Design of a Rice Husk Gasification Cook Stove for Rural Nicaragua

by `small red tile`
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Executive Summary

Improving cooking technology in rural Nicaragua has the potential to lift significant economic and health burdens on the community. Currently, the population served by the NGO Amigos For Christ in Villa Catalina uses wood-fueled open fires for all their cooking needs, which produce dangerous levels of indoor air pollution and impose the need to travel far to collect wood. Women and young girls bear the brunt of these problems. The purpose of the design presented in this report is to address these challenges.

A few miles from the village, a rice milling plant produces tons of rice husk per day as a byproduct of the milling processing. This waste product was identified as a possible alternate fuel source. Currently, the supply of rice husks is free due to an agreement that Amigos for Christ has with the processing plant.

Existing rice husk stove designs have been found to be inadequate for this community. The design challenge is technical, cultural, and social. The stove must be able to be manufactured locally, with available materials and manufacturing techniques. The production of cooking heat from rice husk requires a carefully tuned aero-thermal-chemical process. Replacing the hearth in someone's home introduces a gamut of human-centered design aspects: cooking culture, the experience of meal preparation, and the language of technology in the home. Finally, all of this must be accomplished with a device that can be sold to those living on $1 per day.

The stove design described in this report is a rice husk gasification stove that provides usable cooking heat in 10-20 minute batches. The construction of the stove is one that features rounded sheet metal cylinders that are easy to make in Villa Catalina, as well as a cook top that allows pots to sit inside it, enabling greater heat transfer. The cooking surface is designed to accommodate existing pots and is capable of cooking the range of Nicaraguan dishes. The technology presented in this report was conceived, refined, and demonstrated through a series of functional prototypes.

Keywords: cookstove, Nicaragua, rice husk, gasification, appropriate technology

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Chapter 1

Introduction

Improving cooking technology in rural Nicaragua has the potential to lift significant economic and health burdens on the community. Currently, the population served by the NGO Amigos For Christ in Villa Catalina uses wood-fueled open fires for all their cooking needs. The exposure to indoor air pollution is responsible for over 40% of hospital visits in this community. Also, dwindling fuel supplies force families to travel farther and pay more to be able to cook. There is significant gender disparity with these problems: women and young girls bear the brunt of the hardships. The purpose of the design presented in this report is to address these challenges.

Because of smoke inhalation, women in Villa Catalina are more likely to contract chronic obstructive pulmonary disease, develop lung cancer, asthma, cataracts, and have miscarriages. [21] Some women are not fully aware of the health risks associated with exposure to smoke and other particulate emissions. However, all women using wood or other biomass for fuel understand the time required to collect fuel or the money that is needed to purchase fuel to cook. Many women can develop back problems from carrying wood over long distances and oftentimes girls that would otherwise be in school are required to collect fuel for the family. Unfortunately, some children even become disfigured when they fall into an open fire where someone is cooking. In addition to these setbacks, many people in Villa Catalina earn about $1 per day, which is below the poverty line of $1.25 per day as defined by the World Bank. [12] One week's supply of wood for many people in the community is roughly $5, which results in heavy financial strain for the people. Time, money, and health are all resources that traditional means of cooking in rural areas diminish.

A few miles from the village, a rice milling plant produces tons of rice husk per day as a byproduct of the milling processing. Currently, the rice husk are dumped haphazardly, sometimes even piling up on the side of roads. This waste product could be used as an alternate fuel source. Currently, the supply of rice husks is free due to an agreement that Amigos for Christ has with the processing plant. This would virtually negate all fuel costs, as the resource is abundant as well as close to the community. In the future, the supply and storage of rice husk could provide jobs for the people who live and work in Villa Catalina.

In an attempt to provide a solution to the people of Villa Catalina, the organization Amigos for Christ has tried to introduce two rice husk cook stoves into the community. The two rice husk stoves that have been tested for adoption by a number of families were both designed by Filipino professor and inventor Dr. Alexis Belonio. One was a top-lit up draft (TLUD) stove designed to operate in 30 minute batches that used a battery powered fan to provide air to the stove. The stove could be operated with minimal operator tending, but it required the community to have a supply of batteries, which was not possible to secure at a reasonable price. The other stove that was tried was a continuous-feed stove. The stove provided a large amount of heat, and was suitable for bringing water to a rapid boil, but was very low to the ground, within reach of children. Also, the flame required nearly constant tending to sustain the combustion reaction. These issues made the stove awkward to use, and was an insurmountable barrier to the adoption of the stove into the community.

The materials we use to make the stove will also have an important effect on how easy it is for Villa Catalina to adopt the technology into their community. It must be designed for easy assembly, such as with welding and other mechanical joining methods such as crimping. Ultimately, stove construction will be carried out by small local businesses.

The stove design described in this report is a rice husk gasification stove that provides usable cooking heat in 10-20 minute batches. The construction of the stove is one that features rounded sheet metal cylinders that are easy to make in Villa Catalina, as well as a cook top made of sheet metal that is cut and bent to allow the pot to sit inside it, enabling greater heat transfer. The cooking surface is designed to accommodate existing pots and is capable of cooking the range of Nicaraguan dishes. The technology presented in this report was conceived, refined, and demonstrated through a series of functional prototypes.

Chapter 2

Design Overview

2.1 Design Specifications

The development of appropriate specifications is key to the success of a complex design project. The first step of this process was to define the primary functions necessary for a cook stove in rural Nicaragua. Functions of a stove are defined in solution-neutral terms and aid in revealing the true nature of a design problem. The functions identified stem from research into existing cook stove technology, discussion with Amigos for Christ representatives that have worked in Nicaragua and experience the design team has had building and running their own gasification cook stoves. Figure 2.1 presents a final functional decomposition.

The function tree outlines what the stove must do as well as the constraints that exist on the solutions designed to meet those functions. One of the major constraints that affected the design of the stove was that the stove could not use electricity. The electrical infrastructure in Villa Catalina is very poor, and thus grid electricity is not a reliable resource. Also, a steady supply of batteries cannot be guaranteed, so the use of a battery-powered fan is also not viable for the design. This constraint led to the design of a natural draft stove that operates without the need for electricity.

A specifications list was derived from the above functional decomposition of the stove. The specifications define how the stove must perform the functions listed in the functional decomposition while subject to the list of constraints. As much as possible, each specification was quantified. This served two purposes: as a metric for success for the stove and as an unam-

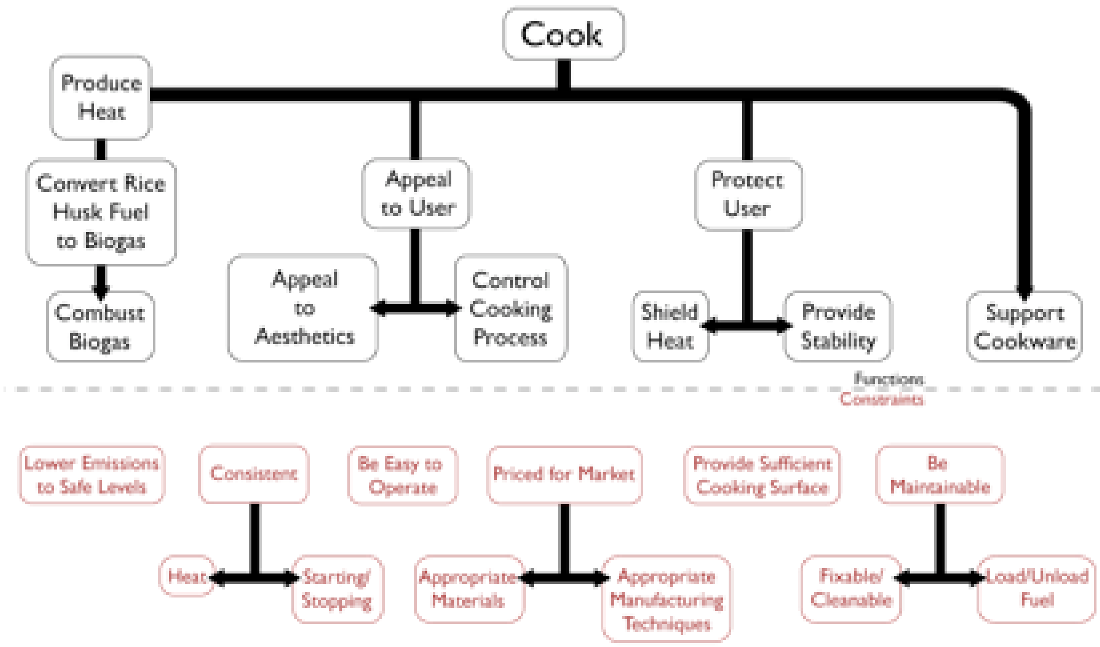

Figure 2.1: Function tree for an improved cook stove.

biguous statement of the design team's understanding. A specifications list is shown in Table 2.1 below.

Specifications are broken up into five subcategories–use locally available fuel, manufacturability and maintenance, turn fuel into heat, transfer heat to pot, and marketability. The first four subcategories describe how the stove must perform the physical aspects of cooking within the context of the Villa Catalina community. One specification that had a major affect on the design of the stove was the requirement that the stove must cost less than \$35. Many people in Villa Catalina must survive on an income of around \$1 per day, which greatly bounds the possible solutions for the stove to those that are not only made of easily obtainable materials, but also designs that are easy to manufacture for sheet metal workers in the community. This cost specification led to the design of a stove that features simple cylinders made of sheet metal and wire mesh. These materials are very inexpensive, and the required manufacturing method fits into the type of metalworking capabilities available in Villa Catalina.

The last subcategory of specifications, having a marketable cooking experience, is highly dependent on how people interact with and use the stove. One of the existing solutions, a continuous-feed quasi-gasifier stove designed by Alexis Belonio, is one that requires nearly constant tending in order to keep a steady flame. Women in Villa Catalina tested the stove and it was clear that the stove was difficult to use and therefore hard to market to other cooks. As such, the continuous-feed design is one that was an adequate cook stove in that it met all of the other four categories of specifications, but it proved inadequate for the community of Villa Catalina in that it did not have a marketable cooking experience. This realization precipitated a greater focus on the human factors of the cook stove use, emphasizing the importance of not only meeting technical requirements of turning fuel into heat, but also realizing the needs and wants of the people who ultimately use the stove.

Table 2.1: Design Specifications.

Requirement	Reason
Use Locally Available Fuel	
Use rice husks as fuel	Use locally available fuel
Easily Manufactured and Maintainable	
Use does not require grid electricity	Electricity is not available
Ability to support pot diameters from 9”-12”	Able to cook local dishes
Must weigh less than 20kg	Able to be transported and moved.
Made of stainless steel, rebar, and/or ceramics	Will not degrade due to rain. Also, able to be made from local materials.
Assembled using basic welding and metalworking/ceramic-making operations	Manufacturable in rural Nicaragua.
Cost $15 or less for user	Able to be marketed to rural poor.
Manufacturing operations requires less than 1 hour total	Able to support a micro-enterprise.
Turn Fuel into Heat	
Stove boils 2.5L of water in 12-15 minutes	Function similar to open fire.
Consume less than 10kg of rice husks per meal cooked	Able to be fueled by supply of rice husk.
Transfer Heat to Food	
Burner head must direct flue gases around sides of pot	Adequate heat transfer for function similar to open fire.
Marketable Cooking Experience	

Table 2.1 – Continued

Requirement	**Reason**
Tending of flame required at most once every ten minutes	Function similar to open fire.
Flame tending must take up a maximum of 10% of cooking time	Function similar to open fire.
Less than two hours of training required to acquire proficiency with stove operation	Able to be marketed by limited Amigos for Christ staff.
Fit adequately under Nicaraguan lean-to (<6' height)	Acceptable in home.
Cooking height of 30"-36"	Comfortable height for average Nicaraguan woman
Non-cooking surface either well-insulated or made from low thermal conductivity material	Users unlikely to be harmed during operation.
No exposed sharp edges or pinch points	Users unlikely to be harmed during operation.
User has no direct contact with flame during normal operation	Users unlikely to be harmed during operation.
Starting stove requires <2 minutes using paper or kindling.	Function similar to open fire.
Stove can be cleaned in less than ten minutes	Function similar to open fire.
Possible to see cooking flame during operation.	Users unlikely to be harmed during operation.
Stove costs less than $35	Affordable to local community

This specifications list reveals the multi-faceted nature of the problem. Interestingly, many of the specifications are not clearly within the territory of engineering or design. These specifications outline the functional requirements of the stove and are used later in the report to evaluate proposed concepts in the process of designing an appropriate stove for the Villa Catalina community.

2.2 Design Solution

2.2.1 Overview

The stove designed for the people of Villa Catalina is shown below in Figure 2.2. It is a natural draft top-lit updraft gasification stove that is designed to provide useful cooking heat in 20-minute batches. It features a gasifier reactor chamber consisting of a group of concentric cylinders, as well as a sheet metal cook top, a chimney, a stand, and a char catcher. The reactor chamber is where the rice husk fuel is gasified, and the flue gas produced from the combustion process flows up into the cook top where heat is transferred to the pot. A hole cut in the cook top allows room for the pot to rest inside the cook top chamber, forcing hot flue gases around the pot and enhancing heat transfer.

A chimney located on the side of the cook top provides the necessary pressure difference to pull flue gases up through the cook top and out of the way of the cook. The stovetop rests on a four-legged stand that provides a stable cooking area for the cook. The cooking space of the stove is at a height of 34 inches, and the stovetop can be cut in Nicaragua for a variety of different pot sizes. A char catcher located at the bottom of the stove is used to hold char while the stove is in operation, and to dispose of char when the catcher is full. The stove is made primarily of sheet metal either rounded into cylinders, or cut and bent to form the cook top.

As mentioned before, the stove is designed to produce usable cooking heat for a duration of 20 minutes per load. Beans, which are cooked nearly every day in households in Villa Catalina, need only to be stirred once every several minutes to cook evenly. The stove is designed to only need to be reloaded as often as the cook would normally spend at the stove. This allows the cook to go perform other tasks and return to both stir beans and tend the stove. Seven families in Villa Catalina tested Alexis Belonios continuous-feed rice husk stove. It was reported that the cooks preferred rice husk stoves, but that the tending that the stove required to keep a consistent flame was deemed undesirable by cooks, and thus hard to market to others in the community. The 20 minute tending intervals that the natural draft stove requires are an

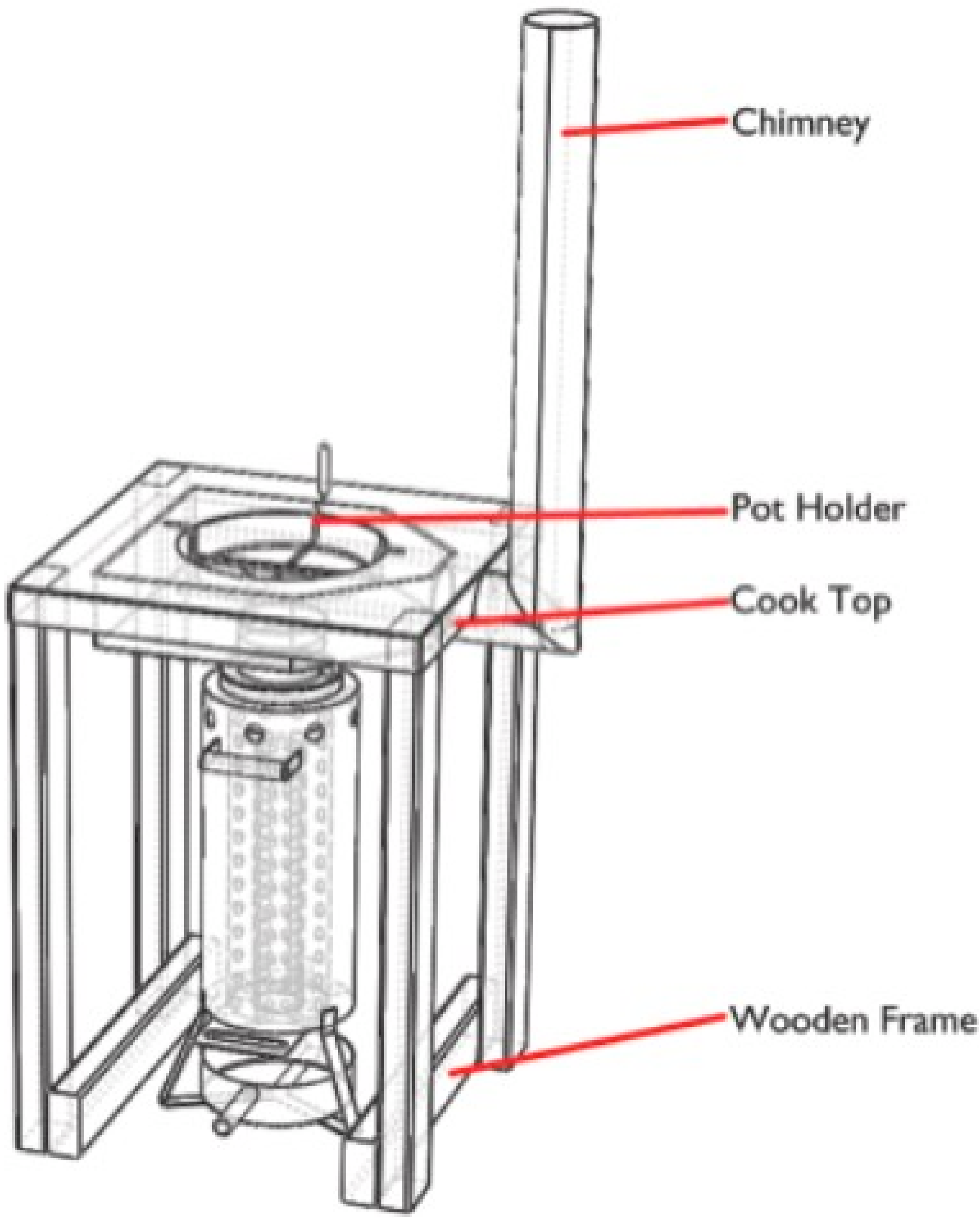

Figure 2.2: Overview of final stove with cooktop.

improvement over the nearly constant effort needed to tend the continuous-feed design.

2.2.2 Airflow

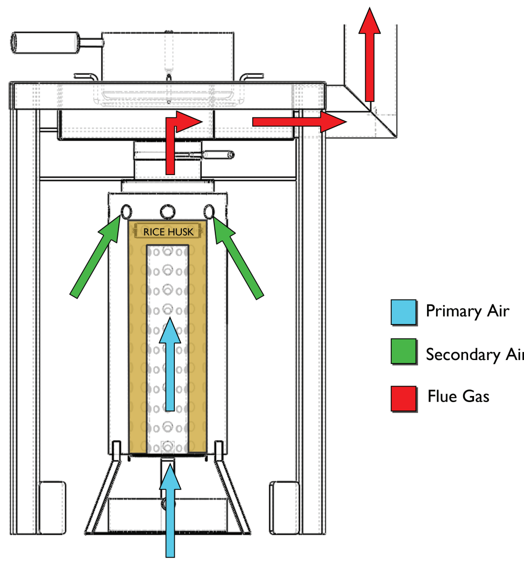

Figure 2.3: Schematic of airflow in reactor.

For continued pyrolysis enough oxygen to maintain combustion of rice husks in the stove must always be present. Due to the natural packing of rice husks the air required to continue pyrolysis is difficult to force through a column of rice husks. The top lit up draft design that was selected uses a chimney to create the pressure drop needed to drive airflow through the column of fuel. However, the draft provided by the chimney is not enough to sustain the gasification process. In order to provide extra inlet holes for adequate oxygen to reach the rice husks the inner fuel cylinder was perforated. Even with the increased area of rice husks exposed the oxygen necessary to fuel pyrolysis was still not getting through the column of rice husks. Hence, a perforated inner cylinder was implemented inside the fuel chamber to create a ring of rice husks that would effectively reduce the layer of fuel air must travel through. Therefore, to generate significant airflow through the fuel chamber of the stove the primary air enters from the bottom into the inner bypass, then because there is a charred layer of rice husks or a cap to block the vertical pathway of the bypass the air travels through the ring of rice husks fueling pyrolysis layer. As the air passes through the ring of rice husks they char and the combustible gas exits the ring of fuel and recombines with secondary air via holes at the top of the outer cylinder and combusts at concentrator lid at the top of the stove. This ring of rice husk allows for the stove to be sized for any height because the thickness of the ring of fuel is what specifies the chimney height or perforation pattern.

2.2.3 Production of Heat

Two configurations can be used to start the stove. The first uses a top layer of rice husk and a inner bypass that has a mesh cap. In this configuration the power output varies as the cross-sectional area changes when the ring around the side begins to gasify. The second configuration uses only the ring of fuel and because the top layer of rice husks is not necessary for the operation of the stove. The ring of pyrolysis during steady state operation is usually preferred for a more consistent operation. The power output is dependent on the cross-sectional area of the rice husks gasifying because that is where the combustible gases are being produced for burning at the top of the stove. This ring is designed so that the radial distance between the inner bypass and the fuel chamber must be around 1.5” to provide necessary power to continue operation and allow airflow from center bypass through fuel ring.

2.2.4 Heat Transfer

It is not enough to produce clean heat, but it must be implemented in a way to use the heat to cook typical Nicaragua meals. This is done through convective heat transfer from the hot flue gases to the pot supported in the cooktop before exiting the chimney. The gases leaving the stove reactor enter the cooktop and swirl around the pot to aid in convective heat transfer. The cooktop is design so that the box containing the hot flue gases is in the middle of the cooktop to prevent the user from burning themselves from the conduction of heat to the metal top. A similar method is used with the outer cylinder on the stove reactor to prevent the user from touching metal that comes in direct contact with the flame inside the stove. A handle is also used on the outer cylinder to allow removal and emptying of the stove immediately after operation without the use of protective gear.

2.2.5 User Experience

Figure 2.4: Mockup of user experience.

The existing rice husk gasification stove used in Nicaragua requires constant tending from the user and has not been adopted largely because of the inconvenience of the operation. This stove design allows for continuous operation for 20 to 25 minutes without any tending from the user while cooking. The stove only requires minimal tending between each batch due to the char removal system. After a batch of fuel has been gasified the user can simply slide the char door out and the char falls into the char collector for disposal without the stove being lifted or rotated. The concentrator lid can then be removed and the fuel reloaded from the top after the char door is replaced. The char removal system minimizes the time dumping char as well as the number of times the user has to bend over to operate the stove. The cooktop and chimney were also deigned to interface with a rural Nicaraguan family. The cooktop was set to a height of 34" to be comfortable for the average woman cooking in Nicaragua of height 5' to 5'2". The chimney has an exit height of 5'10" from the ground, which is taller than the average Nicaraguan woman to ensure the exit gases are above the user.

2.2.6 Structure

Safety and convenience were both incorporated into the overall structure of the stove and cooktop system. A wood or cinder block frame is used to support the cooktop so the stove reactor can be emptied and refilled without moving the food being cooked. This configuration allows for the user to eventually acquire another stove reactor and minimize time between cooking intervals. The cooktop also provides the necessary connection for the chimney on the side to ensure the outlet gases from the chimney exits above the user's breathing space. The pot rest inside the cooktop allows for the cooking pot to be supported and in contact with the hot flue gas without closing of the entrance of the hot gases to the cooktop. Since the stove reactor is separate from the cooktop, a coupler is employed to connect and divert the gases from the reactor of the stove to the cooktop. This coupler is adjustable to accommodate for easy connection and quick removal of the stove reactor during filling or emptying. The outer cylinder of the stove connects directly to the base and the fuel chamber and inner bypass both connect to the outer cylinder to provide stability and eliminate eccentricity with the cylinders inside the stove. The char release door at the bottom of the stove supports the rice husks during operation and after the fuel has completely gasified then the door slides toward the user and the char empties into the char collector. This enables the user to remove the char from their stove without lifting or dumping the entire stove over. The base that supports the cylinders of the reactor has three legs to provide reasonable clearance for the char collector underneath.

Chapter 3

Precedent Review

There has been interest in improved cook stove design for over 50 years, though the need for cooking heat is as old as mankind. Cooking technology has improved as the understanding of the physical processes governing heat transfer and combustion were better understood. In this section the technologies currently capable of turning rice husk into cooking heat are considered. A detail listing of existing products in presented in Appendix A.

Not many technologies have been patented for the type of micro-application of gasification of solid fuel. One in particular is relevant, however. Tom Reed patented the gasification process that powers TLUD cookstoves. [18] This patent does not appear to be a significant roadblock to cook stove projects since Reed actively promotes the development of technologies based on his work.

The first major technology able to turn rice husk into heat was direct combustion. Rice husk would be loaded into a chamber with a stick inserted in the middle. The stick would be removed when the stove was full, and the bottom lit. [14] This process is difficult to control and can result in significant release of smoke. Some research efforts have been undertaken to improve this process. [13]

Besides direct combustion, it is also possible to burn rice husks with gasification. If the syn-gas produced by pyrolysis is burned immediately, the process is termed quasi-gasification. A number of stoves have been developed using this concept, notably by Dr. Alexis Belonio of the Philippines. [7] Stoves based on quasi-gasification have the disadvantage that they require tending every few minutes.

Gasification is possible with rice husk using forced air (i.e. by pushing air through the bed of rice husk using a small fan or blower). There are a range of such stoves currently being developed. Some include novel features such as thermo-electric generators to power their fan. [11] Stove of this sort suffer from the deficiency that fans and electric components are difficult to source in many developing nations. Furthermore, they are much harder to maintain by populations without easy access to electronic components.

Through research of existing designs, it was found that the niche for natural draft rice husk stoves had not been adequately filled. That is, there does not yet exist a stove that is (a) able to be made with local materials, (b) as easy to use as cooking over an open fire, and (c) inexpensive enough for customers living on a few dollars a day.

This project has generated a novel stove design. The stove uses both a chimney and inner perforated cylinder to overcome the resistance to air flow caused by the tight packing of rice husk grains. This stove is capable of running in natural draft mode for without tending for over 20 minutes. There are many low-income communities around the world with access to waste rice husks, and this stove would be an ideal candidate for their cooking needs.

Chapter 4

Design Details

So far, a design solution to the cooking needs of rural Nicaraguans has been presented. In particular, ergonomic and interaction requirements have been shown to have been met. The detailed aspects of the stove's thermodynamic performance and overall life cycle will be presented in this section. Also, results from testing will show the current achieved performance of the stove.

4.1 Thermodynamic Performance

The performance of a stove in converting the energy stored in fuel to usable cooking heat dictates whether it meets many of its design specifications. Thermodynamic performance can be broken down into four major categories:

- Amount of fuel used
- Amount of heat produced
- Amount of heat transferred to pot
- Amount of run time

The theoretical performance in each of these categories will be considered. Since the refinement of the design proved to be out of scope of the timeline for the project, comparison to similar devices will be made in order to show the practical expectations for stove performance. Finally, where available, test results with prototypes will be used.

4.1.1 Fuel Use

The major advantage of using rice husk as a fuel is that it is available in large quantities for no cost (except transportation). Rice paddy produces about 20% of its weight in rice husk after this milling process. The Gemina rice and flour mill complex in Chinandega, Nicaragua produced 18,000 tonne/year of husk in 2002, and was projected to increase production to 25,000 tonne/year in 2003. [20] The 2003 production amount results in 13 tonne of rice husk available per day.

The energy needed for cooking can be calculated using the procedure presented in the Rice Husk Gasifier Handbook. [8] The energy required to cook common foods is presented in Table 4.1. For cooking a meal, the fuel consumption rate can be calculated using the following two relations.

$$Q_n = \frac{M_f E_s}{T} \tag{4.1}$$

where Q_n is the energy need in Kcal/hr, M_f is the mass of food in kg, E_s is the specific energy in KCal/kg, and T is the cook time in hr.

$$FCR = \frac{Q_n}{HV_f \xi_g} \tag{4.2}$$

where FCR is the fuel consumption rate (kg/hr), Q_n is the heat energy needed (Kcal/hr), HV_f is the heating value of fuel (Kcal/kg), and ξ_g is the stove efficiency. Using Equations 4.1 and 4.2, the fuel consumption rate for cooking rice for an hour can be found. To cook a kilogram of rice in 15 minutes, 317.2 Kcal/hr of energy would be needed. An hour's worth of such cooking on a stove with a 17% efficiency would result in 0.62 kg of rice husk used per hour.

Table 4.1: Energy content of common foods.

Food	Specific Heat (Kcal/kg-°C)	Total Energy Needed (Kcal/kg)
Rice	0.42-0.44	79.3
Meat	0.48-0.93	56.5
Vegetables	0.93	74.5
Water	1.0	72

The quantity of fuel available may be limited by logistical challenges. The rice husk must be transported by pick-up or flat-bed truck to the villages served by Amigos for Christ. Since rice husk is not a dense fuel, it may be difficult to transport it in adequate quantities. Initial planning by the sponsoring organization suggests that about one fifty pound bag (22.7 kg) will be available per family per week. This results in about 36 hours of cook time available per family per week.

The previous calculation shows a lower bound on performance of a rice husk gasification cook stove. Natural draft gasification cook stoves have reported efficiencies around 25-35%. [10] Once the challenges of tuning the draft to support gasification are overcome, the stove should achieve these reported efficiencies.

4.1.2 Amount of Heat Produced

The power output of a gasification cook stove depends on the cross-sectional area of the reactor. In the design presented in this report, that area is the area of the circular inner cylinder. Using the previously calculated requirement for Fuel Consumption Rate (FCR), the minimum diameter of the stove can be found using the Specific Gasification Rate (SGR) with the relation in Equation 4.3.

$$D = \left(\frac{1.27FCR}{SGR}\right)^{0.5} \tag{4.3}$$

For a specific gasification rate of 150 kg/m^2-hr and an FCR of 2 kg/hr, the minimum diameter is 13 cm. Therefore, the required area is 133 cm^2. The stove presented in this report has an annular reactor rather than a circular one. The smallest area considered for a working design had an innermost cylinder of 3 in (7.62 cm) and an inner cylinder of 6 in (15.24 cm). The resulting area is 131 cm^2. The 1% difference between these power outputs would result in only a few more seconds of cook time necessary.

Current trials of the stove design can consistently combust a 4 in layer of rice husk in 6-12 minutes. Results from one such test are shown in Figure 4.1. The mass of rice husk burned, assuming a bulk density of 100 kg/m^3, is 0.24 kg. Therefore, the resulting fuel consumption rate is 1.18 kg/hr. Dr. Belonio provides an FCR of 0.62 kg/hr as adequate for cooking in his handbook. This suggests that the stove performance observed is actually overpowered

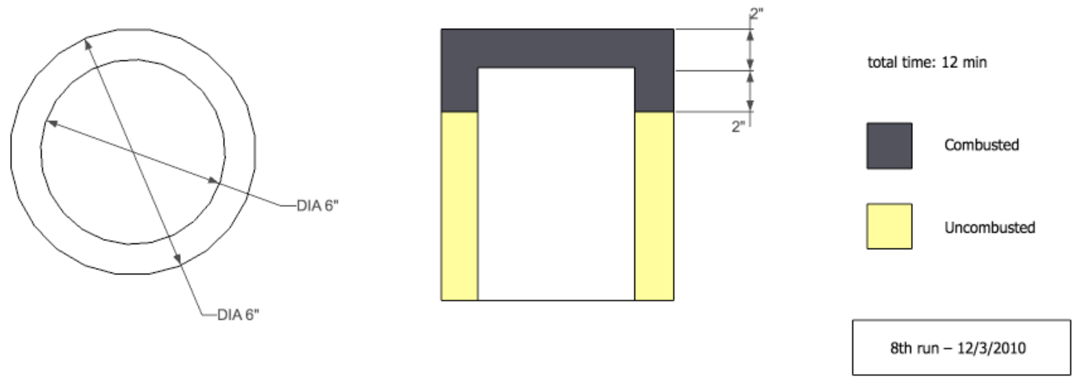

Figure 4.1: Test result from 8th run on 12/3

for cooking needs. It will be possible to turn down the power of the stove by either limiting primary air supply or reducing the cross-sectional area that is gasified. These preliminary results are encouraging since it is easier to scale back power than to try and increase it.

4.1.3 Amount of Heat Transferred to Pot

Optimizing the transfer of heat to pots in improved cook stoves was considered in detail in 1987. [6] Significant improvements in the energy efficiency of cook stove can be achieved by appropriately designing the interface between the stove and the pot (or skillet) that does cooking.

The current state of the art in design for heat transfer to pots suggests accessories to direct the flow of hot flue gas around the sides of the cooking vessel. These are very easily built from scrap metal or mud-based ceramics. There are a number of guides published for the design of such accessories. [19]

The light, modular design of the cook stove presented in this report allows the use of all current skirt and cook top designs. One very popular design in South American countries, the Dona Justa Stove, is applicable to the Nicaragua community. Readers are referred to p. 21 of [19] for details.

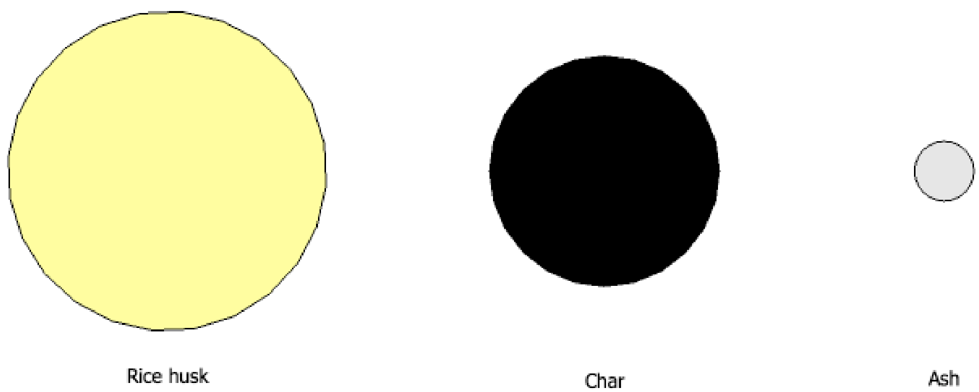

Figure 4.2: Diagram of volume change of rice husk undergoing combustion

4.1.4 Amount of Run Time

The specification for run time of a successful cook stove is 10 minutes. With such a run time, it should not burden users who must be around the stove at least that often in order to prepare food. Current tests achieve this amount of run time burning only a 4 in layer of rice husk. With a 24 in column of fuel, run time could therefore be as high as an hour unattended.

This amount of run time is not consistent the previous calculations for specific gasification rate. This prompted exploration into where the extra energy powering this performance arose. It was found that there are two separate processes from which energy can be extracted. The first is gasification. The second is char gasification. Figure 4.2 shows the volume change of rice husk as it undergoes each of these processes.

The extra energy from char gasification allows the stove to run for longer. This was an unexpected aspect of the design. It remains a promising avenue for further development since the observed emissions from this process are smoke-free.

4.2 Device Life Cycle

Appropriate technology pays particular attention to the impact of design at every stage of a device's life: from material selection and fabrication all the way to eventual disposal or recycling. The bill of materials, production, installation, maintenance, and environmental impacts of the design will be presented in detail in order to show that the proposed design has a sustainable life cycle.

The Bill of Materials (BOM) for a two-pot stove is presented in Table 4.2. There are a number of possible options for the final form of the stove and cook top assembly; so, the one shown is made of components that have been verified as available by contacts in Nicaragua. As shown, there are not many materials required at all since the stove was designed to be simple to construct. Furthermore, pilot projects with other stove designs that use similar materials have shown that it is possible to manufacture devices at a reasonable cost.

Table 4.2: Bill of Materials

Component	Quantity	Unit Price	Total Amount
Sheet Metal	3ft x 4ft sheet	$45.80 for 3ft x 4ft sheet	$45.80
Cinder Block	8 blocks	$0.50	$4.00

According to the Bill of Materials, the stove will cost almost $50.00 to produce. It is possible to reduce this cost by substituting the sheet metal used in various components for found material or wire mesh. The price of these substitutes has not been investigated since their availability is uncertain. It is also possible to replace components of the cook top with earth-based ceramics, reducing the cost to almost nil.

The production of cook stoves will take place at the Amigos for Christ compound. There, sheet metal workers have an array of common metalworking tools (drills, rollers, shears) as well as a MIG welder. The materials will all be sourced locally, made into stoves, then driven the short distance (∼5 miles) to communities that desire the technology.

The design team undertook the manufacturing of several prototypes of the final design. It was found that the stove could be manufactured with only tools available in rural Nicaragua. In fact, it was sometimes a challenge to find the simple tools needed (such as a sheet metal roller) because it is less common in the United States to need to do such basic metal work. A full list of the instructions for manufacturing are attached to the end of the report as a standalone manual. The sponsors of the project aim to deploy stoves to about 160 families in total. It took our inexperienced team about 7 hours to manufacture a single stove from half-finished designs. An efficient team of experienced metal workers, therefore, could produce at least a few stoves a day. At a rate of 3 stoves per day, all 160 families could receive stoves in fewer than 2 months (assuming manufacturing is the primary bottleneck).

Installation of the stove is almost trivial. It is able to be used inside as well as outside since it burns with low smoke. The chimney height is short enough that homes will not need to have a hole cut in the roof. Furthermore, the stove is light enough to be easily moved. The stove can be delivered fully assembled.

A number of simple operations must be done to maintain the stove. The chimney will have to be occasionally cleaned. Char and ash must be cleared from the stove each time that it is used. The life span of gasification cook stoves has been reported to be around 3 years. [8] The design of this stove is modular. So, as components wear out, they can be replaced individually. This reduces the amount of total waste over the life cycle of the product.

The cook stove presented in this report requires a small quantity of sheet metal and is fueled by a waste agriculture material. Its only byproduct is rice husk char, which can be mixed with soil to improve its fertility. It eliminates the need for wood as a cooking fuel. For a meal consisting of just 1 kg of rice, the stoves saves about 160 g of fuel wood. [6] Over the course of a year, a single family will save at least 293 kg of wood.

4.3 Test Results

A number of prototypes capable of producing a flame from rice husk were achieved over the course of the design project. The aspects that were tested during the prototyping performance were the reliability of stove function (i.e. how often it would run for a full 10 minutes), achievable run time, and temperature profile over the course of operation. There are many more tests that could be done, but these initial results help guide the selection of promising configurations for further refinement and reveal the sensitive parameters affecting stove performance.

The initial proof of concept prototype was capable of turning rice husk into a steady flame for cooking. This prototype, however, was only reliable about 15% of the time. Over the course of three weeks, various configurations were tried in a modular testing apparatus to try to achieve better reliability. The results of this three week process are presented in Figure 4.3.

After three weeks, enough was known about stove characteristics that

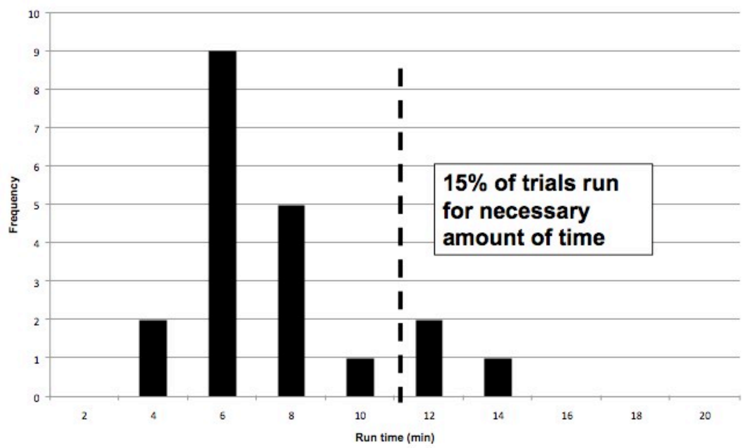

Figure 4.3: Stove run times over a three week prototyping process

its operation could be tuned deliberately. On 12/6/2010, a systematic run through the worst known configurations to the best known configurations was undertaken. The results of this test is shown in Figure 4.4. Briefly, the design features that drastically improved performance were the following:

- Diameter of inner bypass >= 4" (for chimney of 4")
- Highly perforated inner bypass and inner cylinder
- Difference in diameter between inner bypass and inner cylinder of at least 3"

The test results showed that a combination of all of the known techniques for improving performance resulted in a stove that could run for over 20 minutes. This configuration was then run with the cooktop attached and the outlet temperature of the chimney was measured every 30 seconds for the duration of its operation (24 minutes). The resulting temperature profile is shown in Figure 4.5. There were two significant results from this test. First, the power output was high enough during the entire operation to supply heat for boiling water. Second, at minute 17, a dramatic spike in temperature shows the operation going out of control. This was observed in more than one test, and is likely the result of the pyrolysis layer increasing in volume over the course of the stove operation until it reaches a critical tipping point.

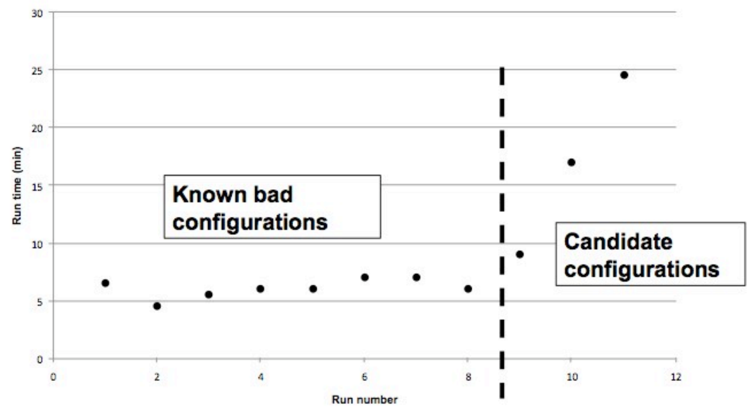

Figure 4.4: Configuration tests on 12/6/2010

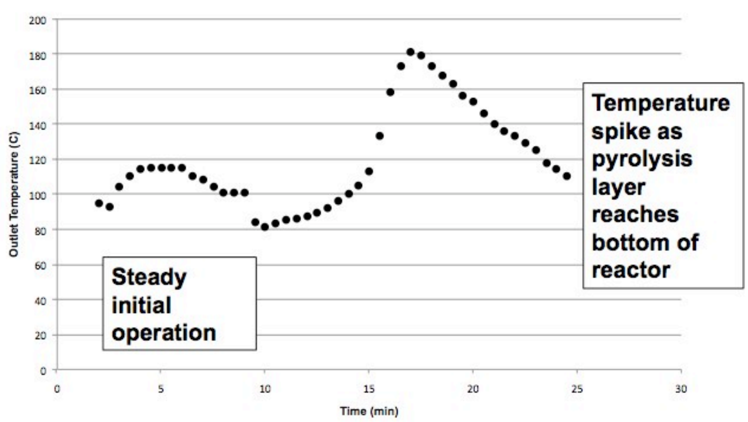

Figure 4.5: Outlet temperature profile of best known stove configuration

Chapter 5

Realization and Deployment

The stove has reached a stage where two techniques can be used to further the stoves progress toward a final design.

Several aspects of the stove are understood enough to deploy 1 to 2 prototypes in Nicaragua and have the members of Amigos for Christ demonstrate the stove operation and let the women cook over the stove and get their reaction. Data collection on the stove and how the people accept it would be valuable knowledge to have while the stove is still flexible and does not have the rigidity of a final design. Different marketing techniques could be discovered and a better understanding of why a Nicaraguan women would want the stove is valuable information even if from only one or two families. The stove is not ready for independent adoption by a family because the design is not finalized enough to trust an untrained person with the stove design. The design that could be used in this 1 to 2 family pilot in Nicaragua is possible because several integral principles for operation are understood. The basic structure and heat application through the cooktop is ready for deployment and the 20 minutes untended operation allow for ease of use. There is enough airflow in the current configuration to gasify a ring of rice husks between two cylinders radially separated by 1.5". This is due to using a chimney of two to three feet. This chimney diameter must be smaller than the diameter of the inner bypass to induce a nozzling effect inside the reactor. Perforated cylinder or wire mesh provide enough air on the sides of the ring of rice husks to continue gasification. Secondary air for combustion is provided by either an opening at the bottom or top of the outer cylinder. With a few basic principles a working gasification stove can be made in Nicaragua. Difficulties may arise in the consistency of the flame during operation and potentially the flame becoming unstable if the air is not controlled. Sometimes tests require the chimney to be removed in order to reduce the air through the reactor and this is why a representative for Amigos for Christ should be present to monitor the operation of the stove. Local fabrication difficulties as well as initial feedback from end users of the product would be very valuable at this stage in the process.

The other technique to further refine the design is effectively controlling the airflow in the stove through further testing here. The challenge with gasifying rice husks is the difficulty of bringing air through the column of rice husks to feed initial combustion. This design has met and exceeded the necessary airflow inside the stove and as a result can vary in power output during operation. The current stove configuration tends to go unstable and uncontrollable after 10 minutes of operation. During this time a significant amount of ash is produced along with char. The opportunity to design the stove to reduce airflow during operation by progressively making the holes on the fuel chamber smaller from the top to the bottom of the stove. Trials have been conducted using cinder blocks to reduce primary air intake and a reduction in power as well as stabilization of the flame has been noticed. The secondary air holes can also be reduced to a flap or damper to control secondary airflow as well. After initial testing results, the geometry will attempt to intrinsically control the airflow through the system to minimize the required input from the user during operation. If the reactor can control the air effectively then the stove will be ready for a larger pilot project of 10 to 12 families who would own the stove and provide feedback to implement in further design iterations. After this iteration, the stove should be ready not only for use in Nicaragua, but all further refinement should be done in the location of deployment. Other design considerations are the potential for increasing power output for a two burner system as well as minimizing materials used in stove.

Chapter 6

Conclusion

A new cooking technology for developing countries has been successfully demonstrated by this design project. This device can be manufactured exclusively from local materials with human-powered manufacturing techniques. The requirements for adoption by users used to cooking over an open fire were found to be possible to achieve. Working prototypes verified many of the designed parameters.

There are refinements to be made to turn the initial invention discovered by this project into a real product. First, the performance has still not achieved adequate levels of reliability, though that milestone is fast approaching. Material selection in rural Nicaragua will need to be considered in more detail by Amigos for Christ staff in order to reduce cost. Finally, pilot projects to gauge user reaction to the technology will need to be undertaken.

This technology is significant because it fills a market niche that was previously completely empty. This positions it not only as a humanitarian contribution for its health impacts but also as a potentially sustainable business for Nicaraguan locals.

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Appendix A

Existing cook stove technologies

The following sections describe, in detail, a number of specific cook stove technologies that are related to the use of rice husk for cooking application.

Bottom-lit Direct Combustion [1] [3] [13] [14]

Direct combustion of fuel made up of small particles is possible by packing the fuel around a central air column then lighting it from the bottom. Such stoves were used to burn sawdust in WWII. A number of improved stoves based on this principle were reported as early as 1981. Depending on the supply of air in the stoves, it has been reported that it is also possible to achieve gasification.

Work has been done by the Kisangani Smith Group to build stoves for sawdust. Their work qualified for an Ashden Award for Sustainability in 2008. Modeling and experimental work was also undertaken at the Bapuji Institute of Engineering and Technology for stoves using small pulverized fuel, ultimately resulting in stove designs that were claimed to be suitable for cooking. Neither of these two efforts, however, applied the technology to the burning of rice husk.

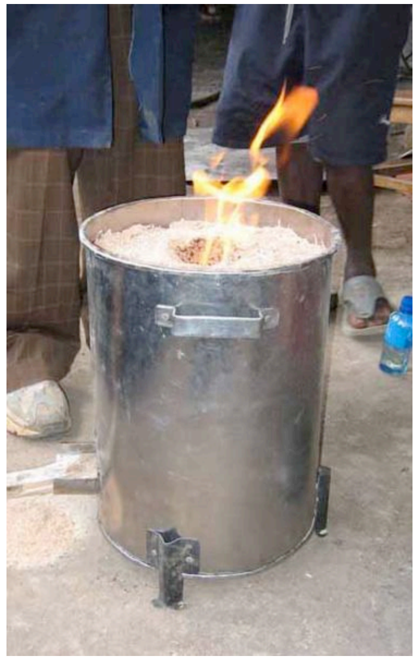


Figure A.1: The sawdust stove produced by the Kisangani Smith Group.

San San Continuous Stove [10]

The San San Continuous Stove was developed in Myanmar by the San San Industrial Cooperative. U. Tun Win is responsible for the design. It is capable of burning rice husk with gasification. It is similar to A.T. Belonio's Conical Grate stove; however, it appears to be able to run for longer without tending than the continuous design.

The stove is referenced in a number of internet publications, but the site is no longer online. There do not appear to be any detailed reports online. Therefore, not much is known about its emissions or efficiency.

Conical Grate Stove [7]

The conical grate stove was developed by Dr. Alexis Belonio at the Appropriate Technology Center of Central Philippine University. It is designed specifically for rice husk as a fuel. It operates by quasi-gasification: pyrolysis gas is immediately mixed with secondary air to produce a flame. Since it

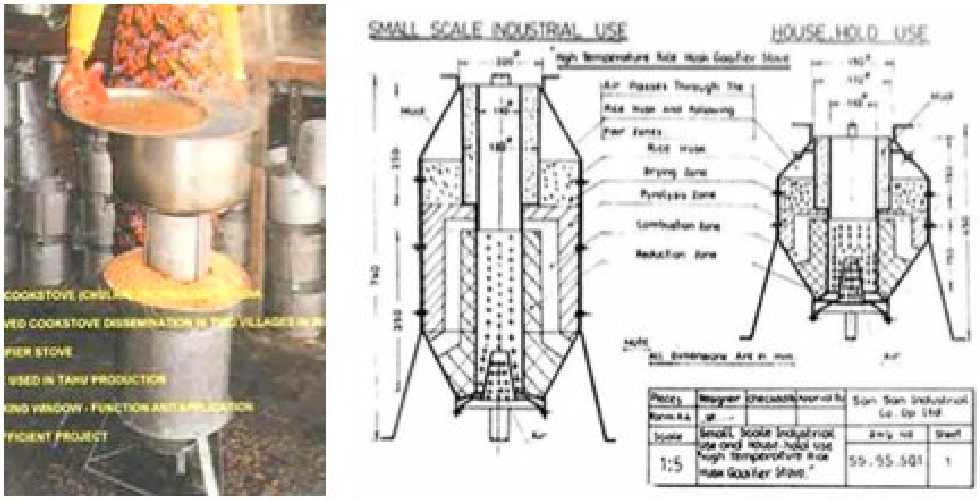


Figure A.2: The San San Continuous Stove developed in Myanmar.

does not completely combust the rice husk, it produces char as a byproduct. The flame is virtually smoke free.

The stove must be tended every few minutes to knock char from the bottom grate into the char pan. It is possible to construct this stove entirely from sheet metal and metal wire.

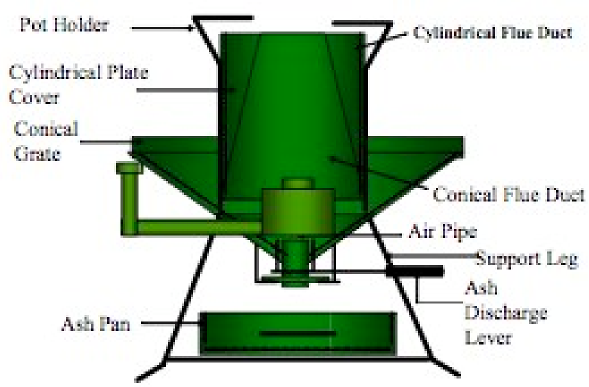


Figure A.3: The conical grate stove developed by Alexis Belonio.

Belonio Rice Husk Gas Stove [2] [8]

The rice husk gas stove was developed in the Philippines by Dr. Alexis T. Belonio. It operates on the principle of gasification. A fan at the bottom of the reactor supplies primary air for the gasification reaction. The produced gas is forced through the bed of char, which results in a blue flame when it is mixed with secondary air. It is capable of running for at least 30 minutes unattended.

The relatively simple design makes the stove easy to manufacture. However, it requires a fan with appropriate power to force air through the column of rice husk. This fan requires battery power, as well. One advantage of using forced air is that the power of the stove can be adjusted during operation by turning down the primary air.

The stove is extensively documented. It was also awarded the 2008 Rolex Award for Enterprise.

Reed/Anderson TLUD Stove [4] [5]

Micro-gasification in a Top-Lit Updraft (TLUD) stove was independently discovered by both Paal Wendelbo and Tom Reed around 1985. These gasification stoves work both by natural draft and with forced air. They are capable of burning many different fuel types. The key design features are pre-heated secondary air, a concentrator lid, and modular construction.

Details on operating principles and current design efforts were presented in 2007. The emissions on TLUD stoves are very low.

A natural draft version has not yet been developed for rice husk fuel because of the resistance of the packed particles in the fuel bed.

Holey Roket Stove [17]

The Holey Roket stove was designed by Master's student Rob Oblak in partnership with the Legacy Foundation, an Oregon-based alternative fuel promoter. The focus of this stove is in the burning of briquettes of various sizes. The work shows the flexibility of rocket-type stove designs. In particular, the author demonstrates stoves made from ceramic, metal, and scrap materials.

Briquettes can be formed from many biomass materials given an appropriate binder material. Simple human-powered mechanical presses can be

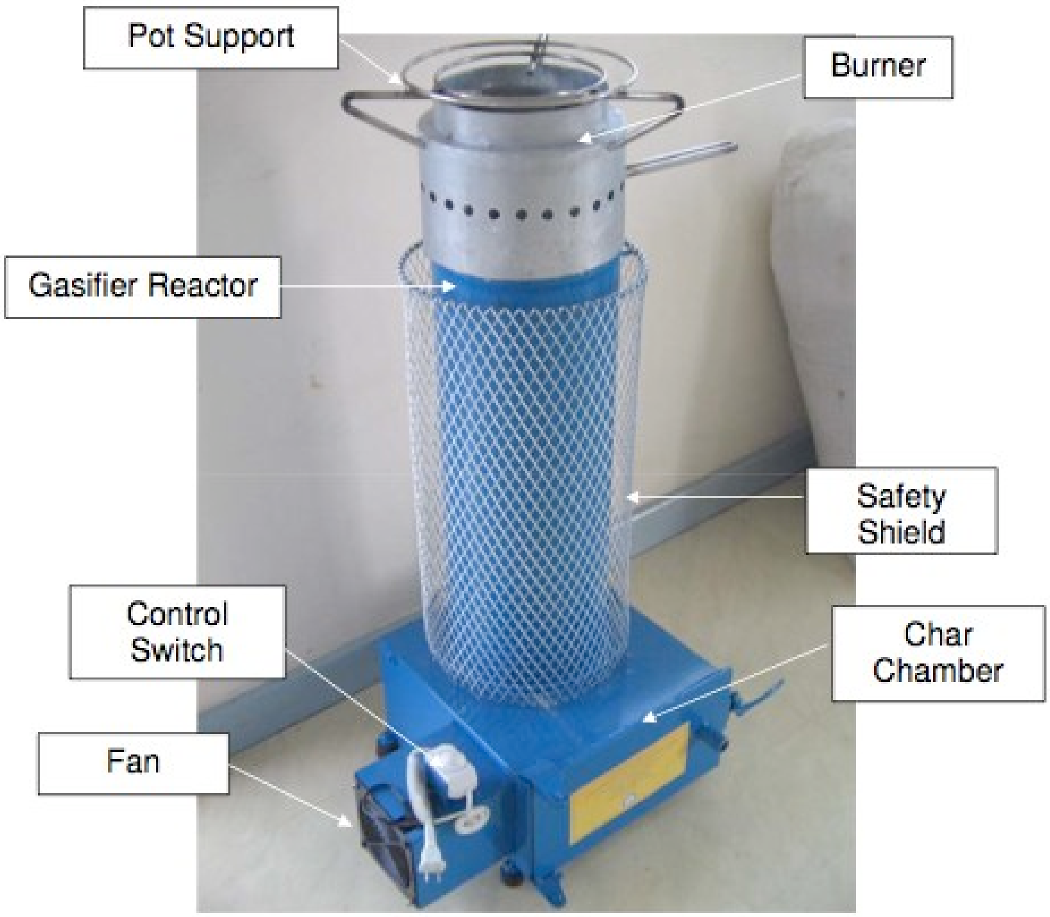


Figure A.4: The rice husk batch stove developed by Alexis Belonio.

Figure A.5: A natural draft TLUD stove made from found materials.

used to make briquettes.

Figure A.6: The Holey Roket stove with pegs for drying briquettes.

AIT Cross-Draft Gasifier Stove [8] [9]

A natural cross-draft gasifier stove was developed by the Asian Institute of Technology for use in institutional cooking. It is reported to work with wood chunks and rice husk briquettes as fuel. The cross-draft process is difficult to start, but able to be run continuously if fuel is reloaded every one to two hours. Once the flame begins in the combustion chamber, the stove is relatively smoke free.

The stove has been tested for fuel efficiency and heat transfer efficiency. Its highest reported efficiency was 27% for wood in a two-pot configuration.

Dr. Belonio mentions trying to validate the performance of this stove in his handbook. Their laboratory was unable to duplicate the low emission results.

Figure A.7: The AIT Cross-Draft stove.

Lucia Stove [15]

The LuciaStove, developed by Italian industrial designer Nathaniel Mulchay, operates on coaxial gasification. It is reported to run in both natural draft and forced-air mode. It is designed to be made from a combination of high-precision machined parts and inexpensive sheet metal. The machined parts are produced in large quantities and shipped to regions that need stoves and assembled on-site.

There have been no published outside verifications of the performance of this stove as of this writing.

Biolite [11]

The Biolite stove uses excess heat from a cook stove to power a fan. The heat is converted to electrical energy by a thermo-electric generator (TEG). The creators report clean emissions and high thermal efficiency. The fan starts almost immediately after lighting. The stove creates a flame by gasification. It could be easily adapted to burn rice husk.

It is unknown what the actual cost of deploying such a stove would be. Furthermore, there does not appear to be discussion of maintenance of stove components.

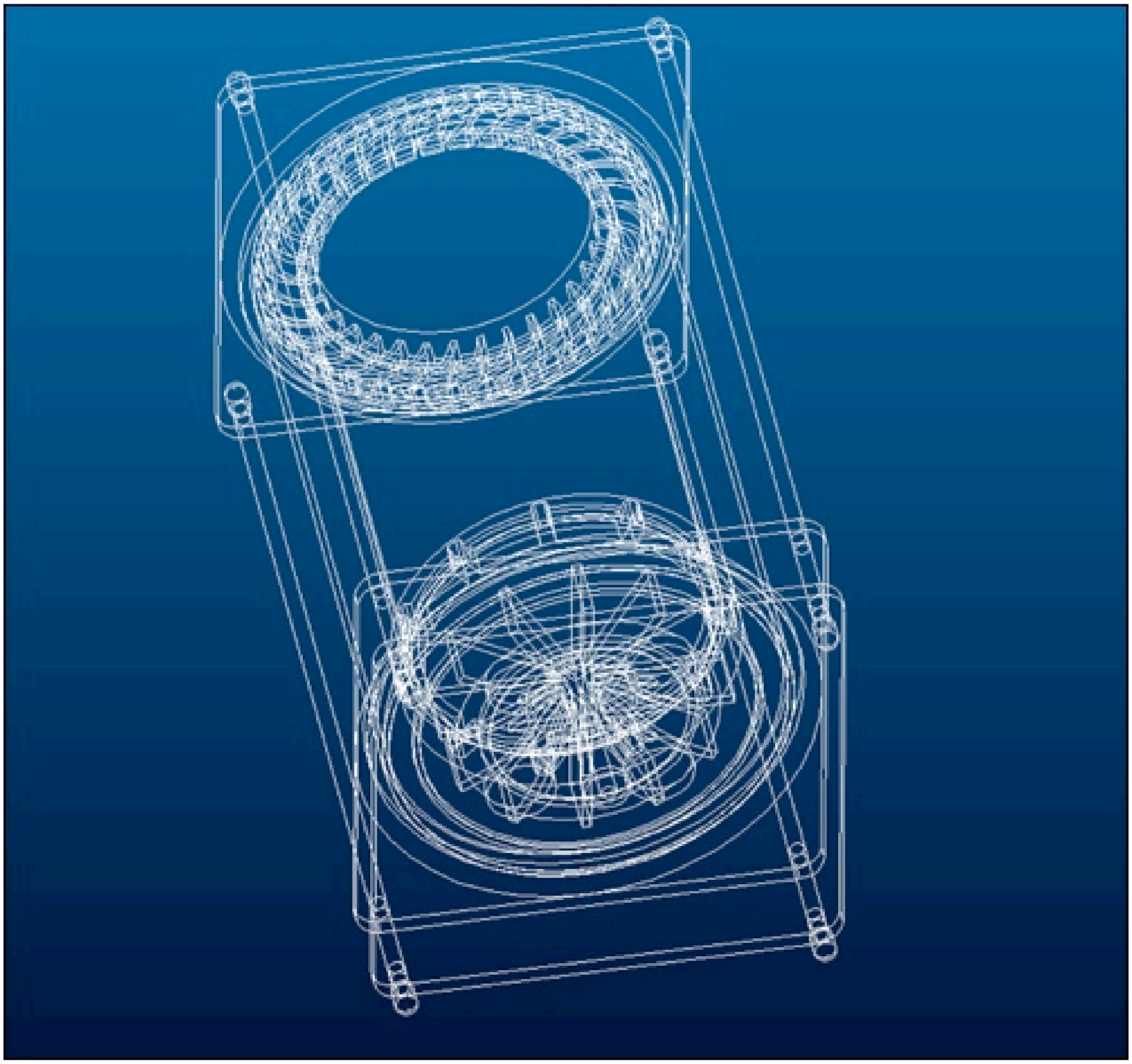


Figure A.8: A CAD model of the Lucia stove.

Figure A.9: The injection-molded components of the Lucia stove.

Figure A.10: The Biolite stove.

Appendix B

Design Alternatives

A number of radically different designs for a rice husk stove were considered before the design presented in this report was chosen for further development. All of the candidate designs listed here were eliminated because of a failure to meet a critical design specification. It was not necessary to perform a detailed matrix of evaluation since these candidate designs could be eliminated quickly by examining their ability to meet basic specifications.

B.1 Mechanical Forced-Air

B.1.1 Concept

In order to replace the fan used to power Dr. Belonio's batch stove design, several ideas to force air using mechanical devices were proposed. The idea of using a falling weight and a system of pulleys to force air through the column of rice husks was investigated, and it was found that for a cooking time of twenty minutes, an air column of 970 ft would be necessary. If pulleys were used to reduce this height, the resulting overall friction would have been to great.

Another proposal was the idea of using a torsion spring to store energy that could be used to force air into the reactor. Theoretically, the operator could turn a wheel and input potential energy into the spring; next, the energy would be released, turning a fan or lifting a plunger to force air through the fuel. However, gearing down the spring to release the energy slowly enough would not have been possible to manufacture using local materials.

B.1.2 Why it wasn't chosen

In these aspects, mechanical substitutes for a fan or other forced-air mechanisms are not appropriate for a stove design in rural Nicaragua in that they are very difficult if not impossible to manufacture locally.

B.2 Rice Husk Briquetting

B.2.1 Concept

One vein of thought is to alter the fuel source in order to use a simpler stove design. It is possible to densify biomass fuel into briquette form, allowing it to burn like wood. Briquetting is a process that requires that the raw fuel be compressed and held together with a binder, or that the fuel be carbonized and the resulting charcoal be formed into briquettes. Both avenues require a binder material to hold the densified fuel together. The briquetting process could be turned into a small, local business that provides jobs. Furthermore, there has been significant development in stove designs that burn briquettes, such as Larry Winiarski's "Rocket Stove".

There are multiple ways to produce a fuel briquette. Amy Smith's D Lab at MIT has been successful in advancing techniques to bind carbonized charcoal together with simple devices. Researchers at the University of Nottingham have been able to use plantain skins to create fuel briquettes from non-carbonized fuel. The briquettes produced from these processes are reported to perform well in cooking and emissions tests.

B.2.2 Why it wasn't chosen

A sufficient supply of binder material turned out to be unavailable in rural Nicaragua. Common materials for binding include paper, plantain skins, and cassava porridge. Mentors at Amigos for stated that none of these materials are available in the necessary quantities to provide enough briquettes for the demand in Villa Catalina. Furthermore, no appropriate alternative material was found. For these reasons, rice husk briquetting was removed from the list of candidate designs.

B.3 Cross-Draft Reactor

B.3.1 Concept

A cross-draft gasification stove consists of a fuel chamber that is loaded from the top and lit on the side of a fuel column. Figure B.1 shows the pyrolysis reaction inside the fuel chamber of a cross-draft gasification stove.

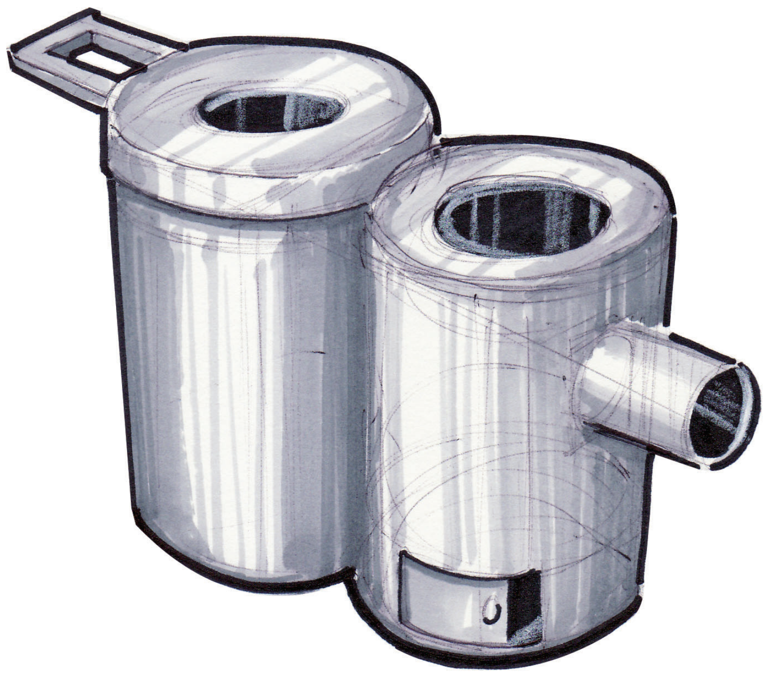


Figure B.1: A cross-draft reactor concept.

Openings on either side of the fuel chamber allow air to flow through the charred biomass and produce combustible gases, which are piped to a burner head located beside the fuel chamber. Charred fuel is removed from the grated bottom of the fuel chamber into the enclosed char collector. This enables the stove to be used continuously with used fuel dumped through the grate at the bottom of the fuel chamber and fresh fuel loaded into the top.

B.3.2 Why it wasn't chosen

The major disadvantage to the cross-draft design is that it is very difficult to light. The stove must be lit from the side, and it is difficult to get enough air to the initial flame to sustain the process. Because of this, Nicaraguan cooks are likely to not use the stove to cook in their homes if it proves difficult to light. Open fires are easy to start and sustain, and will be chosen over stoves that are difficult to light. Because of these factors, the cross-draft design does not meet the specification that the stove starts easily. As such, it is not appropriate for Villa Catalina.

Appendix C

Moisture Content in Rice Husk

The moisture content of the rice husk used during testing was found by experiment in order determine if it was a significant hindrance to performance. This was done using a scale with 1g resolution. The moisture content found was less than 20%, which meant that it would not significantly affect the stove. However, it was uncertain if the scale used, which has a 1g resolution, was actually adequate for performing this experiment. Therefore, error propagation analysis was undertaken.

The measured quantity in this experiment was the weight of rice husk using a scale with 1g resolution. Therefore, the uncertainty for mass measurements was 0.5g.

The calculated quantity was the moisture quantity of the rice husk.

$$\begin{aligned} m_0 &= 100.0 \\ m_f &= 80.0 \\ U_{m_0} &= 0.5 \\ U_{f_0} &= 0.5 \end{aligned} \tag{C.1}$$

$$m_{water} = m_0 - m_f \tag{C.2}$$

$$U_{m_{water}} = \sqrt{U_{m_0}^2 + U_{m_f}^2} \tag{C.3}$$

$$x_{moisture} = \frac{m_{water}}{m_0} \tag{C.4}$$

$$U_{x_{moisture}} = x_{moisture}\sqrt{\left(\frac{U_{m_{water}}}{m_{water}}\right)^2 + \left(\frac{U_{m_0}}{m_0}\right)^2} \tag{C.5}$$

The resulting $U_{x_{moisture}}$ was 0.7% for a moisture content of 20%. Therefore, the scale was adequate in performing this experiment.

Appendix D

Flow through annular region between outer and first inner cylinder

One of the parameters that was suspected to greatly affect stove performance was flow of air between the outer cylinder and the inner cylinder. In particular, it was thought that a diameter that was too small would choke secondary air flow, preventing the stove from performing adequately. Therefore, the flowrate, Q, between these two cylinders was modeled.

Many of the properties of air depend on temperature. The dynamic viscosity does not vary much based on temperature. Density does, however. Also, the relative density difference between the inlet and outlet regions is what causes the buoyant force that drives the flow.

Assume laminar, fully-developed flow. All units are standard SI units, unless otherwise noted.

$$\begin{aligned} \mu &= 3.018{-}5 \\ l &= 55.88{-}2 \\ r_o &= 10.16{-}2 \\ r_i &= 7.62{-}2 \end{aligned} \tag{D.1}$$

Where l is the height of the cylinders, r is the radius (outer and inner), and μ is the dynamic viscosity of air at 600 K. Density calculated using the ideal gas law.

$$
\begin{aligned}
P &= 101.3253 \\
R &= 286.9 \\
T &= 20 + 273 \\
\rho &= \frac{P}{RT}
\end{aligned}
\tag{D.2}
$$

Use expression for steady, axial, laminar flow in an Annulus from Munson. [16]

$$
\begin{aligned}
h &= 60.96{-}2 \\
g &= 9.81 \\
T_i &= 25 + 273 \\
T_o &= 700 + 273 \\
dP &= hg(\rho_{T_i} - \rho_{T_o})
\end{aligned}
\tag{D.3}
$$

$$
Q = \frac{\pi dP}{8\mu l}\left(r_o^4 - r_i^4 - \frac{(r_o^2 - r_i^2)^2}{ln(r_o/r_i)}\right) \tag{D.4}
$$

The resulting relationship between outer diameter and flow rate is shown in Figure D.1.

At values of outer radius r close to 4" (10.16 cm) , the flow rate is close to zero. As it grows to 5" (12.73 cm), the flow rate increases to about 2 m^3/s. This would suggest that there is quite a bit of choking off of secondary air due to the annulus effects.

The numbers for velocity and flow rate found are too high (expected velocity is around 2.4 cm/s). The pressure drop used to calculate was conservative, so it is unlikely that that is the source of error. Perhaps the pressure drop itself decreases as the flow velocity increases, causing it to top out at a value much sooner than the laminar model would predict.

Whatever the case, the trend of Q values shows a very significant difference between the 8" diameter outer cylinder and the 10" diameter cylinder. If that draft is a significant player in the performance of the stove, then swapping between those two configurations will have a huge impact on performance.

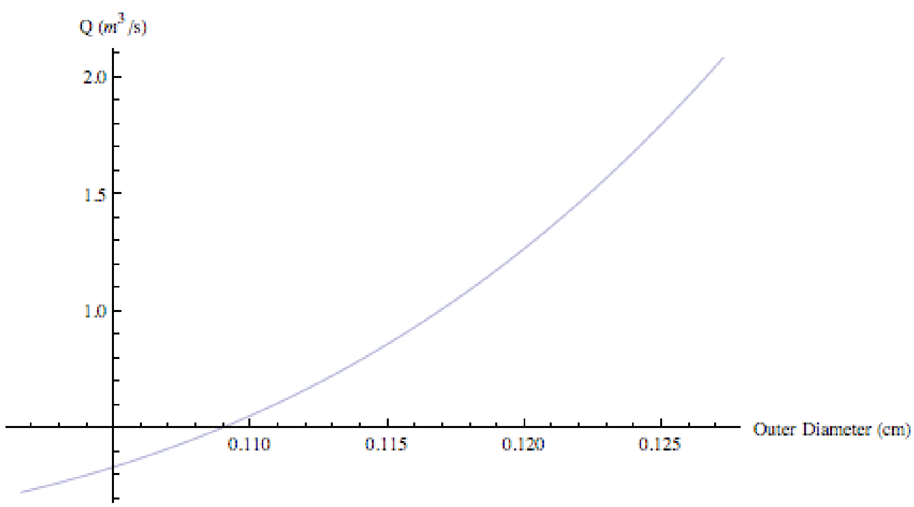


Figure D.1: Effect of varying outer diameter on flow rate between cylinders

Appendix E

Prototype Timeline

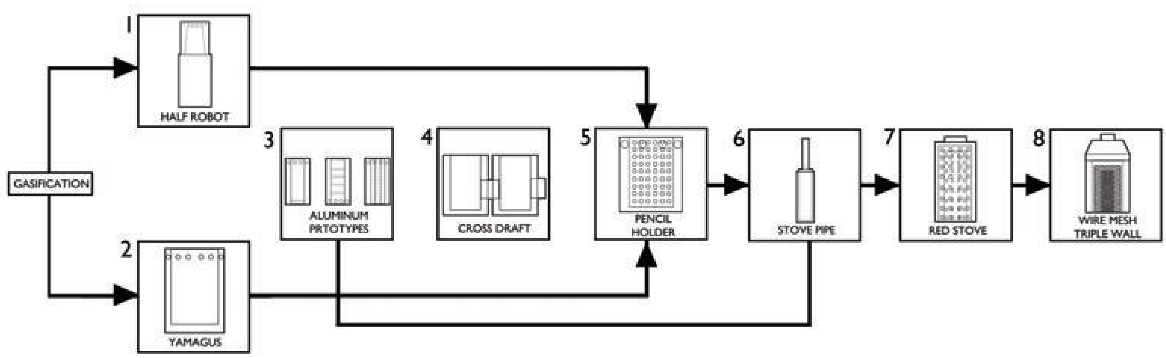
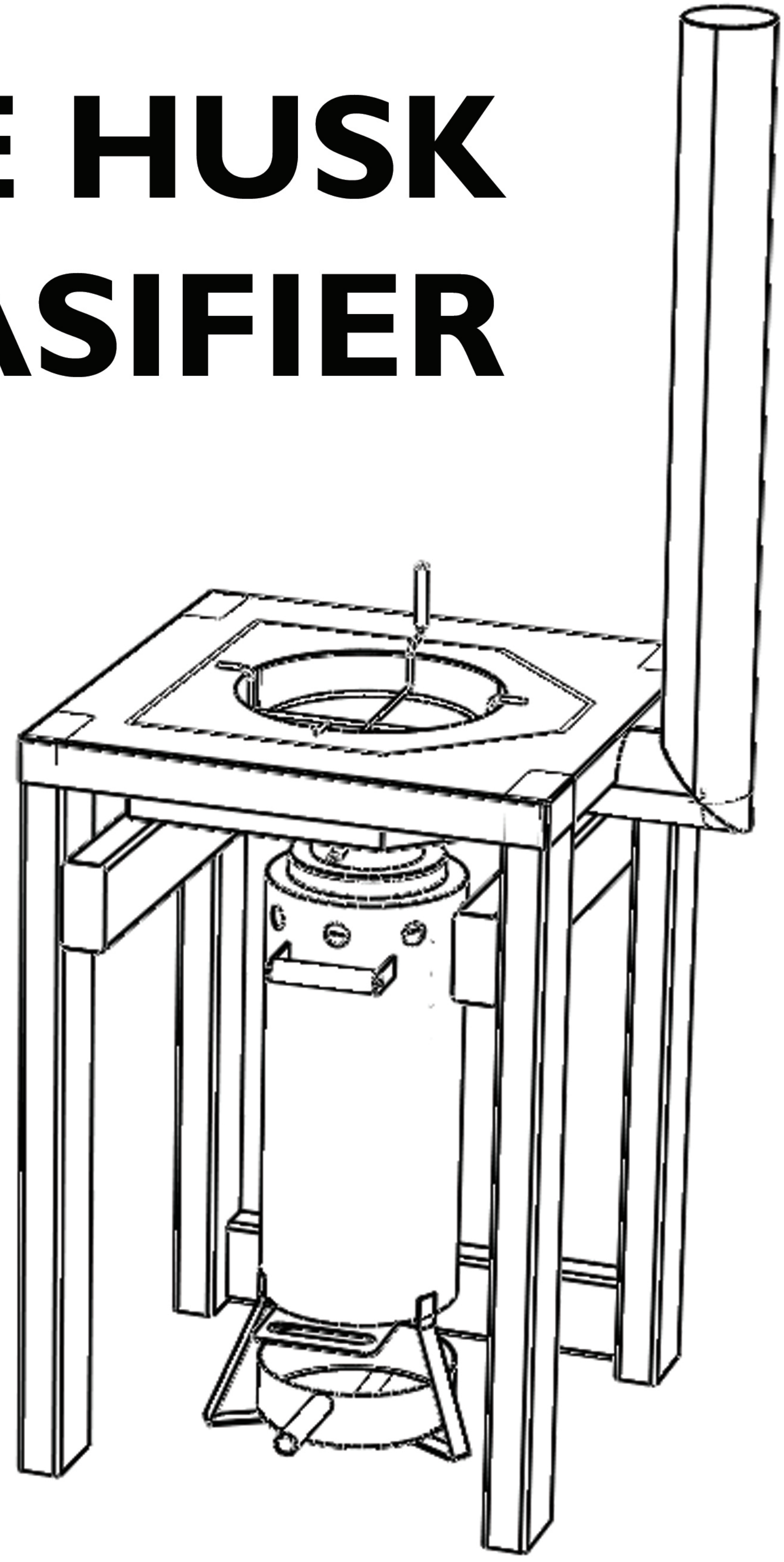


Figure E.1: Representation of prototyping process.

Prototyping through the duration of the design process enabled rapid implementation and evaluation. Each prototype led to further implementation, but not necessarily in sequence and oftentimes illuminated the stage the design was in by the way the form was fabricated.

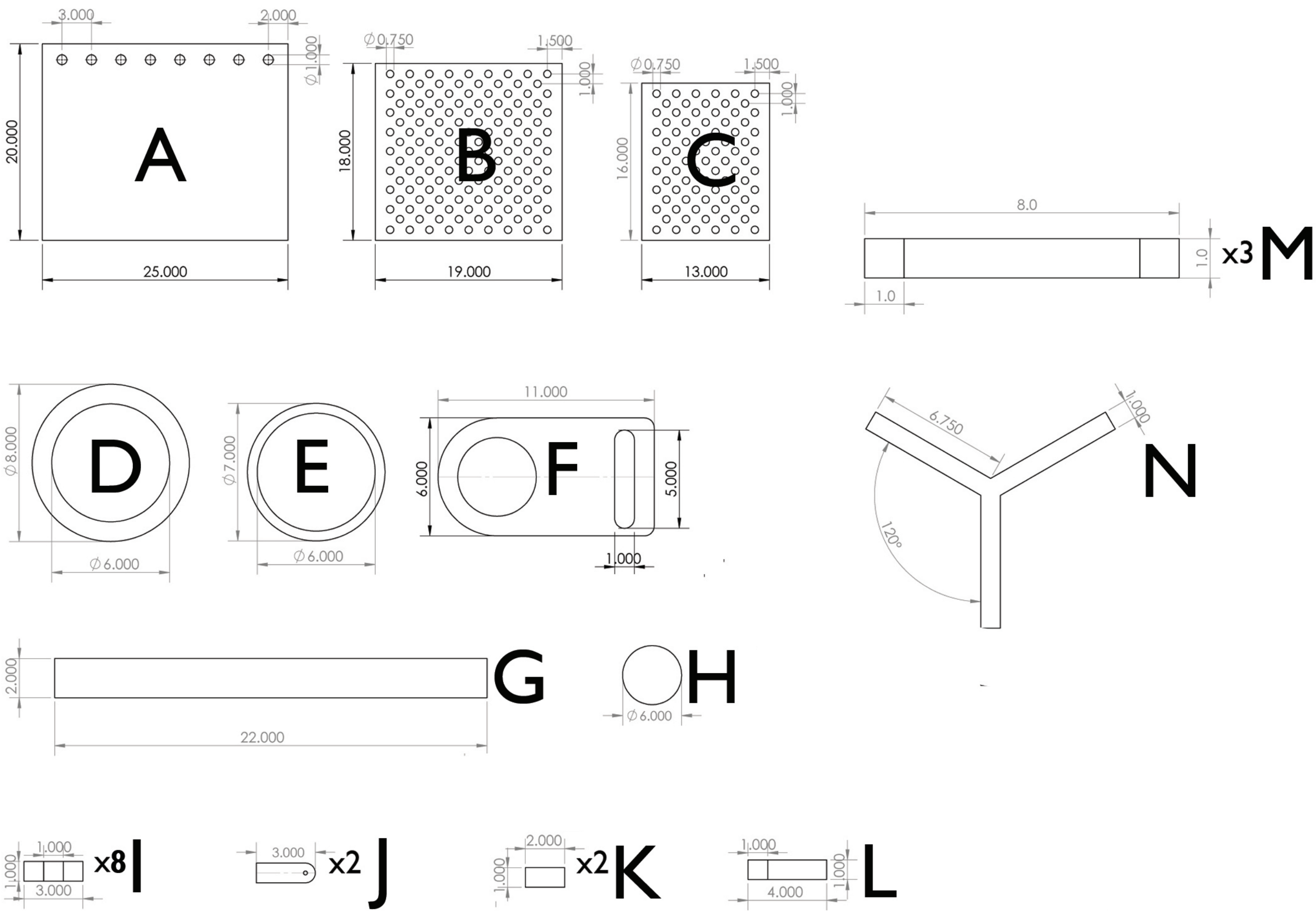
The first two prototypes were done in parallel with two separate groups within the team in order to build a gasification stove. The fuel of choice was not rice husk initially due to the difficulty of making a rice husk gasification stove. The first prototype, the half robot stove was constructed out of two gas cans from a local metal scrap year in Atlanta. The process allowed the team to search and evaluate existing forms not made for components of a stove and look for the basic functionality of the stove past the specific form of the object in the junkyard. The other initial gasification stove, the Yamagus stove was made out of a two tin cans (an asparagus and a yam can). This process showed how quickly a stove could be made from simple everyday waste material. A period of time passed before another prototype was constructed. The existing rice husk gasification stoves were used to cook on to better understand their function. After much deliberation and delay a set of aluminum prototypes were constructed based off of three similar airflow solutions. None of these prototypes was successful. The aluminum was used to quickly prototype, but the lack of insulation directly affected the performance of the stoves. The team was looking for rapid prototyping, but the design was not ready for raw material construction for the first rice husk stove. Several concepts and sketches were produced after the aluminum prototypes and one was the cross-draft gasification stove made from some coffee cans. This prototype was used to illustrate the necessity for a stove that is easy to start with minimal smoke. This was the first stove where air leaks in the stove were noticed to cause performance issues. The stove overall was unsuccessful. Before the next prototype Dr. Paul Anderson visited Atlanta and allowed the team to run a few trials within his Champion TLUD stove. This lead to preliminary calculations toward using a chimney and a perforated cylinder. The team returned to department stores to scavenge items and a kitchen was found to be suitable for the perforated cylinder. Using the tin cans from the cross-draft stove and an available piece of stove pipe a top lit up draft stove with a chimney was created. The stove was still not functioning properly so an idea from the aluminum prototypes of an inner bypass was used in the form of a pencil holder and the first working rice husk gasification prototype was born. Now the design deserved to take its own form instead of borrowing form from another object so a recreation of the stove was constructed using galvanized stove pipe and the chimney already in use. The stove had several operations that resulted in complete gasification of the column of rice husks, but over time the material degraded and deformed and stove stopped working properly. Hence, roofing steel was used due to the opportunity to work with a roofer in his shop to create a replica of the stove pipe stove using better materials. During this stage of the design several iterations of the stove were used until the efficiency of the combustion process reached the heights of melting the steel prototypes. Therefore, a return to rapid prototyping led to the implementation of mesh cylinders due to the time constraints of the project. The mesh cylinders proved to be robust enough to survive extreme heat during operation without any noticeable deformation. The last item to find was an outer cylinder to refine the stove without the fear of melting your prototype during testing. The solution came in the form of triple walled stainless steel stove pipe that happened to be donated to the team to further gasification research.

RICE HUSK GASIFIER

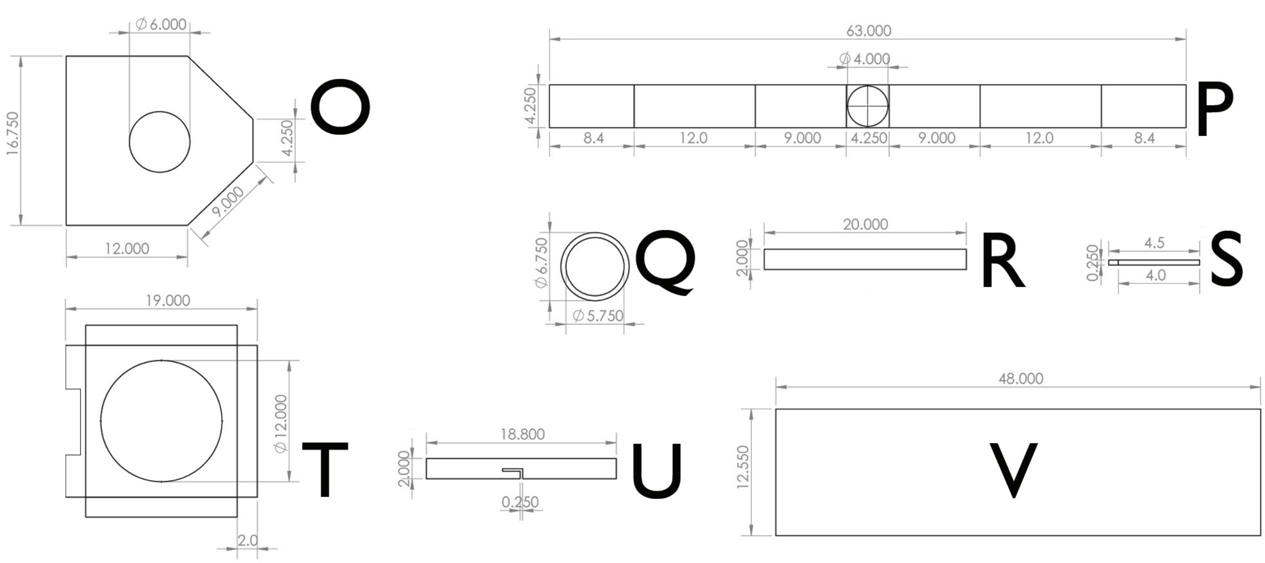


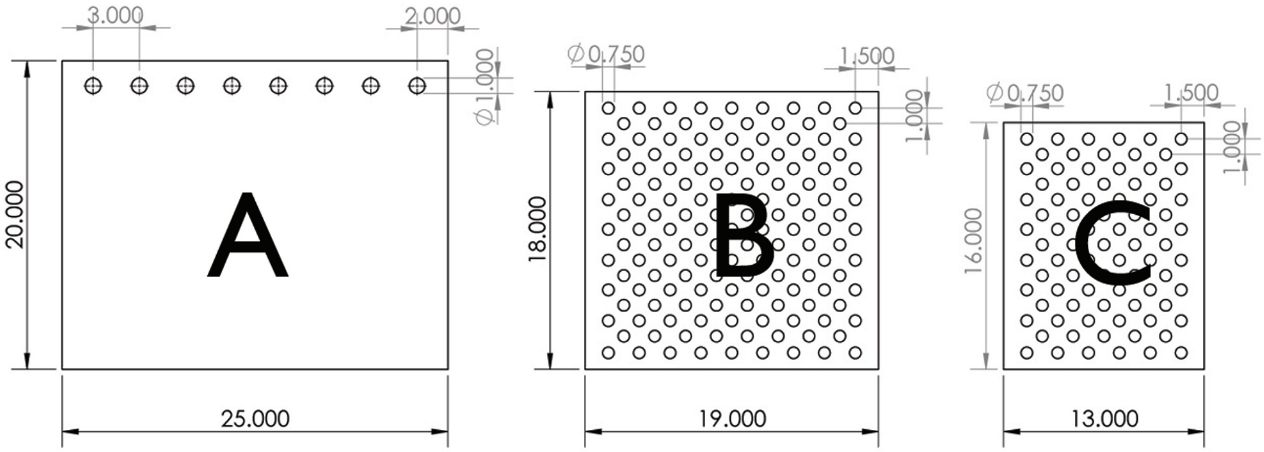
small red tile

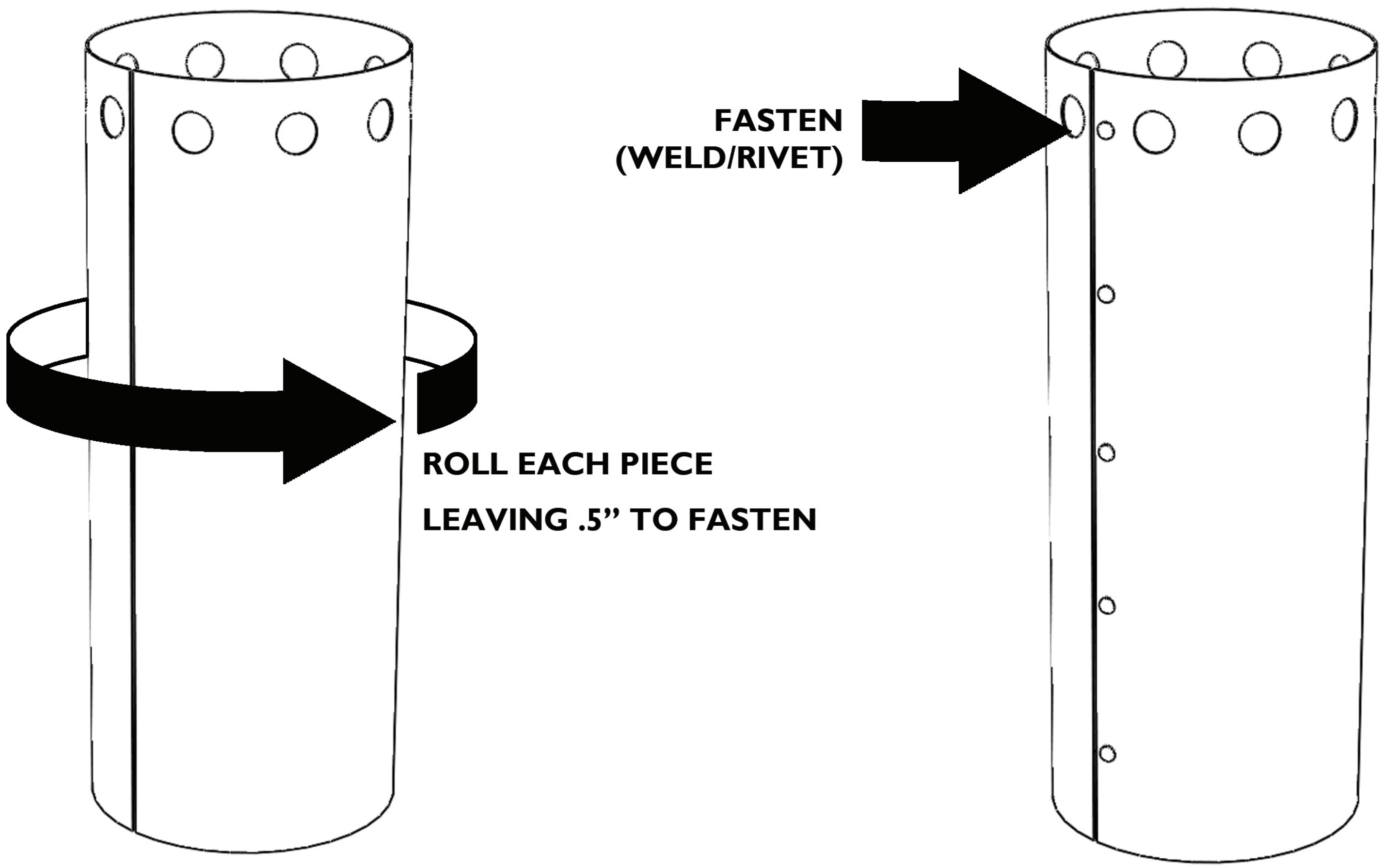
REACTOR PARTS LIST

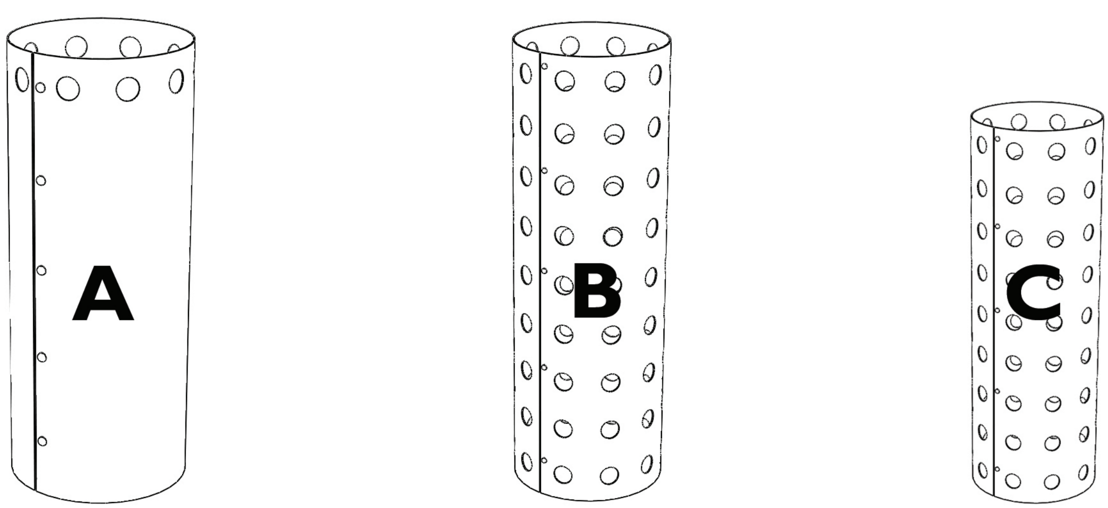


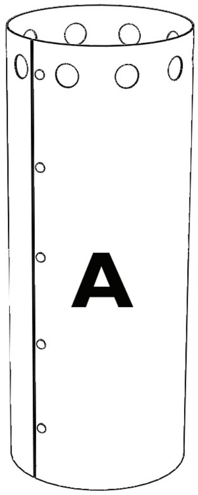
COOK TOP PARTS LIST

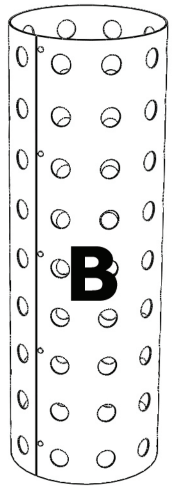


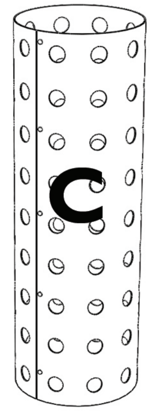

3.000
2.000
∅1.000
20.000
A
25.000
∅0.750
1.500
1.000
18.000
B
19.000
∅0.750
1.500
1.000
16.000
C
13.000

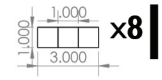

FASTEN
(WELD/RIVET)
ROLL EACH PIECE
LEAVING .5" TO FASTEN

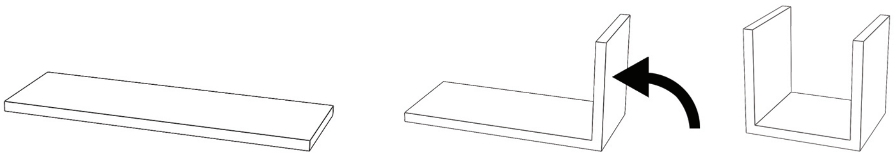

A
B
C



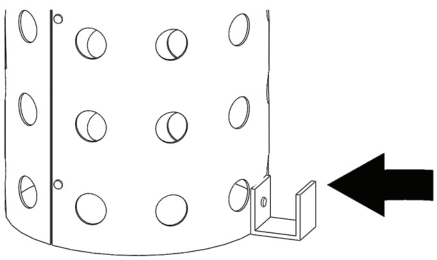




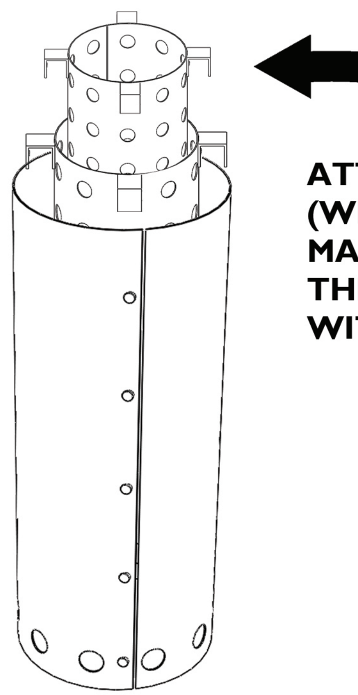




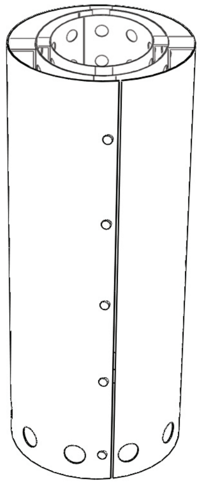
BEND PART I INTO CORRECT SHAPE

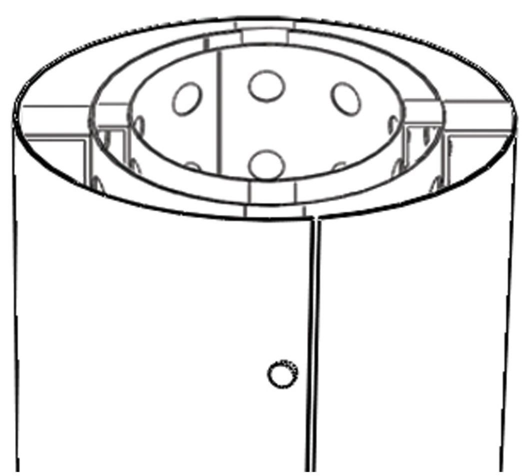


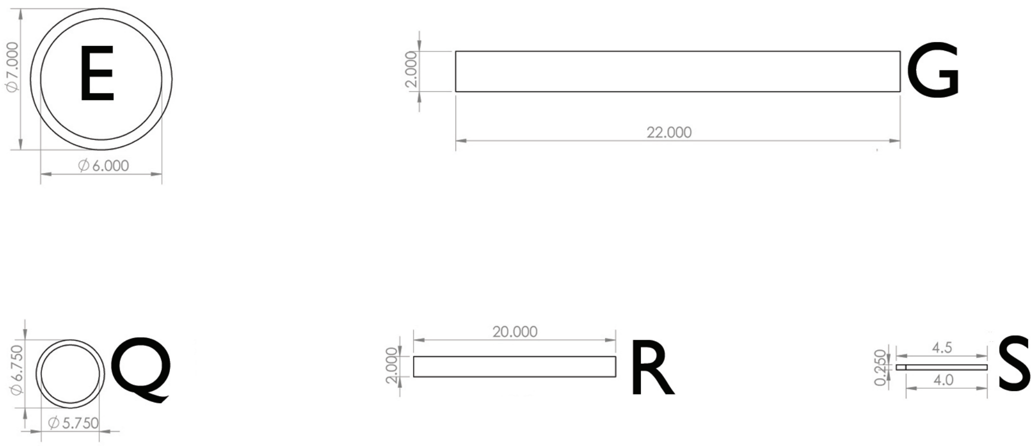
CONNECT (4) PART I TO BOTTOM OF PART B AND (4) PART I TO BOTTOM OF PART C

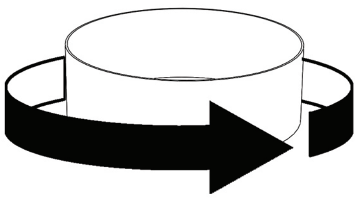


ATTACH CYLINDERS (WELD/RIVET) VIA PART I MAKING SURE TO KEEP THE BOTTOMS ARE FLUSH WITH ONE ANOTHER

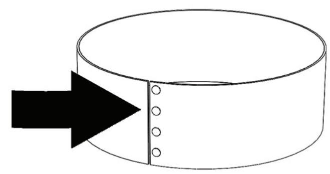




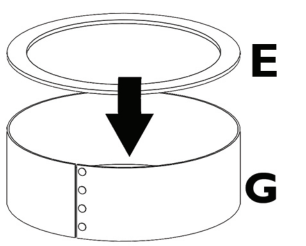




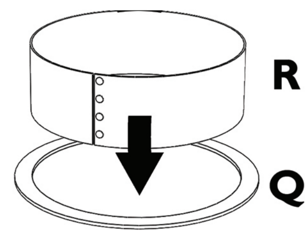
ROLL PART G AND PART R



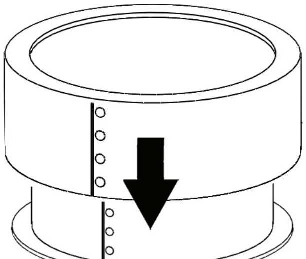
FASTEN PART G AND PART R



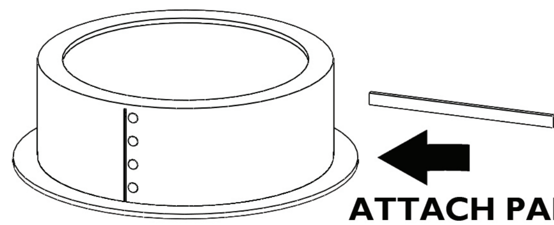
ATTACH PART D TO PART G



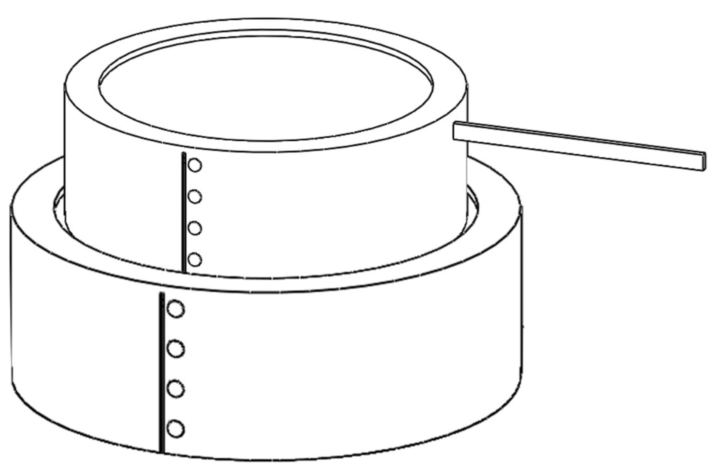
ATTACH PARTS R AND Q

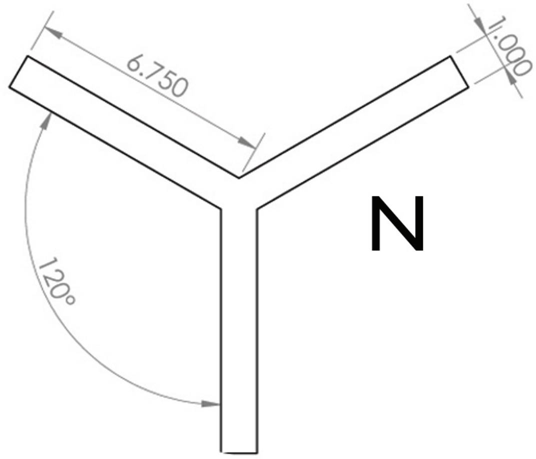


PLACE PART G OVER PART R



ATTACH PART S TO PART R





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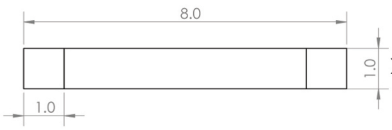
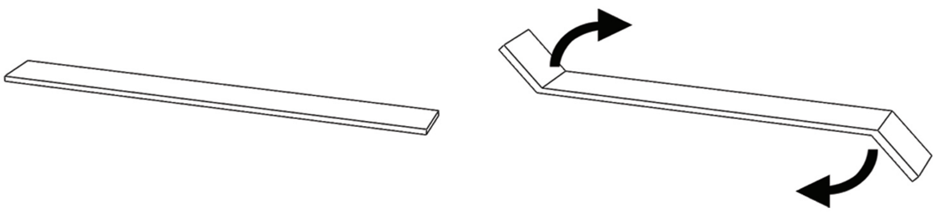
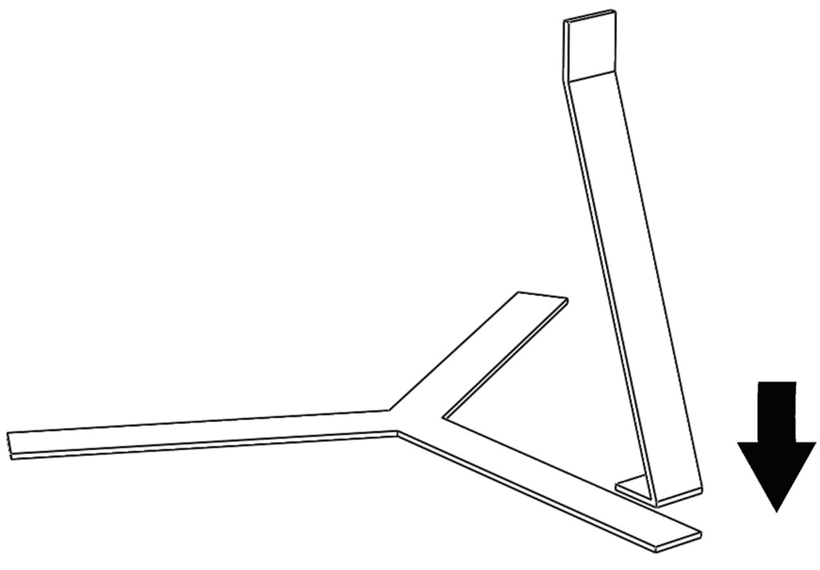


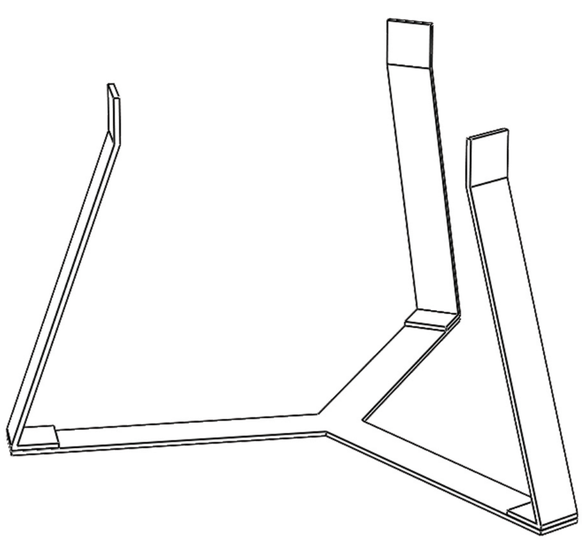
x3 M

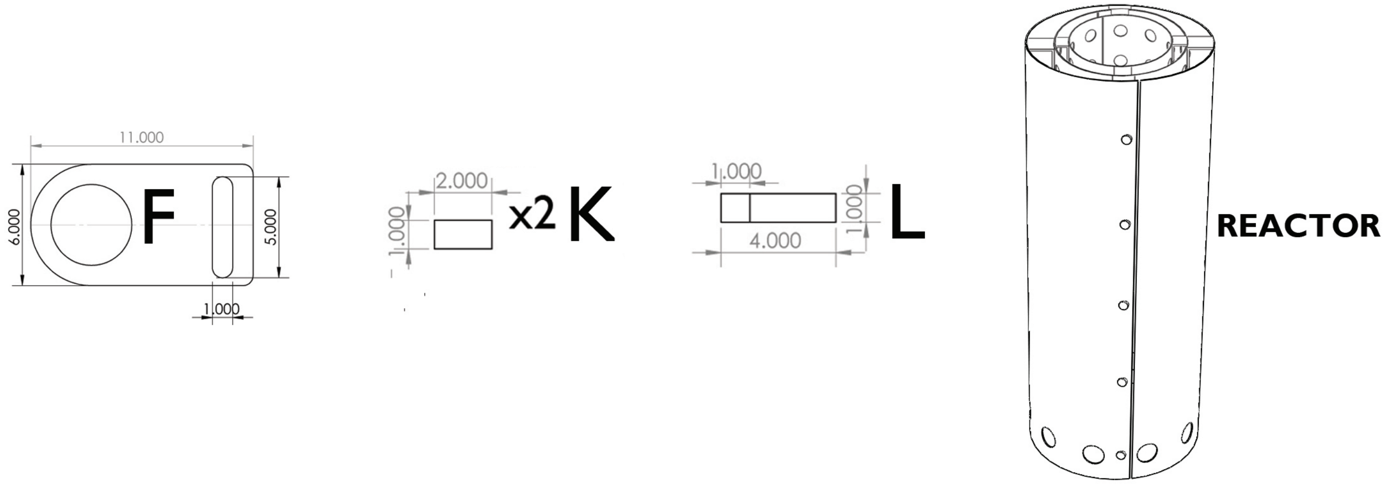


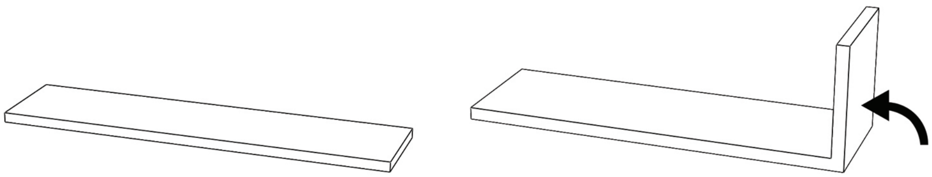
BEND TABS OF PART M



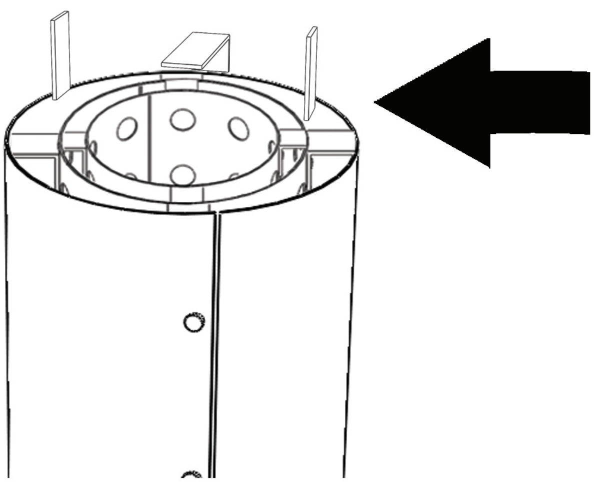
ATTACH PARTS M TO PART N



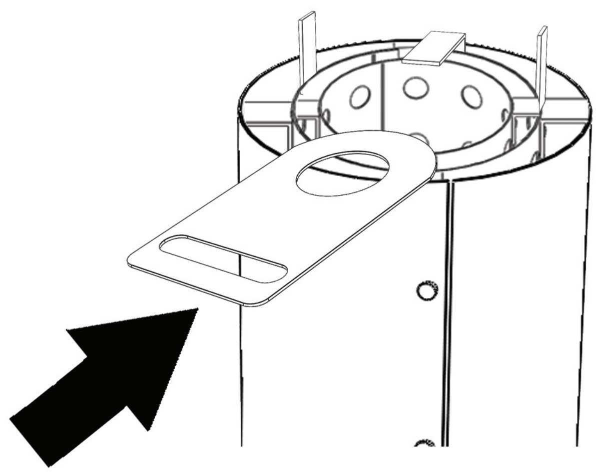




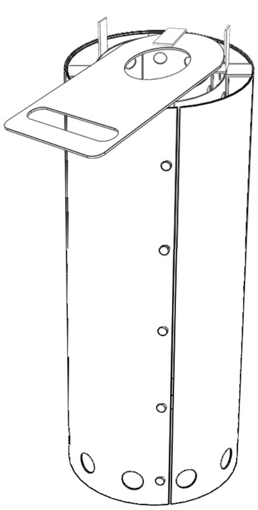
BEND TAB OF PART L

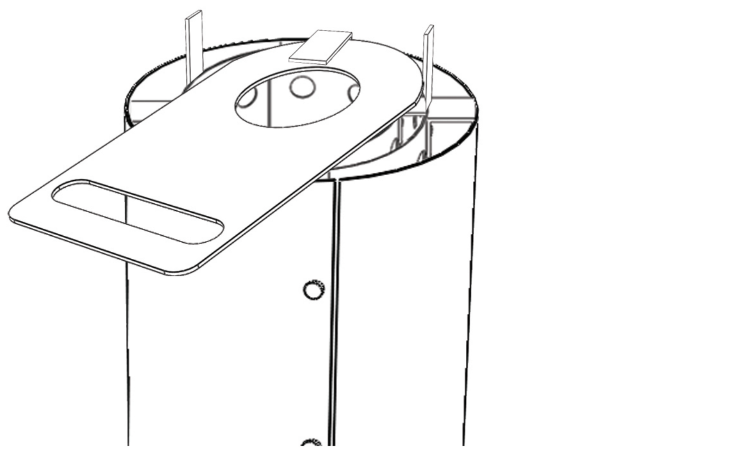


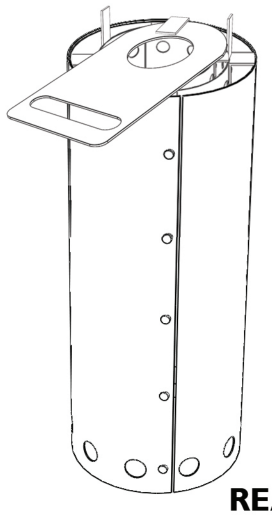
ATTACH PART K AND PART L TO PART B



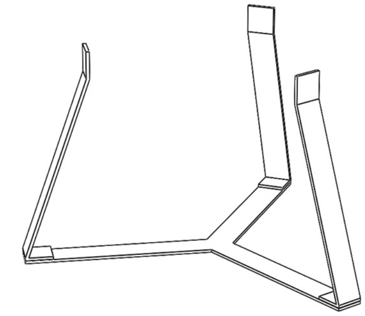
PLACE PART F BETWEEN PART K AND PART L



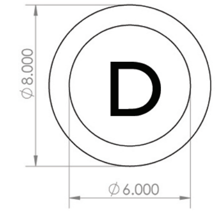


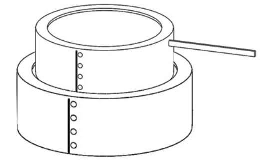


REACTOR

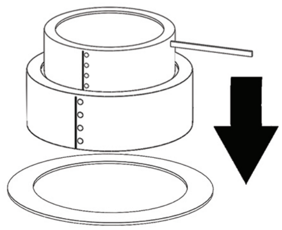


BASE

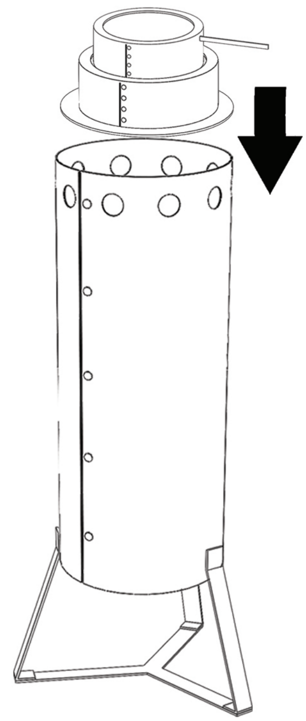




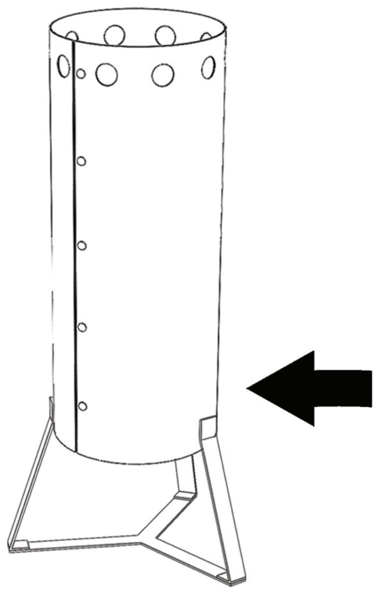
COUPLER



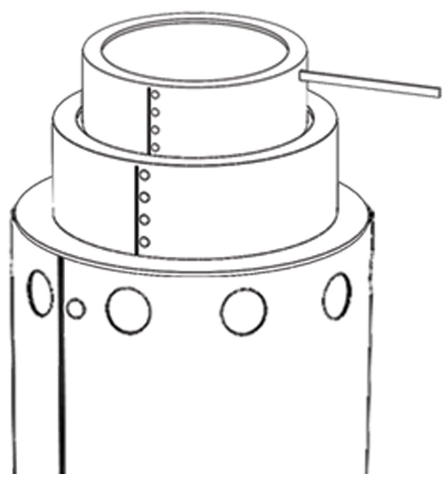
ATTACH COUPLER TO PART D

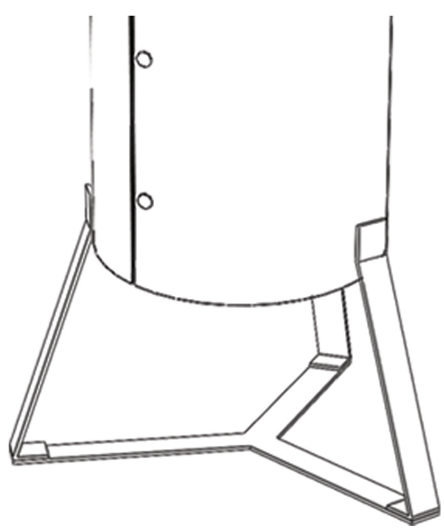


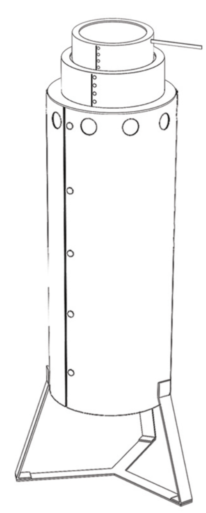
ATTACH COUPLER+ PART D TO REACTOR

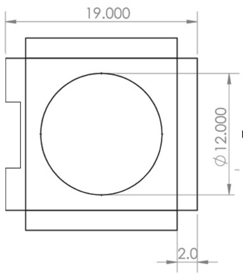


ATTACH BASE TO REACTOR

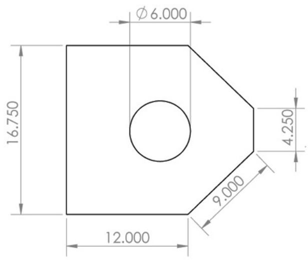




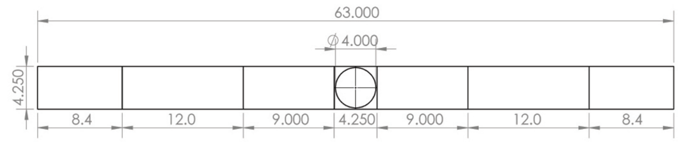




T



O



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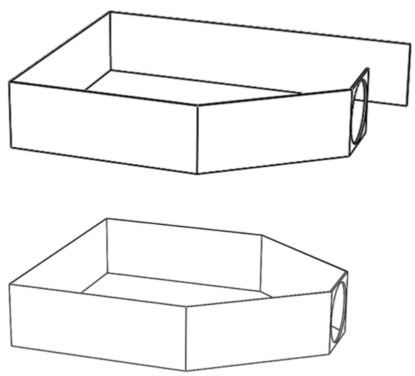
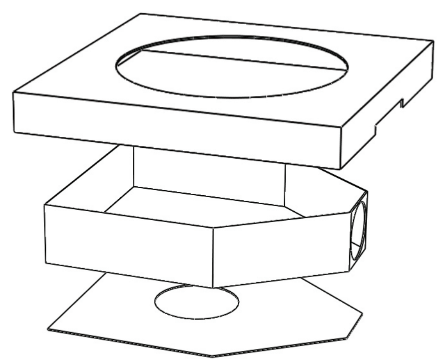
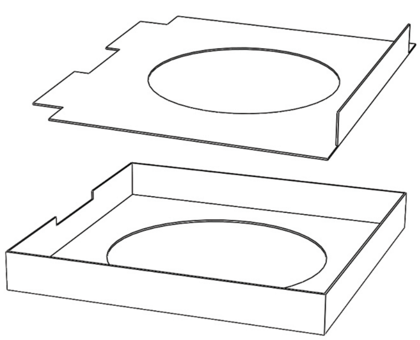


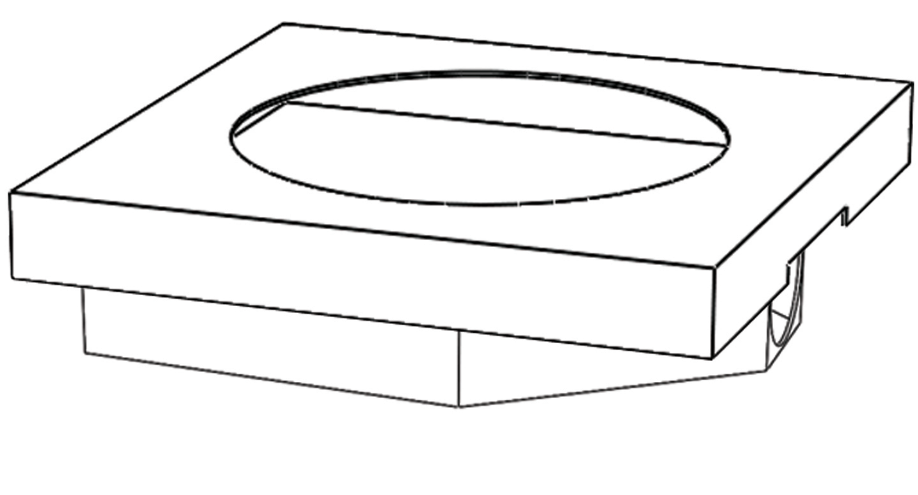
BEND PART P INTO PROPER SHAPE

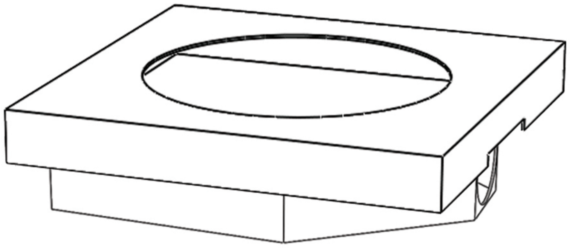


ATTACH PART T, PART O, AND PART P

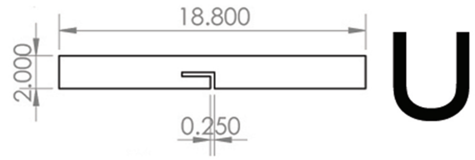


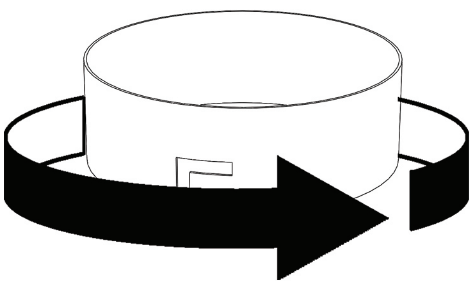
BEND PART T INTO PROPER SHAPE





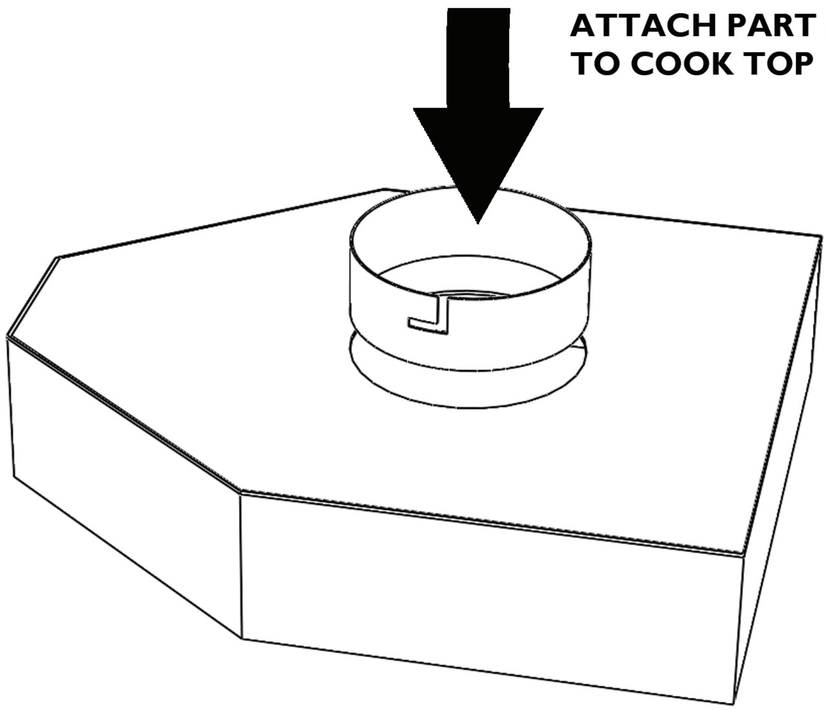
COOK TOP

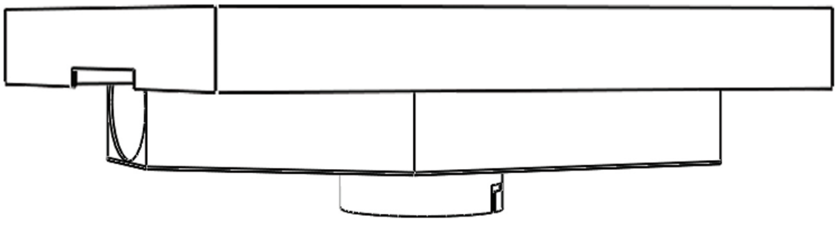


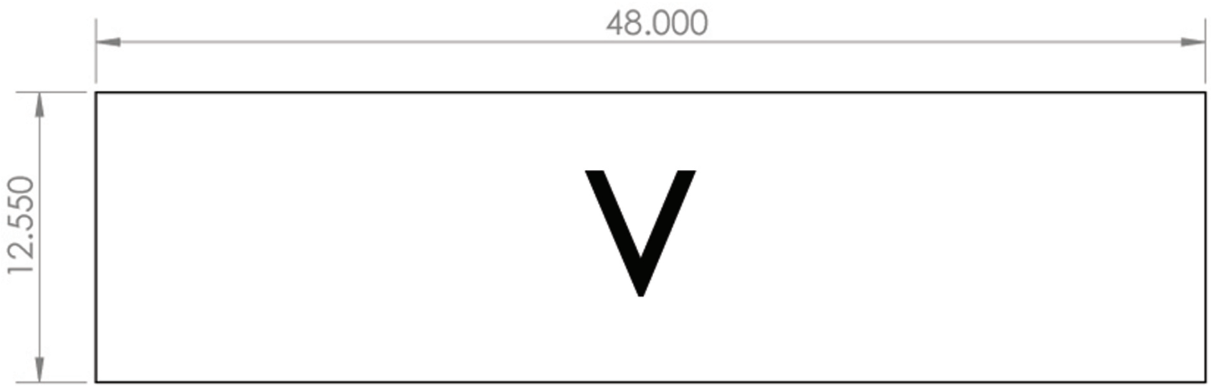


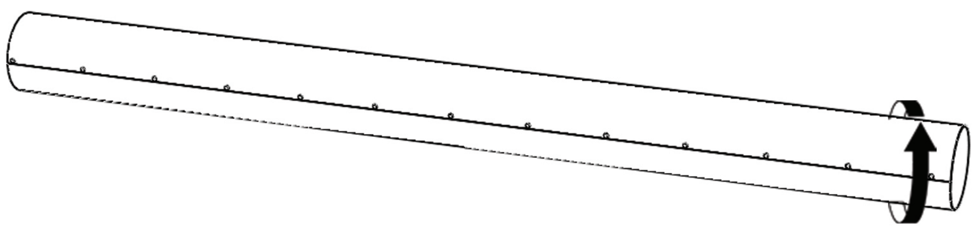
ROLL AND FASTEN PART U
INTO PROPER SHAPE.

ATTACH PART U
TO COOK TOP

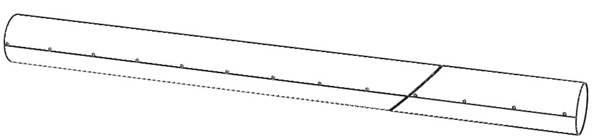




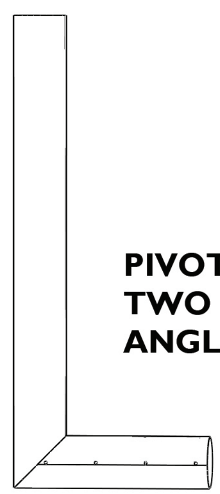




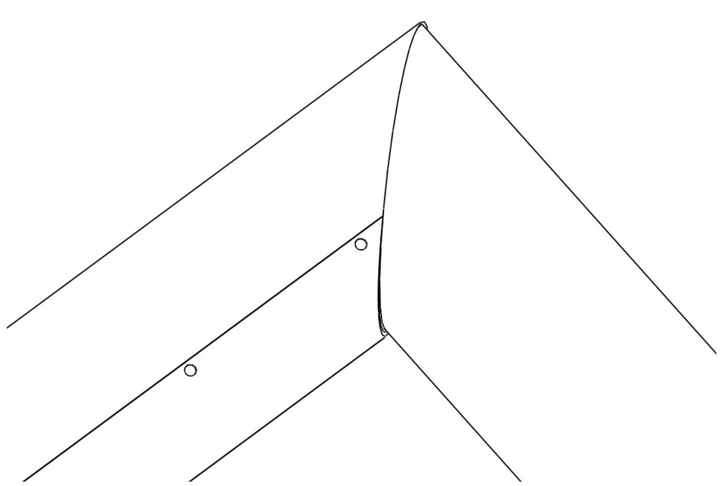
ROLL AND FASTEN PART V INTO PROPER SHAPE

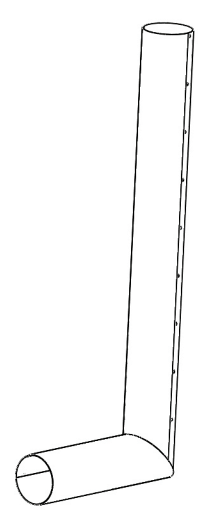


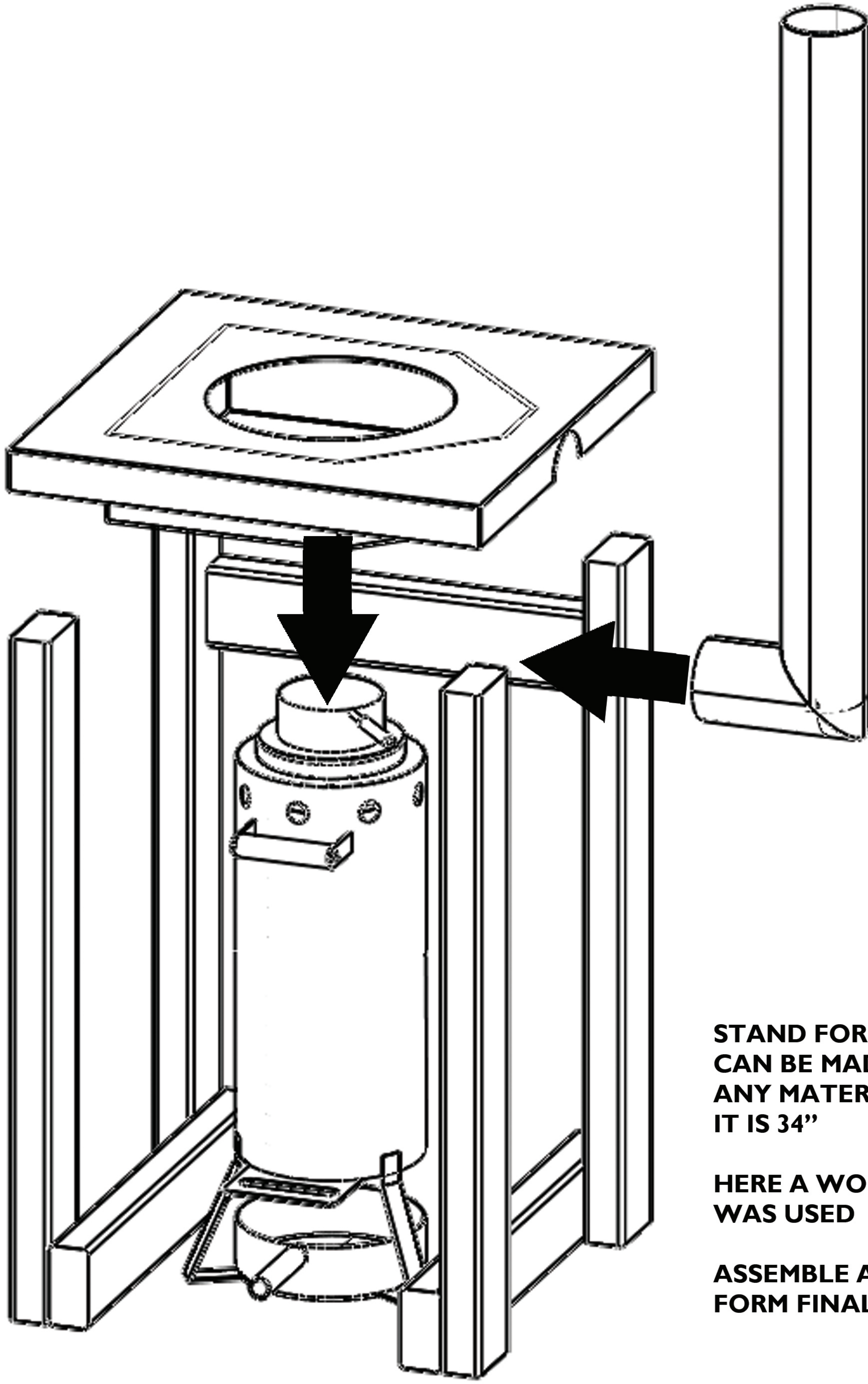
MEASURE 1' FROM END AND MAKE 45° CUT



PIVOT SMALL PIECE UNTIL TWO PIECES FORM A 90° ANGLE







STAND FOR COOKTOP CAN BE MADE OUT OF ANY MATERIAL AS LONG IT IS 34"

HERE A WOODEN FRAME WAS USED

ASSEMBLE ALL PARTS TO FORM FINAL STOVE