Biomass Charcoal

Introduction

The Biomass Charcoal team has worked since 2007 to create a safe indoor cooking fuel from biomass waste. Burning wood or dung indoors causes many health risks, including potentially fatal lung infections. Several countries also face serious deforestation problems that make firewood collection increasingly difficult. The BMC team worked to develop a pyrolyzation process that could create charcoal out of dried corn cobs, husks or coffee shells. The basic mechanics behind pyrolysis is "half burning" a fuel source by supplying the burn very little oxygen, so black charcoal is left over, as opposed to spent ash. This coal can be burned a second time, and it burns hot and cleanly.

The work was catalyzed and guided by MIT's Amy Smith and the D-Lab. EWB has worked on this project in the past; see this page for some notes from the 2007-2008 work at Duke, and See this page for The most current research: Test Results from Duke (Spring 2009).

For more information on the process or to learn how you can get involved, email Daniel Moss (daniel.moss @ duke dot edu)

[The images below show 1) deforestation due to charcoal-making in Nkokonjeru, 2) typical bag of wood charcoal, 3) typical iron charcoal stove with homemade biomass briquettes on top.]

Test results from Uganda (summer 2008)

Background: Existing Charcoal-making Methods

While in Nkokonjeru, the biomass charcoal team first researched the existing methods of charcoal production to glean ideas and concepts off a relatively effective pyrolyzation process. The process for making wood charcoal is as follows: hardwood and softwood (but not banana) trees are cut down and their trunks are sectioned into similar-length logs. The logs and branches are then dried in the sun for 1-2 weeks, to remove some sappy residue. The large logs are then piled compactly together (facing the same direction), creating a squat pyramid (head-on view), and the cracks between the logs are filled with branches of proper dimensions. Green vertical branches are then planted around the pile so they can support a thick layer of green underbrush and grass that vertically insulates the wood pile and blocks oxygen. The brush is placed on three sides and then on the top, which is finally covered with a thick layer of dirt. The fourth, exposed side has a fire lit at the bottom of it, which is allowed to burn for about 30 - 45 minutes uncovered, so that the fire reaches the inside of the pile. At this point, the final side has vertical branches planted around it, green brush stuffed between the pile and the vertical supports, and then a final cover-up of air holes with dirt and plant matter, so that only a small amount of smoke is visibly leaving the pile. These piles can burn for 3-7 days, depending on their size, but they must be monitored closely so that cave-ins in the outer dirt layer can be patched before too much oxygen is allowed to completely combust the wood.

After the piles have burned for enough time, they must be taken apart systematically. After all the outer layers are removed, the pyrolyzed wood is broken into small, two-finger-sized chunks with a hoe, and these pieces are tossed into yet another clearing of dirt, where they are reburned for up to 36 hours to allow them to fully cool down. After that, the charcoal is pulled from the dirt and placed into bags for later usage. In this case, the leftover dirt, mixed with small chunks of charcoal and charcoal dust, was scattered over some nearby bean fields to provide them with better fertilizer.

Keywords: Pyrolyzation - Heating raw fuel with high oxygen deprivation so that the fuel is toasted or "half burned," thus producing charcoal. This half-burn method removes contaminates (SOx, NOx, heavy volatile particulates) from the fuel, as well as its natural color and texture, but allows the cellulose structure to remain mostly intact. After cooling, this highly porous, black charcoal can then be burned a second time, cleanly (little to no smoke) and slowly, to produce ash, a final product consisting of metal oxides.
Background: Available Alternative Fuel Sources

**Corn Cobs**: Corn cobs are moderately available because there is a decent amount of Maize farming in Nkokonjeru. Cobs are already used (albeit rarely) for burning, but they are not pyrolyzed—they are just burnt straight in the fire, making a very smoky, dirty fire. Cobs are also used as a small addition of fertilizer for the fields, but there isn’t a big emphasis on this usage. The corn cobs must be free of kernels and husks, and should be well dried. This type of cob is easy to find because a lot of corn is dried on the cob and stripped off for making corn flour, so the cobs are left over.

**Coffee Shells**: Near RASD is a large coffee shelling factory, which husks the coffee shells to reveal the inner bean. The shells are piled out behind the building, as they would be at almost any plant. Shells are used sparingly as fertilizer and hog waste absorbers, and are only purchased by wealthier individuals. Nevertheless, a 50 kilo (110 lbs) bag of dried shells is very affordable, 2500 shs, or about $1.50, but that price could plummet if more is purchased at a time. Shown below, a large pipe funnels the shells from the factory into a large pile.

**Sawdust**: Sawdust can be collected for a small fee from various workshops around Nkokonjeru, and hopefully from the new vocational school starting at RASD. The sawdust also needs to be dry and hopefully free of too many contaminants, but still it is a very logical substitute for wood charcoal.

Experimentation: Process/Results

*Important*: Listed below are the basic steps for making biomass charcoal, followed by a more detail narrative describing each step. In the narrative, importance is not placed on quantitative measures as much as qualitative ones, and it mostly focuses on the overall process. Thus, some numbers displayed may be somewhat inaccurate but not too much so. Information on oil drum pyrolysis can be double-checked here, though some of it is intentionally different. Though qualitative information dominates this document, the variations in each step of the process have also been numerically ranked within a morphological matrix, which can be found here (pdf), as well as at the bottom of this page. This matrix also includes various options that we have not tested, whose rankings we simply surmised.

- Pyrolyze various fuel sources into a pure charcoal form
- Grind the charcoal into small particulates for better binding
- Boil an optimal ratio of cassava powder and water to make a cohesive paste (binder)
- Mix an optimal ratio of cassava binder to charcoal dust
- Press the charcoal briquette using the most effective and efficient tool
- Dry the briquettes fully to remove all moisture
- Burn the briquettes and perform tests for quality and efficiency
Experimentation: Pyrolysis

Alternative methods for burn:

- underground burial burn (oxygen deprived)
- ground surface burn (oxygen deprived)
- surface torrefaction (open-air)
- above ground oil drum burn (oxygen deprived)--with corn cobs, not coffee shells

Underground Burial Burn with Coffee Shells

This type of burn is the most efficient in regards to extra materials, because instead of building up, one can simply dig down to provide space for pyrolysis. Our steps for completing an underground burial burn were as follows: First we dug a cylindrical hole (2.5 ft in diameter, 2.5 ft deep) into sturdy ground, with straight, vertical edges and a solid floor. Our hole's diameter was then diminished by 1 foot because we lined the wall with bricks (we believe the bricks provide better insulation for the burn and sustain elevated temperatures for a longer period of time). We removed one column of bricks so oxygen could better reach the bottommost source fire. We then built a small wood fire at the bottom of the hole, and after the fire became strong, we carefully placed the coal fuel source (coffee shells) on top of the fire. Because a thick layer of small fuel particles could extinguish the fire if placed on too rapidly, we decided that it would be safer if we placed the shells in an impromptu wire mesh basket before placing on top of the fire. After the fire reached the top of hole with strong flames visible (licking the sides of the basket), we allowed the fuel to burn for 10-15 minutes with partial (70%) oxygen deprivation. To do this, we covered 70% of the opening with green brush and large banana leaves. To support the leaves, we made a simple mesh of fresh, green sticks (relatively incombustible) to place over the hole. After 15 minutes, we fully covered the fire by placing layers of leaves over the fire and then covering those leaves in a thin layer of dirt/sand until very little smoke was visible. We then created two small holes (2-3 inches wide) in the covering (on opposite sides from each other) so enough oxygen could enter to keep the fire from extinguishing itself, and so there was an exit for smoke. We then let the fuel burn freely until there was no longer a source of intense heat (8+ hours).

We performed many trials, with outcomes ranging from a fire that was extinguished within an hour of full coverage, to a fire that burned for a whole 24 hours and was still smoldering. Charcoal outcomes also varied: When the fire was extinguished quickly the mesh of coffee shells were only singed on the outside, while the inner shells didn't pyrolyze at all. When we let the fire burn until it didn't seem to be hot anymore, we removed the mesh to find that an outer layer of shells (1/3 the volume) had turned to ash, the middle layer (1/3 the volume) had turned to charcoal, and then the inner core was still burning, even though it was mostly raw and unpyrolyzed.

ground surface burn (oxygen deprived)

We also tried an alternative method in hopes of allowing for greater oxygen flow, thus heating/pyrolyzing the fuel faster. To do this, we first built a small fire ring two bricks high (second layer is not shown in picture), and then made a direct passageway for oxygen to reach the center of the fire by building a slim passageway made of bricks. This airway would expose the glowing center of the fire. To start the fire we again used a strong wood fire, which we slowly added coffee shells to, making sure not to stifle the fire. After much of the shells had caught fire we put a large amount of shells onto this pyramid-shaped mound, let the flames lick the surface, at which point we took matooke (banana) leaves (see pic below) and placed them over the pyramidal mound, setting the ends of the leaves into the brick wall cracks. We then sealed major holes with small amounts of sand.
After two hours or so of slow burning we removed the leaves to discover that we had transformed a large proportion of the shells to charcoal, but that around 2/5 of the shells were either raw or ashen. Removing the good shell charcoal from the raw shells, ash, and leftover wood charcoal was difficult (especially due to residual heat) and inaccurate.

surface torrefaction (open-air)

To diminish the weaknesses in the two previously mentioned methods, including their inhomogeneous products and slow processing, we tried the method of torrefaction. This method does not require an anoxic environment, but can rather be performed in the open air. The concept here is to place raw shells on top of a highly conductive material, like sheet metal (aluminum roofing, for example), and burn a very hot fire beneath the metal so the shells are toasted into a charcoal state. To make and sustain this fire, we had to use a very large amount of wood, dried leaves (which produce extra-hot flames), and it had to be stoked for close to 30 minutes to finish a batch of about 10 lbs of raw shells. During the toasting process the shells had to be monitored and turned every 5 or so minutes to prevent the bottom ones from catching fire, and to allow the raw shells to get equal exposure to the hot metal.

After 30 minutes of careful mixing and over-turning the shells, our product was very promising: Almost 90% of the shells were completely torrefied, with the rest being a negligible amount of ash. However, because so much fuel was used to perform this process, we have ruled the torrefaction method out of our possibilities.

Another highly challenging setback to mention at this point was the task of cooling the charcoal shells so that they wouldn’t continue smoldering into ash. To stifle their burning, we placed all the shells into a wheelbarrow, covered the top with a layer of thick but empty cement bags (made from fireproof ultra-durable paper), and just let it sit. After over 16 hours of sitting like this, the shells were still burning, now leaving only about 85% of the original shells in good condition. We tried stirring but realized that that would simple feed more oxygen to the shells. Eventually, somehow, the shells put themselves out, but not in a timely enough manner. One option we considered but didn’t pursue was pouring water over the shells. Enough water (1-2 gallons) would have completed the task quickly, but drawbacks include the retrieval and “wasting” of clean water and the subsequent need to dry the shells after they’re soaked.

corn cob oil drum burn (oxygen-deprived) --> method could also be applied to coffee shells

notes from the August 8, 2008 corn cob burn at RASD

kiln characteristics:

• 23" diameter, 34" tall (standard oil drum)
* five holes, 4cm diam, punched into bottom in a pentagon; same as in Duke burns, and as recommended by the D-Lab work
* home-made lid from roofing metal and sticks

**first trial (failed):**

* roughly 6" layer of dried grasses loosely packed used when 3" layer of coarse sawdust wouldn't light
* ~20" layer of corn cobs; dried two months at RASD, various sizes, up to 8" long; unknown mass; some chicken poop and feathers along for the ride
* lit four of the five holes; some grey smoke observed; smoke gone in five minutes; lunch break...

**second trial (successful):**

* 6" layer of dry leaves and sticks for kindling to fire
* kiln layered with corn cobs then a second band of leaves, then corn cobs to the top
* kiln lit with the barrel propped on bricks and no covering over the barrel
* observed thick smoke at 8 minutes (see photo)
* at 23 minutes, still thick yellow smoke from kiln, perhaps more yellow than before
* at 37 minutes (29 minutes of yellow smoke) the emissions vanish *rapidly* (the feedstock fire has become oxygenated, we call this point the smoke change), open flames rise from the top of the barrel; the barrel is covered partially with the lid and the yellow smoke immediately returns
* at 51 minutes with barrel still partially covered, thick smoke still present but not so yellow; concerns voiced over loss of biomass if burn is allowed to continue (one is supposed to wait for another smoke change at this point);
  * ideas raised about using a "chimney" for future burns (a cylindrical gap through the center of the kiln, devoid of feedstock, to encourage airflow), this would hopefully accelerate phase I (the process up to the first smoke change, where most of the feedstock is consumed);
  * though, on second thought, it might not save any feedstock to have a chimney
  * also observed that corn cob coals are falling through the five holes in the kiln's bottom
* at 57 minutes, begin the full seal of the oil drum
* 75 minutes, complete final seal: drum off of the bricks, base surrounded by mud to be airtight, lid placed on fully, cracks covered with mud to seal; several handfuls of mud fell into the barrel during the sealing process here
* results: after leaving the barrel for about 12 hours (longer than necessary) we found the burn yielded one wheelbarrow of pyrolyzed cobs (this is 1/3 to 1/2 the starting volume)
  * ~5% were unpyrolyzed, some lack of pyrolysis through the interior of the cobs (maybe 10% of the cobs)
  * most cobs remain whole
  * small amount of resultant ash
Experimentation: Grinding the shells

Grinding coffee shells, even in their pyrolyzed state, is very difficult. They are very tough and do not powderize well. Then again, we utilized very primitive methods: we placed the charcoal into a shallow plastic bucket and ground them into the bottom of the bucket with a brick. Because plastic isn’t abrasive, the charcoal wasn’t well crushed—luckily the brick stayed intact for this reason as well, thus not polluting the clean charcoal with brick dust.

Because grinding was so difficult, we decided that we would make briquettes with only slight or no grinding at all. Grinding stones, mortar and pestle, or a machine-operate mechanism would all provided better results, even though each the task would be slow and very dusty (bad for breathing). The MIT D-Lab recommends that water is spritzed into the charcoal to keep the dust down, but we are unsure whether spritzing would be sufficient.

We also made a few batches that contained a mixture of crushed pyrolyzed shells and unpyrolyzed shells (about 1:10), hoping that the small amount of charcoal powder would bind the raw shells together into a briquette that could either be burned raw, or pyrolzyed in its briquette form. We never did attempt pyrolyzing a raw briquette (though it holds promise), but the results of binding, drying, and finally burning the mixed briquettes did not differ much from the normal briquettes.

Experimentation: Boiling and Mixing the cassava paste
The cheapest and most ubiquitous "glue" one can find in rural farming areas is most likely a natural starch-based paste, made from some sort of tuber. We used cassava root. To make the paste, two different methods can be employed, both of which we tried:

A) Cassava Powder Method: Cassava root is often dried and ground into a powder, which is sold in markets and used to make soup or porridge. The powder we found was very cheap, price-stable, and ubiquitous. To make the paste, we mixed 1 part powder to 5 parts water, and heated the mixture, stirring constantly, until it thickened (after ~10 minutes of boiling) into a milky white paste (see right picture below). When then let it cool to a lukewarm temperature before we started mixing.

B) Cassava Shavings Method (see left picture below): Instead of buying powdered cassava, the other method for making the paste is to collect small shaving of the clean, white root (tough skin removed) into a pan by holding a sharp knife perpendicular to the root and scraping it downwards. After the root was scraped into shavings, we added about 4 times that amount in water. At this point, one must squeeze the starch out of the peelings by hand, which quickly turns the clear water into milky white. After squeezing the shavings around 20 times, most of the starch has been leached out, at which point one removes the shavings from the milky liquid (these shavings can be used as fertilizer, pig feed, possibly a soup additive). The milky liquid is then boiled and stirred until it becomes pasty, at which point it is cooled to a lukewarm temperature. Leftover paste can be reused if it is first reheated, though after 48 hours the paste may begin to rot, rendering it ineffective.

After the paste cooled to being touchable, we mixed the paste with the charcoal by hand in a plastic bucket. We used the following ratios of paste to charcoal: 1/5, 1/10, 1/20. After briquetting and drying the various ratio mixtures, we determined that 1/10 would be the best if it were compacted very effectively. If not, then 1/5 would have to suffice, even though it requires more drying time and doesn't burn as well.

Experimentation: Pressing (briquetting) and Drying
Briquetting:
To briquette the mixture of charcoal coffee shells and cassava paste (still warm), we used the MIT D-lab's briquette press. The press consists of a 6-inch hollow metal tube/chamber (~2 inches in diameter, with one end restricted by a welded-on washer), and two copies of a 5-inch piece of metal rod with a metal cylinder (~1.9 inches in diameter) welded to one end. To assemble, the first metal rod is inserted into the chamber, rod-side first, so that the rod slides through the small washer hole, resting the cylinder head at the bottom of the chamber. After the packing material has been added to the chamber, the second rod is inserted into the chamber, metal cylinder-side first. The bottom of the chamber is then place onto blocks so that the bottom rod can't touch the ground (sandwiching the rod between two blocks). Finally, the upper rod is compressed downwards using hard impulse force (sledge hammer, etc.). To remove the briquette, the chamber is removed off the blocks and then hit against the ground so that the bottom rod strikes the ground first, pushing the briquette up and out the top.

Important notes: For each briquette we filled the chamber just to the brim with the mixture, not stuffing anything inside by hand. Filling it just to the brim without pre-compaction assures more consistency in mass and density of each briquette. In addition, instead of using one big impulse force (one hit of the sledge hammer), we delivered five blows of a heavy wood block to each briquette, mainly because we hadn't secured the chamber in place very well, and the blows were less powerful and more controlled. The chamber and compression rod had to be held by two hands, while the block was held by another person altogether. This could be avoided with proper securing of the chamber. Also, when removing the briquette, take care not to pinch the skin of your palm when hitting the chamber against the ground.

Drying:
After the briquettes were carefully removed from the press, we placed them on a sheet of corrugated metal roofing to dry in the open air, preferably in the sun. Depending on the how much cassava paste was added, the briquettes would take anywhere from 24 to 96 hours to fully dry.

Experimentation: Briquette Burn Tests, Analysis, Concerns
Charcoal briquettes alone cannot be used to start a fire. Thus, we started all of our fires with either a glowing chunk of wood charcoal or simply a small stick fire (ignited with a match or glowing ember). In either case, we carefully placed the briquettes on the fire, blowing on the embers to stoke the heat, until we were sure the briquettes had caught. Each type of briquette burned differently, though they all caught light within 10 minutes and burned for at least 30 minutes. Their main weakness seemed to be that they would fall apart if disturbed, thus shortening their burn time and dissipating heat.

For the most part, the pyrolyzed coffee shell briquettes burned decently, though the 1:5 cassava mix was a little sluggish in catching and slightly smokey. The 1:20 cassava mix fell apart too easily and thus did not burn well. The 1:10 had the best burning results, but only slightly, and its integrity before it burns is still a concern. An interesting thing to note is that a local from Nkokonjeru raised the point that families sometimes would extinguish hot coals with spritzed water, thus allowing them to reuse the coals in the morning; not surprisingly, when the coffee shell briquettes were spritzed they either fell apart or resisted getting extinguished (because their surface area open to oxygen is so high).
We also made a few batches of sawdust charcoal briquettes, including briquettes that were completely torrefied, partially torrefied, and completely raw (all bound with 1:10 cassava ratio), and their burn results varied in that the raw briquettes would produce far more smoke (the torrefied ones produce close to none), and that the torrefied ones would burn the hottest (and stick together the best).

A big concern about the briquettes is that even with the 1:5 binder ratio, they still are more fragile than wood charcoal and the ones lying at the bottom of a huge 20 kg bag would probably crumble.

Linked here is a morphological matrix of the variations in each step of the process (including variations that we have not tested), numerically ranked on a weighted scale.