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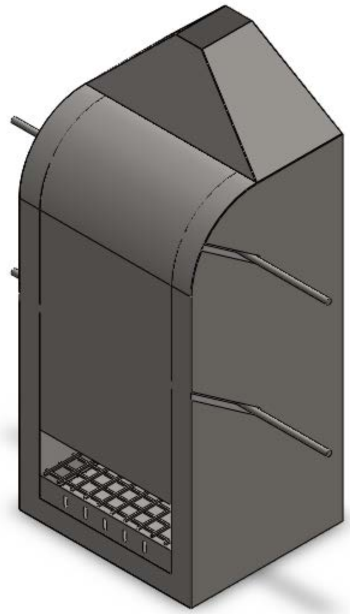

Shea Kernel Roasting Improvement Project – Problem Definition and Opportunity Scoping

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Ghana Agriculture and Natural Resource Management Project

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Agreement Number: AID-641-A-16-00010

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Executive Summary

Shea nuts are grown and harvested across much of West Africa and has become a multi-billion-dollar industry. Despite this, the current process used by smallholders, i.e. hand-crafted butter processors, for roasting shea kernels needs improvement to address significant health and environmental shortcomings, including low thermal efficiency with correspondingly high fuel consumption, inconsistent roasting quality, and high particulate emissions (smoke). To this end, in partnership with AgNRM, Burn Design Lab conducted a study on shea roasters, which identified and prioritized the product design parameters required to create a more efficient and effective shea nut roaster. Objectives for the improved roaster included removing smoke from the cooking environment and reducing purchased fuel consumption by 60% or more. Accordingly, four preliminary design options, which vary in projected cost and performance, have been modeled and shared as potential approaches to address the above-mentioned issues when roasting shea kernels. Cost and performance largely relate to the fuels used for roasting and local manufacturing capabilities, which are important to developing an improved, locally manufactured shea roaster.

The information presented in this report was gathered during a seven-day trip to northern Ghana. Cities and villages that were visited include Tamale, Wa, Wechiau, and Zukpiri. Shea processing facilities, manufacturing companies, and local craftsmen were visited and interviewed. This information has been compiled and documented with the intention to embark on Phase 2: The development of an improved shea roaster.

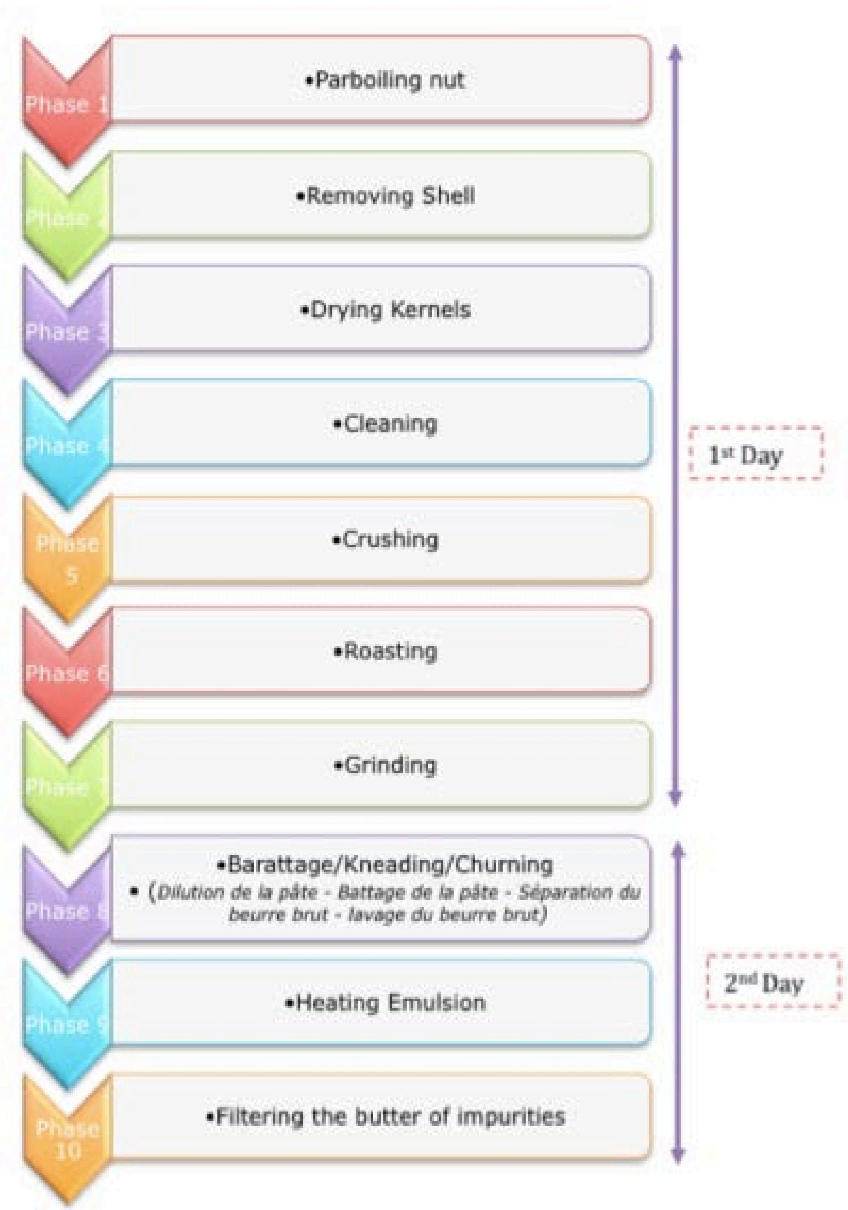
Introduction

More than 6 million women across the Sahel – from Senegal to South Sudan – depend on shea oil production as a livelihood activity. While shea has international appeal as a food additive in the chocolate industry and as an ingredient in the cosmetic sector, across the Sahel, shea is produced and used as a cooking oil and body cream. It provides major nutrients; is used to deep fry food; and is a key ingredient in regional rice dishes.

Processing shea is often the primary source of income for women in Ghana. The process of transforming shea nuts to oil is quite extensive – taking two days to complete the production process. The steps involved are outlined below (see Figure 1):

1. The shea fruit is collected and the pulp is removed, leaving just the shea nut;
2. The nuts are then par boiled to soften the outer covering and extract the kernel;
3. The kernels are then washed, dried, and sorted to remove any rotten or spoiled pieces;
4. The kernels are crushed with bats or sticks;
5. After this, the kernels are roasted in cylindrical drums over an open fire -- This step is the focus of this report;
6. The roasted kernels are then ground into a finer powder sometimes by hand but more often sent to a mill to save time;
7. At this stage, the ground kernels are kneaded into a paste and water is added;
8. The paste is then boiled in a large pot, and the oil (shea butter) emulsifies to the surface and is collected;
9. This butter is then used to make soaps, creams, and a variety of other products.

Figure 1: The Shea Butter Production Process



Burn Design Lab (BDL) has examined the shea production process and believes that several technologies in addition to the roaster could be developed to improve the quality of the final shea product, thereby increasing the money women can earn, while also reducing emissions, fuel and water consumption, and improving the health and labor conditions of producers.

Project Background

In June of 2017, Burn Design Lab (BDL) traveled to Northern Ghana to learn about the shea kernel roasting process. This trip took place under the auspices of Ghana Agriculture and Natural Resource Management (AgNRM) project, which is a five-year program that serves as the main vehicle within USAID that addresses issues of the environment and natural resource management in northern Ghana. AgNRM seeks to provide a scalable, integrated landscapes approach to support sustainable economic development and rural livelihoods, improve nutritional outcomes, expand climate change related risk management options, and strengthen northern Ghana's natural resource base. Ghana is a major exporter of shea butter, and shea nuts and butter provide a sizeable amount of income to rural smallholders, mainly women, in northern Ghana.

Once in Ghana, BDL observed the current roasting process and analyzed the associated issues. Approximately 15 women at the Savannah Fruits Co. (SFC) facility in Wechiau, and about the same number of women in Zukpiri were also asked to describe the issues that they experienced with current roasting methods. Product parameters and goals for an improved roaster were established based on these experiences and with an understanding of combustion and heat transfer, BDL developed four alternative designs for an improved roaster. These preliminary designs remain to be built and tested but have been initially assessed based on their expected performance compared with the established goals and parameters of the project. Additional research and ideation during the development process may well lead to other designs which may be superior to those shown here.

To assess the fuel consumption of the roasting process, BDL took size and moisture measurements, and also tested fuel samples for moisture. Additionally, BDL conducted an assessment of the local manufacturing capabilities in Northern Ghana with the intent to prototype and produce the improved roaster locally. The potential for prototyping in Accra was not explored but may be included as part of the development process in case one or more of the prototype designs include features that exceed the capabilities of what can be manufactured in northern Ghana.

The Current Process

Roasting crushed shea kernels is an essential part of the shea butter process in Ghana, and has a marked potential to be improved. In Ghana, there are two primary methods for roasting shea kernels. The traditional method consists of roasting them in a large aluminum pot over a three-stone fire. This process requires constant stirring of the kernels so that they do not char and burn to the sides of the pot. The second method consists of using a steel roaster drum. The drum is positioned on a rectangular box, which supports the drum via a rebar shaft through the center of the drum (see Figure 2).

Figure 2. Roasting drum positioned above fire

Table 1. Summary of current roaster design	
Cost	US$89-167
Weight	16-20 kg
Performance	1
Usability	3
Capacity	3
Greenhouse Gas Emissions	1

Table 1 shows the cost, weight, and estimated relative performance (on a scale of 1 – 5, where 1 is the worst and 5 is the best. Until the available roaster is formally tested, exact values are not available. The Usability measure will be established with the users at the outset of the development process.

For the traditional drum method, the drum is filled with crushed shea kernels and is then rotated over an open fire by a hand crank on one end of the rebar shaft. The time to roast one drum was observed to take between 50 and 80 minutes. The time to roast varied with the drum size and firepower (burning rate). In the two field tests BDL conducted at Savannah Fruit Company in Wechiau and Zukpiri processing group, it took an average of 50 minutes to roast 38.5kg of crushed shea kernels. At a smaller roasting facility in Tamale, it took more than an hour to roast a similarly sized drum full of crushed nuts, although the mass of this drum was not recorded. This longer roasting time is likely attributable to lower fire power (See Figures 3 and 4 below).

The roasting process is deemed to be complete when a certain odor is detected, or if the kernels sizzle when water is poured on a small sample of them. The ‘sizzle’ simply indicates that the temperature of the kernels is significantly above 100 degrees C. Once roasted, the full drum is carried to a cooling area, where the kernels are poured out of the vessel and spread on the ground, tarp, or other cleaned surface to cool (Figure 5).

Figure 3. Roasting drum in Wechiau - Roasting time is ~50minutes

Figure 4. Roasting drum in Tamale - Roasting time is longer than 1 hour

Figure 5. Roasted kernels spread out to cool

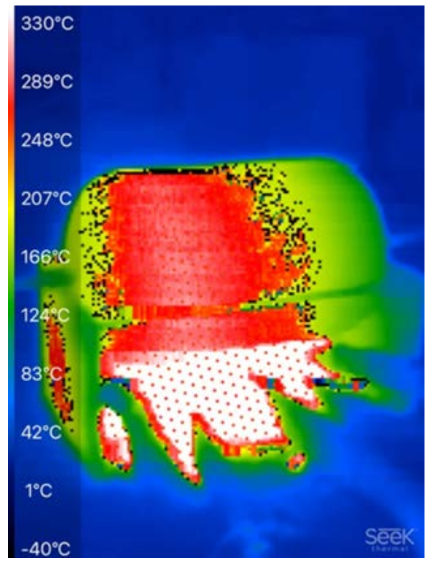


Figure 6. Thermal image showing uneven heating along length of Wechiau roaster

Examining the Current Process

There are a variety of issues associated with both of the roasting methods described above. In BDL's field research, women roasting with either large pots or roasting drums each spoke about the issue of smoke. Roasting in close quarters over open fires for hours on end brought up issues of chest pain, teary eyes, and even loss of visibility for multiple days, all of which are related to smoke. Many women also carry children on their backs or allow them to be in close proximity to the roasters while they are working, which has implications for their welfare as well. Aside from health issues, the other big issue was fuel consumption. Roasting on a three-stone fire is the least efficient way to roast, and although the drum rotating in a three-sided box is an improvement, there are still large amounts of heat lost by burning on the ground with a minimally enclosed drum and uncontrolled air flow.

Furthermore, given increasing deforestation in Ghana, high rates of fuel consumption require that women travel greater distances to collect wood to roast the shea kernel. In Zukpiri, women roasting in large pots described terrible pain in their shoulders, arms, backs, and knees, while women in Wechiau using the roasting drums spoke of the weight of the drums being an issue when completely filled with shea kernels. This not only causes weight issues but also minimizes the mixing of the kernels as the drums are rotated. This lack of mixing results in unevenly roasted kernels (See blackened kernels in Figure 5). It was also observed that the women had a difficult time maintaining even heating along the length of the drum, which is illustrated in the thermal image in Figure 6 and shows the uneven temperature distribution due to inconsistent firepower along the length of the drum. A final issue raised was heat exposure. It was extremely hot sitting next to the roaster for a few minutes, so roasting for 1 to 8 hours per day is a significant hardship. Identifying and understanding these issues was essential to accomplish in Phase 1 of this project.

Parameters and goals for improving the roasting process

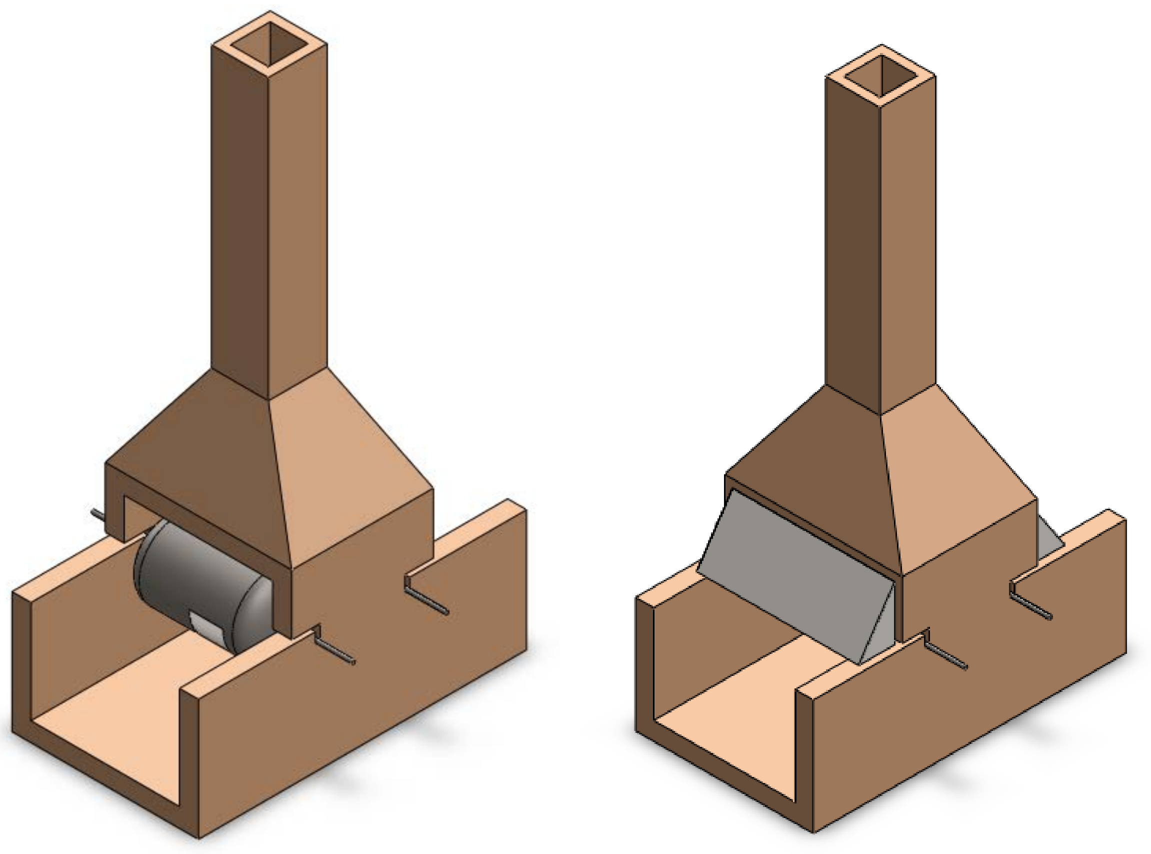
Product parameters (objectives and constraints associated with the new design) and goals have been established based on the issues identified with the current roasting process. Removing smoke from the cooking area is a primary objective for any new prototype and product BDL develops. In addition to addressing the issue of personal exposure to smoke, BDL will design the roaster to reduce total emissions, maintain capacity, and increase thermal efficiency. An efficient roaster will save time and money, and also help to reduce deforestation in the country. The new design can reduce roaster purchased fuel consumption by at least 60%. PM2.5 (particulate <2.5 microns in size) and CO (carbon monoxide) are two emissions parameters that can be significantly reduced. A goal of 90% reduction in PM2.5 and CO exposure is set for the optimized roaster design. Reducing emissions makes the immediate roasting environment safer and healthier, which is the objective of the shea processing facilities.

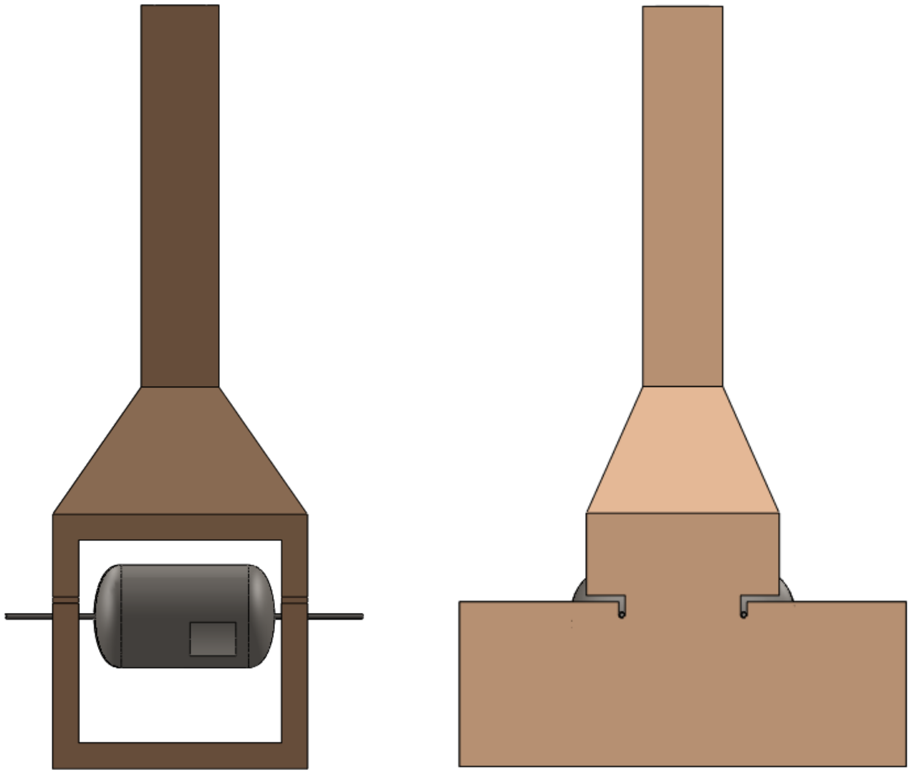
In addition to these goals, roasting capacity is another parameter that will be maintained, or improved upon. In field tests conducted at SFC, ~50 minutes was required to roast ~40kg of crushed shea nuts. In addition to maintaining the capacity, it is important that the nuts be roasted evenly and consistently throughout. The durability goal for an improved roaster is to match or improve upon the durability of the current roasting equipment. This means that the roaster will last at least 2 to 3 years before it is no longer usable. The extent to which these goals are accomplished will be dependent on the final roaster cost. The current cost of the traditional roaster was reported to be GH¢400-750 (US$89-167). A lower cost roaster can be developed, however, it may not meet all the stated product parameters and goals. Alternatively, a more expensive roaster can be developed that has the capability to meet or exceed the identified objectives. Several potential options are presented and assessed in the next section.

Alternative roasting options

BDL conceptualized several improved roaster ideas, and has chosen four to further develop if a follow-on phase is possible. Each option addresses a number of the issues and goals presented above. BDL recognizes that additional parameters may need to be included in a follow-up stage, which would be based on more ground-level work.

Option 1: Existing Roasting Drum with Integrated Clay Chimney





This is a low-cost option that addresses some of the established project goals and parameters:

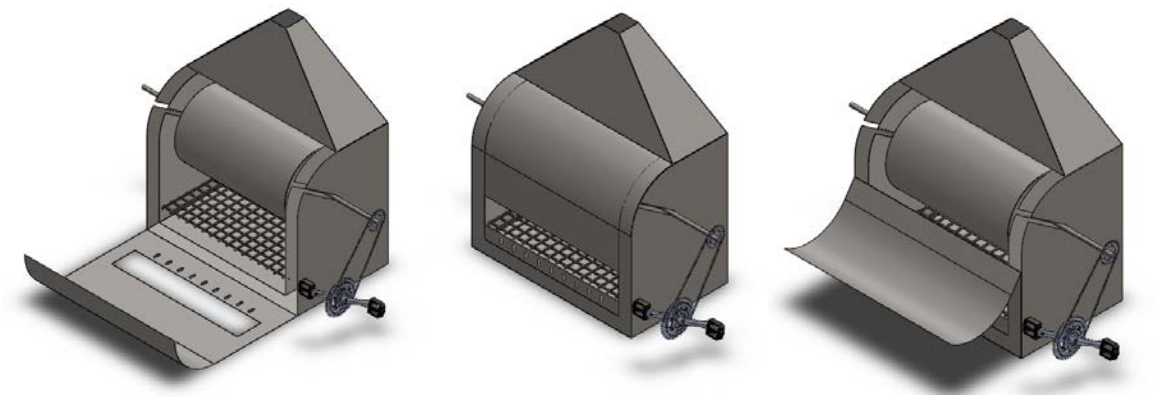
1. This option eliminates most of the smoke from the roasting environment. This is essential in improving the health of the women roasting Shea nuts.
2. The clay fire chamber will reduce the heat of the roasting environment, making it much more tolerable to work in, and will slightly improve roaster efficiency.
3. An optional peddle drive could enable women to comfortably roast Shea nuts. Ideally eliminating neck, back, and arm pain.
4. The two-sided integrated chimney allows for two roasters to rotate over the same fire at once. This reduces the need to build more chimneys and increases efficiency.
5. The roasters will maintain the same dimensions, but intention is to fill the roasters. This simple change will allow for much better mixing inside the drum, resulting in a more evenly roasted batch of nuts. This modification also has potential to reduce the roasting time without affecting production rates.

Potential issues with this design:

1. This option does not address the efficiency or emissions goals outlined in the previous section -- it simply eliminates emissions from the cooking environment.
2. The integrated chimney is immovable. It will be built in a designated roasting area, and will not be portable like the current roaster and box.

3. The durability of the roaster drum will remain the same. Although, an improved roasting drum could be developed and integrated with the fixed clay chimney.
4. The durability of the clay chimney would need to be evaluated but depends on clay quality and local craftsman capacity to work with clay.

Option 2: Enclosed Stainless and Carbon Steel Roaster



This design addresses more of the established goals and parameters:

1. Eliminates smoke from the roasting area via stove pipe (not pictured) connected the top of the hood;
2. Improved combustion chamber increases efficiency and significantly reduces fuel consumption;
3. Optimized roasting oven reduces emissions with injected primary and secondary air, and stove pipe baffle control;
4. Fully enclosed roasting drum enhances heat transfer and reduces roasting time;
5. Hinged door allows for easy drum and char removal;
6. 3-inch insulation on the sides, back, and bottom of the oven reduces the potential for burn injuries and reduces heat loss -- This will reduce the roasting time and increase efficiency;
7. Bicycle peddle drive eliminates neck, shoulder, back, and arm pain from uncomfortable roasting positions that are currently exercised;
8. Stainless steel grate, drum, and inner shell are durable and will meet the lifetime requirements established above;
9. A roaster oven is not fixed and can, therefore, be placed in any desired roasting location but will require adequate space for the stove pipe.

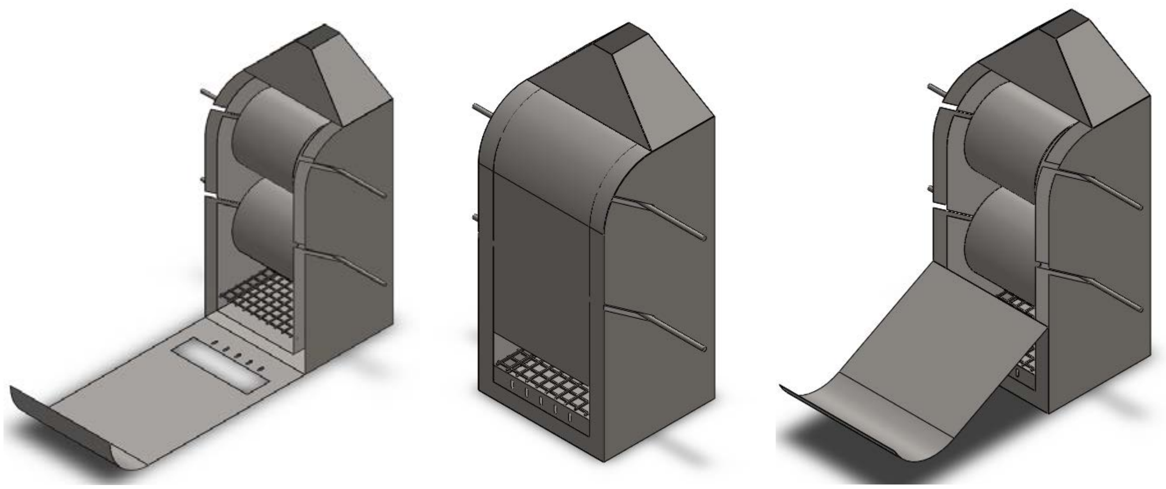
Potential issues with this design:

1. The length of the drum is the same as the current roasting drum, which could lead to issues with evenly heating the drum and the nuts inside;

2. Although mobile, the weight of the entire oven could be an issue if regular relocation is desired;
3. If stainless steel is too expensive, then the drum and inner shell would be made of mild steel, which would have negative durability implications;
4. The durability of the stove pipe could be an issue -- Temperature testing will give insights into this.

Table 3 above has initial parameter estimations for Options 1 and 2. The performance, usability, capacity, and emissions ratings are on a 1 to 5 scale with 1 being the worst and 5 being the best.

Option 3: Short Roasting Oven with Pre-Heating Rack



This is a more advanced roaster, designed with the intention of maximizing performance, and accomplishing all of the established goals of the project:

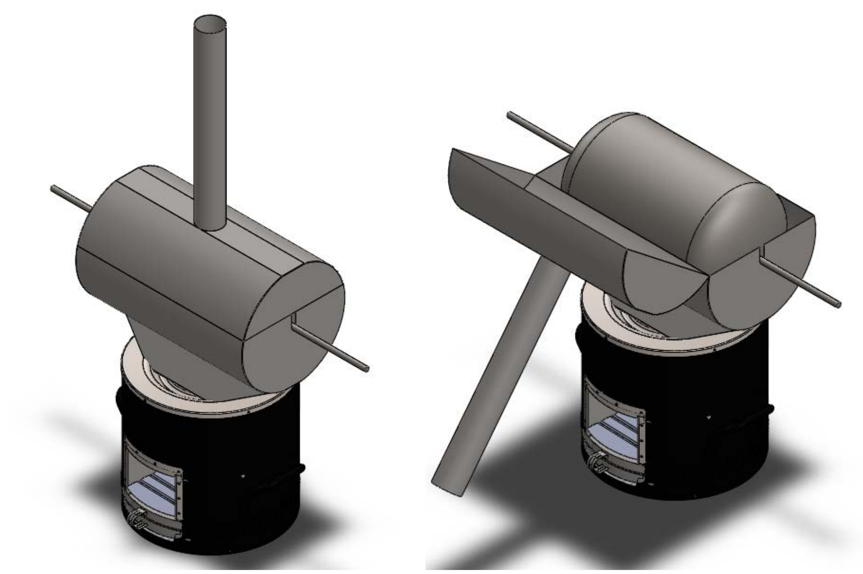
1. Eliminates smoke from the roasting area via stove pipe (not pictured);
2. Optimized combustion chamber increases efficiency and significantly reduces fuel consumption;
3. Optimized roasting oven reduces emissions with primary and secondary air injection, and stove pipe baffles control;
4. The overhead roasting drum rack allows for an upper drum to be pre-heated while the lower drum is rotated. When the lower drum has been roasted, the upper drum will be lowered down and rotated until roasting is complete. While in the upper rack, the drum will remain cool enough such that the nuts do not burn, but roasting time will be reduced once the drum is lowered to the bottom rack. This increase both efficiency and throughput by using heat that would otherwise be lost;
5. Fully enclosed roasting drum enhances heat transfer and reduces roasting time;
6. Hinged door allows for easy drum and char removal;

7. 3-inch insulation on the sides, back, and bottom of the oven reduces the potential for burn injuries and reduces heat loss -- This will also reduce the roasting time and increase efficiency;
8. Bicycle peddle drive (not pictured) eliminates neck, shoulder, back, and arm pain from uncomfortable roasting positions that are currently exercised;
9. Stainless steel grate, drum, and inner shell are durable and will meet the lifetime requirements established above;
10. A roaster oven is not fixed and can, therefore, be placed in any desired roasting location, but will require adequate space for stove pipe similar to Option 2;
11. To optimize mixing, the drum will be filled half way, but the throughput will not be negatively impacted due to decreased roasting time;

Potential issues with this design:

1. The cost of this design is estimated to be several times that of the current roaster design.
2. Although potentially movable, the weight of the entire oven would be an issue if regular relocation is desired;
3. If stainless is too expensive, then the drum and inner shell would be made of mild steel, and that would have negative durability implication;
4. The durability of the stove pipe could be an issue – Temperature testing will give insights into this.

Option 4: Rocket Stove Roaster



This design consists of a rocket stove positioned under an enclosed shea roasting drum. It addresses the following issues:

1. Stove pipe removes emissions from cooking area;
2. Optimized combustion chamber reduces fuel consumption and emissions;

3. Drum enclosure increases efficiency, and hinges allow for easy drum removal;
4. Insulated rocket stove increases roasting efficiency;
5. Stainless steel enclosure will meet the durability requirements of an improved roaster.

Potential issues with the design:

1. The flow dynamics around the drum are unknown, so testing will be necessary to ensure even heating of the kernels;
2. The rocket stove is large and will need to be tested for performance and emissions;

Table 2 below includes the initial parameter estimations for all four proposed options. The performance, usability, capacity, and emissions ratings are on a 1 to 5 scale with 1 being the worst and 5 being the best.

Table 2. Comparative Summary of Improved Roaster Options

	Option #1	Option #2	Option #3	Option #4
Cost	TBD	TBD	TBD	TBD
Weight	Heavy - Fixed	85 kg	100 kg	53 kg
Performance	2	3	4	3
Usability	4	5	5	5
Capacity	3	4	5	4
Greenhouse Gas Emissions	2	4	4	4
Average Score	2.75	4	4.5	4

These 4 options are all viable methods for improving the current roasting process. The clearances and specific dimensions will be optimized to maximize performance. Additionally, these designs will be modified and further improved upon as part of Phase 2 of the Shea roaster project.

It is important to note, that with any new technology, training of the users will be necessary to achieve the benefits of the design. In particular, proper filling of the roaster will be important to assure both target production rates and roasting quality.

Fuel option and their impact on roaster performance and emissions

A variety of fuels are used in the roasting of shea kernels. Wood, shea cake, and plastic are typically used as fuels. Wood was the primary fuel used, with species of Neem, Teak, and Mahogany commonly burned. Dawadawa and shea wood were sometimes used if the tree had fallen. Fuel scarcity is leading to the use of firewood from trees that should not be cut down as they contribute to livelihoods (mango, avocado, dawadawa, and shea trees) or their commercial value as wood for furniture surpasses their value as firewood (i.e. teak and mahogany). Shea cakes provide a viable solution to the fuel scarcity and a partial solution to the waste issue.

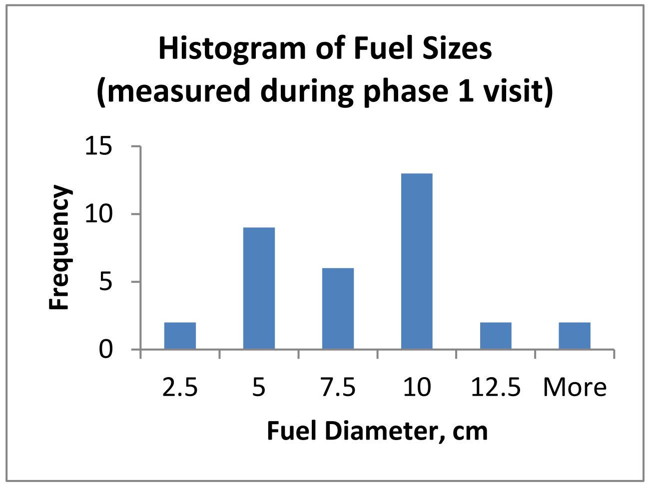


Figure 6. Histogram of measured wood diameter

BDL also measured fuel wood diameter and moisture content, as understanding the implications of potential fuels is essential when developing a new roaster. Larger diameter wood burns slower, and takes longer to light, while smaller diameter wood burns faster and lights readily. Larger wood takes much longer to dry and therefore could have higher moisture content when it is burned. Smaller wood will dry quickly and will burn more consistently. During Phase 1, the average wood diameter was 7.3 cm, and the average moisture content was 14.4% A histogram of wood diameter can be seen in Figure 6. The frequency is the number of fuel pieces of a given size in use during the Phase 1 visit. Shea cake was another fuel that was used in the shea production areas that BDL visited. In the final stage of shea butter production, the shea paste is boiled to emulsify the shea butter, and shea cake is left over from this process. The shea cake is spread out to dry in the sun and then used as fuel in the roasting process. The shea cake was measured to have the moisture of around 40%. In field tests that BDL conducted at SFC in Wechiau, an average of 4.5kg of shea cake was burned (with 4 kg of wood) in 50 minutes to roast approximately 39 kg of shea kernels.

Figure 7. Wood and Shea Cake burning under a roasting drum

The size of fuel to be burned puts limitations on new roaster designs. The combustion chamber must be designed for the appropriately sized fuel, and that can affect the combustion process significantly. For example, a large combustion chamber and opening are needed for larger diameter wood fuels, and therefore the amount of excess air introduced for combustion will be large, and difficult to control. Smaller diameter fuels allow for a smaller opening and more control over the combustion process. Designing a roaster to take smaller fuel has other implications. If a roaster can only fit smaller fuels, then the need to split wood would become necessary. This will impact either the cost paid for fuel or the time required to gather and prepare the fuel. It is important to explain the advantages of using small fuel from a combustion standpoint to ensure that an improved roaster is used correctly and effectively. Understanding the implications of different fuels is critical when considering the design and adoption of an improved shea roaster.

Preliminary assessment of local manufacturing capabilities

The manufacturing capabilities of several locations were evaluated by BDL during their trip to Ghana. The Ghana Regional Appropriate Technology Industrial Service (GRATIS) facilities were visited in Wa and Tamale, as well as some small craftsmen constructing the existing roaster design in Tamale. The GRATIS personnel in Wa were very friendly and eager to work with BDL. Their manufacturing capabilities included rolling, drill press, welding (No MIG or TIG welders), and hand shearing. They are unable to weld aluminum. They have a roaster drum that they manufacture and sell upon request (Figure 7). It is made from scratch and is not made from a water heater like the roasters at SFC. It is lighter in weight, and primarily welded construction. They also manufacture other mechanical products for processing shea, including electric grinders and kneaders. The GRATIS facility in Wa is a potential partner for prototyping and small-scale production of an improved roaster.

Figure 8. Roaster manufactured by GRATIS in Wa

The GRATIS facility in Tamale was visited as well. It was a much larger shop and had more machines that would allow for larger scale production. The Tamale facility had both a large mechanical shear and a five-ton press, both of which are not available at the Wa facility. The Tamale location also has a shea roaster drum that they manufacture and build from old water heaters. The design includes paddles, which are welded onto the rebar shaft inside of the drum. The paddles mix the kernels as the roaster rotates. Additionally, they had manufactured a roaster that rotates on an electric motor and heats the drum with gas. The GRATIS operation in Tamale has manufacturing capabilities that make them another viable option for local production of an improved roaster.

Project development timeline, including major milestones and tasks

Overall Development Plan & Cost

The project timeline includes five major steps for developing an improved roaster. A variety of tasks and objectives are contained within each of these major headings.

1. Conceptual Design

Conceptual design is the stage in which product parameters are established; market and user research is conducted; the roasting process is researched and understood; and baseline field testing is conducted. Concepts for improved roasters are generated during this time, and several of these concepts are modeled in Solid works to further develop them. This report contains a portion of the information for the conceptual design stage. This stage is expected to end around December 2017, at which point BDL will be well prepared for Preliminary Design phase.

2. Preliminary Design

At this stage, the product parameters are confirmed by all stakeholders of the project. The baseline roaster will be built for laboratory testing, as well as promising prototypes. Once these prototypes have been tested for performance and emissions data, and the results compared to those of the baseline roaster, the most successful prototypes will developed for field testing, durability testing, and user compatibility. The roaster prototypes will be placed in continuous operation and monitored for signs of corrosion and other potential shortcomings. Focus groups will be held to compare the prototypes with the baseline roaster and analyzed for each of their market potential. At the end of the preliminary design phase, a single roaster design will be selected to move forward to the detailed design stage.

3. Detailed Design

In the detailed design stage, the selected roaster design is prepared for manufacture. Durability testing continues, material selection is finalized, and tooling is designed and developed. A manufacturing process model is created, and any final risks are assessed. At the end of this stage, the design is evaluated for a beta run.

Table 3. Detailed Design Timeline

	2018											
Task Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Detailed Design												
Design for manufacturability to reduce cost, assure quality, &												
Continue Durability Testing in Field												
Finalize material selection												
Develop Part List												
Develop, analyze and document manufacturing process												
Conceive, design, & develop tooling												
Develop master manufacturing model including process flow												
Pilot Design												
Any remaining risks are idenfitied and addressed												
Any significant design changes will require new market, lab,												
Estimate BOM's, COG's, Equipment Req. & Capital Cost												
Identify and Vet Pilot Manufacturing and Assembly Partners												
GATE 3 Proceed to Beta Production Run?												

4. Pilot Production and Field Evaluation

Ten or more roasters will be manufactured and placed into continuous production at multiple roasting sites. The beta model will be field tested for performance and emissions data, and market research will be conducted on the beta model.

5. Final Design

The final design will update final details, both for the model and for the tooling based on the what was learned during the pilot run and field performance.
This five-stage product development process is expected to take less than two years, with the beta run beginning around in late 2018 or early 2019. These stages will include multiple trips to Ghana for field testing, user research, and market assessments.

Estimated Project Cost

The total estimated cost for development, including pilot (beta) production run and the basic manufacturing process design is $251,312. A breakdown of costs is shown in Table 11.

Conclusion

Burn Design Lab is approaching the completion of Phase 1, which looked at improving the shea roaster process, and is enthusiastic about the project's potential. Through Phase 1, BDL has learned about the extensive shea process and seen first-hand the need for an improved shea kernel roaster for smallholders. Roasting is both a health and environmental hazard. Improved combustion and stack ventilation will largely eliminate the health issue. With proper heat transfer and insulation, the purchased fuel can be reduced by more than 60%. BDL's understanding of the fuels currently used, along with its extensive knowledge of combustion principles has allowed for the conceptualization of improved roasters and building and testing them iteratively in its combustion and emissions laboratory. BDL is not new to developing improved combustion products and brings that experience to this project. Product parameters have been established, timelines created, and a development plan has been prepared. The current goal is to conduct a beta run in late 2018, with user and market research, iterative design, prototype construction, lab testing, and field testing taking place until then.

Appendix I: Complete Project Timeline