monitor 8530 (which was employed in a laboratory-grade combustion chamber), for one representative experiment during which carbonized briquettes using cassava as a binder was combusted in a chamber. The left figure shows the UCB Particle Monitor readout (red) and DuskTrak readout (blue) in time, with close correspondence between the two. The right figure shows a pairwise correlation plot

between the readouts of UCB Particle Monitor (x-axis) and DustTrak (y-axis). While the UCB Particle Monitor is less sensitive compared to DustTrak (as illustrated by the vertical line of data points at about 0.1 mg/m^3), the correlation between the readout pairs is highly positive and statistically significant.

Particulate matter data

We first measured the particulate matter emissions in different types of briquettes, and the results are summarized in Fig. 5 below. As can be seen in Fig. 5 (a), over a typical combustion time course, our briquettes ("Takachar recipe") has particulate emission levels that do not exceed those of the wood charcoal, illustrating that the charcoal briquettes, when made properly, do not pose an additional health risk to the households in terms of particulate emissions. In Fig. 5 (b), we tested various briquetting techniques and binding agents, and showed the mean particulate emission levels for some of these recipes. As can be seen, while some binders (such as avocado and cloth) are unsuitable for briquetting purposes due to excessive smoke emissions, there exists many briquetting recipes whose smoke emissions reside in safe levels with respect to the traditional wood charcoal.

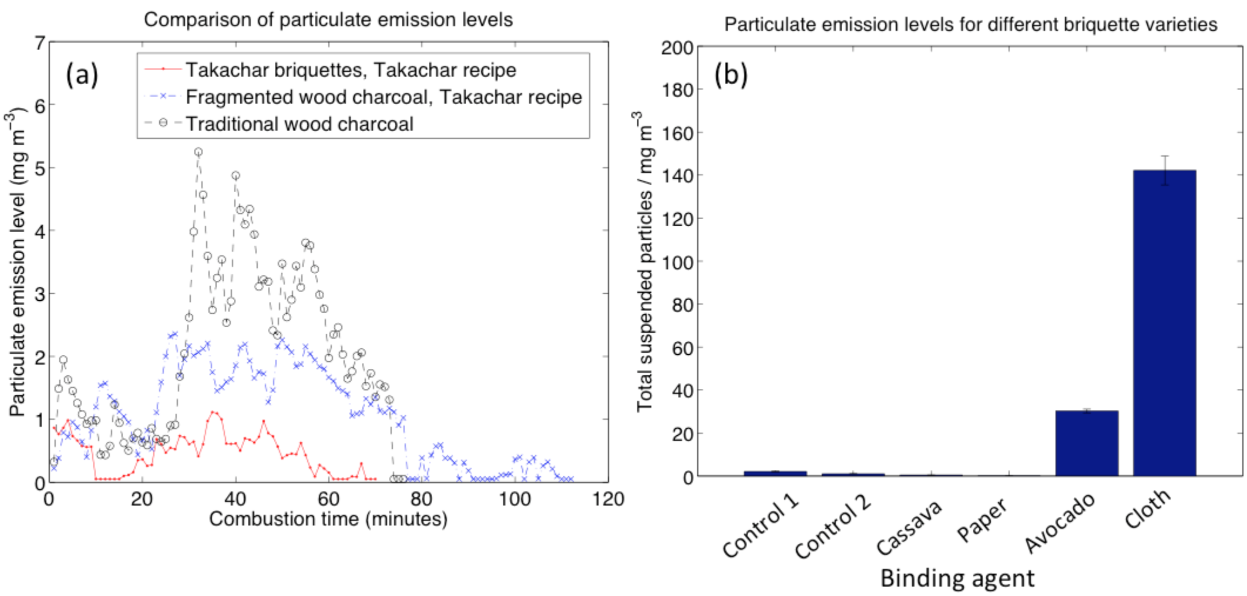

Fig. 5. Particulate emissions from the combustion of various charcoal briquettes. The left plot (a) shows sample combustion time course (on the x-axis) as well as the particulate emission readout (on the y-axis) inside a typical Kenyan household, using the UCB Particle Monitor. The right plot (b) illustrates the mean particulate emission levels of charcoal briquettes produced under various briquetting and binding conditions as described on the x-axis. Control 1 refers to the combustion of regular wood charcoal. Control 2 refers to the combustion of fragmented wood charcoal pieces that are re-briquetted together using cassava as a binding agent. Based on the plot, for example, we can rule out avocado and cloth as potential binders owing to excessive smoke emissions.

Carbon monoxide data

We subsequently measured the carbon monoxide emissions in different types of briquettes, and the results are summarized in Fig. 6 below. As can be seen in Fig. 6 (a), over a typical combustion time course, our briquettes ("Takachar recipe") has carbon monoxide levels are safer than those of the wood charcoal, illustrating that the charcoal briquettes, when made properly, reduce the risk of carbon monoxide positioning in indoor cooking. In Fig. 6 (b), we tested various briquetting techniques and binding agents, and showed the mean carbon monoxide levels for some of these recipes. In general, we qualitatively noted a correlation between the carbon monoxide level and the total exposed surface area of the briquettes: in briquettes that have a higher surface area (such as cloth), there is a greater risk of incomplete combustion and hence carbon monoxide emissions.

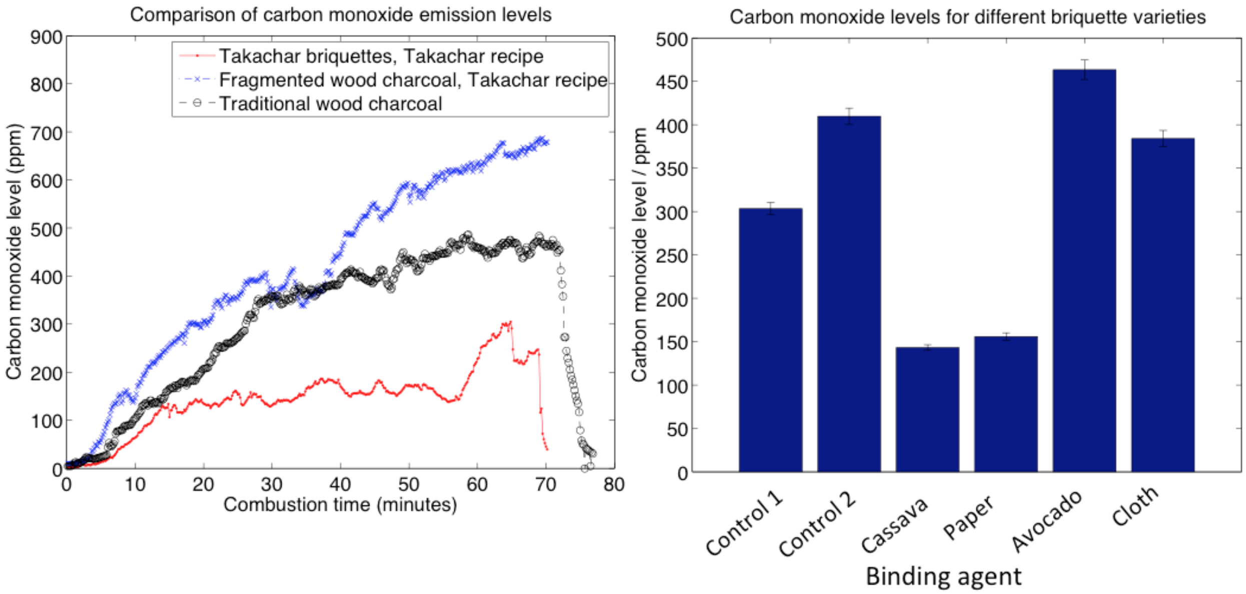

Fig. 6. Carbon monoxide emissions from the combustion of various charcoal briquettes. The left plot (a) shows sample combustion time course (on the x-axis) as well as the carbon monoxide readout (on the y-axis) inside a typical Kenyan household, using the Lascar CO Datalogger. The right plot (b) illustrates the mean carbon monoxide levels of charcoal briquettes produced under various briquetting and binding conditions as described on the x-axis. Control 1 refers to the combustion of regular wood charcoal. Control 2 refers to the combustion of fragmented wood charcoal pieces that are re-briquetted together using cassava as a binding agent. We can see that with proper briquetting methods, the risk for carbon monoxide can be reduced with respect to regular wood charcoal.

PROJECT IMPLEMENTATION

As organic waste is available in both urban and rural areas, the carbonization process can be applied to both places. In this section, we comment on our work in both contexts, drawing out some promises as well as challenges. These insights were obtained both through active implementation (in rural Rumuruti as well as urban Kibera), as well as through extensive interviews with various existing briquetting projects/enterprises in East Africa (5 in rural areas, and 17 in urban areas).

Rural implementation

Since 2012, we implemented a charcoal project in partnership with the Rumuruti Forest Association in Rumuruti, Kenya, where charcoal-induced deforestation is especially severe. The community, consisting of about 5,000 households in 7 villages, scaled the process up and now there are about 50 kilns in the community, amounting to a full-time production capacity of about 2 tons/day. In the Rumuruti area, corn cobs/husks are abundant, and this quantity far exceeds what is needed for competing purposes (such as using the same waste for chicken feed). However, the marketing of briquettes has been a significant challenge: many rural households are reliant upon firewood rather than charcoal as the cooking fuel of choice, and unlike the exorbitant prices (about US$17/bag) in the urban area, charcoal is relatively low cost near the source of production (about US$5/bag), so it is rather difficult for the alternative briquettes to compete in this environment. More recently, we have seen the same limitation amongst rice farmers in Mwea. In both cases, these farmers are actively looking for an urban market to sell their carbonized biomass. The Rumuruti community, for example, plans to partner with a briquette seller to package and market the briquettes in the nearby town Nyahururu, where the price of charcoal doubled (about US$9/bag) compared to that in Rumuruti. Therefore, we concluded that while the rural farms are a promising source of waste in reliable and steady supply, the briquettes should be sold in urban areas.

Urban implementation

In many urban areas such as Nairobi, the waste is informally collected by waste-picker cooperatives, which also perform value-added sorting in order to sell plastics, metals, etc. Since all the municipal waste passes through their sorting procedure, our original hypothesis was that these groups could also easily segregate the organic waste for charcoal production, which they could run. For the past 15 months, we have been working with such a cooperative in Kibera, Nairobi, Kenya. The first lesson that we learned was that it is very difficult to make use of household organic waste, unless there exists an incentive system to source separate (such as the model employed by Waste Ventures in India). For charcoal-making, the easier waste source to start would be marketplaces or informal food stalls, where such waste is available in large quantities without needing pre-sorting. The cooperative was able to collect daily from the closest Toi Market, carbonize such waste, make briquettes at a small scale (about 10 kg/day), and sell such briquettes to households at a price that is 70% of that of regular wood charcoal. This project was subsequently demonstrated at the Nairobi International Trade Fair, and received certification from the Kenyan Ministry of Agriculture.

However, the main operational challenge is the lack of scale: ultimately, charcoal is a low-margin, high-volume commodity, and we have seen that, in order for an operation to be financially sustainable in order to support a local micro-entrepreneur as well as 3-4 workers on site, it needs to quickly achieve a minimally viable scale of at least 500 kg/day. Groups (our own and others that we have interviewed) that first started at a small scale of production often used crude presses or even hand-molded the briquettes, which offered poor quality control and low market pricing. Even if there is a small positive profit margin, at a small scale, such a margin is typically not interesting, and as a result, the groups often had to undertake other income-generating activities, such as car-washing, to make ends meet. Given that the initial marketing for selling the briquettes requires considerable effort, such other activities tend to distract the focus of the groups away from charcoal briquette production, so that they are also less likely to spend time/effort focusing on scaling up the charcoal briquette production.

Another relevant challenge is the lack of standardization in the briquettes, as there are many different briquetting recipes even within the same operation. Such variations jeopardize the quality of the briquettes, such that households cannot reliably count on the purchased briquettes to behave the same way every time. This lack of standardization in the briquettes has created, in some urban communities, a negative perception of briquettes in general compared to wood charcoal.

DISCUSSION AND CONCLUSIONS

Despite the challenges of green briquetting operations, there exist possible commercialization paths that offer sustainability and profitability. In this section, we discuss a series of steps required for viable commercialization effort and conclude with a hypothesis on possible viable commercialization path for these ventures.

Need for standardization

The variability in briquette quality due to differing briquette production processes creates a negative perception of an already unknown product. Reduction in this quality-variability is paramount to establish trust and brand of the green charcoal briquettes. Establishment of standards in size, color, emissions, and heat dissipation will be necessary to have green charcoal briquettes achieve the scale necessary for commercialization efforts to prosper.

Micro-franchising model

The challenge for existing entrepreneurs within the green charcoal briquette production is the lack of scale. The low-margin, high-volume nature of the business has led to insufficient profit margins for green charcoal producers. Based on our pilot deployment in Rumuruti, Kenya with local farmers and subsequent deployment in partnership with waste pickers Kibera, Nairobi, Kenya, we propose a micro-franchising model and establish an incentive scheme for each partner in the process. We hypothesize that this structure has the potential to reach the minimum production volume required for profitability and continued operations of green charcoal producer.

In this micro-franchising model, we propose the "outsourcing" of char-powder production to waste picker cooperatives or rural farmers who can source biomass from their local communities/farms and use low-cost carbonization process to produce char-powder, so that it costs almost nothing to obtain the waste. Green charcoal producers (e.g. run by local micro-entrepreneurs) can purchase this char powder providing the waste picker groups and farmers an additional avenue for income generation.

By establishing a reliable source of raw materials, green charcoal producer can focus on producing high-quality standardized charcoal briquettes and uniform branding for the urban market, where the solid fuel has the maximum premium. The next step in this model is the establishment of partnerships or "micro-franchises" that serve as dealers, retailers, and/or retailers of the green charcoal briquettes. By building a profit-sharing structure with local micro-entrepreneurs, the green charcoal producers can effectively outsource the marketing and sales operations allowing them to focus on the quality and scaling up the production operations.

This proposed model builds an incentive based structure to tackle the identified issues in sustainable operations of a green charcoal briquette production. There do exist green charcoal producers that are experimenting with some flavor proposed model – organizations such as ARTI-TZ in Dar es Salam, Tanzania, as well as EcoFuel-Africa in Kampala are in the early stages of this innovative approach.

ACKNOWLEDGEMENTS

We would like to thank Daisy Chang, Lyndsy Muri, and Amy Banzaert for the particulate and carbon monoxide emission testing; Yvonne Wangare for designing and implementing the top-lit drum kiln in the context of Rumuruti, Kenya; Dickson Kamau, Tabitha Wangare, Jacob Young, and William Ruddick for project implementation in Rumuruti, Kenya; the Zulu Youth Group and the Carolina for Kibera staff for project implementation in Nairobi, Kenya; Richard Ondiek for facilitating group interviews; MIT Public Service Center, MIT IDEAS/Global Challenge, Legatum Center, IDEO, International Telecommunications Union, Orange, GE, Walmart, and the Robert & Patricia Switzer Foundation for funding.

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