Design and Engineering of a Cleaner Burning Cook Stove for India

Submitted by:

Chris Thompson

Greg Scott

Jon Neal

Jenny Baca

May 6, 2011

X PRIZE
Northern Arizona University
Clean Burning Stove Team

May 6, 2011

Dr. John Tester
Mechanical Engineering Professor
Northern Arizona University
John.Tester@nau.edu

Dear Dr. Tester:

Thank you for allowing us to be your engineering team for the clean burning cook stove. We are pleased to have the opportunity to provide our services for this interesting design problem. The clean burning cook stove has been a challenging yet very rewarding project which we are excited to be a part of.

On Friday April 29, 2011, our team presented and had a poster session for the Undergraduate Symposium at Northern Arizona University. Our presentation went very well with many professors in attendance. Our poster session also went well. We tied for second place at the poster competition which exhibits the ability of the students to share their knowledge with a non-expert audience.

Our cookstove met all specifications except one. We could not get a unit cost of under \$10; we came out to \$19.25. We still believe that this is a success because Aprovecho states that their stove are currently produced for a \$20 unit cost. We also believe that the benefits and efficiency of our stove outweigh this single deficiency.

Being the engineering team on this project, we have learned many things. The greatest being the experimental method. It was new for us to design and implement our own testing rigs as well as learn about different topics we have not studied in an academic environment (i.e. pollution). Overall, this project was a great way to learn and grow as engineers.

More documentation (including detailed drawings, testing data, our final presentation and poster, project pictures, and sheet metal manufacturing templates for our stove) can be viewed on our website at http://www.cefns.nau.edu/Research/D4P/EGR486/ME/11-Projects/X-Prize/ or by using the QR Code below on a smart phone. Please submit a final review and commentary to our ME 486C professor, Dr. Byran Cooperrider, at Bryan.Cooperrider@nau.edu. Thank you again for allowing us to work on this challenging project.

Sincerely,
Northern Arizona University Team X-Prize
Chris Thompson
Greg Scott
Jon Neal
Jenny Baca

QR Code to electronically take you to NAU Team X Prize's website via a smart phone

Abstract

In 2000, more than 1.6 million deaths worldwide were caused by indoor air pollution (IAP), making it the second largest environmental contributor to poor health. Most developing countries use open fires or dirty solid fuel (wood or coal) burning stoves, which causes IAP and subsequently health problems and fatalities. For example, 70 percent of Indian households depend on these dirty stoves, and between 400,000 and 550,000 Indians die yearly from IAP. Outdoor air pollution (OAP) is also affected by these current conditions. Our team developed an inexpensive cleaner burning wood stove with the explicit purpose of reducing IAP/OAP and saving lives. Our design features a well-insulated fire path which will reduce black carbon emission by greater than 60 percent. We will also increase heat transfer to our pot in many ways, and utilize properly calibrated intake and exhaust systems to reduce fuel consumption by 50 percent.

Table of Contents:

1.0 Introduction

Project Goal

The X Prize Foundation wishes to promote cleaner, safer use of cook stoves in the third world. The NAU Clean Burning Stove Team's efforts will reflect this objective by developing a functioning solid fuel stove complete with thorough analysis.

Problem Background

Based off a study by the World Health Organization (WHO), in 2000 more than 1.6 million deaths were caused by indoor air pollution. This is the second largest environmental contributor to poor health. Most developing countries use simple but dirty solid fuel (wood or coal) burning stoves. These stoves create air pollution that kills the people that breathe in the exhaust; the pollution also can cause pneumonia, cataracts, and tuberculosis. For example, 70 percent of Indian households depend on these dirty stoves and between 400,000 and 550,000 Indians die yearly. External air pollution is also a danger to the environment. Clean burning stoves can help reduce the risk of dying pre-maturely and create less harmful exhaust that goes into the air. Pictured below in Figure 1 is a typical are typical examples of current indoor cooking conditions and the resulting outdoor pollution.

Figure 1 - Indoor air pollution (left), outdoor air pollution (right) (http://www.ahuyu.org/why-stoves.html)

2.0 State-of-the-Art Research

This project has a multitude of facets involved that affect the design; all of these facets had to be researched to assure complete understanding before approaching the design work. Listed below are the five categories of research topics that have been pursued throughout the year.

2.1 Combustion and Fuel Research

Combustion is one of the major aspects of this project, due to the fact that proper combustion drives nearly all of the essential parameters to success. Due to this the team researched as much as they could about all aspects of external combustion within wood stoves. The team was referred by Dr. Acker to what he said was the "most concise introduction to combustion he knew of"; *An Introduction to Combustion* by Stephen R. Turns[41]. This proved to be a useful review of thermodynamics knowledge and thermochemical properties, it also introduced the basic concepts of combustion. Many of the resources came from a journal called *Fuel* which contained multiple different papers on combustion and fuel analysis[9, 11].

Additionally, professional and scholarly articles were found with field research findings, laboratory tests, and theoretical models[16,28,35].

After reading through all of these articles and diving deeper into certain topics explained within them, the team gained a better understanding of the thermal and fluid conditions within a wood burning stove, and conclusions were made about which parameters should be controlled within the design. These parameters were the heat of the flame, the air speed of the flue gases, and the stoichiometry of the system (in a general sense). Parameters that are not able to be controlled are the specific combustion properties of the fuels and the chemical kinetics of the fire due to large non-uniformity of thermal properties within our fuels.

2.2 Pollution and Health Effects Research

The next topic of research is pollution and health effects, this need comes from the fact that the project exists due to air pollution and health concerns in India. Essentially, these topics follow immediately after combustion because improper combustion causes pollution. A multitude of official U.S. Environmental Protection Agency (EPA) websites and databases were recommended by the pollution technical advisor Dr. Auberle, which proved to house a plethora of useful information[40,42,43]. The team also found a number of useful articles from *Fuel*[8,11,27]. Additionally, a large number of other professional and scholarly reports were found as well, many of these reports ranged in location, from Central America to China[1,19,20,22,27]. Regardless of the source's location of field-or lab testing, the data was still considered valid and useful due to the fact that the team will also be testing in a locale other than the implementation site.

The team acknowledges that this field is a very large one, and is one outside of our specialty. As such a large majority of our research was not that of articles, but simple instruction and education from our technical advisor on pollution concerns, Dr. Auberle. Multiple forms of carcinogens have been identified, especially within the PAH (Polycyclic aromatic hydrocarbon) family of chemical compounds, that cause adverse health effects as well. Additionally, testing for particulate matter has been identified, and the sampling technology involved. Meetings with Dr. Auberle refined our knowledge into a dedicated experimentation plan. Towards the end of the semester, multiple additional research articles[44,45,46,53,56,57,58,59] were sought out to specifically quantify what we wanted to test (see Section 9.0). This research focused on identifying average CO, CO_2, C_xH_x concentrations in wood fires, as well as particulate matter, ash, and black carbon emissions studies.

2.3 Stove Design Research

Since most of engineering is simply redesign, the team focused heavily on researching existing designs. Many articles about stove design were found, with comparisons, field test results, and data on cultural acceptance of these designs. Most of these articles came from the Aprovecho Research Center in Cottage Grove, OR, or from their affiliates[21,23,25,26,27]. One of the most beneficial sources was a "catch-all" how-to about wood burning stoves for third world implementation, written by researchers at Aprovecho[21]. Additionally, some reports from other university design teams as well as Masters and PhD students were found[5,33].

In an overall sense, many stove designs are relatively similar in concept, varying slightly in dimension changes and fuel and air control designs. A large difference of stove design parameters were found among stoves that differed by area of implementation and type of fuel used. The team gained useful information from these articles, and are basing many of the specifications off of recommendations made by Aprovecho Research Center[21]. "Design Principles for Wood Burning Cookstoves"[21], has essentially turned into the team's reference manual for basic stove parameters. This article contains a list of 10 essential stove design principles; our team has condensed these into four stove design principles. These four stove design principles are the primary goals for all of the designs, without these, the designs fail. These design principles are as follows:

i. All stoves need a well-insulated heat path (chimney); this chimney is recommended to have a height three times larger than its diameter.
ii. Burn the tips of the fuel sticks as they enter the fire; do not arrange the fuel in a stacked pattern. The main goal is to only heat up what is burning, so that pyrolysis does not occur elsewhere on the stick and cause unwanted smoke.
iii. Intake and exhaust systems must be properly calibrated. The ultimate goal is to keep air moving within the stove; it is recommended to utilize grates under the fuel. Utilize constant cross-sectional area across the flue gas path and meter your air according to the fire size.
iv. Increase heat transfer to the pot in any way, keep our flue gases hot and fast moving, increase the surface area of the pot in contact with these gases, and benefit from radiation as much as possible.

2.4 Stove Implementation Research

A large factor of consideration within the field of humanitarian aid is that of acceptance, that is, the question of "will this group of people accept what we are doing?" The preliminary research showed that many initial efforts to introduce clean burning stoves within third world communities have failed due to cultural rejection. Due to this, the team focused a good deal of research on success or failure stories of humanitarian implementation of these stoves (including government subsidization, testing allowances, upkeep records, etc.). A few sources proved very useful to this field, and had information on interactions with locals, observations of cooking styles, and types of foods prepared[18,23].

While much of the research findings were varied and inconsistent in this field, the team recognized that heavy focus should be placed on culturally-aware designs. We have expanded our knowledge of traditional cooking, ingredients, and eating practices in the area. We have also learned about the family roles of women in India, and that most, if not all of the cooking is done by women. The team will be attempting to replicate Indian cooking with Indian tools, and styles, when designing and testing the stoves.

2.5 Manufacturing, Materials and Economics Research

On top of all of the already listed research efforts, a focus has also been placed on manufacturing, materials, and economic aspects to the design. Many considerations of manufacturing can be answered in-house, and do not need be researched. However, due to the fact that the oven will theoretically be manufactured in India (on a large scale), knowledge of manufacturing processes in that nation is required. Additionally, knowledge of materials available, costs, inflation rates, labor rates, and all other manufacturing and business factors in India is required.

This type of research is continuing heavily and much more is expected to be acquired in later phases. We have already acquired a good deal of articles on the topic and have reached a good baseline of what we need to know. We have been surprised by how cheap some designs are reported to be manufactured at, although these prices may be skewed due to inflation and exchange rates[23]. These findings are stimulating the team to further research how to reduce manufacturing costs, in order to create the most versatile, efficient stoves, while keeping costs at a minimum.

3.0 Specifications and Requirements

All specifications have come from the Environmental Protection Agency's (EPA) Waxman – Markey Bill[42] as well as research conducted from the Aprovecho Research Center. We decided to use the specifications from the Waxman – Markey Bill and Aprovecho's interpretation of the Waxman Markey Bill since the X Prize Foundation hasn't given us any specifications or requirements. The specifications state that a clean burning cook stove should:

- Have a total unit cost of $10 or under when produced on a mass scale.
- Reduce fuel use by greater than 50% as compared to a three stone fire.
- Reduce black carbon emissions by greater that 60% when compared to a three stone fire.
- Theoretically reduce the incidence of pneumonia in children under five by 30% or greater. Since this is difficult to test within the time frame of this project, theoretical analysis will be done to determine this quantity.

In order for a project like this to be successful, there are other qualitative requirements that must be met. These include:

- The stove must be accepted by the local user
- Must be safe to user and by-standers. No extreme temperatures on the outside body of the stove. No sharp edges, corners, handles or parts can be present. Mainly catered towards women, children, and elderly as they will be the ones using the stove the most.
- Must be easy to operate, ergonomic and compatible with the end-user technology.
- Must abide by any emissions laws in India
- Must be easy to service and clean.

4.0 Other Design Concepts

Before the team could get started building a cook stove, we had to come up with ideas on how to make a more efficient stove. This brainstorming resulted in three design ideas. One of which was chosen for our final design and the other two being discarded. These two are described in the following sections.

4.1 Design 1: Modified Open Fire

Starting with the basic idea of pre-existing cooking methods in India, our first design concept was a slight modification of an open fire style cooking stove, which can be seen in Figure 2. This design improves the efficiency of the traditional open fire by placing a column over the fire to channel heat to the pot more effectively and also promote better burning of combustion gases. The stove utilizes a grate which holds the fuel and allows air flow from underneath the fire which has been shown to increase combustion efficiency. Another important design characteristic is the implementation of a skirt that adjusts to wrap around the pot and serves to maximize heat transfer to the pot itself. A basic flow analysis was performed in SolidWorks Flow Simulation and a velocity profile due to buoyancy forces from the fire was generated. We can see in Figure 3 that this design results in fairly uniform, steady flows up the chimney.

This design was not chosen because the team and client decided that it was not a truly original idea. Since heat would be escaping near the fire, this stove would be less efficient as well.

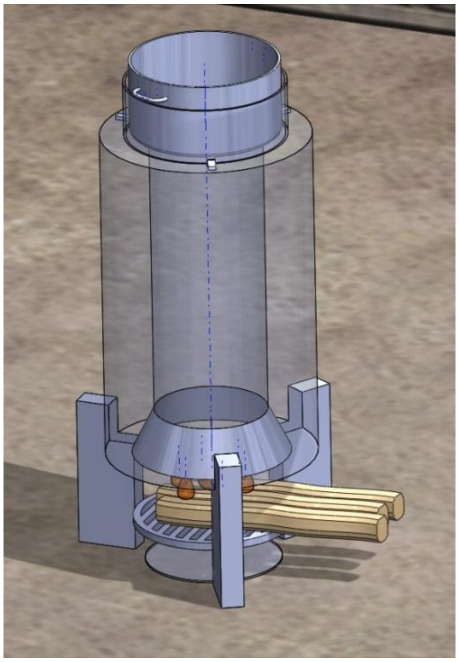


Figure 2 - Design 1: Open stove modification

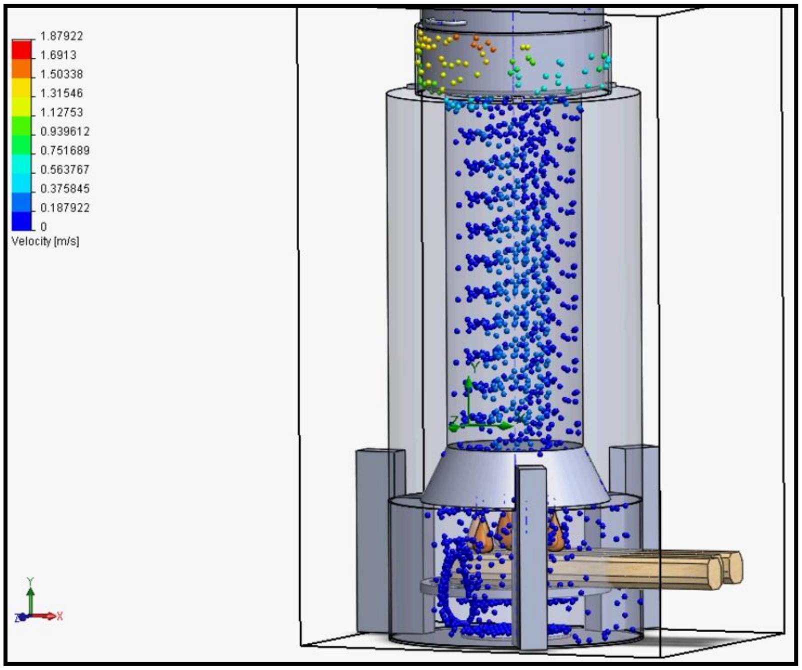


Figure 3 - Design 1 Flow Analysis, Velocity Profile

4.2 Design 2: Aprovecho Inspired Rocket Stove

Design concept two is essentially modeled off of the already existing "Rocket Stove" created at Aprovecho Research Center with some minor modifications. This design can be seen in Figure 4. Again this stove implements both a pot skirt and a grate to support proper burning of the solid fuel. The column height and width will be determined to account for maximum combustion efficiency. Designs similar to this have been used with great success. Again, a flow analysis of this model was performed; this flow simulation was more promising due to fewer assumptions having to be made since its inlets and outlets were the same as a real life situation. Figure 5 shows the SolidWorks Flow Simulation of this stove. We can see a larger influence of the fire on buoyancy force and such air speed; we assume this is due to the larger amount of air and fuel constriction within the inlet passages and fire path.

This design was not chosen because it had already been heavily researched and implemented. We would just be reinventing the wheel and our client agreed that this would not be a useful endeavor. We wanted to attempt to create something entirely new, and see if we couldn't make a startling breakthrough in this science.

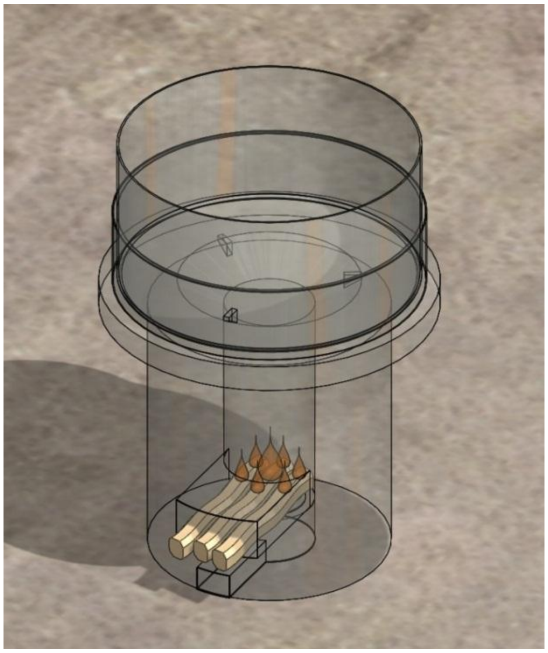


Figure 4 – Design 2: Aprovecho Inspired Rocket Stove

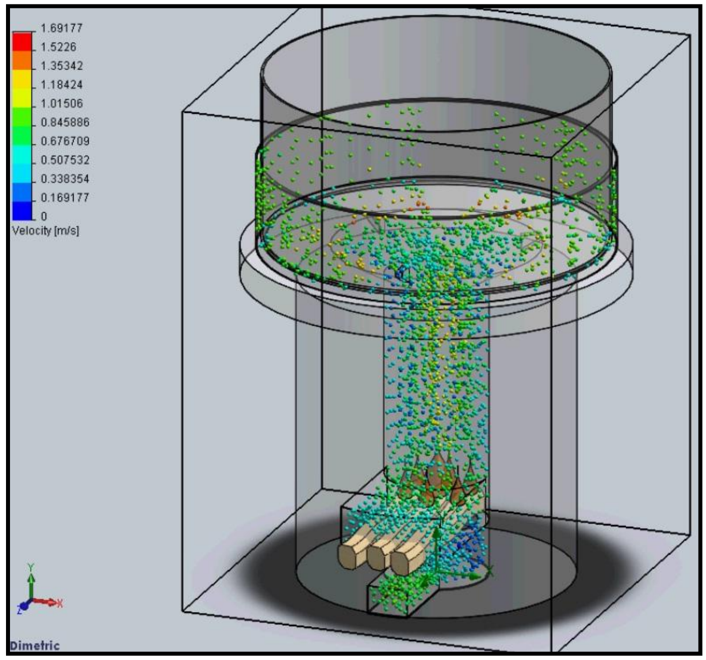


Figure 5– Design 2 Flow Analysis, Velocity Profile

4.3 Universal Design Additions

Each of the three proposed design concepts described above are based on the four design principles that have been found to be vital to the performance of an efficient stove. Research of current clean wood stove initiatives has shown that several other design additions can be incorporated to improve stove efficiency and user response. These design additions include chimneys, expansion for variable types and sizes of cooking surfaces, and gravity fed fuel chutes. These additions have been incorporated in order to better suit the needs of individual users and will be compatible with any of the three design concepts. Our stove has been designed with compatibility with these additions in mind.

Externally Venting Chimneys

Research has shown that there is disagreement between clean burning cook stove developers on the issue of using chimneys. Incorporating a chimney allows harmful pollution to be directed out of the building and away from the user. However, this addition may require penetrations through the exterior of the structure in which the stove is used. This poses a problem in the cost and time required to implement the stove. The optional chimney would attach to the pot skirt or upper portion of the stove flue column and will allow the user to further decrease their exposure to harmful pollutants if he/she decides it is appropriate. Since our pot skirt is separate from the stove body, a chimney attachment would be easy to attach in the same manner the pot skirt is.

Multiple & Variable Size Pot Adjustments

The stove should be designed to suit the needs of different user groups. The universal cooking interface inherent to the design would allow the stove to work with varying size pots as well as flat griddle type surfaces. These additions will be incorporated into the stove design and may include a large, flat surface for the pot or griddle to rest. The design will allow for the use of an adjustable pot skirt which will also be included with the stove. Also, the stove will be designed to allow for an optional second cooking surface which would allow the user to cook two dishes at once. It should be noted that this addition will decrease efficiency of the stove; combustion and pollution analysis on the stove will be performed without the addition of the second cooking surface. A secondary cooking surface could easily be added as a "slip-over" attachment to our top portion of the stove.

Gravity Fed Fuel Chutes

The third design addition uses a sloped fuel chute to facilitate automatic fuel feed into the combustion chamber. This allows the user to spend less time tending the fire and more time cooking. The fuel chute would be long enough to fit long sticks. The basic design involves a self-closing fuel door at the inlet of the chute which would close as the fuel recedes into the chute. This would close off air supply to the fire from the fuel opening so that combustion air is only supplied from below the fire, thus increasing combustion efficiency. This addition has actually been implemented in our final design and has proven to work quite well.

5.0 Final Design

Our final design was chosen by the client and team because of the originality of the design and the potential to severely increase thermal efficiency and decrease pollution emissions.

5.1 Heat Exchanger Style Preheat Stove

The biggest design characteristic of concept three is the implementation of a preheating system that can be seen in Figure 6 and 7. The idea comes from large-scale solid fuel furnaces and home use, wood burning heating stoves, both of which utilize preheating systems. This design is equivalent to a concentric cross flow heat exchanger (see Figure 8). This design was chosen as the final design because research and testing has shown that this method will provide the combustion process with preheated air to further improve combustion efficiency without disturbing the natural draft produced by the fire. Flow Simulations have been performed on this design concept, and we see that the buoyancy force from the fire is predicted to drive air in from the top inlet ports, down our outside tube, and direct the preheated heated air into our combustion chamber. Theoretically, this preheated air will cause the fire to burn hotter, and consequently cleaner, emitting fewer pollutants. Similar to design concepts one and two, concept three will also use a grate and pot skirt. Several SolidWorks CAD (computer aided design) models were created. More detailed drawings can be seen in Appendix D.

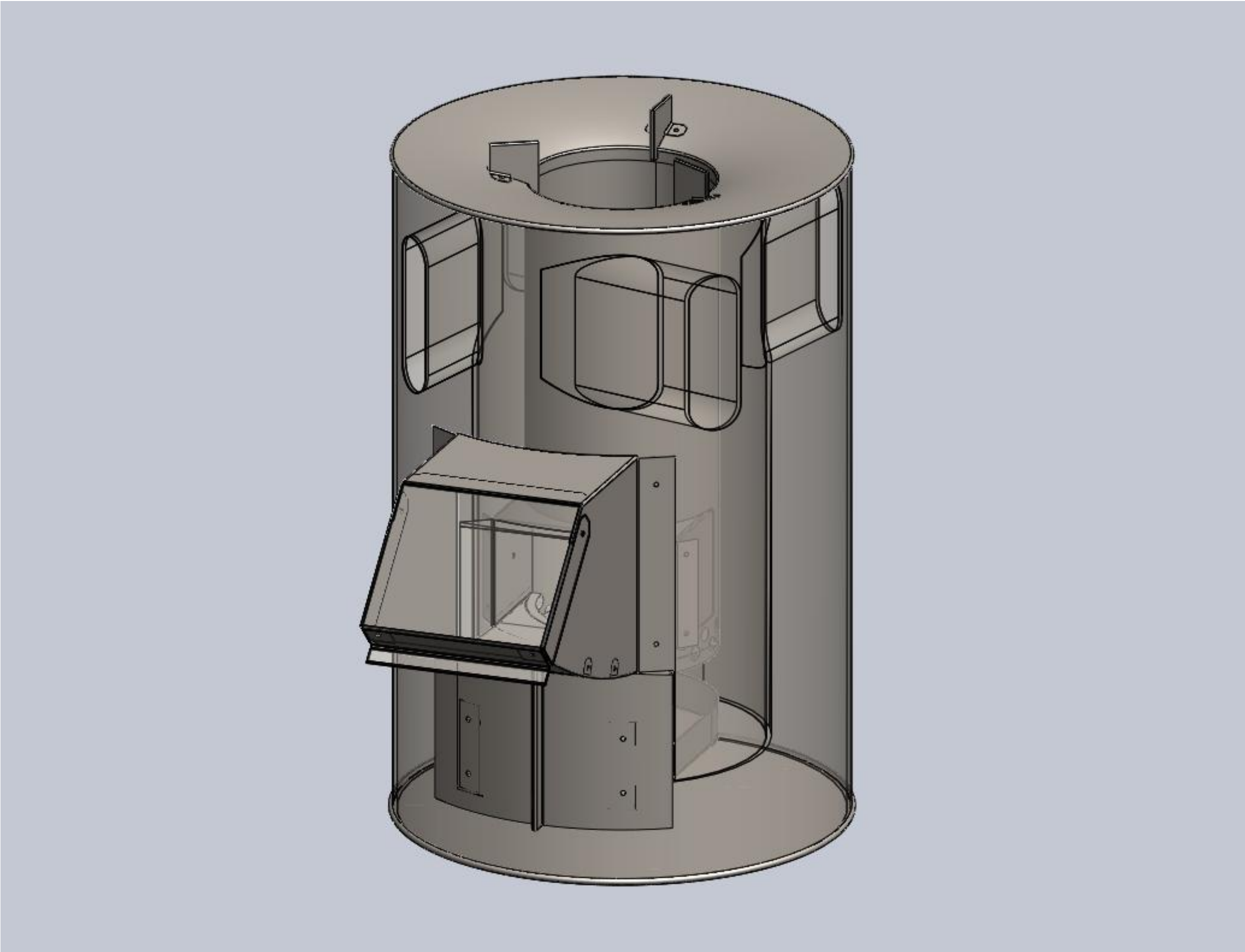


Figure 6 - Final Prototype CAD Model

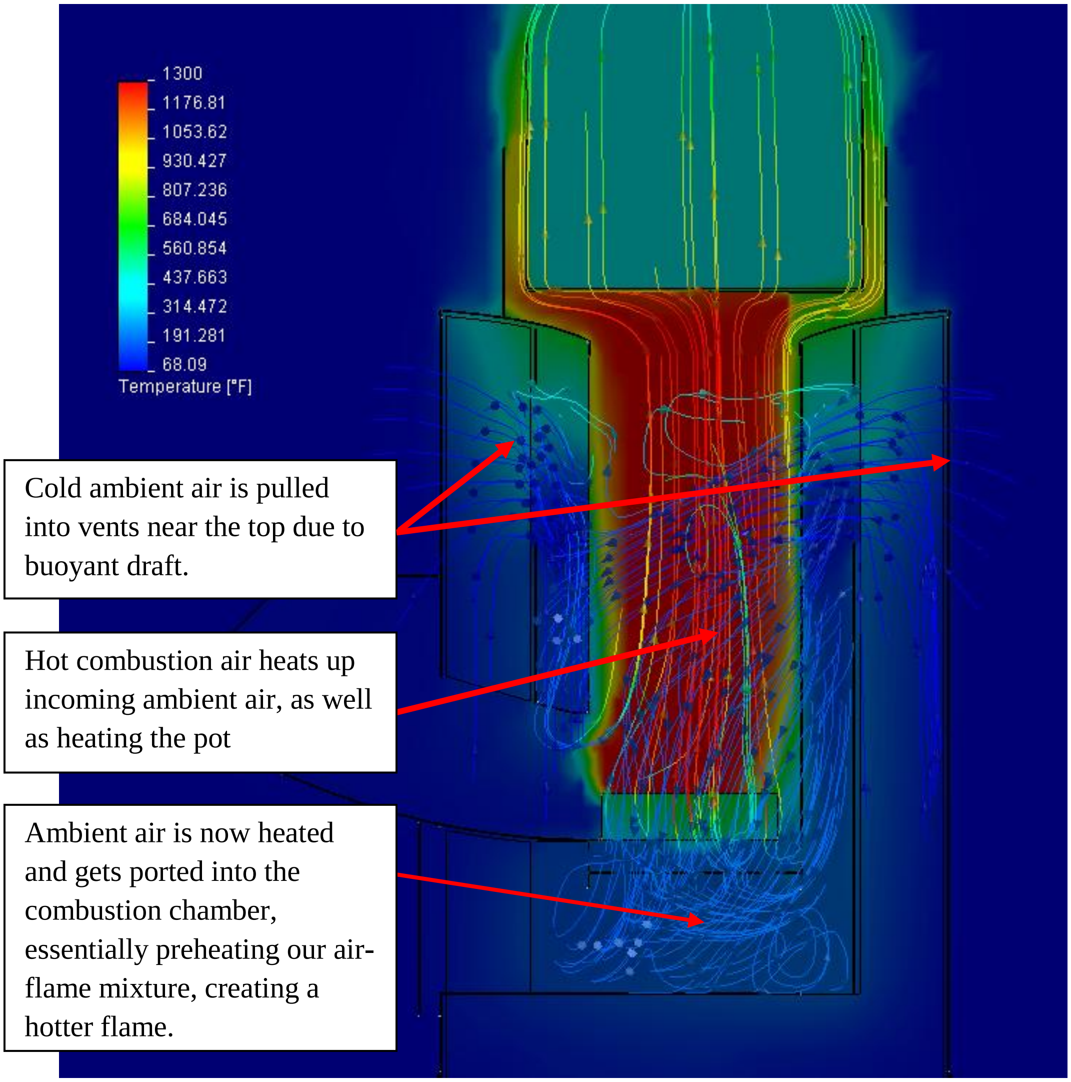


Figure 7 - Design 3 Flow Simulation, Temperature Profiles

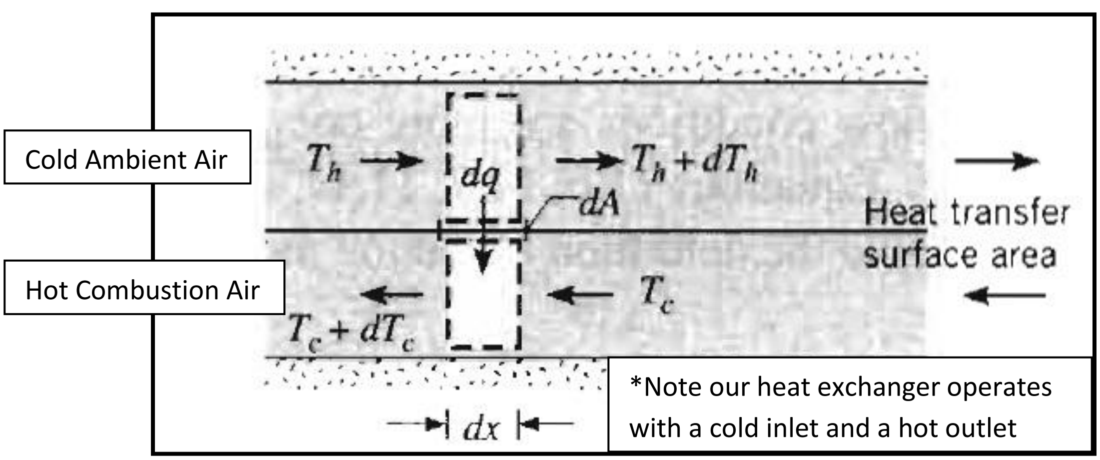
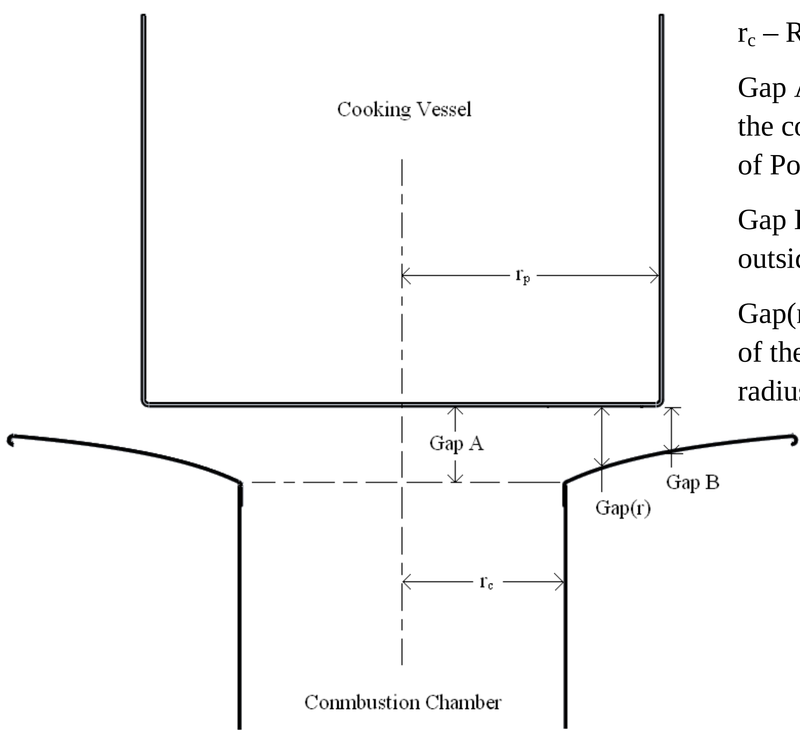


Figure 8 - Schematic of a Cross-Flow Heat Exchanger, Section view of one "wall" only, does not show the inlet and outlet ports.

5.2 The Ideal Stovetop Shape

Efficient combustion requires proper air circulation. For this reason, improved solid fuel stoves are designed to have a constant cross-sectional area for the path of airflow through the stove. Additionally, maintaining a constant cross sectional area for the air flow path can improve heat transfer to those surfaces in direct contact with the hot gasses by increasing the flow velocities at these surfaces. This improvement in heat transfer is especially important where the flue gasses are in direct contact with the cooking vessel. By optimizing the shape of the stovetop to maintain constant cross-sectional flow, the amount of heat transferred to the food can be increased.

The following derivation, presented in Figure 9, presents the ideal stovetop shape to maintain a constant cross sectional area through the path of the flue gases exiting the stove. The following derivation assumes the cooking vessel has a flat bottom and the combustion chamber has a circular cross section at the exit.



r_p – Radius of the pot

r_c – Radius of combustion chamber

Gap A – Needed gap from the top of the combustion chamber exit to bottom of Pot

Gap B - Needed gap from the bottom outside edge of pot to the stovetop

Gap(r) – Needed gap from the bottom of the pot to stovetop as a function of radius

Figure 9 - Schematic of Stove and Flat-bottom CookingVessel

Since we want to maintain a constant cross sectional area for the air flow path, we begin be calculation the cross sectional area of the combustion chamber, "A" from the area of a circle.

$$A = \pi {r_c}^2$$

Gap A represents the needed gap to maintain this same area through the imaginary cylinder at the top of the combustion chamber. From the area of a cylinder with the same radius as the combustion chamber,

$$A = \pi {r_c}^2 = 2\pi r_c \cdot Gap\ A$$

$$Gap\ A = \frac{\pi r_c{}^2}{2\pi r_c} = \frac{r_c}{2}$$

Similarly, the needed gap from the bottom of the pot to the stovetop as a function of radius can be found from the area, A.

$$A = \pi r_c{}^2 = 2\pi r \cdot Gap(r)$$

$$Gap(r) = \frac{\pi r_c{}^2}{2\pi r} = \frac{r_c{}^2}{2r}$$

The next step is to find the function, f(r) that represents the ideal shape of the stovetop to maintain the proper gap, Gap(r). The ideal shape is a function of the needed gap, Gap(r) and the shape of the bottom surface of the cooking vessel. Since the cooking vessel is assumed to have a flat bottom, this function will be a constant minus the needed gap:

$$f(r) = C - Gap(r)$$

By setting a boundary condition to the function such as $f(r_c)=0$, we can solve for the constant, C. Then solve for f(r) that represents the ideal shape of the stovetop to maintain the proper gap (Figure 10).

$$f(r_c) = 0 = C - Gap(r_c) = C - Gap\ A = C - \frac{r_c}{2}$$

$$C = \frac{r_c}{2} = Gap\ A$$

$$f(r) = Gap\ A - Gap(r) = \frac{r_c}{2} - \frac{r_c{}^2}{2r}$$

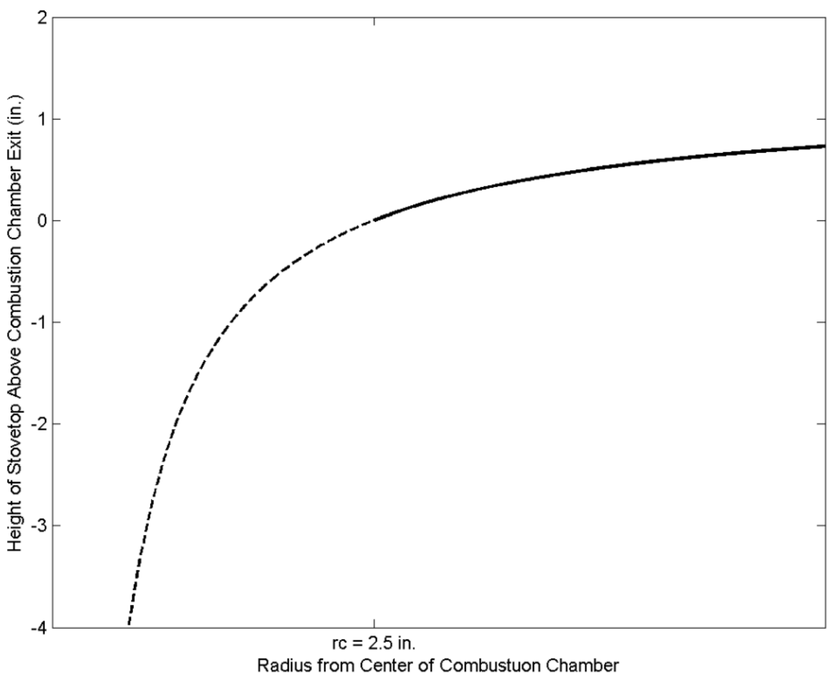


Figure 10 - Ideal Stovetop Shape as a Function of Radius for a 2.5 in. Radius Combustion Chamber (Solid line is where the actual stove geometry starts, i.e. the radius of the combustion chamber)

This ideal stovetop shape was compared to cone-shaped stovetop using SolidWorks Flow Simulation. Figure 11 shows the simulation results for a cone-shaped stovetop (left) to the ideal stovetop shape (right). The two simulations are identical in every way except for the shape of the stovetop. The simulation predicts a slight increase in the amount of heat being transferred to the pot. This is because the ideal shape forces the hot flue gasses to be pressed against the bottom surface of the pot, which increases flow velocities, thus increasing heat transfer.

Because of these results, the team decided to use this ideal stovetop shape in the final design of our stove even though this increase in heat transfer is slight. This shape was also chosen because the change does not add any cost to the stove. The stovetop is made from thin gauge sheet metal and will be drawn to achieve the desired shape; this shape does not change the press force requirements drastically. This process will be the same whether the stovetop shape is conical or idealized.

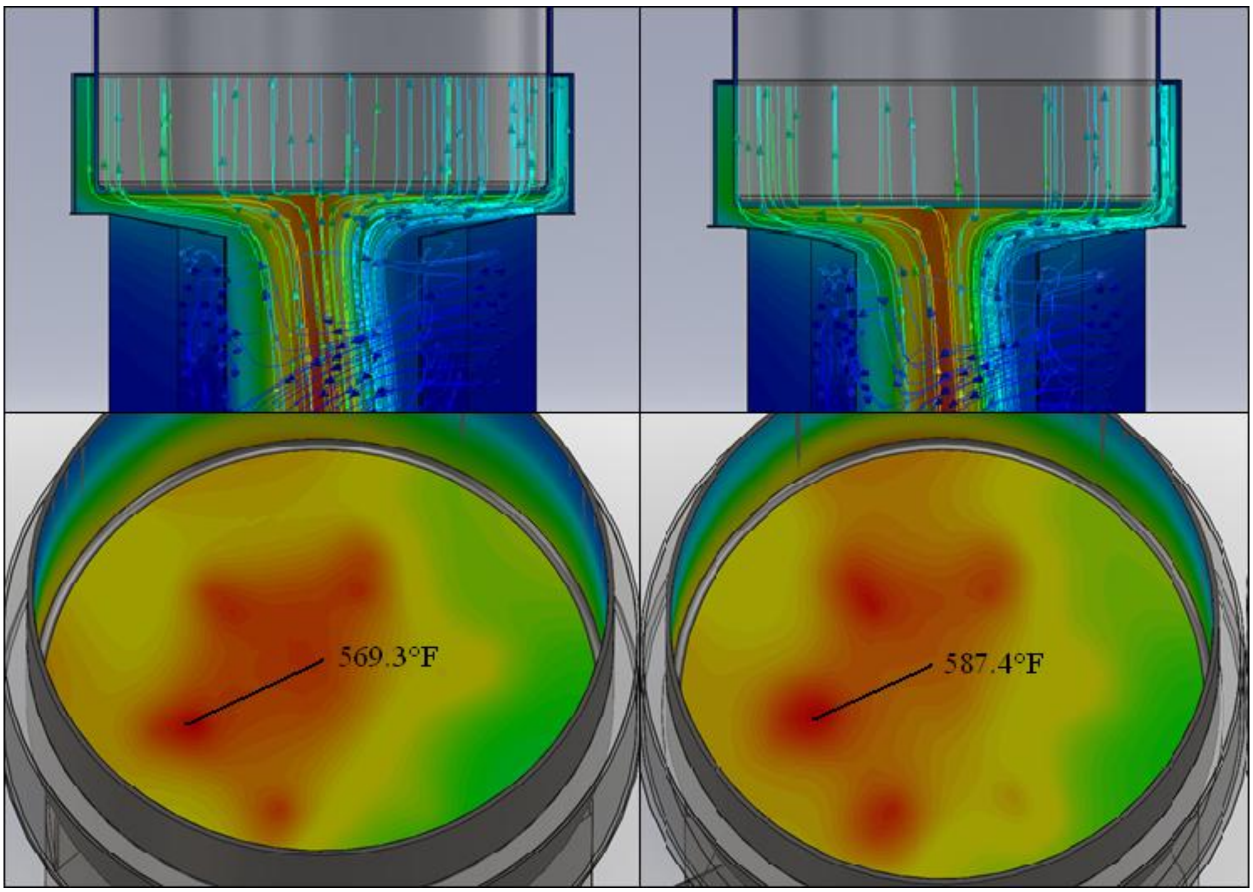


Figure 11 - Comparison of Cone-Shaped Stovetop and Ideal Stovetop Shape for a Flat Bottom Cooking Vessel

5.3 Three Prototypes

During the course of the project, our team decided to create three prototypes. Each prototype built off of the deficiencies observed in the previous prototype's general functionality.

5.3.1 First Prototype

Figure 11 – First Prototype

The first prototype was created to determine the functionality of the heat exchanger concept. This prototype can be seen Figure 11. This prototype was fabricated from donated material which included galvanized steel sheet metal, aluminum sheet metal, thick aluminum tubes, and loose fill vermiculite and lava rock as insulation.

Although this prototype successfully demonstrated the heat exchanger concept, there were several issues with its fabrication and usability. The fabrication of this prototype involved excessive welding and riveting. The pot stands extended to the outer radius of the stove which interfered with the pot skirt. The horizontal fuel chute allowed excessive air to enter the stove where we did not want it to. The bottom of the stove lacked insulation. Additionally, air inlet ducts had to be made in order to keep the loose fill insulation from falling out. Overall, this prototype was a success and was useful in developing our design. Based off the deficiencies of this prototype, a second prototype was created.

5.3.2 Second Prototype

Figure 12 - Prototype Two

The second prototype was created using scavenged steel and purchased materials for the insulation core. This prototype can be seen in Figure 12. The purpose of this prototype was to conduct fuel consumption tests and thermal behavior tests as well as improve upon the previous prototype. These results can be seen in Section 7.0 and 8.0. Changes from the first prototype include:

- Exclude galvanized steel and aluminum – Galvanized steel emits harmful chemicals when heated. Aluminum acts as a heat sink due to its high thermal conductivity, drawing heat away from the cooking food.
- Solid refractory insulation core - The refractory insulation core was created out of 75% vermiculite and 25% sand/cement/lime combination and enough water to make the mixture uniformly moist. The mixture was tamped into a cardboard and wood mold in order to give it strength and
- Change fuel chute – Instead of having a horizontal short chute, we want to change it to be a gravity fed fuel chute so that the user will not have to tend the fire as often.
- The pot stands were altered to allow for the use of a pot skirt.

5.3.3 Third Prototype

Figure 13 – Prototype Three

This prototype is the final design. This prototype can be seen Figure 13. The purpose of this design was to improve upon previous prototypes in terms of cooking efficiency and manufacturability. This design incorporates all manufacturing aspects that will be used if the stove is mass-produced. This prototype was designed to be manufactured efficiently and quickly. It uses only sheet metal processing equipment, concrete refractory ingredients and rivets to assemble. A more detailed account of the manufacturing can be seen in Section 10.0 and 11.0. All edges are more rounded to create less sharp edges. The insulation was increased by half so that during steady state operation, the outer surfaces of the stove would be safe to touch. There is a hinged fuel chute cover to prevent cold air from entering the fuel chute. Additionally, this design utilizes the ideal stovetop shape discussed in Section 5.2 to increase thermal efficiency.

6.0 Theoretical Modeling and Prototypes

The team conducted an extensive theoretical model using SolidWorks Flow Simulations to approximate thermal and air flow behaviors of all three prototypes. The inputs for these models are the stove dimensions, material properties, flame temperature, and atmospheric conditions. These simulations lead us to the design or our angled air inlets which induce a swirl of air entering the stove. This rifling effect of the air entering the stove creates less pressure loss which allows the air to flow more freely and also increases the area of contact on the heat exchanger surface which increases the temperature of the air before combustion. The results of this model predict temperature and velocity distributions throughout the stove. The model of our first prototype helped us to refine our design by showing the problem areas. For instance, our first model predicted that hot air was escaping out the air vents at the top of the stove and that the flow was being obstructed by the “fingers” supporting the combustion chamber as seen in Figure 14.

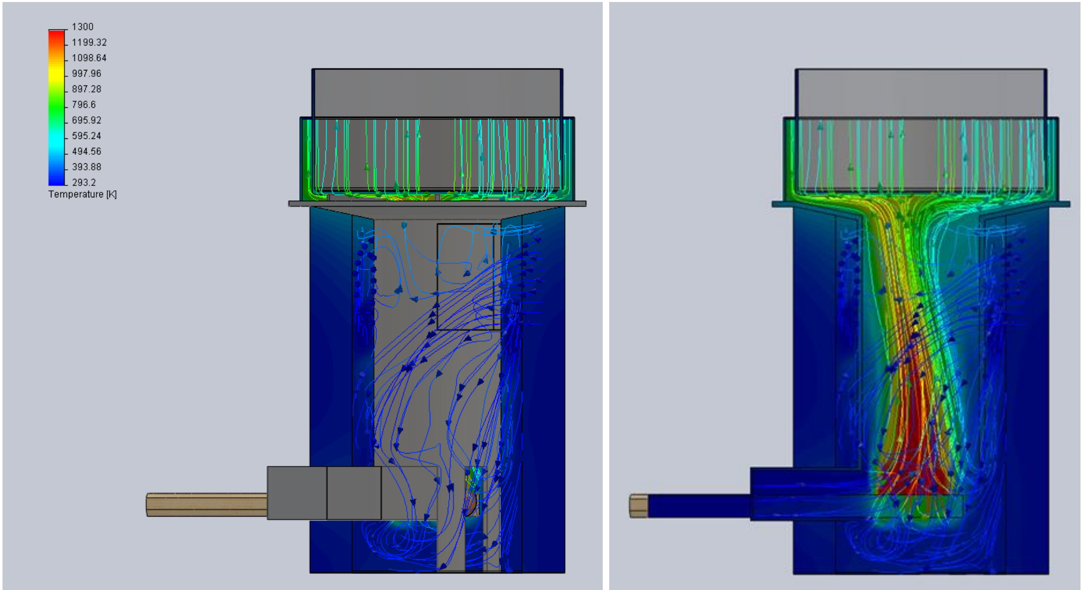


Figure 12 –Cross-section of Prototype 1 Theoretical Model - Temperature Plot (293-1300K)

Using the insight from these simulation results and testing, we have refined our stove design and have built a second prototype with a corresponding theoretical model. Our new stove has an angled (gravity fed) fuel chute, steel instead of aluminum or galvanized metal, air flow is less obstructed and the insulation material has changed to lightweight refractory cement. The model corresponding to our second prototype predicts improvements in air flow and heat transfer to the cooking surface as seen in Figure 15. The next stage of this theoretical model was to modify it with experimental data. We used plots like the ones in Figure 15 to compare with temperature measurements of our second prototype during operation. The model inputs were then refined to better predict the stoves behavior.

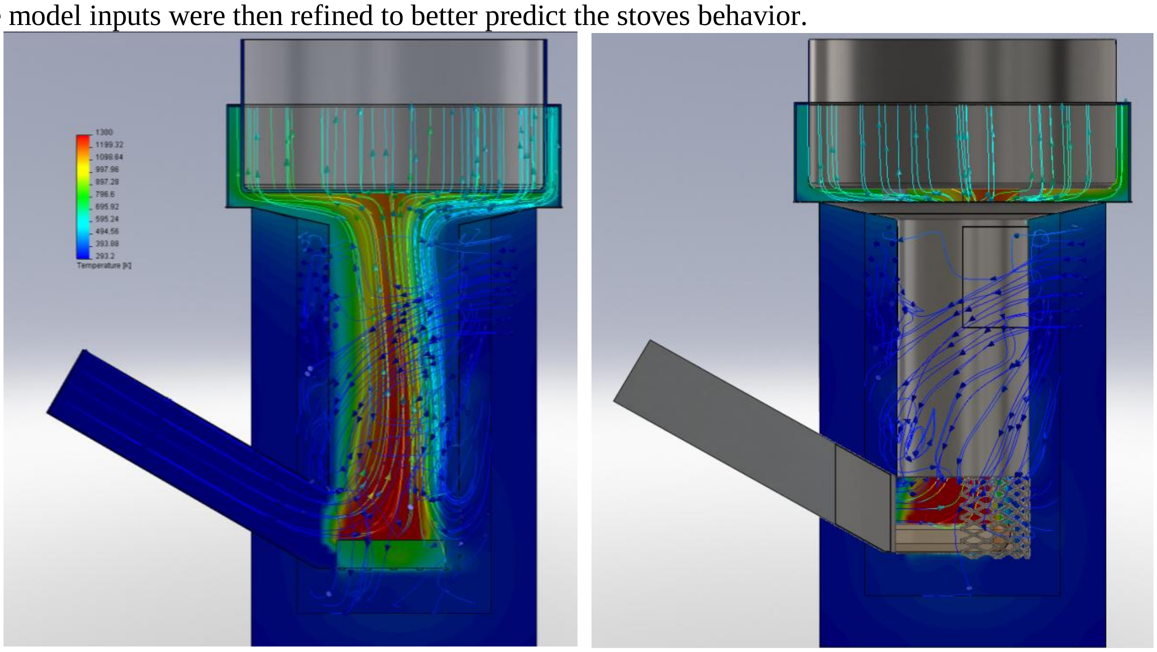


Figure 15 –Cross-section of Prototype 2 Model 1 - Temperature Plot (293-1300K)

After extensive testing of our second prototype (see section 7.0 for a complete description), the team was able to observe the discrepancies between the test results and the theoretical stove model. The updated flow model, which can be seen in Figure 16, was converted into U.S. customary units to match our testing data. The model also uses the same size pot and pot skirt as used for the testing. The most significant changes to the old model were the size, shape and temperature of the virtual flame in the model. The volume of this flame is set at a constant temperature which air is able to pass through. This induces the draft force in the stove which in turn transfers heat to the pot. The parameters of this virtual flame have a large effect on temperature distributions in the stove, because of this, the team improved on this area of the model. The updated model has larger taller flames that extend nearly to the bottom of the pot and the flame temperature was changed from 1880° Fahrenheit (F) to 1300° F. These new flame parameters closely represent the flame conditions during testing which results in a more accurate model. Table 1 shows the temperatures predicted by the model at the locations where thermocouple data was taken in the stove. The second part of the table shows the error in the model associated with each measurement. The largest errors in this model are in the bottom of the combustion chamber. The team believes this is due to the inconsistent and chaotic nature of diffusion flames, and that the thermocouples were not verified to be physically in the hottest part of the flame. The thermocouples seemed to "max out" at 1000° F, signifying either a limit in our LabVIEW VI or thermocouple readings. All of these factors caused the team to believe that we should leave our theoretical flame temp at the value of 1300° F (a conservative flame temperature value) and not the measured values of 800° F.

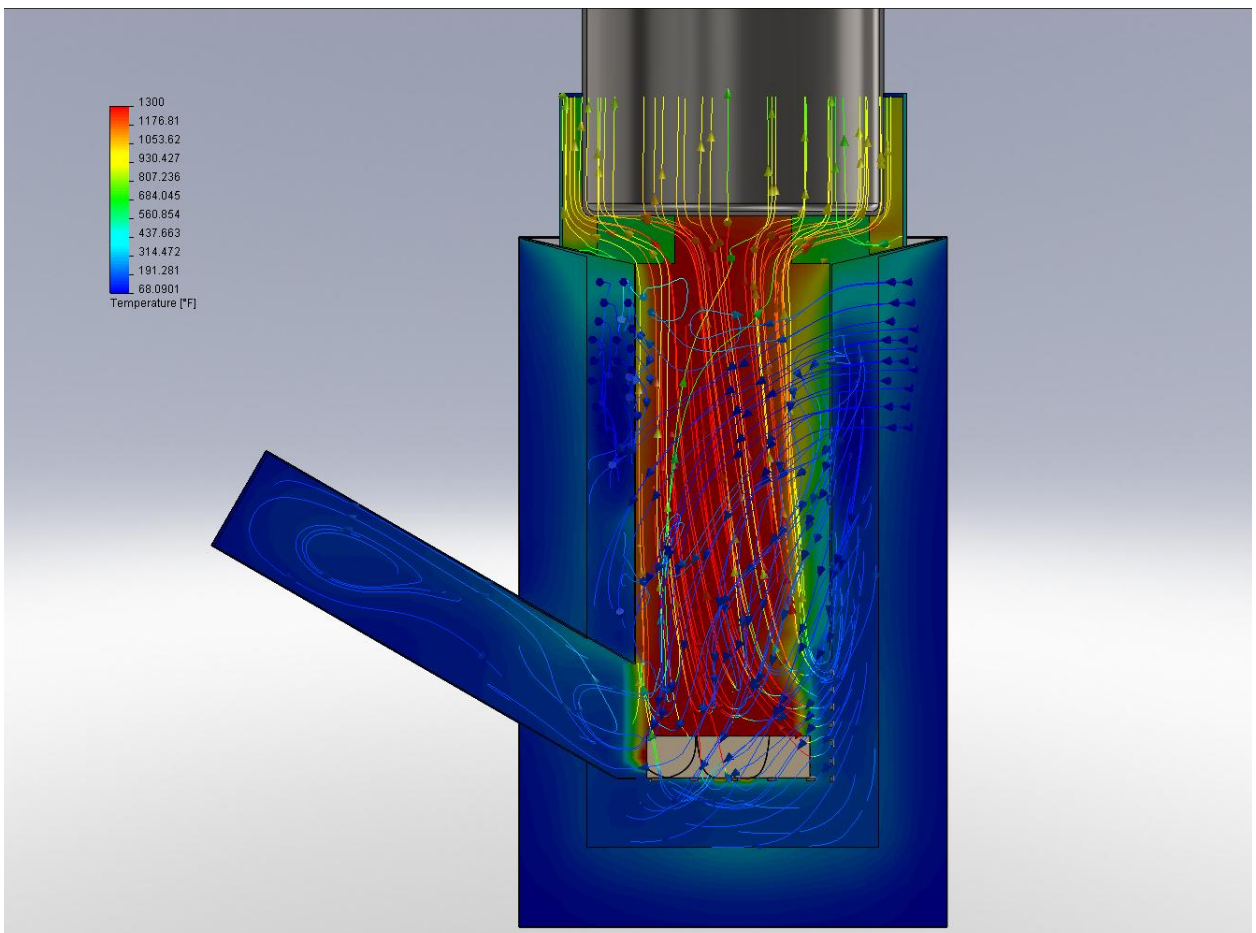


Figure 16 –Cross-section of Prototype 2 - Updated Model - Temperature Plot (68-1300F)

Table 1: Temperatures Predicted by Model and Associated Errors

Test: Type	Bottom of Combustion Chamber (°F)	Top of Combustion Chamber (°F)	Bottom of Heat Exchanger Surface (°F)	Top of Heat Exchanger Surface (°F)	Top of Inner Insulation (°F)	Bottom of Outer Insulation (°F)
Temperatures Predicted by Model						
Model	1300	1176	684	437	437	68
Percent Difference from Test Data (See Figure 1) % Difference = Absolute Value[(Theoretical-Experimental)/Experimental]						
Test 2: CS	65%	46%	16%	5%	No Data	49%
Test 3: HS	66%	74%	6%	5%	6%	59%
Test 4: CS	113%	47%	16%	3%	22%	44%
Test 5: HS	52%	No Data	No Data	No Data	No Data	No Data
Test 6: CS	102%	47%	17%	14%	11%	55%
Test 7: HS	56%	40%	12%	3%	10%	65%

Using the results of the simulation and testing results corresponding to the second prototype, we refined our stove design and have built a third and final prototype with a corresponding theoretical model that can be seen in Figure 17. Our new stove still has an angled fuel chute and uses steel instead of aluminum or galvanized metal. The results of the second prototype simulation revealed an imbalance in the temperatures within the combustion chamber of the stove. Figure 15 shows colder temperatures toward one side of the combustion chamber of prototype two. This was caused by cooler air entering the combustion chamber prematurely through the opening on the back side. Because of this, the design of the final prototype does not include air openings on the back side of the combustion chamber. The model corresponding to our final prototype predicts improvements in air flow and heat transfer to the cooking surface. The theoretical analysis can be seen in Figure 17.

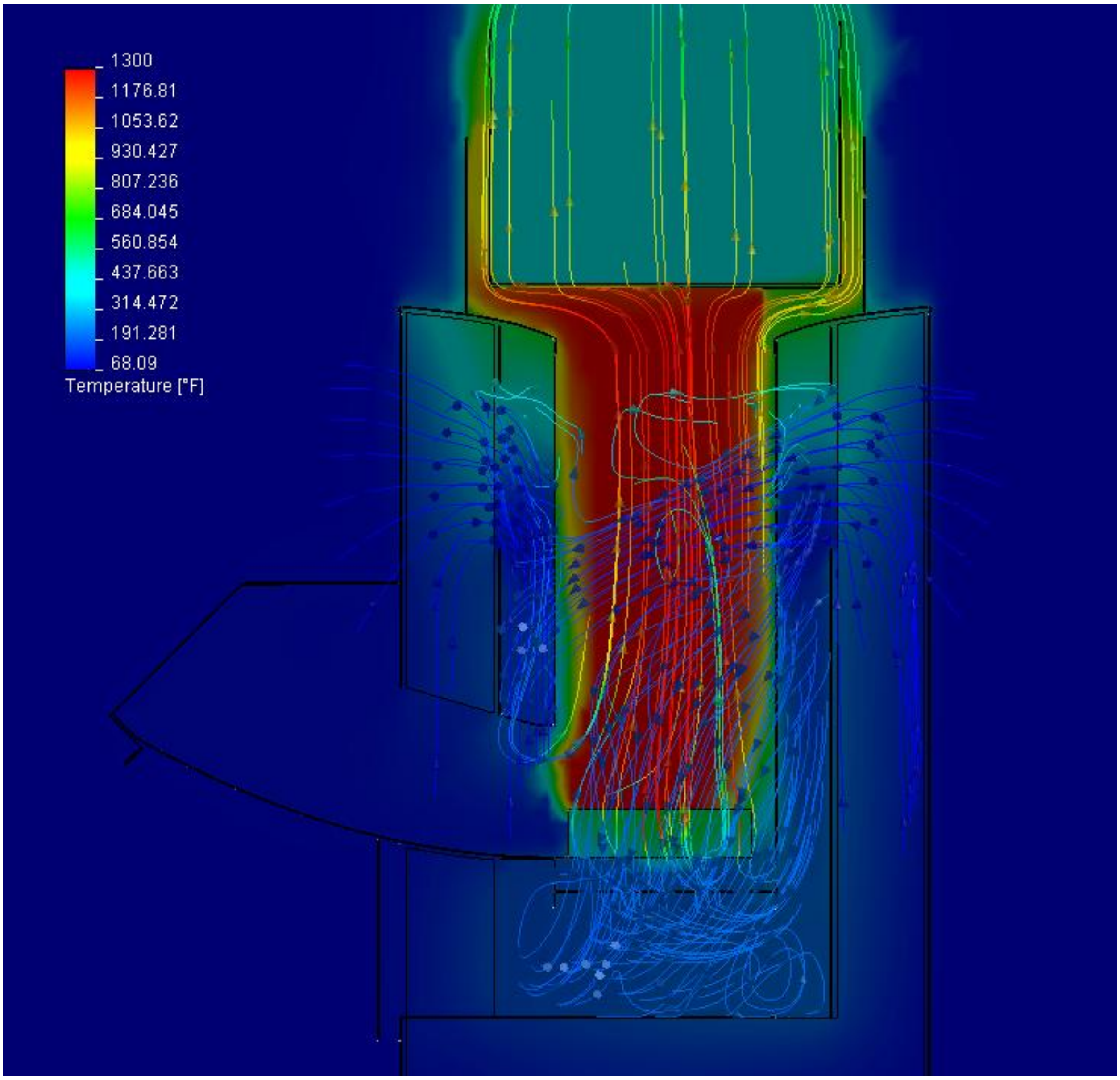


Figure 17 - Cross-section of Prototype 3 Theoretical Model Temperature Plot

7.0 Fuel Consumption Testing

Fuel consumption was recorded so that our team can determine if we reduce fuel use by the specified 50%. This testing was conducted throughout our project and the methods below were conducted during any type of testing of our stove (since these measurements were always able to be taken, regardless of the other measurements being made).

7.1 Method

The team tested the stove for a few functionality parameters aside from thermal and airflow behaviors that are described in Section 8.0. These parameters will be related to the speed and ease of cooking, as well as the fuel consumption and useability. Many of these parameters are qualitative ones, simply related to how "easy" we feel it is to use our stove. The parameters that will be numerically measured are as follows:

- *Fuel Consumption:* Fuel will be measured before the burn, and remaining ash/unburnt fuel will be measured afterwards. The remaining ash vs. burnt fuel will be measured and compared to other tests, as well as the Aprovecho Rocket Stove. The team will use this test to ensure we are meeting one of our main design requirements of decreasing fuel consumption by greater than 50%.
- *Time to First Boil:* The team will measure the time it takes to boil water from cold-start, this will be conducted by tending to the fire as regulary as possible to ensure a semi steady-state heating source. This test will ensure that our stove is adequately fast in order to be just as appealing as an open-fire to the end user.
- *Simmering Time without Fuel Addition:* The team will measure the time the water will continue simmering after a boil has been reached, no fuel will be added and this time will purely be powered by the existing hot coals in the stove. This will test to see how feasibly one can "slow-cook" on a lower temperature with our stove to compete with an open fire's functionality.

The team conducted multiple water boil and cooking tests. These tests were conducted outdoors during varying times of the day with varying temperatures and wind conditions. These tests closely resembled the water boil test format proposed by Aprovecho Research Center[62]. The process involved in these tests is as follows:

Test Type 1 - Cold Start Boil Test: The stove is initially at a "cold" state (all surfaces roughly less than 120 degrees Fahrenheit), and a fire is lit/kindled in this state until a steady flame is reached. Upon reaching a steady flame, a timer is started and our boil test timing begins. We time how long it takes to boil 64 ounces (1.89 liters) of water in a 5 quart (4.73 liters) stockpot (capped with lid). This time and all amounts of wood needed to get there are recorded (including kindling and starter). Once a boil is reached, time is recorded again. If there is still wood left in the fuel chute, a "duration of boil" time is recorded. This allows all boiling due to burning wood to be accounted for. Once this wood is fully consumed and in charcoal format (i.e. no brown wood left) time is recorded again. This recorded time is now considered the start of our "simmer" phase, where the stove simmers water only on the heat of the coals. Once the water reaches roughly 165° F (when the bubbles stop), the time is recorded again and the simmer length is re-calculated. The heat is allowed to cool a bit more and then the ash remains are weighed. At the end of the test the user will have collected data on boil times, simmer times, total wood use, total ash produced, and consequently the ash/fuel ratio (an efficiency parameter).

Test Type 2 - Hot Start Boil Test: This test must follow directly after another burn test (usually a cold start test). This is simply due to the fact that this test revolves around starting a new fire after the stove is heated up from previous use (to simulate sequential cooking of meals/dishes). This new fire is set up in a clean chamber (ash is cleaned out and weighed for the previous test). The test setup is exactly the same as the aforementioned cold start test, with one major parameter changed. This parameter is that upon simmer, the fire is not allowed to die out on its own, and the user is required to continue adding fuel to maintain a constant simmer. This new simmer stage is our "third test" described next.

Test Type 3 – Simmer Functionality Test: The simmer reached in test two is to be maintained for 45 minutes and the amount of added fuel during this time period is measured. This measured amount of fuel will still be added to the total amount of fuel used (as both test types are conducted in one "run" or "test"). At the end of this test (which includes test types two and three), the user will have all the same data collected as in a cold start test. Additionally, one more parameter (the wood used for simmer) is collected to gather an understanding of the stove's efficiency during cooking operations in comparison to startup operations.

Additional Test Changes – Food Preparation: During three tests (noted in Table 2 as 0B, 2, 7) food was prepared using the simmer stages of these boiling tests. As such the water amounts changed and certain timings were skewed to match the food preparation. These tests were done primarily to ensure that the stove behaved well for food preparation instead of only water boiling. In general, the only negative impact observed on cooking food was that of a slightly unsteady heating source (due to the chaotic nature of wood fires).

7.2 Fuel Consumption Results

Table 2 shows the average fuel consumption for prototype 2 whereas Table 3 shows the average fuel consumption for prototype 3. The full data for fuel consumption for prototypes two and three can be seen in Appendix A.

Table 2: Individual Test Results, Cold Start average results, and Hot Start/Simmer average results for prototype two

Test: Type	Time to Boil	Boil Duration	Simmer Duration	Wood For Simmer	Total Wood Used	Ash	Ash/Fuel Ratio (A/W)
Test 0A: CS No TCs	11m 30s	13m	8m	n/a	13.5oz	0.6oz	0.044
*Test 0B: CS No TCs (Rice)**	12m 30s	n/a	24m 50s	4.0oz	18.7oz	0.3oz	0.016
Test 1: CS	16m 45s	15m	19m 15s	n/a	18.2oz	0.3oz	0.016
Test 2: CS	17m	8m	15m	n/a	17.2oz	0.5oz	0.029
Test 3: HS/S	9m 30s	6m 30s	45m	5.8oz	18.2oz	0.2oz	0.011
Test 4: CS	13m 20s	4m 10s	11m 20s	n/a	8.6oz	0.2oz	0.023
Test 5: HS/S	11m	4m	45m	9.3oz	19.9oz	0.2oz	0.010
Test 6: CS	12m 30s	4m 10s	14m 20s	n/a	11.3oz	0.4oz	0.035
Test 7: HS (Rice)*	8m	5m	23m	n/a	12.4oz	0.3oz	0.024
CS Averages	**14m 13s**	**8m 52s**	**13m**	**n/a**	**13.76oz**	**0.4oz**	**0.030**
HS/Simmer Averages	**10m 15s**	**5m 15s**	**45m**	**7.55oz**	**19.05oz**	**0.2oz**	**0.0175**

*Test 0-B used 32oz water, Test 7 used 36oz water, not the Standard 64oz. These are not included in any averages except a/f ratio (since it is a dimensionless value not affected by scale).

Table 3 – Individual Test Results, Cold Start Average Results, and Hot Start/Simmer Average Results for prototype three

Test: Type	Time to Boil	Boil Duration	Simmer Duration	Wood For Simmer	Total Wood Used	Ash	Ash/Fuel Ratio (A/W)
Test CS1	7 m 30 s	4 m 30 s	9 m	n/a	8.9	0.4	0.045
Test HS/S1	10m 45 s	4 m	45 m	5.8	16.3	0.2	0.012
Test CS2	9m 45 s	4m	6 m	n/a	8.7	0.4	0.046
Test HS/S2	9 m	3m 30 s	45 m	9.4	15.8	0.4	0.025
Test CS3	9 m 15 s	4 m	10 m	n/a	14.3	0.2	0.014
Test HS/S3	8 m	4 m	45 m	n/a	16.5	0.2	0.012
Poll. Test 1	17 m	9 m	14 m	n/a	13	0.2	0.015
Poll. Test 2	10 m	4 m	16 m	n/a	12.5	0.2	0.016
Poll. Test 3	11 m	6 m	13 m	n/a	8.3	0.2	0.024
Poll. Test 4	11 m 30 s	4 m 30 s	15 m	n/a	9.1	0.2	0.022
CS Averages	**10 m 54 s**	**4 m**	**10 m 30 s**	**n/a**	**10.64**	**0.28**	**0.0288**
HS/Simmer Averages	**8 m**	**4 m**	**33 m 12 s**	**7.6**	**14.04**	**0.24**	**0.0174**

It can be seen from Tables 2 and 3 that our average fuel consumption values for our final prototype are 10.64oz to boil on cold start, 14.04oz to boil and simmer on a hot start (6.98 to boil, 7.6 for simmering). Aprovecho Research Center's StoveTec rocket stove has been tested for fuel consumption as well, and compared to a three stone fire. Several sources cite that the stove reduces fuel consumption by anywhere from 41% to 54% depending on test conditions[44,45,46]. Our team conducted a few "baseline" tests on the StoveTec stove to ensure that the data matches our test conditions, Table 4 shows these test results. As you can see, the StoveTec stove averages roughly 10.3 oz to boil on a cold start, this matches our data and allows us to tie our stove to their consumption rates directly. Since we are using approximately the same amount of fuel as they are, we also reduce fuel consumption by approximately 50% and we deem that we are meeting our specification in this matter.

Table 4 – Individual Test Results and Cold Start Average Results Results for StoveTec Stove

Test: Type	**Time to Boil**	**Boil/Simmer Duration**	**Total Wood Used**	**Ash**	**Ash/Fuel Ratio (A/W)**
Test CS1	14m, 30s	5m	8.7oz	0.7oz	0.08
Pollution Test CS1	16m, 30s	~10m	11.9oz	0.6oz	0.05
Averages	**15m, 30s**	**7.5m**	**10.3oz**	**0.65oz**	**0.065**

7.3 Qualitative Cooking Feasibility and Design Functionality

The team continually checked for particularly unsafe, difficult to use, or otherwise improvable design features during our tests. We noticed that the outside temperatures of the stove ranged from 90° F to 140° F; these are fairly safe, and can probably be pushed into a safer, touchable range (below 120° F) by adding half-inch of insulation thickness. The fuel chute and top cooking surface (along with its attachment flanges) were reaching temperatures of up to 180° F, and unsafe to touch during operation. It should be noted that these high temperatures were aided by solar radiation heating up our metal stove, and temperatures were roughly 30 degrees lower when observed during a test conducted at night. Generally, the user will not need to directly touch the cooking surface or fuel chute, as pan holders and fire pokers should be used. These higher temperature surfaces were deemed safe since the user would not need to touch these bare-handed during normal, suggested operation. The stove was generally stable and the pot supports were fairly level, giving the pot a sturdy resting place and placing no danger of upsetting or toppling. The team noticed a few things that we wish to improve for our final build, these are listed below:

- The ash tray needs more clearance beneath the fuel chute grate: sticks and kindling sticking through the grate interfered with the ash tray insertion. It was impossible to insert the ash tray without reaching in and pushing these sticks back through the grate. This grate reaches very high temperatures and requires the user to push fuel back through, this is not safe.
- Flanges mating hot to less hot surfaces need to be constructed in a manner that the hot surfaces are the "inner" flange (aka the hidden surface to the user). This will prevent accidental burning of the user.
- More detail is required in the rounding/grinding of outer edges and surfaces; the team cut themselves multiple times on our prototype. The final product will require a higher level of finishing.
- The fuel chute angle/transition to the grate is too abrupt; sticks and fuel were consistently becoming 'stuck" on this transition. A "step" down that allows the fuel to fall onto the grate, or a much larger transition bend radius is required, allowing the fuel to fall more easily into the grate/combustion area.

8.0 Thermal and Air-Flow Behavior Testing

In order to verify the theoretical models created in SolidWorks Flow Simulation, experimental testing needed to be conducted. The team will use thermocouples and an infrared gun to collect data on the thermal behavior of the stove (the 2nd prototype was used). We then compared these results to the theoretical results and draw conclusions from that as to how to further improve the final prototype from the 2nd.

8.1 Methods and Devices

Thermal and air flow behavior testing was performed on the second prototype. The team set up a series of thermocouples (TC) that were placed in various areas of interest within our stove. These areas can be seen in Figure 18. Originally, the team planned on taking 15 total experimental temperature measurements on the stove using LabVIEW software. However, due to the limitations of the Data Acquisition System (DAQ), we were only able to use eight total thermocouples. Additionally, the team acquired an infra-red (IR) heat measurement gun. We used this to take measurements of the cooking pots, substances being cooked, stove body surface, and combustion chamber measurements. Figure 18 shows these measurement distributions.

- ★ 2 TC Measures – Top and bottom along the inner combustion area
- ★ 2 TC Measures – Top and bottom along the heat exchange surface ("outside" of inner tube)
- ★ 2 TC Measures – Top inner and outer bottom insulation surfaces of the insulation ring
- ★ Multiple IR measurements - various locations of the cooking pot (bottom, side, within water/food), stove body surface temperatures, combustion chamber average temperatures
- ★ 4 Cancelled and 2 Failed TC Measures – four not used due to DAQ limitations and two bad data from TC errors

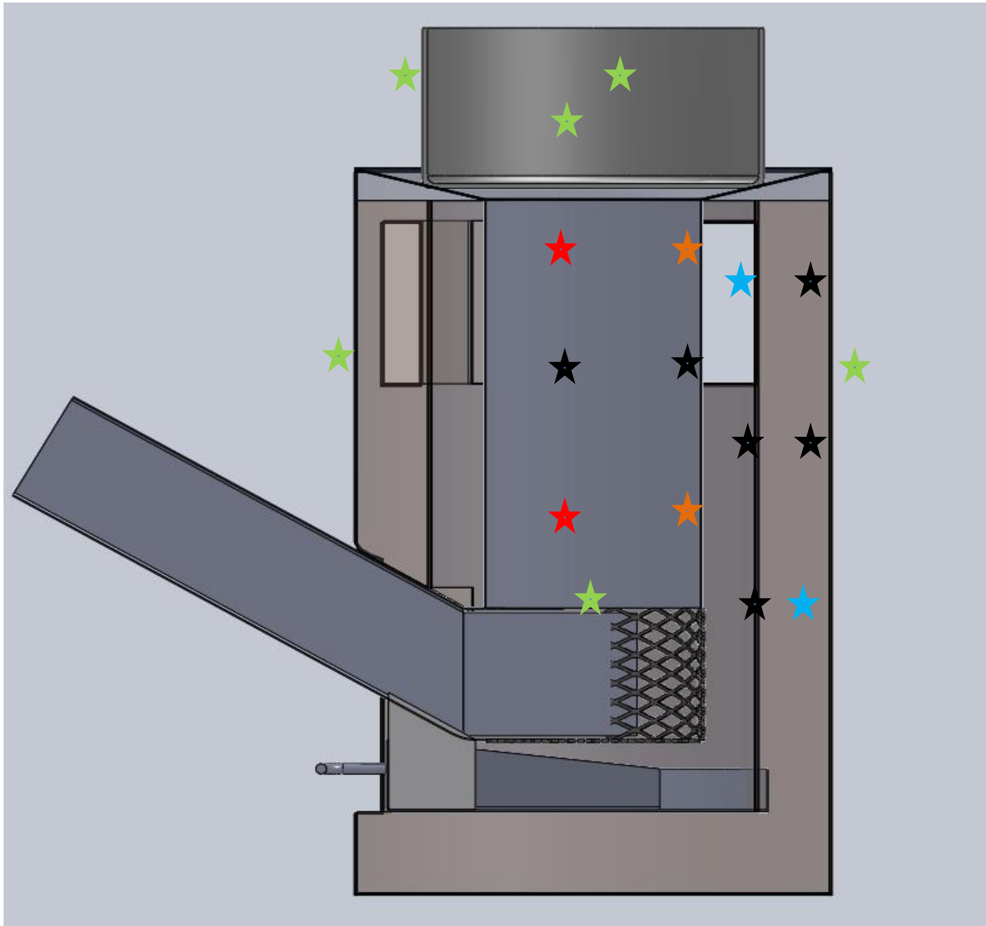


Figure 18 – Cross-sectional view of stove with placement of the thermocouples

The thermocouple measurements were collected in a LabVIEW Virtual Instrument (VI) in order to create a correlation with our theoretical temperature model. The thermocouples were calibrated by comparing to room temperature and verifying that they were reading room temperature, no state of the art calibration devices were used. We tested for functionality of our heat exchanger (the red and orange stars). We tested for at least a 100 degree temperature differential between the air inlets and the bottom orange star point. We also tested to see how much of our maximum flame temperature is reaching our pot (bottom red star to top red star). Additionally, the team tested the temperature differential of the stoves insulation (blue stars) to ensure safe outer temperatures. We planned on testing the insulation's thermal conductivity; however, the top outer and bottom inner insulation thermocouples (two of the black stars) only reported data during two tests. Due to the temperamental nature of these thermocouples, their data was not included in this report. Lastly, the green star points were measured by the IR gun to ensure proper cooking temperatures were present within the stove, as well as safe handling temperatures.

8.2 Temperature Measurement Results

Our team conducted a total of seven water boil/thermal behavior tests with thermocouple measurements being taken via a LabVIEW VI on the second prototype. The seven tests were broken down into three sub-categories, cold start (CS), hot start (HT), and simmer test. The cold start tests were conducted by first taking a "cold" or not preheated stove, igniting a fire, and tending to the fire until boil. Upon boiling, no fuel was added and the time the stove simmered water purely off of the hot coals remaining was measured. The hot start tests were conducted by lighting the stove immediately after the cold start tests. We once again tested to see how fast the water now came to a boil. After this boil, we then transitioned into the simmer test, where we attempted to keep the pot simmering at a constant temperature for 45 minutes. The amount of wood needed to sustain a simmer was measured. To clarify, the hot start and simmer categories were tested during only one test period. All tests were concurrent with our fuel consumption tests; as such, wood weights, ash weights, and times were all recorded (this process is detailed in section 7.0). We conducted a total of four cold start tests, and three hot start/simmer tests on the second prototype. Table 5 shows the average readings of the stove at the various thermocouple locations. Average steady-state temperature results, as well as graphical results of our "cleanest" time vs. temperature plots are presented in Figures 19-24.

Table 5: Temperature Readings of Stove, All Measures in Fahrenheit

Test: Type	**Bottom of Combustion Chamber (°F)**	**Top of Combustion Chamber (°F)**	**Bottom of Heat Exchanger Surface (°F)**	**Top of Heat Exchanger Surface (°F)**	**Top of Inner Insulation (°F)**	**Bottom of Outer Insulation (°F)**
Test 2: CS	789	806	812	462	No Data	134
Test 3: HS	783	678	728	460	463	167
Test 4: CS	610	801	590	426	360	122
Test 5: HS	855	No Data	No Data	No Data	No Data	No Data
Test 6: CS	643	801	822	508	493	152
Test 7: HS	834	840	774	452	488	191
CS Averages	**681**	**803**	**741**	**466**	**426**	**136**
HS/Simmer Averages	**824**	**759**	**751**	**456**	**475**	**179**

*All temperature measurements have an assumed uncertainty of ±20°F, Combustion Chamber Measures have an uncertainty of ±50°F

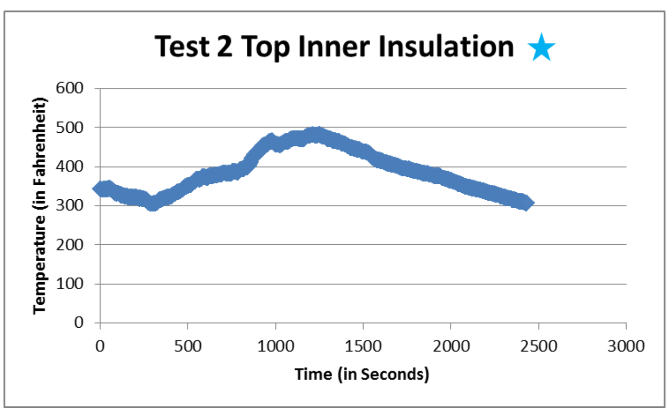


Figure 19: Inner Insulation Temperature-Time Response

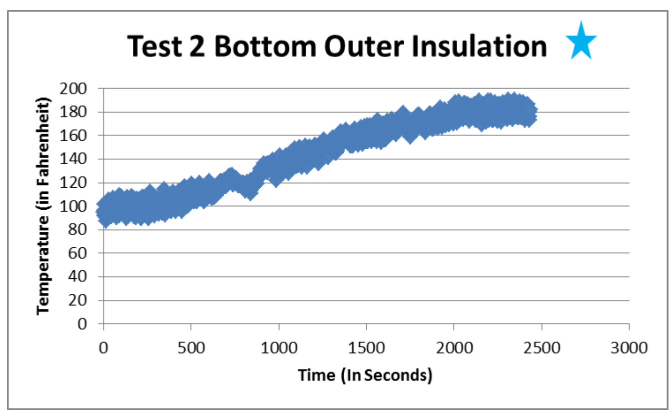


Figure 20: Outer Insulation Temperature-Time Response

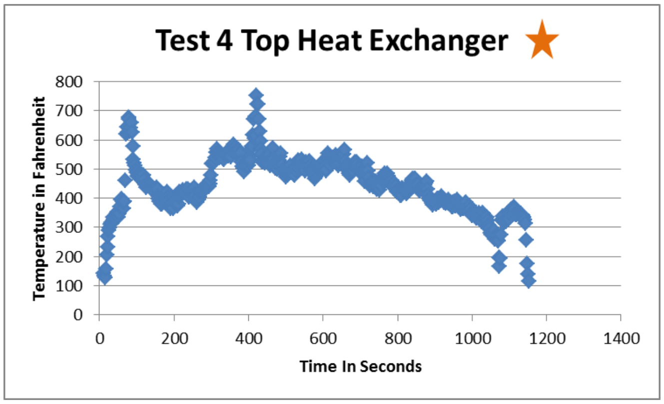


Figure 21: Top of Heat Exchanger (Inlet) Temperature-Time Response

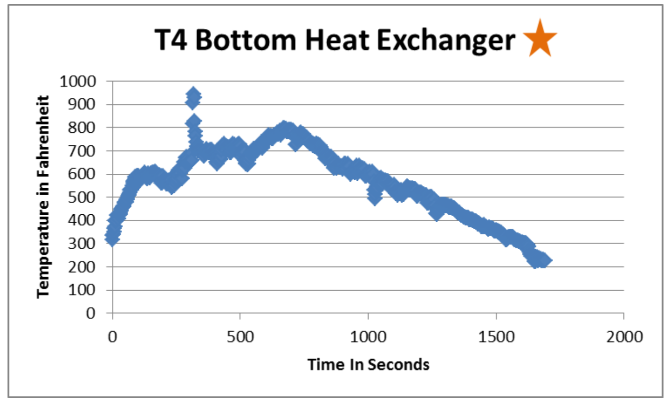


Figure 22: Bottom of Heat Exchanger (Fire Area) Temperature-Time Response

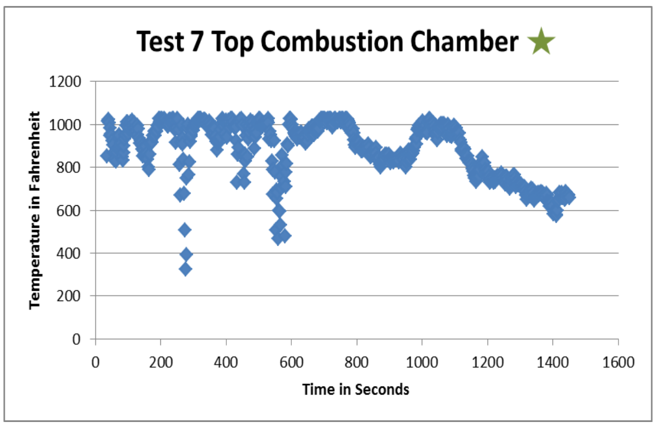


Figure 23: Top of Combustion Chamber Temperature-Time Response

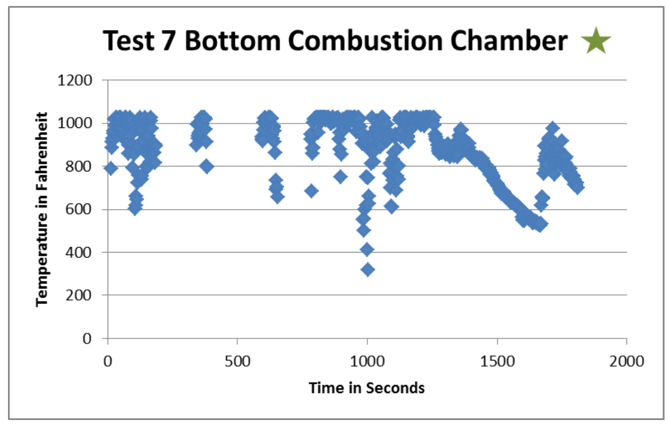


Figure 24: Bottom of Combustion Chamber Temperature Time Response

8.3 Air Flow Verification

Air flow verification was done primarily through the use of SolidWorks flow models. This is due to the expensive nature of devices which are able to accurately detect and measure low velocity air flows. Ideally, with adequate funding, the team would have liked to acquire a hot-wire anemometer for model verification, however this was not possible. The team had to rely on some very basic tests which simply established knowledge of the presence of flow, not actual velocity measurements.

We attempted to use a small pinwheel device fabricated out of a thin-wall aluminum can, which would spin if flow was present in an air inlet port. However, the velocities present were too slow to overcome the friction on the pinwheel, and this test was inconclusive. The team did visually inspect the stove during operation, and observed no significant inlets or outlets of air separate from the established ones. This visual establishment was based on being able to see the hot gases diffracting light through the air. Upon covering the fuel inlet, sealing the fuel chute, and using high temperature tape to seal off cracks, there were only two inlet/outlets of air on the stove, the top hole leading to the pot, and the heat exchanger inlets. Since air was visibly leaving the pot hole, the only possible route for air entry was in the heat exchanger inlets. Furthermore, a temperature differential was verified through the VI between the combustion chamber and ambient air. This creates a “hot”, less dense column of air, which is pushed up and out of the stove and displaced with the “cold”, denser ambient air. Once again, the only possible way for this cold air to be let in was through the heat exchanger inlets; therefore we are certain that these inlets are serving their function.

9.0 Pollution Testing

In order to properly evaluate the performance of our stove (aside from cooking efficiency and thermal functionality), the team had to evaluate emissions reductions of our cook stove. Our two initial main goals were to prove that our stove met the two pollution-related specifications mentioned in Section 3.0. These goals were to: 1) reduce black carbon emission by greater than 60% and 2) theoretically reduce the incidence of childhood pneumonia by greater than 30%. In order to measure these parameters two types of testing needed to be conducted, particulate matter (PM) testing and gaseous emissions testing. Naturally, it would follow that the team would measure PM exiting the stove, and all pertinent gaseous emissions exiting the stove; these measures would then be correlated to the aforementioned requirements.

However, due to the high temperatures of the flue gases exiting our stove, standard PM filters were not an option. The NAU facilities did not have any high-temperature ceramic filters, and as such direct PM measurements were not an option. Gaseous emissions tubes were acquired for the basic three carbon-based emissions from wood combustion (CO, CO_2, C_6H_6). With these, the team would be able to perform a balance of the gaseous carbon entering and exiting the stove. Separate from this, ash was measured after each burn, this ash being our bottom ash. This ash was then correlated to fly ash, total ash content, and inorganic ash content, and a balance performed to find the inorganic ash (black carbon). Through the knowledge of the gaseous emissions, ash measures, and existing documentation on the matter, the team was able to draw some sound conclusions regarding the emissions of our stove. The following subsections will delve into the details of our findings.

9.1 Gaseous Emissions Measurement Methodology

The team acquired 16 CO_2 (carbon dioxide) detector tubes, nine CO (carbon monoxide) detector tubes, and five aromatic hydrocarbon (C_6H_6 a.k.a. Benzene) detector tubes. These tubes were of two brands; Dräger (all C_6H_6 and six CO_2 tubes) & Kitagawa (all CO & 10 CO_2), each came with their own respective 100 millileter (ml) pump set.

Our team performed our pollution measurements during the three standardized tests detailed earlier in Section 7.0. In addition to the classification of test type, our team has identified four phases of emission states per test, these phases are listed below.

1) ***"Dirty" Startup Phase:*** this is when our kindling is starting to burn, a lot of smoke is generated as the stove is not heated up and we are burning in a relatively cold environment.
2) ***Pre-Boil "Clean" Burn:*** this is when our fire is starting to build up, our stove is heating up, and the standardized 64oz of water in our stove has not started boiling yet.
3) ***Boil Phase "Clean" Burn:*** This phase takes place during boil (large constantly rolling bubbles, water temperature near 200° F), the stove is fully heated and we believe operating at its most efficient in conjunction with phase 4.
4) ***Simmer Phase "Clean" Burn:*** This phase takes place after the boil phase, with minimal wood being added to maintain a slow rolling boil or simmer (smaller bubbles rising slower than boil phase). We believe that aside from the addition of small amounts of new wood, this is one of our two most efficient phases.

The team pulled samples of air exiting our stove at the pot area, within the gap between our pot and pot skirt. Attempts were made to ensure the tube tip was inside the pot skirt gap and not in open air, in order to minimize dilution effects from wind. These samples were taken at the boil (3) and simmer (4) phases only due to the limited amount of measurement tubes. Table 6 shows were we want to take samples and when during the testing. It is also believed that these two phases will be the most efficient, as well as the most time-consuming to the user (i.e., the phases with the largest exposure times).

Table 6 – Samples taken and when during four starts of the stove

Burn Test Type	Burn Test Phase	Sampling Start Time	Samples Taken
Cold Start 1	3 - Boil	17:00 min	2 CO_2,
Cold Start 1	4 - Simmer	26:00 min	2 CO_2, 1 CO, 1 C_6H_6
Hot Start/Simmer 1	3 - Boil	9:45 min	2 CO2, 1 CO
Hot Start/Simmer 1	4 - Simmer	23:00 min	2 CO_2, 1 CO, 1 C_6H_6
Cold Start 2	3 - Boil	11:00 min	2 CO2, 1 CO
Cold Start 2	4 - Simmer	17:00 min	1 CO_2, 1 CO, 1 C_6H_6
Hot Start/Simmer 2	3 – Boil	9:00 min	1 CO_2, 1 CO
Hot Start/Simmer 2	4 – Simmer	20:00 min	1 CO_2, 1 CO, 1 C_6H_6
StoveTec Cold Start	3 – Boil	4:00 min	2 CO_2, 1 CO, 1 C_6H_6
StoveTec Cold Start	4 - Simmer	13:00 min	1 CO_2

9.2 Ash Generation Testing Methodology

Our team measured all of our remaining drop ash (the ash settling in our stove body) after a burn test via a weight measured, in ounces (oz.), on a digital scale. The ash is scraped off of the grate and any other surfaces and into the ash tray to the best of our ability, ensuring all drop ash is measured. Due to the constant high winds in our testing location (Flagstaff, AZ), 0.1 oz. is added to this measure as slight amounts of ash flew off during the transport from the stove to the scale. This measured “drop ash” is then correlated to our fly ash, and subsequently our PM and black carbon. Our results and correlations are presented in Section 9.3.

9.3 Testing Results

Summarized within Tables 7 & 9 are the results of our pollution testing conducted on our final (3rd) prototype. Also presented, in Tables 8 & 10, is a baseline test done on the donated StoveTec rocket stove, to ensure the correlative data provided by StoveTec matched our testing environment. For full details of our pollution results, one should consult Appendix A.2.

Northern Arizona University
Clean Burning Stove Team

Table 7 – Averages of samples pulled during pollution testing

Final Prototype Data Averages	**CO_2**	**CO**	**C_6H_6**
Cold Start Boil Averages	38,000	4200	n/a
Hot Start Boil Averages	25,222	1500	n/a
Cold Start Simmer Averages	9,111	1150	1175
Hot Start Simmer Averages	26,222	1350	833.35
Total Boil Phase Averages	**31,611**	**2850**	**n/a**
Total Simmer Phase Averages	**17,667**	**1250**	**1004.175**
Overall Stove Performance Averages	***24,639***	***2050***	***1004.175***

Table 8– Emissions Data for StoveTec Stove

StoveTec Data Groups	**CO2**	**CO**	**C6H6**
CS Boil Averages	12,917	500	266.67
CS Simmer Averages	3333.3	n/a	n/a

Table 9– Ash to fuel ratios for final prototype

Final Prototype	**4-22 Cold Start 1**	**4-22 Hot Start 1**	**4-24 Cold Start 2**	**4-24 Hot Start 2**	**4-24 Cold Start 3**	**4-24 Hot Start 3**
Total Fuel (oz)	8.9	16.3	8.7	15.8	14.3	16.5
Ash (oz)	0.4	0.2	0.4	0.4	0.2	0.2
Ash/Wood Ratio	***0.045***	***0.012***	***0.046***	***0.025***	***0.014***	***0.012***

Final Prototype	**4-26 Pollution Test 1**	**4-26 Pollution Test 2**	**4-26 Pollution Test 3**	**4-26 Pollution Test 4**	**Averages for all Tests**
Total Fuel (oz)	13	12.5	8.3	9.1	**12.34**
Ash (oz)	0.2	0.2	0.3	0.2	**0.27**
Ash/Wood Ratio	***0.015***	***0.016***	***0.036***	***0.022***	**0.024**

Table 10– Ash to fuel ratios for StoveTec Stove

Stove Tec Rocket Stove	**4-26 Pollution Test**	**3-10 Cooking Test**	**Averages**
Total Fuel	11.9	8.7	**10.3**
Ash	0.6	0.7	**0.65**
Ash/Wood Ratio	*0.050*	*0.080*	***0.065***

9.4 Correlations to Design Specifications

In order to properly correlate our measured data to quantifiable values that corresponded to our project specifications, a number of resources were used. The most important of these resources was two documents from Aprovecho Research Center[57, 45], as well as a document by Richard Boubel of Oregon State University on wood combustion[61]. These documents covered various topics on pollution emissions and material properties involving wood combustion. Most importantly was the comparison between particulate matter and CO emissions. These were ultimately used to draw our final results for the stove's behavior. The Aprovecho documents went over multiple types of their stoves, and their data sets were based off of multiples tests of each. This was very helpful to our team as we could get large averages with decent statistical accuracies of their stove performance. Many of our values were actually compared to their stove, and then the correlations of their stove to an open fire were used to ultimately compare our stove to an open fire. Table 11 and Figure 25 show the reported results from Stove-Tec on their stoves.

Table 11 – Aprovecho Research Center percent reduction of CO, PM emissions, cooking time and fuel use of rocket stove compared to traditional stoves and three stone fires

	One-Pot	Two-Pot	Chimney
To Traditional			
Fuel Reduction	18%	35%	28%
CO Reduction	41%	45%	41%
PM Reduction	46%	44%	37%
To Three-Stone Fire			
Fuel Reduction	41%	47%	39%
CO Reduction	46%	60%	86%
PM Reduction	56%	57%	78%

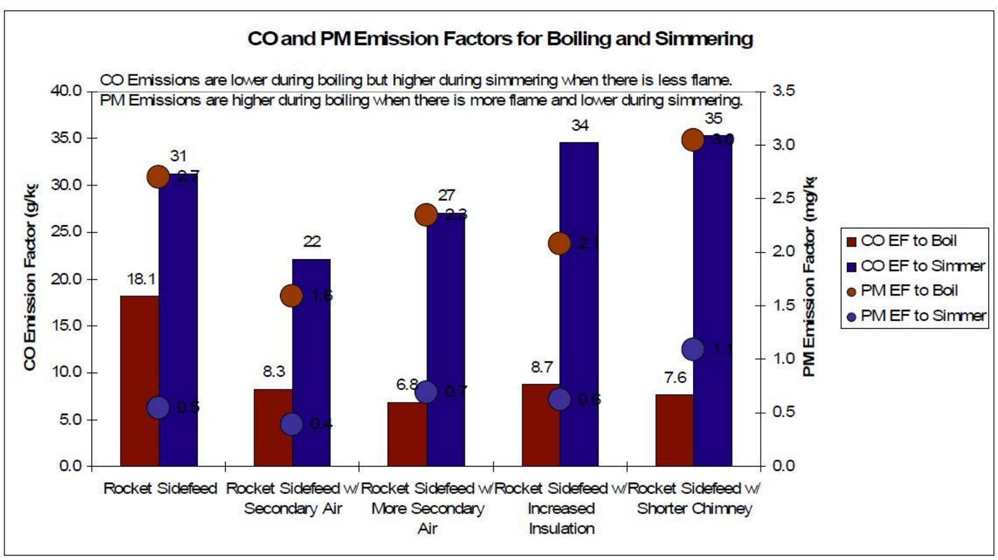


Figure 25 – CO and PM Emission Factors for Boiling and Simmering from Aprovecho Research Center

Once we established what data we had available both from our physical data collection and research articles, we set out to figure out everything we could about the pollution emissions. First, it is crucial that one understands the general process occurring that all equations are based on in this section.

$$Wood\ Fuel + Oxygen \rightarrow Emissions\ Gases + Solid\ Particulates\ (Ash)$$

This breaks down into the following chemical reactions

$$C_xH_x\ Solid \rightarrow heat \rightarrow C_xH_x\ gases\ released + some\ Solid\ C_XH_X\ left$$

$$Solid\ Reactions:\ \ C_XH_X + Inorganics \rightarrow combust \rightarrow Bottom\ Ash\ and\ Fly\ Ash$$

$$Gas\ Reactions:\ \ C_XH_X + O_2 \rightarrow combust \rightarrow H_2O + CO + CO_2 +\ C_XH_X$$

From testing, we had obtained measures for CO, CO_2, C_6H_6 (assumed correlative of all CxHx above x = 6), and weight measures of our input wood, and output ash. These measured values were then analyzed in two separate analyses; solids and particulate testing, or gaseous emissions.

9.4.1 Solids and Particulates

Our average wood weight is 10.725 oz., and the weight percent of the wood used (ponderosa pine) is 49.25% carbon[63]. This becomes our input value for our input C_xH_x, we will use this to solve for our output emissions since the total carbon in the system must balance and the carbon out must equal this input value.

$$Total\ Input\ C_xH_x = .4925\ (10.725\ oz) = 5.28206\ oz$$

Ash content is also given in this article as 0.29% (which is a measure of the inherent inorganic minerals in a wood that will not burn and are known to always form ash). Our average weighed drop ash can be correlated to this ash content, if the two do not match (weighed ash being higher) then there is excess un-burnt hydrocarbons within the ash. This is what we classify as black carbon.

$$Average\ Total\ Wood\ Used = 10.725\ oz, \qquad Estimated\ Inorganic\ Ash\ Content = 0.29\%$$

$$10.725\ oz * 0.0029 = 0.0311 oz\ of\ Inorganic\ Ash\ in\ our\ wood$$

In Richard Boubel's document [CITE], it is stated that for wood-fires, fly ash is generally equivalent to bottom ash on a weight basis (that is, each takes up 50% of the total ash content). Our fly ash black carbon is the most important parameter to watch due to the fact that it is the ash that is exposed to the user and causes health problems. Richard Boubel states that from observation of many tests conducted on wood emissions, 95% of fly ash is PM_{10} or lower. PM_{10} stands for particulate matter 10 microns in size. This is the important parameter in regards to health as anything larger is usually filtered out by the nostrils before causing respiratory issues. The following inferences can be made:

$$Average\ Total\ \ Measured\ Drop\ Ash = 0.225\ oz$$

$$0.225 oz * 2 = \mathbf{0.45 oz\ Total\ Ash}\ (\mathbf{0.225\ Fly\ Ash}\ \&\ \mathbf{0.225\ Bottom\ Ash})$$

$$Our\ Cook\ Stove's\ Average\ PM_{10}\ Emission = 0.95 * .50 * .225 oz = \mathbf{0.107 oz\ per\ burn}$$

$$0.45 oz\ Total\ Ash - 0.0311\ Inorganic\ Ash = \mathbf{0.4189\ oz\ Total\ Black\ Carbon\ Ash}\ (\boldsymbol{Solid\ C_xH_x})$$

$$where\ \mathbf{0.20945oz}\ (\mathbf{50\%}) = \boldsymbol{Fly\ Ash\ Black\ Carbon}$$

The 50% of fly ash black carbon is the main contributor to outdoor air pollution hazards as the heavy radiation-absorbent particles absorb the solar irradiation, heating the atmosphere and increase melting of permanent snow (in our location this is an issue in the Himalayas).

Comparing our ash output to the three stone fires is fairly simple, the StoveTec Rocket Stove is reported to reduce particulate matter emission 46% greater than a three stone fire (based on multiple tests conducted by Aprovecho Research Center[45]). Our stove's recorded ash to fuel ratios (See Tables 7 &9 above) average out to be 63% less than the StoveTec stove. This equates to us producing 63% less total ash than their stove. Due to the fact that we have black carbon measured in a "per cooking period" quantity, and not a rate measurement, we cannot directly calculate our black carbon reduction in comparison to an open fire. However, we can say that since we reduce black carbon by 60% more than the StoveTec stove, we can qualitatively say that we definitely reduce black carbon by greater than 60%. Thus, we are meeting our specification of black carbon reduction stated in Section 3.0. In Table 12, we have summarized this data for ease of viewing.

Table 12 – Summary of the data and calculations for black carbon creation of StoveTec's stove and our final prototype

	StoveTec Cold Start Averages	**Our Stove Cold Start Averages**	**Our Stove Hot Start Averages**
Total Fuel Used	10.3oz	10.64oz	14.04oz
% Fuel Reduction to 3 Stone Fire	49.3%	47.6%	n/a
Ash	0.65oz	0.28oz	0.24oz
Ash/Fuel Ratio	*0.065*	0.029	0.018
Black Carbon Created	1.2689oz	0.5289oz	0.4489oz

9.4.2 Gaseous Emissions

Now that we have classified and quantified all particulate matter and solid behavior above we can move on to our gaseous analysis. We know the approximate percentages associated with our gas reaction outputs from the direct measurements taken. If we follow the chemical balances presented in the beginning of this section, we can calculate the mass values of our gas emissions by utilizing the remaining total mass not lost in the solid emissions reactions. We utilize this gas data to prove that our stove theoretically reduces in the onset of pneumonia by at least 30%[58, 59]. Articles[58, 59] show correlations between CO inhalation, PM inhalation and pneumonia. When PM_{10} is inhaled, it settles in the breather's lungs, creating a barrier between their oxygen transport membranes. This reduced transport of oxygen leads to a decrease in carboxyhemoglobin (COHb) in the bloodstream. Reduced levels of COHb cause degradation of the human immune system, and in turn increased levels of contracted pneumonia. Additional correlations are shown to increased levels of CO inhalation leading to degradation of the immune system, and once again an increase in pneumonia onsets.

$$Total\ Input\ C_xH_x = 5.28206\ oz - 0.4189oz\ Solid\ C_xH_x = 4.86316oz\ Gaseous\ C_xH_x$$

So, knowing that we have 4.86316 oz. of input carbon into our carbon balance (below), we can easily calculate the mass of output gasses per burn.

$$4.8631oz\ of\ C_XH_X \rightarrow combust \rightarrow 88.97\%\ CO_2 + 7.40\%\ CO + \ 3.63\%\ C_xH_x$$

$$so{:}\ CO_2\ weight = \ 4.8631oz * .8897 = \mathbf{4.32675oz\ of\ CO_2}$$

$$CO\ weight = 4.8631oz * .0740 = \mathbf{0.359874oz\ of\ CO}$$

$$C_xH_x\ weight = 4.8631oz * .0363 = \mathbf{0.176533oz\ of\ C_xH_x}$$

These values need to be converted into a mass/volume concentration to be compared to most existing literature published by the EPA[AP42], Aprovecho Research Center[45, 57], and USAID[46]. Since flue gas volume sampling was not possible, we do not have the volume that these discrete masses relate to. As such this data could not be correlated to a three stone fire directly; however it is presented for documentation purposes.

If we approach our gaseous emissions output simply from a qualitative standpoint, we recognize that from Aprovecho documentation[57], a StoveTec stove reduces carbon monoxide and black carbon by the values in Table 11. Our stove emits an order of 10 less CO than a StoveTec according to our testing. The documentation[57] shows a direct correlation between CO and PM, this correlation was utilized to generate a constant of proportionality. This constant was multiplied into our measured CO emissions, giving us our PM emissions.

Due to many discrepancies in our process and limitations on number of sampling tubes, we expect high errors in these calculations. It should be noted that we do not claim any sort of statistical accuracy in our readings, much more testing would have to be conducted to fully verify these results. Since the StoveTec stove is roughly 50% more efficient than an open fire[45,46,57], our stove must be within this range or better. By reducing the CO and PM emission by much greater than StoveTec's 50%, pneumonia effects caused by CO & PM are reduced by at least 50% and we can assure that pneumonia onset due to use of this stove is reduced by at least 30%. Below, Table 13 condenses the data on this matter. Once again, the reader should note that we only validate qualitatively that our stove emits less than a rocket stove, these numbers are purely for reference and not deemed entirely accurate. Detailed testing documentation and data spreadsheets are presented in Appendix A.2.

Table 13 – Summary of Particulate Matter and Carbon Monoxide with in StoveTec and our stove

	Stove Tec Boil Phase	**Our Stove Boil Phase**	**Stove Tec Simmer Phase**	**Our Stove Simmer Phase**
Total Carbon Monoxide (CO) & Reduction	23800 ppm	2850 ppm	27666 ppm	1250 ppm
	46%	93.3%	46%	94.4%
Total Particulate Matter & Reduction	2000 ppb	240 ppb	567 ppb	25.6 ppb
	56%	94.7%	56%	98.0%

10.0 Manufacturing

Presented in the following sections are specifications for the manufacture of our final product; these specifications are representative of the final, theoretically mass-produced product. Additionally, all manufacturing detail drawings are attached in Appendix_. Our final prototype will closely resemble these manufacturing drawings and specifications, however due to the limitations of the Northern Arizona University (NAU) machine shop; several manufacturing processes will vary when our team makes this prototype. Each one of these part descriptions directly ties into our machining calculations, which we utilized to estimate the capabilities needed for our processing machinery (seen in Section 10.3). Finally, a proposed factory setup is detailed in Section 10.4 to simulate how these processes would be conducted in the most time-efficient manner. The values generated in these sections are then correlated to the mass production environment in Section 11.0 and associated costs, allowing us to calculate our stove's unit cost.

10.1 Parts with Processes Required to Manufacture

Presented in this section is a listing of every part of our cook stove. Each part's required processes to manufacture are listed in chronological, itemized order. These required processes are used to estimate assembly line work times and tooling layout on our assembly lines. Attached are part drawings of each part with detailed dimensions that one could use to build one of our stoves provided they had proper equipment. One should note no tolerances are presented in this section or the appendix, none of our parts have any stringent tolerance requirements, only the requirement that they fit together into one assembly.

10.1.1 Outer Body Cylinder

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Inlets/Fuel Chute Opening	Sheet Metal Blanking Press
Rolling into Tube Form	Sheet Metal Motorized Bend Roller
Seaming of Edges to form finished tube	Sheet Metal Vertical Seaming Machine

10.1.2 Heat Exchanger Cylinder

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Fuel Chute Opening	Sheet Metal Blanking Press
Rolling into Tube Form	Sheet Metal Motorized Bend Roller
Seaming of Edges to form finished tube	Sheet Metal Vertical Seaming Machine

10.1.3 Inner Combustion Chamber Cylinder

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Inlet Holes/Fuel Chute Opening	Sheet Metal Blanking Press
Rolling into Tube Form	Sheet Metal Motorized Bend Roller
Seaming of Edges to form finished tube	Sheet Metal Vertical Seaming Machine

10.1.4 Bottom Plate

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Perimeter	Sheet Metal Blanking Press

10.1.5 Top Pot Rest Surface

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Perimeter	Sheet Metal Blanking Press
Drawing of Conical Part Shape and Small Flange	Sheet Metal Drawing Press & Custom Punch/Die

10.1.6 Top Pot Rest Tabs

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Perimeter (x3 Tabs)	Sheet Metal Blanking Press
Bending of Tabs to Final Shape	Sheet Metal Wiping Brake/Edge Bender

10.1.7 Fuel Chute Top Body

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Perimeter	Sheet Metal Blanking Press
Bending to Final Shape	Sheet Metal Wiping Brake/Edge Bender

10.1.8 Fuel Chute Bottom Body

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Perimeter	Sheet Metal Blanking Press
Rolling of Contour	Sheet Metal Motorized Bend Roller

10.1.9 Fuel Chute Door

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Perimeter	Sheet Metal Blanking Press
Bending to Final Shape	Sheet Metal Wiping Brake/Edge Bender

10.1.10 Fuel Chute Connector Flange

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Perimeter	Sheet Metal Blanking Press
Bending to Final Shape	Sheet Metal Wiping Brake

10.1.11 Grate

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Perimeter/Holes	Sheet Metal Blanking Press

10.1.12 Ash Tray Part 1

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Perimeter	Sheet Metal Blanking Press
Bending to Final Shape	Sheet Metal Wiping Brake

10.1.13 Ash Tray Part 2

Process	***Tooling Required***
Shearing Bulk Stock to Size	Sheet Metal Shearing Press
Blanking of Perimeter	Sheet Metal Blanking Press
Bending to Final Shape	Sheet Metal Wiping Brake

10.1.14 Ceramic Core

Process	***Tooling Required***
Mixing of Raw Materials	Cement Mixers
Pouring into Molds	Hydraulic Press for Compressing Mold Size, Sheet Metal Outer Form to Hold the Core
Remove From Outer Forms	Possible Hand Tools
Machine Fuel Chute Inlets and Air Inlets	Automated Router or Drilling Machine
Air Drying	Possible Heaters

10.2 Assembly Processes and Required Fasteners

Our stove was specifically designed so that during assembly, only rivets would be required as additional material. All other connections are made with sheet metal seaming processes (which overlap two edges and force the two parts to bond). We believe this will reduce cost as no material-removal, welding, or cutting processes are required, all parts are made with sheet metal equipment, and the only expendables required to fasten are blind rivets. Presented in Table 14 is a summary of each assembly process expected to be present in our factory, including the corresponding tooling and fasteners required.

Table 14 – Total fastener counts per process of the cook stove

Process	*Tooling Required*	*Rivets Required*
Seaming of Outer Body to Bottom Plate	Sheet Metal Seamer	
Assembly of Fuel Chute	Rivet Gun	x6
Assembly of Ash Tray	Rivet Gun	x4
Placement of Core in Outer Body and Heat Exchanger Cylinder in Core	None	
Assembly of Combustion Chamber Cylinder, Grate & Fuel Chute Connector Flange	Rivet Gun	x2
Attachment of Top Pot Support Plate to Combustion Chamber Cylinder	Rivet Gun	x4
Attachment of Top Support Tabs to Top Pot Support	Rivet Gun	x6
Seam Top Pot Support to Outer Body Cylinder	Sheet Metal Seamer	
Attachment of Fuel Chute to Stove Body	Rivet Gun	x4
Ash Tray Insertion, Quality Check of Whole Stove	None	
	Total Rivets Required:	**26**

10.3 Machining Calculations

In order to properly assess equipment costs and performance characteristics the team needed to calculate some basic machining process force values. The current processes in the building of our stove involve sheet metal working, riveting, and hand-assembly. The main values of interest are all of sheet-metal working, as these processes require the largest forces and most complex machinery. Riveting calculations are not presented as proper choice of rivet sizing and rivet gun use (common knowledge to any shop worker) is all that is required for these processes.

Specifically, our sheet-metal working processes consist of shearing, blanking, rolling, edge-bending, seaming, and drawing. One with experience in sheet metal working will notice that each one of these processes will involve a different type of machine. Additionally, each separate part will require its own separate die set for each machine (excluding shears and benders). Presented next is calculations used to estimate the force requirements of the various types of machinery needed to properly process all of our sheet metal parts presented in Section 1.1. All calculations assume use of 24 gage (0.0239 inch) thick, half-hard cold-rolled steel, with a shear modulus of 310MPa (44.962 ksi), elastic modulus of 806MPa (116.9 ksi), yield strength of 241.3 Mpa (35 ksi), and an ultimate tensile strength of 344.7 MPa (50 ksi)[64].

***Shearing Process Force Requirements*:** Presented is the maximum-force case; shearing of the outer cylinder (which has the longest stock length of 18 inches).

$$F = S * t * L$$
$$where\ F = cutting\ forced\ required, t = stock\ thickness$$
$$L = shearing\ length, S = shear\ modulus\ of\ the\ material$$

$$F = (44.962 * 10^3\ psi) * (0.0239 \text{ inch}) * (18 \text{ inch})$$

$$F = 19342.6524\ lbs = \mathbf{9.7\ US\ tons}$$

Blanking Process Force Requirements: Presented is the maximum force case; blanking/punching of the grate. This part has 61 holes and an outer perimeter consisting of one circle's circumference plus the tab circumferences (see appendix). The perimeter to shear is of the outer perimeter and all interior holes.

$$F = S * \mathrm{t} * \mathrm{L}$$

where all variables are as in above example

$$L = 61(Holes) + Outer\ Perimeter = 61(0.375 * \pi) + (5 * \pi + 3 * .375 * \pi)$$

$$F = (44.962 * 10^3\ psi) * (0.0239 \text{ inch}) * (88.69\text{inch})$$

$$F = 95305.5\ lbs = \mathbf{47.7\ US\ tons}$$

Edge Bending Process Force Requirements: Presented are two maximum force cases for edge bending which occurs on our fuel chute. This first process is a 105 degree bend, the second is a 90 degree bend on a longer edge, a K-factor of 0.33 and a Die opening dimension of 6*thickness (.1434inch) is assumed for an edge bending brake.

$$F = \frac{K(TS)wt^2}{D}$$

$$where\ K = Sheet\ Metal\ Bending\ K\ Factor,\ TS = Ultimate\ Tensile\ Strength\ of\ the\ Material$$

$$W = width\ of\ the\ bend,\ t = thickness\ of\ the\ material$$

$$case\ 1: F = \frac{0.33(50000psi)(5in)(0.0239in)^2}{(0.1434in)} = \mathbf{328.6\ lbs}$$

$$case\ 2: F = \frac{0.33(50000psi)(5.66in)(0.0239in)^2}{D(0.1434in)} = \mathbf{372\ lbs}$$

Drawing Process Force Requirements: Presented now is our only drawing operation, this operation only requires the drawing of a shallow conical shape with a small flange (see appendix). The presented calculations feature a reduction factor of 0.5, this is because the drawing calculation is for a conical (90 degree bend) drawn part, and we estimate our part will feature only a quarter of this amount of bending at force due to a less drastic bending angle. Due to the strange shape, our reduction factor is kept at a conservative 0.5.

$$F = \pi D_p t(TS)\left(\frac{D_b}{D_p} - 0.7\right)$$

$$where\ F = Drawing\ Force\ Required, D_p = Starting\ punch\ \ diameter,$$

$$Db = Starting\ blank\ diameter, t = stock\ thickness, TS = Ultimate\ Tensile\ Strengthh$$

$$F = 0.5 * \pi * 12in * 0.0239 * (50000psi)\left(\frac{13in}{12in} - 0.7\right)$$

$$F = 8634.67\ lbs = \mathbf{4.3\ US\ Tons}$$

In conclusion, we can see that our facility would require sheet metal presses of moderate capacity. Our most strenuous operation would require a press capable of 75 tons press-force for a F.O.S. of 1.6. In addition to these presses, industrial grade seamers, rollers and brakes would be needed, with the only parameter that these machines be rated for thicknesses above 24 gage (0.0239inch for standard steel).

10.4 Proposed Factory Workflow

Now that we have established our machinery requirements and processes involved we can set up a theoretical factory model. Our factory workflow model, as seen in Figure 26, revolves around three independent assembly lines that each fabricates multiple parts, and a final 4th assembly line that puts all parts together. The first two assembly lines will be processing sheet metal equipment, punches, rollers, and brakes will all be aligned in successive order, as all sheet metal processes are near-instantaneous. Timing is not extremely crucial on these lines due to the major bottleneck of the 3rd assembly line. This assembly line is that of the ceramic core processing. With the ceramic cores requiring at least a 24-hour period to cure inside the mold and then another 24-hour period to dry outside of the mold. Once all three of these lines have completed their parts, assembly line 4 can start operation, which completes our product. Presented in Figure 26 is a flowchart of our proposed general factory workflow; times are all educated estimates verified by our manufacturing advisor Dr. Tester and have not been tested in a manufacturing environment.

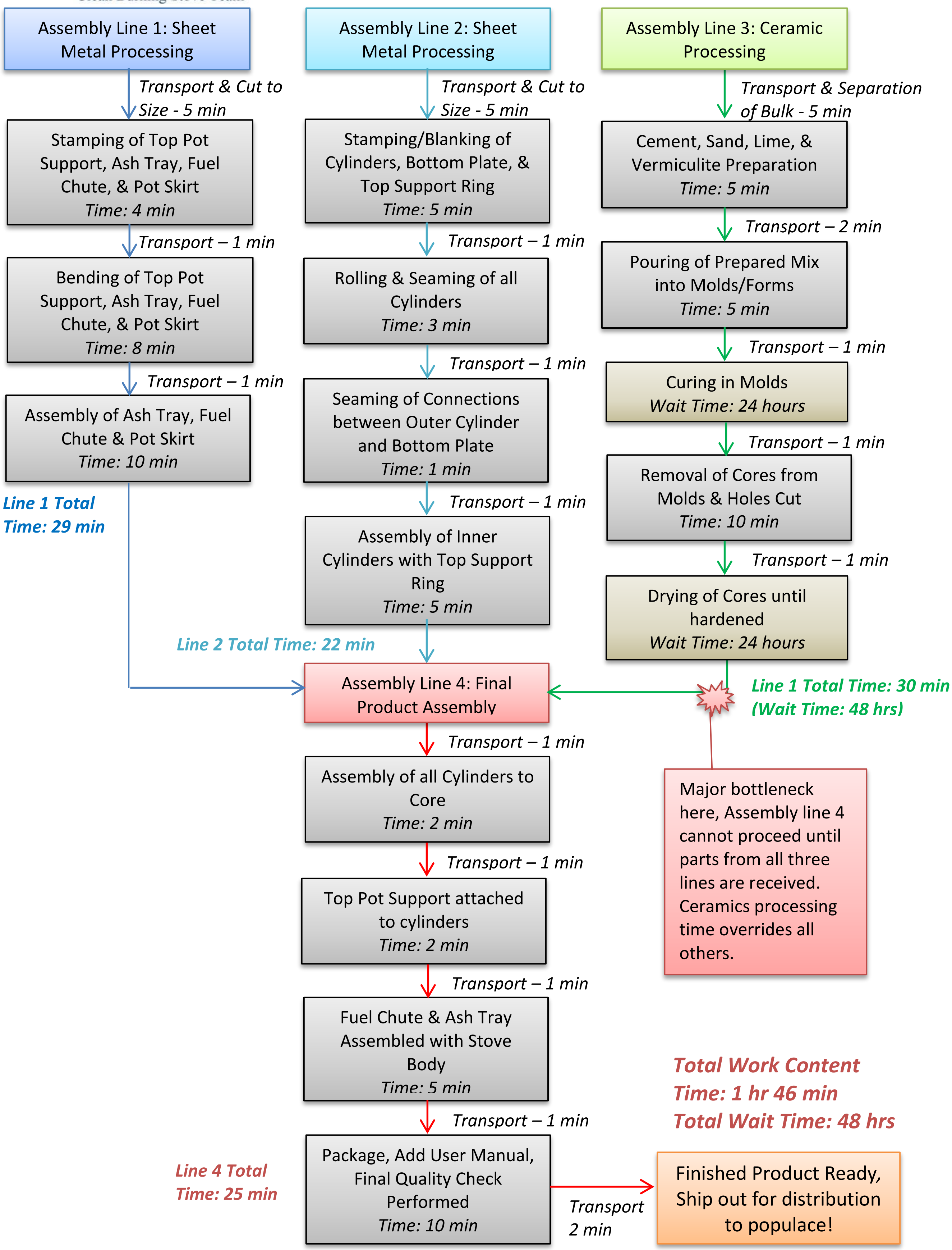


Figure 26: Proposed Workflow for Manufacturing

11.0 Mass Production Environment

In addition to the knowledge of the manufacturing parameters surrounding our stove itself, the team needed to analyze the environment it would be made in, and the end user demand for the product. As such, the U.S. Census and Labor Bureaus as well as the Indian Census and Labor Bureaus were consulted for pertinent data. Multiple manufacturer websites were consulted for machinery costing, and multiple supplier websites were consulted for materials costing. All of these values were combined to gain an understanding of our unit cost (presented in section 11.4)

11.1 Labor Rates in India

Documents were obtained from the Indian Ministry of Labor and Employment on average minimum wages[48, 50]. Additionally, documents from the US Census Bureau's International Database, and the US Department of Labor, Bureau of Labor Statistics regarding population growth and minimum wages in India[47, 48]. Census data was utilized to calculate an estimated demand for our product and in turn calculate our projected production rates, which can be seen in Table 15. Table 16 shows the minimum wage data that was utilized to create a rough baseline for our labor expenses on the factory floor. The calculations utilized to estimate demand are below:

$$Total\ Population * (70\%) = Total\ Population\ Without\ Stoves$$

$$\frac{Total\ Population\ Without\ Stoves}{Average\ Family\ Size\ in\ India} = Total\ \ Amount\ of\ Stoves\ Needed$$

The total estimated production amount currently needed was now our starting point. A simple relation was written where the increase in needy households is added to this production amount, and the production rate for that year is subtracted. This relation repeats itself until the demand has been "whittled away" to zero, at this point, production is equivalent to the simple population increase of needy families.

$$\begin{aligned} &Total\ Amount\ of\ Stoves\ Needed + Increase\ in\ Needy\ Families - Yearly\ Production \\ &\quad = Amount\ of\ Stoves\ Still\ Needed \end{aligned}$$

Our data based on these calculations is presented in Table 15 to give the reader an estimate of what kinds of production rates would be necessary in order to make a significant, timely impact in India. The assumption is made that the annual production rate of 10 million stoves a year is achieved by operating 10 factories in parallel, with each factory producing approximately 1 million stoves a year. It is also assumed that a pilot factory would first be opened producing a half million stoves, with additional factories opening soon after, and a full ramp-up of production to full force within three years. At these theoretical rates, it is expected that demand would be fully met by the year 2034, a reasonable amount for such a massive endeavor.

Table 15 – The estimated demand for the cook stove and the projected production rates

Year	Population Using Primitive Cook stoves	Growth Since Prev. Yr.	Proposed Annual Production	Remaining Population without new Stoves
2011	1,189,172,906	16,064,888	500,000	172,921,049
2012	1,205,073,612	15,900,706	1,000,000	174,239,902
2013	1,220,800,359	15,726,747	5,000,000	171,533,386
2014	1,236,344,631	15,544,272	10,000,000	163,800,259
2015	1,251,695,584	15,350,953	10,000,000	156,038,939
2016	1,266,883,598	15,188,014	10,000,000	148,253,858
2017	1,281,935,911	15,052,313	10,000,000	140,448,987
2018	1,296,834,042	14,898,131	10,000,000	132,621,631
2019	1,311,559,204	14,725,162	10,000,000	124,769,051
2020	1,326,093,247	14,534,043	10,000,000	116,888,599
2021	1,340,451,141	14,357,894	10,000,000	108,982,458
2022	1,354,646,111	14,194,970	10,000,000	101,052,558
2023	1,368,657,241	14,011,130	10,000,000	93,095,848
2024	1,382,464,004	13,806,763	10,000,000	85,109,334
2025	1,396,046,308	13,582,304	10,000,000	77,090,087
2026	1,409,416,720	13,370,412	10,000,000	69,039,938
2027	1,422,588,029	13,171,309	10,000,000	60,960,754
2028	1,435,542,802	12,954,773	10,000,000	52,849,992
2029	1,448,265,990	12,723,188	10,000,000	44,705,457
2030	1,460,743,172	12,477,182	10,000,000	36,525,046
2031	1,472,981,100	12,237,928	10,000,000	28,309,744
2032	1,484,986,826	12,005,726	10,000,000	20,060,579
2033	1,496,747,583	11,760,757	10,000,000	11,775,689
2034	1,508,252,196	11,504,613	10,000,000	3,453,445
2035	1,519,490,869	11,238,673	5,092,418	0
2036	1,530,465,755	10,974,886	1,600,504	0
2037	1,541,181,144	10,715,389	1,562,661	0
2038	1,551,631,500	10,450,356	1,524,010	0
2039	1,561,811,109	10,179,609	1,484,526	0
2040	1,571,715,199	9,904,090	1,444,346	0

Table 16 - Minimum wage data utilized to create a rough baseline for our labor expenses on the factory floor

Type of Estimate	Rupees/Hr	Dollars/Hr
Average of Minimum Wages Across Indian States/Union Territory, 2009 (Indian Ministry of Labor and Employment)	134.60 INR	3.05 USD
Average of Industry Specific Minimum Wages within the Ceramics, Cement, Factory Work, and Engineering Industries (Indian Ministry of Labor and Employment)	124.85 INR	2.83 USD
Hourly Compensation Costs in Manufacturing in India (Bureau of Labor Statistics U.S. Department of Labor) (2007)	51.57 INR	1.17 USD
Team's Personal Estimate of Labor Costs on Factory Floor (2011)	176.32 INR	4.00 USD

11.2 Capitol Expenses

If these stoves were to be produced on a large scale, our company would be a non-profit, humanitarian aid organization in the case of mass-production. This generally means that we would be operating out of free locations subsidized by the Indian government. However, it is unlikely that the government would cover our non-capitol or land based overhead costs. As a general "rule of thumb" overhead cost in a general manufacturing sense is the unit cost (only labor and materials) multiplied by 200% to give us our overhead costs per unit. As mentioned earlier, we expect our capitol and land to be subsidized by the government, because of this we estimate our overhead cost as only 150% times our subtotal.

11.3 Materials Costing

Due to the relatively low cost of labor in India as well as other developing countries, it is expected that a majority of production cost will be the cost of materials. Due to the constantly fluctuating prices of raw building materials as well as the complications revolving around purchasing materials in a different country, United States prices were used unless otherwise specified in Table 17. Using a rough average of steel prices for the last five years of the range \$0.6/lb to \$0.4/lb, the cost of the steel required for the construction of the stove is between \$7.2 to \$4.8 per stove. The low end of this range is chosen since our factory would be able to selectively buy steel on such a large scale, it is believed the lowest prices would be found. The steel is projected to be the single most important factor in the total unit cost of the stove. Tables 17 and 18 show the estimated cost of materials and machining.

Table 17 – Estimated cost of materials for the cook stove

Material Type	Estimated Costing Rate
Steel Coil (Sheet Metal) [65]	$ 0.6/lb.
Portland Cement[66]	$ 93.38/us ton
Lime	$60.00/us ton
Sand (Silica)	$ 48.00/us tone
Vermiculite[67, 68]	$ 308.50/us ton
Fasteners (Rivets)[69]	$ 0.03/rivet

Table 18 – Machines/Tooling Costing

Machine Type	Estimated Unit Cost[71]
Mechanical Shearing Press (~20 Ton ~18 gage)	$7,000.00
Mechanical Blanking Press (~75 Ton)	$50,000.00
Press Brakes	$5000.00
Pinch Bending Rolls	$9,000.00
Sheet Metal Drawing Press (~20 Ton)	$50,000.00
Vertical Sheet Metal Seamer	$125,000.00
Cement Mixer (Motorized)	$1000.00
Cement Core Molding Press Equipment (~20 Ton)	$20,000.00
Rivet Tool (Pneumatic)	$2380.00

11.4 Unit Cost

The overall unit cost of the stove was calculated using the labor rates in India and our proposed factory work flow plan. Ideally 10,000,000 stoves would be manufactured annually in order to address India's indoor pollution issue. However it is unlikely to achieve this number during the first stages of implementation due to initial costs and logistics. Therefore a much smaller production run was assumed for an initial plant of 500,000/year. This number represents a reasonable initial annual production run for a single facility or assembly process and can be increased in magnitude by adding either more facilities or increasing the size of the facilities to accommodate multiple assembly lines. Using the labor rates outlined in Section 11.1, the team predicts a labor rate for the facility to be about \$3.50/hour. India mandates at least two weeks of vacation time per year so the number of weeks worked annually would be 50. The equations to determine the final labor costs assuming an annual production run of 500,000 were taken from *Fundamentals of Modern Manufacturing*[64] and can be seen below.

$$R_p = D_a/(50 * S_w * H_{SH})$$

$$Where: R_p = actual\ average\ production\ rate$$

$$and: D_a = annual\ demand$$

$$and: S_w = nuber\ of\ shits\ per\ week$$

$$and: H_{SH} = hours\ per\ shift$$

Using the above equation and assuming a 50 week work year, two 10 hour shifts, a six day work week, and an annual demand of 500,000 units, actual production rate (R_p) equals about 83.3units/hour. This number represents the production rate that must be achieved to produce 500,000 units per year. This results in a stove being produced about every 43 seconds. Assuming an assembly line efficiency of 80% result in a stove being produced every 35 seconds. With this and the work content time gathered from Figure 26 of 106 seconds, the number of workers can be estimated by dividing the work content time by the cycle time of 35 seconds. This results in about 185 workers need to satisfy the annual demand working the hours and shifts stated above. Converting the production rate from seconds to hours, results in .0096 hours/stove. The total cost can then be estimated by multiplying the number of workers by the hourly wage and the production rate. The final calculation can be seen in the following equation.

$$185\ workers * \left(\frac{\$4}{hour}\right) * \left(.0096\frac{hours}{stove}\right) = \$6.22/stove$$

It should be noted that this number does not estimate the total cost of the stove, as it only takes into account the cost of labor and is merely part of the total cost equation.

The second part of the equation of our stove's unit cost is that of materials costing. Materials costs were found in bulk pricing estimates, these estimates were translated down into the volumes of aggregate and weights of metal we would require for the stove. From the previous sections, we know the rough cost of steel per stove to be \$4.8 per stove. The aggregate was calculated to be \$1.81, each individual components prices are listed in Table 19. In order to calculate the overall total unit cost per stove, labor must be added to the total materials cost per stove. The total cost of materials on a per stove basis (excluding overhead) can be seen in Table 20.

Table 19 – Total cost of materials on a per stove basis, excluding overhead

Material Type	Estimated Material Cost	Amount Needed per Stove	Cost of Material per Stove
Steel Coil (Sheet Metal)	\$ 0.4/lb	12 lb	4.8
Portland Cement	\$ 93.38/U.S. Ton	6 lb	0.279
Lime (Binding Agent)	\$ 60.00/U.S. Ton	2.5065 lb	0.0753
Sand (Refractory Agent)	\$ 44.00/U.S. Ton	7.5 lb	0.165
Vermiculite (Insulation)	\$ 308.50/U.S. Ton	3.342 lb	0.5082
Fasteners (Rivets)	\$ 0.03/rivet	26	0.78
Total Material Cost per Stove			6.6075

Combining the material cost of the stove with the labor costs puts the stove at a unit cost of about \$12.83. Multiplying this unit cost by the cost of overhead, stated in Section 11.2, of about 150% and adding that to our total cost brings the grand total of the stove to about **\$19.25**. This represents the total unit cost on a mass manufacturing scale.

12.0 User Guide

The user guide will be placed on the packaging of the cook stove. It shows the proper way and conditions for using the stove. Figure 26 and 27 shows the pictorial representation of the user guide.

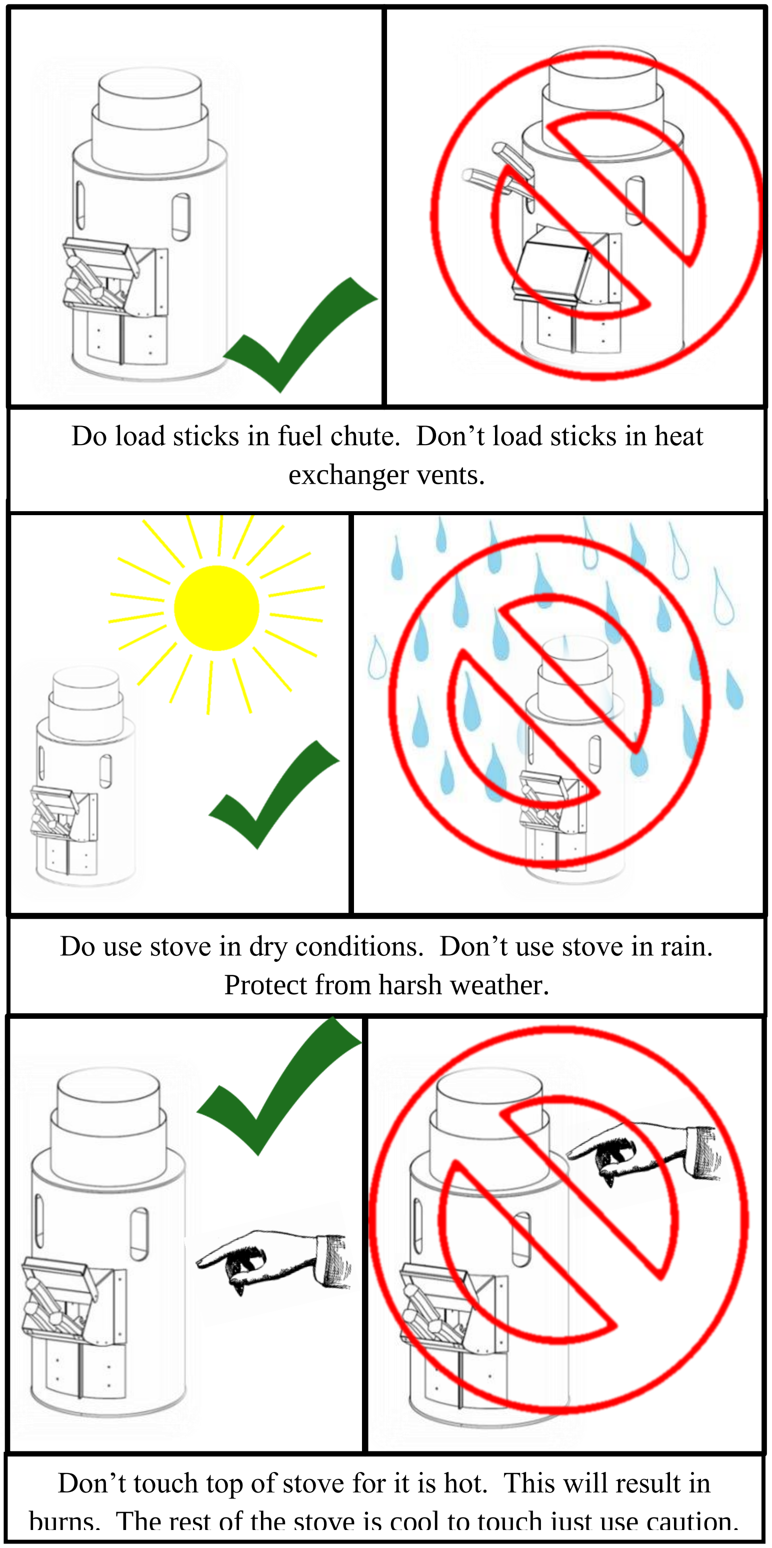
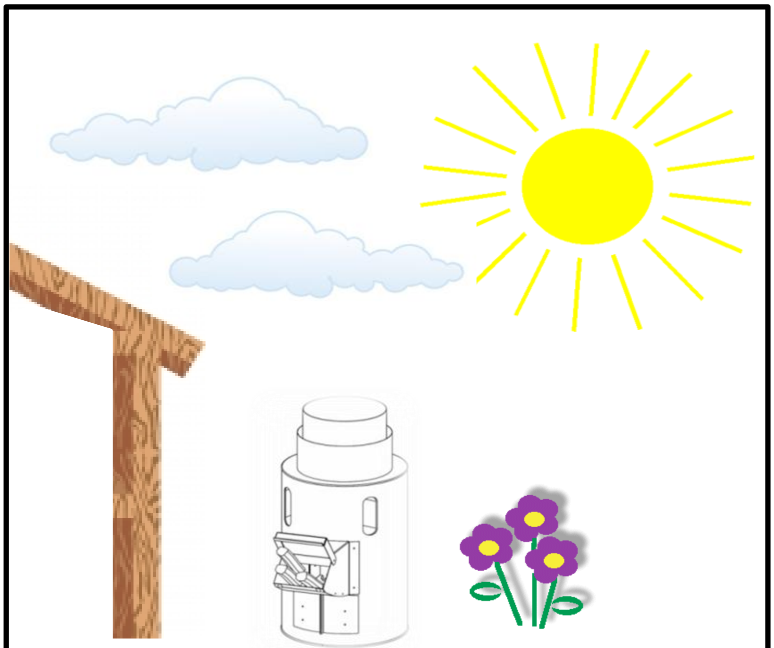


Figure 26 – Pictorial representation of the user guide for the cook stove



Use in well ventilated areas.

Figure 27 – Pictorial representation of the user guide for the cook stove

13.0 Project Timeline

Presented in this section is our team's general project timeline, this timeline is broken down into our major identified phases and major milestones and achievements. Two methods were used to keep our team on-task and organized. The first of these, implemented during our first semester of work, was that of a Gantt chart system. We used this to give us a visual depiction of all of our long term goals and keep everyone working with the big picture timeline in mind. However, due to the difficulty to read, and clunky nature of the program, we quickly abandoned it. By the start of our second semester of work, the team had developed a simple calendar with all of our dates inside. The team enjoyed using this much better as it allowed us to use this calendar as a general planner, and schedule in all of our other activities, while still allowing for project time. Presented in Appendix B are both our original Gantt chart and our more recent calendar schedule.

Phase 1: Preliminary Measures and Research

Phase Duration: 9/17/10 to 10/28/10 (41days)

In this phase the primary focus was be to gather relevant information regarding the project as well as outline specific team requirements and rules. Initial meetings with team as well as client and technical advisors were conducted. Goals, responsibilities, and major objectives were established. Most importantly, State-of-the-Art (SOTA) research was conducted to ensure the team fully understood all variables affecting our project.

Important Dates:

10/28/2010 - Preliminary measures and SOTA research have been fully completed. Team has full understanding of the problem at hand.

Phase 2: Initial Proposal and Design Concept Work

Phase Duration: 9/30/10 to 12/15/10 (76 days)

In this phase a project proposal to our client (Dr. John Tester) was developed detailing all aspects of what we plan to do. Additionally, a design proposal was submitted with three different concept designs to the client. Additional research on the general legal environment and manufacturing concerns was conducted in order to facilitate pre-emptive judgment on design options. A budget considering prototyping, testing, and final manufacturing costs was drafted. The largest portion of time spent in this phase was that of modeling our initial design concepts, performing theoretical analyses on them and determining their functionality. Three design proposals were ultimately created and delivered to our client, with the purpose of being looked over, discussed, and having the best option chosen for continuation into the second semester of work.

Important Dates:

12/15/2010 **-** Three final design concepts were submitted to our client Dr. Tester. These were discussed and eventually our third design (Heat Exchanger Design) was chosen.

Phase 3: Overall Design Development

Phase Duration: 1/18/11 to 2/15/11 (28 days)

In this phase, the functionality and detailed design issues were analyzed in the heat exchanger stove concept. The concept was refined into more detailed, realistic assemblies via Solidworks, and further heat and air flow analysis was performed. Pollution, combustion, and manufacturing aspects were all investigated and considered while refining this design. Finally, an initial works-like (able to cook) stove prototype was built.

Important Dates:

2/5/11 **-** First prototype design was finalized and modeled in CAD.
2/17/11 **-** First prototype was built and was functional (boiled water successfully).

Phases 4a, 4b, 4c: Final Design Refinements, Prototyping, Analysis, Testing

Phase Duration: 2/15/11 to 4/27/11 (71 days)

These phases were separated into the subsections "4a, 4b, 4c" because the team had initially planned on tackling our final design refinements in sections of functionality. These sections were: 4a) Housing and Support Design, 4b) Combustion, Intake, Exhaust and Pollution Control Design, 4c) Cultural Aesthetics and Ergonomics Design. As one can infer from the title, the team had anticipated working on one stove and simultaneously refining the thermal behavior, pollution behavior, manufacturing feasibility, and usability of the stove. What actually ended up occurring was more of a step-by-step process. Our first stove was tested for basic usability, boiling times, and proof of concept. Immediately after testing this stove the team saw a multitude of refinements that could be made. The second prototype was built based on these refinements, and was utilized to conduct thermal testing, as well as documented fuel consumption measures and boiling times. The team saw room for improvement upon this prototype, and a third (and final) was agreed to be built. Before building this third stove, a manufacturing and mass-production analysis was conducted, ensuring this final design was as inexpensive, easy to manufacture, and practical as possible. This third prototype was then tested for pollution emissions, some thermal behavior, fuel consumption, time to boil, and general usability. This phase was not expected to run as late as it did, however due to the iterative process of designing, testing, and re-designing our stoves, this phase carried out until nearly the end of our last semester of work.

Important Dates:

3/21/2010 – Second prototype design is finalized with all necessary refinements from the prototype one.
3/29/2010 – Second prototype is built and ready to start testing
3/31/2010 – Thermal testing approach is developed, documented, and approved by technical advisor Dr. Acker
4/7/2010 – Thermal testing data is collected and results are discussed in a document, this document has been signed off by our advisor Dr. Acker.
4/13/2010 – The team presented at the Global Learning Symposium with other students who participated in globally diverse projects.
4/14/2010 – Third prototype was designed and ready to fabricate, manufacturing analysis was conducted on this stove and processes required to make it.

Phase 5: Design Finishing Touches, Fabrication, and Documentation

Phase Duration: 4/8/11 to 5/10/11 (32 days)

In this phase, the team had originally planned on taking all of our data from the previous testing on another stove, and creating a final stove. This did happen, however a large amount of testing was conducted simultaneously (as mentioned in Phase 4). This did not adversely affect our team; we were able to get our final product completed in a timely manner. The analysis conducted prior to this prototype was very indicative of exactly how our stove should be designed. This third prototype was used for the one last unknown factor of pollution testing. This pollution testing went well (see Section 9.0) and our third prototype became our final prototype and end product. After testing and the third prototype was fabricated, the logistics were taken care of to prepare for end-of-course presentations and documentation.

Important Dates:

4/16/2011 – Greg presented on the team’s efforts at the American Society of Mechanical Engineers (ASME) Student Professional Development Conference (SPDC) at the University of Nevada, Las Vegas and placed 2nd in the oral presentation competition.
4/23/2011 – Third prototype finished building, ready to finish up all testing.
4/26/2011 – Pollution testing conducted and all pollution data, health correlations, and relations to project specifications are calculated.
4/29/2011 – Final documentation is completed, the team presents at the Undergraduate Symposium at Northern Arizona University, the team also presents a technical poster on our project and won 2nd place in the engineering design category for the poster competition.

14.0 Budget and Bill of Materials

Presented here is the general budget of the team (Table 20), with costs sorted by major activities. An itemized budget can be seen in Appendix C. We would like to mention that this project would not have been as inexpensive as it was without the help of Aprovecho research center generously donating a rocket stove to our team to use for testing. We would also like to mention that thanks to a generous donation of pollution testing supplies by the Environmental Engineering Department and Dr. Auberle, we were able to conduct a lot of state-of-the-art testing for free. This testing would have cost us upwards of thousands of dollars if we would have had to purchase these testing devices.

Table 20 – Overall budget for our project

Description of Purchase	***Purchase Time(s)***	***Cost***
Aprovecho Rocket Stove	Donated on Feb 10th	Free
Initial Prototype Materials and Fuels	Feb 12th – Feb 17th	$70
Secondary Prototype Materials and Fuels	March 7th – March 27th	$70
Final Build Materials	March 6th – April 25th	$130
Pollution Testing Devices and Materials	Donated on April 25th – April 29th	Free
Final Presentation Poster	April 28th	$145
	Total Cost of Project	**$415**

The construction of our various prototype stoves was aided largely by the use of scavenged or donated materials. Both of our first two prototypes utilized chimney and stovepipe scraps, found near the Northern Arizona University surplus facilities. Several materials were purchased to complete these prototypes from local hardware stores and machine shops such as Ace, Home Depot, Boyer heating and cooling, and Mayorga's Welding. Presented in Table 22 is a bill of materials of what we as a team used to develop our third and final prototype. One should reference section 10 for full documentation on the materials, processes, and assembly required for our final stove design, as our final specifications all relate to a mass-production factory environment. The processes below are simply what was available to us as a team, and should not be referenced in regards to our final design's actual construction specifications.

Northern Arizona University
Clean Burning Stove Team

Table 21 – Bill of materials for third and final prototype

Component	Material Used	Processes Used
Outer Body Cylinder	-24 ga Sheet Steel	-Shape cut out with handheld Router -Cylinder shape rolled with 3-roll bender
Heat Exchanger Cylinder	-24 ga Sheet Steel	-Shape cut out with handheld Router -Cylinder shape rolled with 3-roll bender
Inner Combustion Chamber Cylinder	-24 ga Sheet Steel	-Shape cut out with handheld Router -Holes cut with drill press -Cylinder shape rolled with 3-roll bender
Bottom Plate	-24 ga Sheet Steel -8 1/8" blind rivets	-Shape cut out with sheet metal shears -Connected to Outer Body Cylinder with hand drill and rivet gun
Top Pot Rest Surface	-24 ga Sheet Steel -12 1/8" blind rivets	-Shape cut out with sheet metal shears and handheld router -tabs bent with sheet metal press brake -Connected to stove body with hand drill and rivet gun
Top Pot Rest Tabs	-24 ga Sheet Steel	-Shape cut out with hand held router and hand drills -Final form bent with sheet metal press brake -connected to top surface with hand drill and rivet gun
Fuel Chute Top Body	-26 ga Sheet Steel	-Shape cut out with hand held router -Final form bent with sheet metal press brake
Fuel Chute Bottom Body	-24 ga Sheet Steel	-Shape cut out with hand held router -Final form bent with sheet metal press brake
Fuel Chute Door	-24 ga Sheet Steel	-Shape cut out with hand held router -Final form bent with sheet metal press brake
Fuel Chute Connector Flange	-24 ga Sheet Steel	-Shape cut out with hand held router -Final form bent with sheet metal press brake
Grate	-24 ga Sheet Steel	-Shape cut out with hand held router -Holes drilled with a dress press
Ash Tray Body	-24 ga Sheet Steel	-Shape cut out with hand held router -Final form bent with sheet metal press brake
Ash Tray Cap/Handle	-24 ga Sheet Steel	-Shape cut out with hand held router -Final form bent with sheet metal press brake
Ceramic Core	-Vermiculite, Sand, Portland Cement, Lime, Concrete Forms	-Raw aggregate mixed with water and packed into concrete forms -Core is pulled out and fuel and air inlets are cut with hand saws.
Ceramic Ash Tray Liner	-Vermiculite, Sand, Portland Cement, Lime, Concrete Forms	-Cut from ceramic core fuel inlet hole -finish top side so ash tray slides into stove properly
Final Assembly of All Components	-26 rivets (not including rivets above)	-All parts are riveted together into final assembly

XPRIZE
Northern Arizona University
Clean Burning Stove Team

15.0 Conclusions

Our team had initially set out to create a cleaner burning cook stove for India, we now stand at the end of a year's worth of work with exactly that, a well-designed, efficient, functional, cleaner burning cook stove for India. During the course of the school year, the team accomplished nearly all goal, with only one specification not met. Presented next is a summary of each of our specifications and requirements, and commentary on whether or not they were met, as well as how they were met.

Table 22 – Specification and commentary for overall project

Specification/Requirement	***Results/Commentary***
Have a total unit cost of $10 or less on mass scale	**Our team did not meet this specification**. We do not take this a as a defeat however, largely due to the fact that we set this specification blindly, trusting the Aprovecho Research Center's interpretation of the Waxman-Markey Bill we based it upon. Our estimated unit cost of our stove is actually $19.45, which we feel is very reasonable and worth the benefits provided by our stove
Reduce fuel by greater than 50% as compared to a three stone fire	**This specification was met.** Our stove consumes an average of 10.64 oz of wood to boil, 14.04 oz of wood to boil on hot start and carry on to a simmer. An Aprovecho StoveTec rocket stove is reported to reduce fuel use by approximately 50% compared to a three stone fire[46], these stoves average about 10.3oz to boil on a cold start according to our tests. Because our stove burns roughly the same fuel as the StoveTec rocket stoves, we believe we meet this requirement.
Reduce black carbon emissions by greater than 60% when compared to a three stone fire	**This specification was met.** Comparing our stove to an Aprovecho rocket stove once again, we can see that we exceed this specification greatly. A StoveTec rocket stove reduces particulate matter emissions 46% greater than a three stone fire[45], these particulate matter emissions are directly correlative of ash production, which correlates to black carbon emission. Based on our ash measurement tests, we reduce ash production (for the same amount of wood) by 63% as compared to a Stove-Tec stove. If we reduce Black carbon by 63% more than a Stove-Tec stove, and it is shown that the Stove-Tec stoves reduce black carbon by a signifigant (40%-50%) amount, we can safely say our stove reduces much greater than 60% of black carbon emission as compared to a three stone fire.
Theoretically reduce the incidence of pneumonia in children under five by 30% or greater.	**This specification was met.** As described in section 9.4 of our document, correlations can be drawn to pneumonia onset via the increase in PM inhalation and CO inhalation. Our stove reduces the emissions of PM and CO by approximately 90% to a three stone fire. This 90% increase of emissions does not directly tie to a percentage of pneumonia onset rates. However, due to how large of a difference our stove emits in comparison to a three stone, and as all other factors of harmful emissions have been reduced, we are confident we are meeting this requirement.
The stove must be accepted by local user	**This requirement is believed met.** We believe that the stove would be accepted by the end user because it does not fundamentally change the way they cook or the fuel they use to do so. We are simply placing a new object between the fire, their food, and the user.

Must be safe to user and by-standers	**This requirement is met.** The stove contains no sharp edges and is safe to the touch on almost all surfaces during operation (all surfaces excluding top surface are less than 100°F). The only surfaces that may be deemed unsafe are the top cooking surfaces. One naturally knows that the surface closest to ones cooking pot is not safe, so it is expected that this one surface will not pose a threat.
Must be easy to operate, ergonomic, and compatible with end-user technology	**This requirement is met.** Simply put, we as a team enjoyed cooking with our stove and found it extremely easy to light, maintain a fire, and cook with. We are not experts at cooking on wood fires, and have not been doing so our whole lives such as many of our end users. We believe that if the stove is easy to use for us, the end user in India should have no problem with it.
Must abide by any emissions laws in India	**This requirement is believed met.** Because our stove abides by all the emissions parameters set by the US EPA's Waxman-Markey Bill and its standards, we believe that we will be able to meet any emissions laws in India. This is largely due to the general lack of emissions laws in India, it is assumed that the Waxman-Markey Bill exceeds and Indian emissions standards.
Must be easy to service and clean	**This requirement is met.** The design of our stove is such that removal of the ash tray facilitates cleaning; all surfaces that may be fouled with ash or soot on the internal geometries can be reached from the bottom after removing the ash tray. All combustion chamber surfaces can be reached by reaching down through the top. All outer surfaces are easy to clean as well.

Overall, the team had a wonderful experience in the development and testing of our cleaner burning cook stove. We wish to express that there is always room for improvement, and that as efficient as our stove is, others should not view it as the end solution to this problem. We believe that any who read this document and others documents should gain inspiration and knowledge from our findings and apply them to their own studies and designs. We hope that one day; a stove similar to ours will be implemented on a large scale in India. Ideally, within a few decades, all needy families would have an improved cook stove, and via this improvement to their quality of life, illness and death would be largely reduced. We thank you for reading this document and considering our findings.

16.0 References

01 - Pokhrel, Amod K, et al. "Tuberculosis and Indoor Biomass and Kerosene Use in Nepal: A Case--Control Study." Environmental Health Perspectives (2010): 558-564.

02 - Dasgupta, S, et al. "Improving indoor air quality for poor families: a controlled experiment in Bangladesh." Indoor Air, Vol. 19 Issue 1 (2009): 22-32.

03 - Reed, M. D, et al. "Health Effects of Subchronic Exposure to Environmental Levels of Hardwood Smoke." S. K. Inhalation Toxicology, Vol. 18 (2006): 523-539.

04 - Kausley, Shankar B and Aniruddha B Pandit. "Modeling of Solid Fuel Stoves." Fuel 89.3 (2010): 782-791.

05 - Verhaart, P. Natural Draft for Better Biomass Burning Cookstoves. Technical Paper. Eindhoven, Netherlands: Faculty of Mechanical Engineering, Eindhoven University of Technology, n.d.

06 - Fitzpatrick, E.M, et al. "The mechanism of the formation of soot and other pollutants during the co-firing." Fuel 88.9 (2009): 2409-2418.

07 - Norbert, Senf. A Comparison of Masonry Fireplace Emission Testing Methods Prepared for: The Brick Institute of America, Reston VA 22091. Testing Report. Shawville, Quebec: Masonry Stove Builders, 1995.

08 - Werkelin, Johan, et al. "Chemical Forms of Ash-Forming Elements in Woody Biomass Fuels." Fuel 88.3 (2009): 481-493.

09 - Porteiro, J, et al. "Experimental analysis of the ignition front propagation of several biomass." Fuel 89.1 (2010): 26-35.

10 - Ayoub, Josef and Eric Brunet. Performance of large portable metal woodstoves for community kitchens. Research Paper. Ste Anne de Bellevue, Quebec: Brace Research Institute, Facutly of Engineering, McGill University, 1995.

11 - Gregory, Dunnnu, et al. "Characterisation of large solid recovered fuel particles for direct co-firing in large PF power plants." Fuel 88.12 (2009): 2403-2408.

12 - Stefan, Hjärtstam, et al. "Combustion characteristics of lignite-fired oxy-fuel flames." Fuel 88.11 (2009): 2216-2224.

13 - Hardy, Peter S. Portable Cook Stove. Invention Patent of Stove. Bridgeport, Conn.: United States Patent Office, 1962.

14 - Lertsatitthanakorn, C. "Electrical performance analysis and economic evaluation of combined biomass cook stove thermoelectric (BITE) generator." Science Direct 98 (2006): 1670-1674.

15 - Pohekar, S.D., Dinesh Kumar and M. Ramachandran. "Dissemination of cooking energy alternatives in India—a review." Renewable and Sustainable Energy Reviews 9 (2005): 379-393.

16 - Kandpal, J.B and R.C Maheshwari. "Combustion Of Biomass Fuels In Two Cookstoves For Their Conservation."." Energy Conservation Mgmt. 36.10 (1995): 1015-1021.

17 - Reed, T.B, E Anselmo and K Kircher. Testing and Modeling the Wood-Gas Turbo Stove. Testing and Research Paper. Littleton Colorado: The Community Power Corporation & The Colorado School of Mines, 2000.

18 - Fuller, Dorian Q. Ceramics, Seeds and Culinary Change in Prehistoric India. Research Paper. United Kingdom: Institute of Archaeology, University College London, 2004.

19 - Bharagava, Anuh, et al. "Exposure risk to carcinogenic PAHs in indoor-air during biomass combustion whilst cooking in rural India." Atmospheric Environment 38 (2004): 4761-4767.

20 - Zuk, Miriam, et al. "The impact of improved wood-burning stoves on fine particulate matter concentrations in rural Mexican homes." Journal of Exposure Science & Environmental Epidemiology (2007): 224-232.

21 - Bryden, Mark, et al. "Design Principles for Wood Burning Cook Stoves." Field Research Documentation. n.d.

22 - Armendariz Arnez, Cynthia, et al. "Reduction in personal exposures to particulate matter and carbon monoxide as a result of the installation of a Patsari improved cookstove in Michoacan Mexico." Indoor Air 13.3 (2003): 253-259.

23 - Baldwin, Sam, et al. "Improved Woodburning Cookstoves: Signs of Success." Ambio 14.4/5 (1985): 50-62.

24 - Nienhuys, Sjoerd. Improved Cooking Stove. Field Results Report. Tajikistan: MOP-ICS Production, 2010.

25 - Scott, Peter. Simple Plans to Build the Justa stove. Design Report. Cottage Grove, OR: Aprovecho Research Center, n.d.

26 - Ogle, Damon. Making Light Weight Refractory Ceramic From Perlite and Clay. Research Report. Cottage Grove, OR: Aprovecho Research Center, 2003.

27 - MacCarty, Nordica, Dean Still and Damon Ogle. "Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance." Fuel (2010): 161-172.

28 - Yuntenwi, Ernistine, et al. Laboratory study of the effects of moisture content on heat transfer and combustion efficiency of three biomass cook stoves. Technical Report. Cottbus, Germany & Cottage Grove, OR: Brandenburg University of Technology, Aprevecho Research Center, n.d.

29 - Gunnar Barrefors, Goran Petersson. "Volatile Hydrocarbons from Domestic Wood Burning." Chemosphere (1995): 1551-1556.

30 - J. Jeffrey Peirce, Ruth F. Weiner, P. Aarne Vesilind. "Environmental Pollution and Control." Woburn: Butterworth-Heinemann, 1998. 245-324.

31 - Jacob D. McDonald, Barara Zielinska, Eric M. Fujita, John C. Zagbiel, Judith C. Chow, John G. Watson. "Fine Particle and Gasious Emission Rates from Residential Wood Compbustion." Environmental Science Technology (2000): 2080-2091.

32 - James J. Schauer, Michael J. Kleeman, Glen R. Cass, Bernd R. T. Simoneit. "Measurement of Emissions from Air Pollution Sources." Environmental Science Technololgy (2001): 1716-1728.

33 - Jawurek, G. Ballard-Tremeer and H. H. "Comparison of Five Rural, Wood-burning Cooking Devices: efficiencies and Emissions." Biomass and Bioenergy (1996): 419-430.

34 - John Twidell, Tony Weir. "Renewable Energy Resources." New York: Taylor and Francis, 2006. 351-397.

35 - K. W. Ragland, D.J. Aerts. "Properties of Wood for Combustions Analysis." Bioresource Technology (1991): 161-168.

36 - Strehler, A. "Technologies of Wood Combustion." Ecological Engineering (2000): 25-40.

37 - Tillman, D. A., Amadeo, J.R., Kitto, W. D.,. Wood Combustion, Principles, Processes, and Economics. New York: Academic Press, 1981.

38 - Lindfors, L.E. and Kalantar Neyestnaki. Catalytic clean-up of emissions from small-scale combustion of biofuels. Technical Report. Biskopstgatan 8, Finland: Laboratory of Industrial Chemistry, Abo Akademi University, 1998.

39 - Bruce, Nigel, et al. "Impact of improved stoves, house construction and child location on levels of indoor air pollution exposure in young guatemalan children." Exposure Analysis and Enviromental Epidemiology (2004): 1-8.

40 - Houck, James E. and Paul E. Tiegs. Residential Wood Combustion Technology Review Volume 1. Technical Report. Beaverton, OR: MONI Environmental Services, Inc., 1998.

41 - Turns, Stephen R. An Introduction to Combustion. New York: McGraw-Hill, 1996.

42 - 111th Congress, 1st Session. Waxman Markey Bill. Washington DC: US Government, 2009.

43 - Agency, U.S. Environmental Protection. http://www.epa.gov/ttn/chief/ap42/. 3 September 2010. December 2010.

44 - Group, Berkeley Air Monitoring. "Evaluation of Manufactured Wood-Burning Stoves in Dadaab Refugee Camps, Kenya." 2010.

45 - MacCarty, Nordica, Dean Still, Damon Ogle, Thomas Drouin. "Assessing Cook Stove Performance: Field and Lab Studies of Three Rocket Stoves Comparing the Open Fire and Traditional Stoves in Tamil Nadu, India on Measures of time to Cook, Fuel Use, Total Emissions, and Indoor Air Pollution." Aprovecho Research Center (January 2008).

46 - United States Agency International Development. "Assessment of Haiti Alternative Cooking Technologies Program." (November 2010).

47 - Sincavage, Jessica R., Carl Haub, O.P. Sharma. "Manufacturing in India: Labor costs in India's organized manufacturing sector." Mothly Labor Review (May 2010).

48. "Comparative minimum waeg rates prevailing ins cheduled employments in central sphere/states/union territories." (2009).

49 - Bureau of Labor Statistics, U.S. Department of Labor. "International comparison of hourly compenstation costs in manufacturing." (2009).

50 - Sabha, Rajya. "Variation of minimum wage rates in states." Press information bureau governments of India (2011).

51, -. "Comparitive statement of financial bids for outsourcing of semi skilled workers in ministry of labour and employment." (n.d.).

52 - Steel prices in india 2011, 2010, and 2009. 2011. <file:///S:/Capstone/ME/xprize/Research/52%20-%20Greg%20-%20indian%20steel%20prices.htm>.

53 - Environmental Protection Agency. "Guidance for quantifying and using emission reductions from voluntary woodstove changeout programs in state implementation plans." (January 2006).

54 - Ali, Habiba. "Planting tress: Is this enough?" December 2008.

55 - Wang, Y., J.W. Munger, S. Xu, M.B. McElroy, J.Hao, C.P. Nielsen, and H. Ma. "CO2 and its correlation with CO at ruarl site near Beijing: implications for combustion efficiency in China." Atmospheric Chemistry and Physics (2010).

56 - Winrock International. "Household energy, indoor air pollution and health: Overview of experiences and elssons in Inida." (octover 2004).

57 - Still, Dean and Nordica MacCarty. "The Relationship between Higha dn Low Power Carbon Monoxide and Particulate Matter Emissions in Rocket Stoves." 2006.

58 - EPA, American Lung Association, American Medical Association, U.S. Consumer Product Safety Commission. "Indoor Air Pollution: An Introduction for Health Professionals." (n.d.).

59 - Peabody, Francis W., M.D. "The Carbon Dioxide Content of the Blood in Pneumonia." n.d. 701 - 718.

60 - Misra, Mahendra K., Kenneth W. Ragland, and Andrew J. Baker. "Wood Ash Composition as a Function of Furnace Temperature." Biomass and Bioenergy (1993).

61 - Boubel, Richard W., Ph.D., Donald J. Henz, P.E. "Control of Particulate Emissions from Wood - Fired Boilers." (n.d.).

62 - Aprovecho Research Center. The Water Boiling Test Version 4.1.2. October 1, 2009.

63 - Wood Gas Densification Promixate and Ultimate Analyses. n.d. <http://www.woodgas.com/proximat.htm>.

64 - Groover, Mikell P. Fundamentals of Modern Manufacturing: Materials, Processes and Systems. Danvers: John Wiley & Sons, 2010.

65 - Free Charts for Your Website. *Metal Prices & News on the Internet.* [Online] [Cited: April 13, 2011.] http://www.metalprices.com/pubcharts/Public/SteelBenchmarker_Steel_Price_Charts.asp?WeightSelect=&SizeSelect=&ccs=&cid=.

66 - Portland Cement Prices. *Portland Cement 42.5 - Portland Cement Supplier.* [Online] 2009. [Cited: April 13, 2011.] http://www.portland-cement.net/portland_cement_prices.html.

67 - What is the Average Cost of Vermiculite Per Ounce/Gram/Pound/Ton? *kaycircle everyday reference.* [Online] [Cited: April 13, 2011.] http://www.kaycircle.com/What-Is-the-Average-Cost-of-Vermiculite-Per-Ounce-Gram-Pound-Ton-Average-Vermiculite-Price.

68 - Potter, Michael J. Vermiculite. *USGS Mineral Resources Program.* [Online] January 28, 2011. [Cited: April 13, 2011.]

69 - Blind Rivets. *U.S. Industrial Fasteners of Arizona, Inc.* [Online] [Cited: April 13, 2011.] http://www.usifaz.com/rivets1.html.

70 - Cement Prices. *Official Website of the State of Connecticut.* [Online] 2011. [Cited: April 13, 2011.] http://www.ct.gov/dot/lib/dot/documents/dconstruction/cement.pdf.

71 - Sheet Metal Machines. *Van Sant.* [Online] http://www.vansantent.com/sheet_metal_machines/sheet_metal_machines.htm.

Prototype 2: Fuel Cunsumption/Water Boil Results

4/4/11 Test A in the morning			
64 oz water			
Target Pot			
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	2.100	00:00.0	Added 2.1
	0.800	00:00.0	Added .8
		00:50.0	Clean Burn
	10.600	02:25.0	Added 10.6
		05:30.0	Saw Bubbles
		11:30.0	Boil
		24:30.0	Simmer/All wood now charred
		32:30.0	Simmer stop
		37:00.0	Coals out, heat gone
Total Wood	13.500		
Ash and tray	16.300		
Tray	15.700		
Ash	0.600		
Ash/Wood Ratio	*0.044*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/4/11 Test B at Night			
	Let's cook rice!	Zatarain's rice brand	
	30 oz Water		
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	1.2	00:00.0	Added 1.2
	4.2	00:00.0	Added 4.2
		05:27.0	Saw bubbles
	5.1	08:55.0	Added 5.1
	4.2	11:42.0	Added 4.2
		12:30.0	Boil
		13:00.0	Rice on the pot
	4	26:15.0	Add 4.0
		27:36.0	Pot top rattle
		37:17.0	Rice cooked
Total Fuel	18.7		
Ash + Tray	15.8		
Tray	15.6		
Ash	0.3		
Ash/Wood Ratio	*0.016*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/5/11 Test I			
	64 oz water	Cold Start	Target Pot
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	2.600	00:00.0	Added 2.6
	6.700	03:00.0	Added 6.7
		04:00.0	Saw Bubbles
	3.400	07:00.0	Added 3.4
	5.500	14:00.0	Added 5.5 still no boil
		16:45.0	Boil
		29:20.0	Still boil, coming to an end only bubbles in the middle
		31:45.0	Simmer phase begins, all wood consumed/coals
		48:00.0	Simmer stop
		51:00.0	IR measurments Water - 170F, Stove body - 115F, Fuel chute - 120F, Ash tray handle - 90F, Coals - 300-500F
Total Wood	18.200		
Ash and tray	15.800		
Tray	15.600		
Ash	0.300		
Ash/Wood Ratio	*0.016*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/5/11 Test II			
	64 oz Water	Cold Start	
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	3.7	00:00.0	Added 3.7
	3.8	00:00.0	Added 3.8
		03:30.0	Saw bubbles IR Gun: Water - 130F, Pot - 140F, Body - 120F, CC - 600+F
	3.6	08:00.0	Added 3.6
	6.1	13:00.0	Added 6.1
		17:00.0	Boil IR Gun: Water - 200F, Pot - 260, Body - 140F, CC - 800+F
		25:00.0	Simmer start/Added 3 bags Romen IR Gun: Water - 180F, Pot - 140F, Body - 140F, CC - 200+F
		34:00.0	Romen Ready
		40:00.0	Cooking heat gone
Total Fuel	17.2		
Ash + Tray	16		
Tray	15.6		
Ash	0.5		
Ash/Wood Ratio	*0.029*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/5/11 Test III			
64 oz water	Hot start		
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	1.9	00:00.0	Added 1.9
	4.3	00:00.0	Added 4.3
		05:00.0	Saw bubbles IR Gun: Water - 140F, Pot - 160F, Body - 145F, CC - 800+F
	6.2	08:00.0	Added 6.2
		09:30.0	Boiling IR Gun: Water - 200, Pot - 190, Body - 160F, CC - 900+F
		15:00.0	Simmer start
Start Simmer Test (amount of fuel to keep at a simmer for 45min)			
	3.2	25:00.0	Added 3.2
	2.6	31:00.0	Added 2.6
		59:59.9	Successful Simmer IR Gun: Water - 174F, Pot - 110F, Body - 145F, CC - 500F
Fuel to keep simmering for 45min	*5.8*		
Total Fuel	18.2		
Ash + Tray	15.8		
Tray	15.6		
Ash	0.2		
Ash/Wood Ratio	*0.011*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/5/11 Test IV			
64 oz Water	Cold Start		
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	2.0	00:00.0	Added 2.0
	3.9	00:00.0	Added 3.9
		07:30.0	Saw bubbles IR Gun: Water - 150F, Pot - 190F, Body - 120F, CC - 800-900F
	2.7	11:30.0	Added 2.7
		13:30.0	Boil IR Gun: Water - 195F, Pot - 215F, Body - 140F, CC - 1000+F
		17:40.0	Simmer Begins and only coals
		23:00.0	Still simmering IR Gun: Water - 170F, Pot - 120F, Body - 140F, CC - 700-900F
		29:00.0	End Simmer with IR Gun water temp - 165F
Total Fuel	8.6		
Ash + Tray	15.7		
Tray	15.6		
Ash	0.2		
Ash/Wood Ratio	*0.023*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/5/11 Test V			
64 oz Water	Hot Start		
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	1.8	00:00.0	Added 1.8
	3.2	00:00.0	Added 3.2
	5.6	08:50.0	Added 5.6 Saw bubbles IR Gun: Water - 180F, Pot - 230F, Body - 140F, CC - 900+F
		11:00.0	Boil IR Gun: Water - 200F, Pot - 250F, Body - 145F
		15:00.0	Simmer Begins and only coals
Start Simmer Test (amount of fuel to keep at a simmer for 45min)			
	6.3	15:00.0	Simmer Begins and only coals IR Gun: Water - 185F, Pot - 140F, Body - 145F, CC - 800+F
	0.3	26:00.0	Fire died shortly but got started back up
	2.7	59:59.9	Sim End IR Gun: Water - 175F, Pot - 135F, Body - 140F
Fuel to keep simmering for 45 min	*9.3*		
Total Fuel	19.9		
Ash + Tray	15.7		
Tray	15.6		
Ash	0.2		
Ash/Wood Ratio	*0.010*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/5/11 Test VI			
	Cold Start	Cold pot and 6	61bs 10.2oz
	64 oz Water	Hot pot and bo	6lbs 6.2 oz
		Water lost	*4oz*
	Wood Amount (o	**Time (min:sec**	**Comments**
	1.7	00:00.0	Added 1.7
	5.7	00:00.0	Added 5.7
	3.9	08:40.0	Added 3.9
		11:30.0	Saw bubbles IR Gun: Water - 180F, Pot - 150F, Body - 120F, CC - 900+F
		12:30.0	Boil IR Gun: Water - 200F, Pot - 160F, Body - 130F, CC - 1000+F
		16:40.0	Simmer Begins and only coals
		00:00.0	Still simmering IR Gun: Water - 85F, Pot - 160F, Body - 130F, CC - Err
		31:00.0	End Simmer with IR Gun water temp - 165F
Total Fuel	11.3		
Ash + Tray	15.9		
Tray	15.6		
Ash	0.4		
Ash/Wood Ratio	*0.035*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/5/11 Test IV			
	Hot Start	Cooking Spanish Jambalayan Rice	
	36 oz Water		
	Wood Amount (o	**Time (min:sec**	**Comments**
	2.3	00:00.0	Added 2.3
	4.5	00:00.0	Added 4.5
	5.6	06:30.0	Added 5.6
		07:18.0	Saw bubbles IR Gun: Water - 182F, Pot - 130F, Body - 140F, CC - Err
		08:00.0	Added Rice Boil IR Gun: Water - 200F, Pot - 130F, Body - 150F, CC - Err
		31:00.0	End Cooking rice IR Gun: Rice - 150F, Pot - 110F, Body - 140F
Total Fuel	12.4		
Ash + Tray	15.8		
Tray	15.6		
Ash	0.3		
Ash/Wood Ratio	*0.024*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

Averages

	4-5 Test I	4-5 Test II	4-5 Test III	4-5 Test IV	4-5 Test V	4-5 Test VI	4-5 Test VII
Total Wood	18.200	17.2	18.2	8.6	19.9	11.3	12.4
Ash	0.300	0.5	0.2	0.2	0.2	0.4	0.3
Ash/Wood Ratio	*0.016*	*0.029*	*0.011*	*0.023*	*0.010*	*0.035*	*0.024*

Cold Start	4-5 Test II	4-5 Test IV	4-5 Test VI	Averages
Total Wood	17.2	8.6	11.3	12.367
Ash	0.5	0.2	0.4	0.367
Ash/Wood Ratio	*0.029*	*0.023*	*0.035*	0.029

Hot Start	4-5 Test III	4-5 Test V	4-5 Test VII	Averages
Total Wood	18.2	19.9	12.4	16.83
Ash	0.2	0.2	0.3	0.23
Ash/Wood Ratio	*0.011*	*0.010*	*0.024*	0.015

Prototype 3: Fuel Consumption/Water Boil Results

4/22/11 Test			
Cold Start	64 oz Water		had some rice on the sides of the pot
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	1.1	00:00.0	Added 1.1
	2.9	00:00.0	Added 2.9
	4.9	06:00.0	Bubbles Water - 170, Pot - 200, Stove - 80
		07:30.0	Boil Pot 170, Water - 200, Body - 77
		12:00.0	Boil turned to simmer Water - 190, Pot - 140, Body 100 (sun effects)
		21:00.0	Simmer stopped but still cooking temperatures Water - 170, Pot 120, Body 100
		29:00.0	End of Cooking temp - Water 167, CC >800
Total Fuel	8.9		
Ash + Tray	115.9		
Tray	115.6		
Ash	0.4		
Ash/Wood Ratio	*0.045*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/22/11 Test			
Hot start	64 oz water		
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	5.9	00:00.0	Added 5.9
	4.8	08:00.0	Added 4.8
		10:00.0	Bubbles Water - 180, Pot - 170, Stove - 80
		10:45.0	Boil Water - 180, Pot - 166, Stove - 90
		15:00.0	Simmer start
Start Simmer Test (amount of fuel to keep at a simmer for 45min)			
		15:00.0	Simmer start
	3.7	23:00.0	Added 3.7 Water - 180, Stove - 90, Pot - 150
	1.9	45:00.0	Added 1.9 Water - 170, Stove - 80, Pot - 150
	0.6	50:00.0	Added 0.6
		59:59.9	End simmer Water - 165, Stove - 90, Pot - 120
Fuel to keep simmering for 45min	*5.8*		
Total Fuel	16.3		
Ash + Tray	15.8		
Tray	15.6		
Ash	0.2		
Ash/Wood Ratio	*0.012*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/24/11 Test			
Cold Start	64 oz Water	48F weather	30 - 45 mph wind
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	4.8	00:00.0	Added 4.8
	3.9	06:00.0	Added 3.9
		08:00.0	Bubbles Water - 175, Pot - 180, Pot - 180, Body - 60
		09:45.0	Boil Water - 200, Pot - 200, Stove - 60
		13:48.0	Simmer start
		20:00.0	Cooking temp/simmer over
Total Fuel	8.7		
Ash + Tray	113.6		
Tray	113.3		
Ash	0.4		
Ash/Wood Ratio	*0.046*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/24/11 Test			
Hot Start	64 oz Water	50 F weather	30 - 45 mph winds
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	4.5	00:00.0	Added 4.5
	5.1	05:00.0	Added 5.1
		08:00.0	Bubbles Water - 129, Pot - 190, Stove - 80
		09:00.0	Boil Water - 200, pot - 190, stove - 80
		12:30.0	Simmer Begins and only coals
Start Simmer Test (amount of fuel to keep at a simmer for 45min)			
		12:30.0	Simmer Begins and only coals
		18:00.0	1st stick
	3.5	25:40.0	2nd stick
	2.7	28:40.0	3rd stick
	3.2	35:00.0	4th stick
		40:00.0	5th stick
		57:00.0	end of simmer
Fuel to keep simmering for 45min	*9.4*		
Total Fuel	15.8		
Ash + Tray	113.1		
Tray	112.8		
Ash	0.4		
Ash/Wood Ratio	*0.025*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/24/11 Test			
Cold Start	64 oz Water		
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	2.7	00:00.0	Added 2.7
	3.3	01:00.0	Added 3.3
	8.3	05:00.0	Added 8.3
		06:50.0	Bubbles Water: 165F
		09:15.0	Full Boil Water: 198F
		33:00.0	End Simmer
Total Fuel	14.3		
Ash + Tray	112.5		
Tray	112.4		
Ash	0.2		
Ash/Wood Ratio	*0.014*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/24/11 Test IV			
Hot Start	36 oz Water		
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	4.3	00:00.0	Added 4.3 smoky wet wood is bad
	6.3	03:30.0	Added 6.3
		05:40.0	Bubbles
		07:50.0	Full Boil Water: 199F
	5.9	20:00.0	2 large pieces slowly added
		53:00.0	end of simmer
Total Fuel	16.5		
Ash + Tray	112		
Tray	111.9		
Ash	0.2		
Ash/Wood Ratio	*0.012*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/24/11 Test CS3			
Cold Start	64 oz Water	CS	
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	2.7	00:00.0	Added 2.7
	3.3	01:00.0	Added 3.3
	8.3	05:00.0	Added 8.3
		06:50.0	Bubbles Water: 165F
		09:15.0	Full Boil Water: 198F
		33:00.0	End Simmer
Total Fuel	14.3		
Ash + Tray	112.5		
Tray	112.4		
Ash	0.2		
Ash/Wood Ratio	*0.014*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

4/24/11 Test HS3			
Hot Start	36 oz Water		
	Wood Amount (oz)	**Time (min:sec)**	**Comments**
	4.3	00:00.0	Added 4.3 smoky wet wood is bad
	6.3	03:30.0	Added 6.3
		05:40.0	Bubbles
		07:50.0	Full Boil Water: 199F
	5.9	20:00.0	2 large pieces slowly added
		53:00.0	end of simmer
Total Fuel	16.5		
Ash + Tray	112		
Tray	111.9		
Ash	0.2		
Ash/Wood Ratio	*0.012*		
*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for			

Averages

Cold Start						
	4-22 Test CS1	4-24 Test CS2	4-24 Test CS3	4-26 P Test 1	4-26 P Test 3	CS Averages
Total Fuel	8.9	8.7	14.3	13	8.3	10.64
Ash	0.4	0.4	0.2	0.2	0.2	0.28
Ash/Wood Ratio	*0.045*	*0.046*	*0.014*	*0.015*	*0.024*	*0.029*

Hot Start						
	4-22 Test HS1	4-24 Test HS2	4-24 Test HS3	4-26 P Test 2	4-26 P Test 4	HS Averages
Total Fuel	16.3	15.8	16.5	12.5	9.1	14.04
Ash	0.2	0.4	0.2	0.2	0.2	0.24
Ash/Wood Ratio	*0.012*	*0.025*	*0.012*	*0.016*	*0.022*	*0.018*

Prototype 3 and StoveTec Pollution Results

4/26/2011 Cold Start (Test 1), Pollution Test									
Cold Start	64 oz of Water	Winds up to 45mph		Temperatures 30-50 degrees					
	Wood Amount (oz)	**Time (min:sec)**	**Temperatures**	**Comments**	**Pollutant Measured**	**Reading**	**Volume Pulled**	**Volume Pulled**	**Real Concentration**
	1.3	0:00		Tindered with Grass					
	4.7	0:00							
	5.8	5:00							
		16:00	Pot 185, Water 200	Bubbles					
	5.9	17:15	Pot 185, Water 200	Boil	New CO2 Tube	>3000 ppm, off scale	100 ml (1/10th)	1000ml	30,000 ppm
					Old CO2 Tube	0.6	50 ml (half) * 15%	100ml	80,000 ppm
					Old CO Tube	180	50ml (1/6th) * 15%	300ml	7200 ppm
	1.2	26:00:00		Simmer	New CO2 Tube	400 ppm	100ml (1/10th)	1000ml	4000 ppm
					New C6H6 Tube	100ppm	50ml (1/20th)	1000ml	2000 ppm
					Old CO2 Tube	0.1	100 ml (whole) * 15%	correct	6666.7 ppm
					Old CO Tube	40	100ml (third) * 15%	300ml	800 ppm
		38:00:00		End of Simmer					
Total Fuel	13								
Ash + Tray	111.4								
Tray	-111.3								
Ash	0.2								
Ash/Wood Ratio	0.015384615								

*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for

** C6H6 Tubes coloration was a brown/yellow that was difficult to distinguish from the white starting substrate, also there was no clear "line" of where the color ended

***Don’t count this test towards any fuel consumption calcs, it was not timed well and was behaving strange.
Skewing of data is due to the fact that we did not pull in the stated amount of air per each tube, and as such needed to adjust, the old tubes had a pump
that needed to be locked in place, we did not know this and were actually reading only 10-20% of the desired pull

4/26/2011 Hot Start (Test 2), Pollution Test									
Cold Start	64 oz of Water	Winds up to 45mph		Temperatures 30-50 degrees					
	Wood Amount (oz)	**Time (min:sec)**	**Temperatures**	**Comments**	**Pollutant Measured**	**Reading**	**Volume Pulled**	**Volume Pulled**	**Real Concentration**
	1.5	0:00		Tindered with Grass					
	2.4	0:00							
	5.5	0:00							
		8:00		Bubbles					
	3.1	9:40	Pot 220, Water 200	Boil	New CO2	450 ppm	50 ml (1/20th)	1000ml	9000 ppm
					Old CO2	0.35	100 ml (whole) *15%	correct	23333.3 ppm
					Old CO	110	100 ml (third) *15%	300ml	2200 ppm
					Old C6H6	Inconclusive (D	100ml (whole) *15%	correct	n/a
		14:15		Simmer Phase Start	New CO2	1600	50 ml (1/20th)	1000ml	32,000 ppm
					New C6H6	50	50ml (1/20th)	1000ml	1000 ppm
					Old CO2	0.3	100 ml (whole) *15%	correct	20000 ppm
					Old CO	60	100ml (third) *15%	300ml	1200 ppm
					Old C6H6	inconclusive	100 ml full *15%	100ml	n/a
		23:00	Pot 170, Water 180	Simmer					
		30:00:00		End of Simmer					
Total Fuel	12.5								
Ash + Tray	111.2								
Tray	111.1								
Ash	0.2								
Ash/Wood Ratio	0.016								

*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for

** C6H6 Tubes coloration was a brown/yellow that was difficult to distinguish from the white starting substrate, also there was no clear "line" of where the color ended

New CO2 Pro	1000ml	
Old CO2 Prop	100ml	
Old CO Prope	300ml	
New C6H6 Pr	1000ml	
Old C6H6 Prc	100 ml	*doesn't matter, invalid without primer tube.

4/26/2011 Cold Start (Test 3), Pollution Test									
Cold Start	64 oz of Water	Winds up to 45mph		Temperatures 30-50 degrees					
	Wood Amount (oz)	**Time (min:sec)**	**Temperatures**	**Comments**	**Pollutant Measured**	**Reading**	**Volume Pulled**	**Volume Pulled**	**Real Concentration**
	2.7	0:00		Tindered with Grass					
	5.6	2:00							
		10:00		Bubbles					
		11:00	Pot 220, Water 200	Boil	New CO2	1100 ppm	50ml (1/20th)	1000ml	22,000 ppm
		12:00			Old CO2	0.18	100ml (whole) *15%	correct	12,000 ppm
		13:00			Old CO	60	100 ml (third) * 15%	300ml	1200 ppm
		13:30			Old C6H6	inconclusive	100 ml (whole) *15%	correct	n/a
		17:00		Simmer	Old CO2	0.25	100 ml (whole) *15%	correct	16666.7 ppm
		20:00			Old CO	75	100 ml (third) *15%	300 ml	1500 ppm
		21:00			New C6H6	70	200 ml (1/5th)	1000 ml	350 ppm
		30:00:00	Pot 170, Water 180	End of Simmer					
Total Fuel	8.3								
Ash + Tray	111.2								
Tray	111								
Ash	0.2								
Ash/Wood Ratio	0.024096386								

*Didn't round up on the ash content since we had so much extra kindling ash from trying to burn this

** C6H6 Tubes coloration was a brown/yellow that was difficult to distinguish from the white starting substrate, also there was no clear "line" of where the color ended

New CO2 Pro	1000ml	
Old CO2 Proj	100ml	
Old CO Prope	300ml	
New C6H6 Pr	1000ml	
Old C6H6 Pro	100 ml	*doesn't matter, invalid without primer tube.

4/26/2011 Hot Start (Test 4), Pollution Test									
Cold Start	64 oz of Water	Winds up to 45mph		Temperatures 30-50 degrees					
	Wood Amount (oz)	**Time (min:sec)**	**Temperatures**	**Comments**	**Pollutant Measured**	**Reading**	**Volume Pulled**	**Volume Pulled**	**Real Concentration**
	2.4	0:00		Tindered with Grass					
	2.9	2:30							
	1.8	8:50							
	1.5	10:03		Bubbles					
		11:30	Pot 200, Water 200	Boil	Old CO2	0.8	100 ml (full) *15%	correct	43333.3 ppm
					Old CO	40	100 ml (third) *15%	300ml	800 ppm
	0.5	15:00	Pot 200, Water 200	Simmer	Old CO2	0.4	100 ml (full) *15%	correct	26666.7 ppm
					Old CO	75	100 ml (third) *15%	300ml	1500 ppm
					New C6H6	200	300 ml (3/10ths)	1000ml	666.7ppm
		30:00:00		End of Simmer					
Total Fuel	9.1								
Ash + Tray	111								
Tray	110.9								
Ash	0.2								
Ash/Wood Ratio	0.021978022								

*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for

** C6H6 Tubes coloration was a brown/yellow that was difficult to distinguish from the white starting substrate, also there was no clear "line" of where the color ended

New CO2 Pro	100ml	
Old CO2 Prop	100ml	
Old CO Prope	300ml	
New C6H6 Pr	1000ml	
Old C6H6 Pro	100 ml	*doesn't matter, invalid without primer tube.

4/26/2011 Cold Start Stove-Tec Stove, Pollution Test									
Cold Start	64 oz of Water	Winds up to 45mph		Temperatures 30-50 degrees					
	Wood Amount (oz)	**Time (min:sec)**	**Temperatures**	**Comments**	**Pollutant Measured**	**Reading**	**Volume Pulled**	**Volume Pulled**	**Real Concentration**
	4	0:00		Tindered with Grass					
	4	5:00							
	1.4	12:15							
	1.7								
	0.8								
		15:00		Bubbles					
		16:30	Body 230. Pot 190, Water 180	Boil	New C6H6	80	300 ml (3/10ths)	1000 ml	266.67 ppm
					New CO2	1250	100 ml (1/10th)	1000 ml	12,500 ppm
					Old CO2	0.2	100 ml (full) *15%	correct	13333.3 ppm
					Old Co	25	100 ml (third) *15%	300 ml	500 ppm
				Simmer	Old CO2	0.05	100 ml (full) *15%	correct	3333.3 ppm
		30:00:00		End of Simmer					
Total Fuel	11.9								
Ash + Our Tray	111.3								
Tray	110.9								
Ash	0.6								
Ash/Wood Ratio	0.050420168								

*Added 0.1oz of Ash to Ash weight for fly aways that we couldn't account for

** C6H6 Tubes coloration was a brown/yellow that was difficult to distinguish from the white starting substrate, also there was no clear "line" of where the color ended

New CO2 Pro	100ml	
Old CO2 Pro	100ml	
Old CO Prope	300ml	
New C6H6 Pr	1000ml	
Old C6H6 Pro	100 ml	*doesn’t matter, invalid without primer tube.

Pollution Averages					
	4-26 P Test 1	4-26 P Test 2	4-26 P Test 3	4-26 P Test 4	Averages
Total Fuel	13	12.5	8.3	9.1	10.725
Ash	0.2	0.2	0.2	0.2	0.2
Ash/Wood Ratio	*0.015*	*0.016*	*0.024*	*0.022*	*0.019*

Comparisons						
	P2 CS Averages	P2 HS Averages	P3 CS Averages	P3 HS Averages	ST CS Averages	Open Fire
Total Fuel	13.825	16.83	10.64	14.04	10.3	20.3
% Fuel Reduction	0.319	0.171	0.476	0.308	0.493	0%
Ash	0.350	0.23	0.26	0.24	0.65	
Ash/Wood Ratio	0.029	0.015	0.023	0.018	*0.065*	
				% Diff Ash/Fuel	0.6485	

	StoveTec Boil Phase	Our Stove Boil Phase	StoveTec Simmer Phase	Our Stove Simmer Phase	Three Stone Boil	Three Stone Simmer
Total Carbon Monoxide (CO) & Reduction	23800	2850	27666	1250	44074	51233
	46%	93.53%	46%	94.44%		
Total Particulate Matter & Reduction	2000	240	567	25.6	4545	1288.64
	56%	94.72%	56%	98.01%		

All Real Life Concentrations of Meaured Pollutants

Test 1 Phases	Pollutant Measured	Real Concentration (PPM)
CS, Boil Phase (3)	New CO2 Tube	30,000 or more
CS, Boil Phase (3)	Old CO2 Tube	80,000
CS, Boil Phase (3)	Old CO Tube	7200
CS, Simmer Phase (4)	New CO2 Tube	4000
CS, Simmer Phase (4)	New C6H6 Tube	2000
CS, Simmer Phase (4)	Old CO2 Tube	6666.7
CS, Simmer Phase (4)	Old CO Tube	800

Test 2 Phases	Pollutant Measured	Real Concentration (PPM)
HS, Boil Phase (3)	New CO2	9000
HS, Boil Phase (3)	Old CO2	23333.3
HS, Boil Phase (3)	Old CO	2200
HS, Simmer Phase (4)	New CO2	32,000
HS, Simmer Phase (4)	New C6H6	1000
HS, Simmer Phase (4)	Old CO2	20000
HS, Simmer Phase (4)	Old CO	1200

Test 3 Phases	Pollutant Measured	Real Concentration (PPM)
CS, Boil Phase (3)	New CO2	22,000
CS, Boil Phase (3)	Old CO2	12,000
CS, Boil Phase (3)	Old CO	1200
CS, Simmer Phase (4)	Old CO2	16666.7
CS, Simmer Phase (4)	Old CO	1500
CS, Simmer Phase (4)	New C6H6	350

Test 4 Phases	Pollutant Measured	Real Concentration (PPM)
HS, Boil Phase (3)	Old CO2	43333.3
HS, Boil Phase (3)	Old CO	800
HS, Simmer Phase (4)	Old CO2	26666.7
HS, Simmer Phase (4)	Old CO	1500
HS, Simmer Phase (4)	New C6H6	666.7

Stovetec Test Phases	Pollutant Measured	Real Concentration (PPM)	
CS, Boil Phase (3)	New C6H6	266.67	
CS, Boil Phase (3)	New CO2	12,500	
CS, Boil Phase (3)	Old CO2	13333.3	
CS, Boil Phase (3)	Old Co	500	
CS, Simmer Phase (4)	Old CO2	3333.3	
	ash	inorganics	black carbon
Stovetech Ash Averages	1.30	0.0311	1.2689
Cold Start Ash Averages	0.56	0.0311	0.5289
Hot Start Ash Averages	0.48	0.0311	0.4489

Average Data Group	CO2	CO	C6H6
Cold Start Boil Averages	38,000	4200	n/a
Hot Start Boil Averages	25,222	1500	n/a
Cold Start Simmer Averages	9,111	1150	1175
Hot Start Simmer Averages	26,222	1350	833.35
Total Boil Phase Averages	**31,611**	**2850**	**n/a**
Total Simmer Phase Averages	**17,667**	**1250**	**1004.175**
Overall Stove Performance Averages	***24,639***	***2050***	***1004.175***

Stovetec Data Groups	CO2	CO	C6H6
CS Boil Averages	12,917	500	266.67
CS Simmer Averages	3333.3	n/a	n/a

Carbon Balance Ratios (Boil and Simmer)	CO2%	CO%	C6H6%
Our Stove Carbon Balance Components	0.88971337	0.074025749	0.036260881
Stove Tec Carbon Balance Componenets	0.943970469	0.03654084	0.019488691

Document 57 - Relationship between CO and Pm emissions on High and Lower Power

Rocket Sidefeed with Secondary Air, More Secondary Air, and Increased Insulation Properties are averaged for comparision

Average CO EF to Boil	23.8	g/kg	23800 ppm
Average PM EF to Boil	0.002	g/kg	2000 ppb
PM to CO Ratio During Boil	8.40336E-05		
Average CO EF to Simmer	27.66666667	g/kg	27666 ppm
Average PM Ef to Simmer	0.000566667	g/kg	567 ppb
PM to CO Ratio During Simmer	2.04819E-05		
Our Stove Boiling CO Emissions	2.85	g/kg	2850 ppm
Estimated Boil PM Emissions (CO*Ratio)	0.000239496	g/kg	240 ppb
Our Stove Simmering CO Emissions	1.25	g/kg	1250 ppm
Estimated Simmer PM Emissions (CO*Ratio)	2.56024E-05	g/kg	25.6 ppb
Percent Difference in Boil CO Emissions	-0.880252101		0.4048
Percentage of PM Emissions	-0.880252101		0.4928
Percent Difference in Simmer CO Emissions	-0.954819277		-0.439216867
Percent Difference in Simmer PM Emissions	-0.954819277		-0.534698795

X-Prize Gantt Project

Tasks

Name	Begin date	End date
P1: Organizational Measures and Research	9/17/10	10/23/10
Team formation	9/17/10	9/18/10
10 SOTA articles each	10/21/10	10/22/10
All SOTA articles found	10/22/10	10/23/10
P2: Desing Concept Work	10/21/10	12/11/10
Initial Proposal Due	10/21/10	10/22/10
Read SOTA articles	10/25/10	11/18/10
Meet with Cooperrider *Go over initial proposal revision 1*	11/16/10	11/17/10
Meet with Tester *Final review of proposal and signing*	11/18/10	11/19/10
All SOTA read/works cited to Greg	11/18/10	11/19/10
Team Meeting 1 *Gantt chart to all members* *Articles and works cited to Greg* *Talk about articles* *Go over what is to come in coming weeks and plan accordingly*	11/22/10	11/23/10
Team Meeting 2 *Brainstorming/designs to be discussed* *gantt chart completion* *Website/Outline* *Start reading best of articles from each member* *Shared drive update/Put all files into* *Deadlines for after Thx day*	11/23/10	11/24/10
Team Meeting 3 *Recap on previous meetings/current progress/prototypes*	11/24/10	11/25/10
Thanksgiving Holiday *Read Best of Articles from each member*	11/24/10	11/27/10
READ: Best of articles	11/29/10	11/30/10
Team Meeting 4 *prototypes/descision on what designs are being used*	11/30/10	12/1/10
Team Meeting 5 *Designs* *Make Presentation/final proposal* *REHEARSE REHEARSE REHEARSE*	12/1/10	12/2/10
Meet with Auberle	12/3/10	12/4/10
Team Meeting 6 *Final Final Designs decided upon* *Everyone do action items that were emailed out* *Compile website* *Compile presentation/proposal*	12/6/10	12/7/10
Team Meeting 7 *Meet in 314* *CAD drawings/drawings finished!!*	12/7/10	12/8/10
Team Meeting 8 *Presentation must be done by today!!* *Proposal write up too* *Everyone has own action items*	12/8/10	12/9/10
Team Meeting 9 *Finishing touches on presentation (no major work to be done)* *Coordinate with other groups to practice* *Practice Practice Practice*	12/9/10	12/10/10
Final Presentation	12/9/10	12/10/10

X-Prize Gantt Project

Tasks

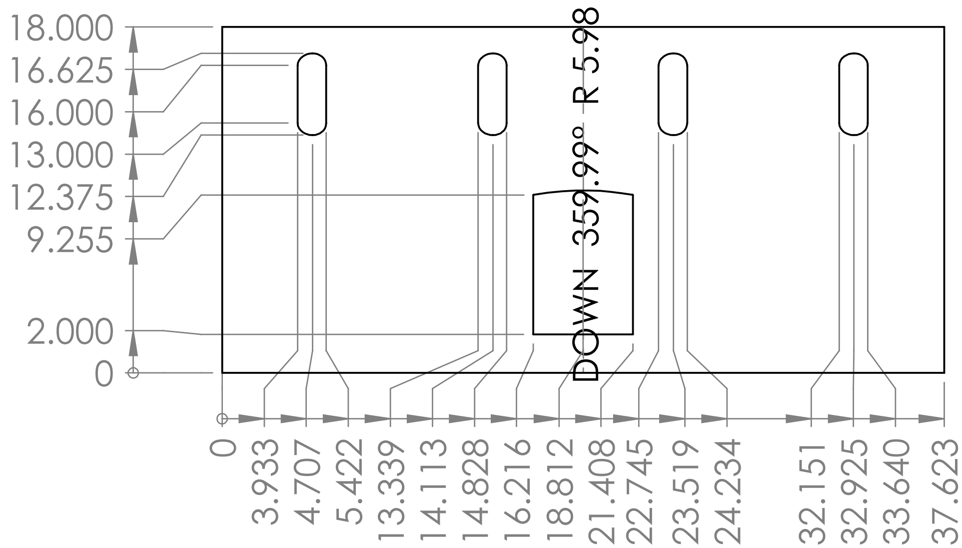
Name	Begin date	End date
Team Meeting 10 *Finish website* *Finish Proposal*	12/10/10	12/11/10
Final Design Proposal	12/10/10	12/11/10
Website and Log books due	12/10/10	12/11/10
Christmas Break	12/15/10	1/18/11
P3: Overall Design Development	1/18/11	2/16/11
Team Meeting 5 *Regrouping meeting to discuss progress and what did over winter break*	1/18/11	1/19/11
Overall Design Development	2/15/11	2/16/11
P4a: Housing and Support Design	2/15/11	3/8/11
Initial Meeting for P4	2/15/11	2/16/11
SOTA specific research to housing/supports	2/15/11	2/26/11
Housing /Support designed to specifications	3/7/11	3/8/11
P4b: Combustions, Intake, Exhaust and Pollution Controls Design	2/15/11	3/8/11
Initial Meeting for P4	2/15/11	2/16/11
SOTA specific research to combustion/intake/exhaust	2/15/11	2/26/11
Combustion, Intake, Exhaust ad Pollution Designed	3/7/11	3/8/11
P4c: Cultural Aesthetics and Ergonomics Design	2/15/11	3/8/11
Initial Meeting for P4	2/15/11	2/16/11
SOTA specific research to aesthetics/ergonomics	2/15/11	2/26/11
Aesthetics and Ergonomics designed to be accepted by the end user	3/7/11	3/8/11
P5: Design Fabrication and Finishing Touches	3/9/11	5/11/11
Part can be ordered no later than today!!	3/9/11	3/10/11
Spring Break	3/14/11	3/18/11
SPDC design competion?????? *Las Vegas, NV* *Host: University of Nevada, Las Vegas* *Cheney, Washington* *Host: Eastern Washington University*	4/15/11	4/16/11
Final Design	5/5/11	5/6/11
Final Design Presentation	5/10/11	5/11/11

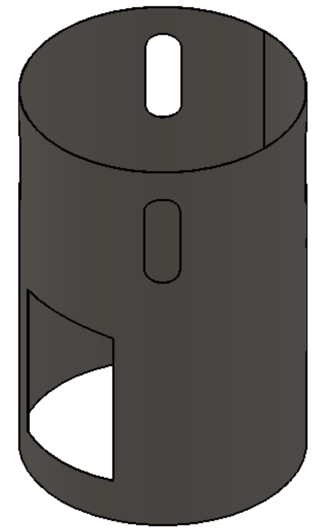
Red = Deadline or Essential Task, Green = Team Activity, Blue = Class Activity, Black = Other Class Deadlines

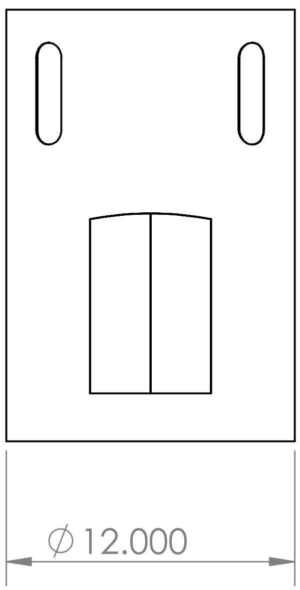
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Jan 16	17	18 Class – Intro	19	20 No Class – Work Day Team Meet: Organize	21	22
23 Jon and Greg Meet @ 1pm	24	25 Class – Brainstorming Team Meet: After Class to Discuss Status Report	26	27 Class – 1st Status Report (1st, Chris)	28	29
30	31	**Feb** 1 Class – Brainstorming	2	3 No Class Team Meet: Discuss Airflow Design Mechanisms, Manufacturing of Prototype, Brainstorming, etc.	4	5 Weekend Meeting for Construction (Finish P1 Design) -Mail order parts if needed
6	7 Meet with Acker 8:30am	8 Class – We Lead Brainstorm Sesh (Greg Lead, Jon Record)	9	10 No Class	11 PEER 1	12
13	14	15 Class – Brainstorming PHASE 3 ENDS	16 Deliverable 1 (1st Prototype) is Due by 5:00pm	17 Class – 2nd Status Report (4th, Greg)	18	19
20	21	22 Class - Brainstorming	23	24 No Class	25	26
27	28	**Mar** 1 Class – We Lead Brainstorm Sesh (Chris Lead, Jenny Record) Website Splash Page Due ME 454 Exam	2 ME 499 Exam	3 Class – Design Presentations	4	5
6	7 U-Grad Abstract To Cooperrider By Today	8 Class – Design Presentations	9	10 Class – Design Presentations **WE PRESENT Today**	11 PEER 2	12
13 Spring Break	14 Spring Break	15 Spring Break	16 Spring Break	17 Spring Break	18 Spring Break	19 Spring Break
20 Team Meeting-Finalize 2nd prototype design	21	22 Team Build Meet 12:45 – end	23	24 Class – 3rd Status Report (4th, Jenny)	25	26

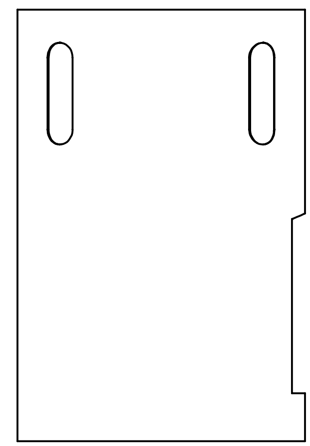
27 Team Meeting	28 Team Meeting 5pm-or later	29 Team Build/Testing Meet 12:45 – end Have 2nd Prototype Built by Now! Eat at Granny's today for ASME	30 Lab view work and TC installation by now.	31 Class - 4th Status Report (3rd, Jon)	**Apr** 1 ME 482 Exam 2 Must have Ackers sig on document 1 by now	2 Testing
3 Testing	4 Testing	5 No Class Testing	6 Testing, Final Report must get Ackers final approval by today or tomorrow.	7 Class – Ethics Lecture Deliverable 2 (Analysis of Final) is Due by 5:00pm	8 Final Design Work	9 Final Design Work Team Meeting!
10 Final Design Work	11 Final Design Work Presentation work ME499 Exam 2	12 -2nd Project Design Pres. -Website Secondary Pages Due Eat at Chili's Tonight for ASME	13 Global Learning Symposium Presentation Gardner Auditorium (Biz bldg) be there at 11:30, we present at 12:28 (8 mins)	14 -Deliverable 3 (Final Design Components are all ready to Fabricate or Order) -WE PRESENT, 2ND DESIGN PRESENTATION ME454 Exam?	15 Greg To SPDC Poster "Due" to Ed Anderson For Free Printing/At least contact him about it.	16 SPDC Presentations Final Build, have cement core curing by now
17 Final Build	18 Final Build	19 2nd Project Design Pres. NEED TO HAVE CORES DONE/CURING BY NOW	20 SHEET METAL FAB FOR STOVE	21 2nd Project Design Pres. STOVE ASSEMBLY FINISH STOVE BY TODAY	22 **PEER 3** POLLUTION TESTING DAY	23 -Pollution Results Documentation -Universal Design Build
24 -Pollution Results Doc -Universal Design Build	25 -Pollution Results Doc -Universal Design Build -Finish Timesheets	26 No Class?? -Team Timesheets Due -Team Capstone Prep	27 ME482 Exam 3 -Finish Poster Today -Presentation Practice, Final Polishing, Final Report	28 No Class? -Poster Due Presentation Practice, Final Polishing, Final Report	29 UGRAD CONFERENCE Freemont Rm 11:00am (tentative) -ME482 Rapid Prototype Due	30 Final Report Work
May 1 Final Report Work	2 Final Report Work	3 Final Report Review -Final Final Webpage Due	4 Final Report Revisions	5 No Class Final Report Revisions	6 -FINAL REPORT DUE -LOGBOOKS DUE -ME482 Final Project Due	7
8	9	10 **PEER 4**	11 ME482 Final	12	13 Graduation	14

Purchase Info	Quantity	Cost (Each)	Total + Tax	Date	Vendor	Cleared with Blue Form?	Purchasee
4" Grinder Wheels	x5	$1.97					
Gloves	x1	$1.97					
			$12.94	2/13/2011	Home Depot	Yes (2/18/2011)	Greg
Bulk Bag of Vermiculite	x1	$10.48					
			$11.47	2/12/2011	Home Depot	Yes (2/18/2011)	Greg
High Temp HVAC Tape	x1	$19.89					
Sharpies (2-pack)	x1	$1.68					
			$23.61	2/15/2011	Home Depot	Yes (2/18/2011)	Greg
Sheet Aluminum Scraps (1/8")	x2	$5.00					
			$10.00	2/14/2011	Mayorgas Welding	Yes	Greg
Lava Rock (Bag)	x2	$3.97					
Large Bucket	x1	$2.54					
			$11.47	2/16/2011	Home Depot	Yes	Greg
5" Stove Piping	x5	$1.00					
			$5.00	3/15/2011	ERIC Building Supply	Yes	Greg
Sheet Steel (~16 Ga)	x2	$5.00					
			$10.00	3/23/2011	Mayorga's Welding	Yes	Greg
Portland Cement	x1	$9.17					
Homer Bucket	x1	$2.54					
Sand	x1	$4.70					
Lime	x1	$9.23					
Concrete Tube 10"	x1	$8.30					
Concrete Tube 8"	x1	$6.23					
			$43.96	3/22/2011	Home Depot	Yes	Jon
Concrete Tube 8"	x1	$6.23					
Concrete Tube 12"	x1	$10.37					
			$18.16	4/19/2011	Home Depot	Yes	Chris
Life Size Sheet Metal Template Prints	x2	$3.20					
			$7.00	4/20/2011	AEC Reprographics and Design	Yes	Jon
Router Bit for Sheet Metal	x1	$8.49					
			$9.29	4/21/2011	Home Depot	Yes	Chris
22 Gage 6" x 24" Steel	x1	$6.99					
3M Spray Adhesive for Templates	x1	$11.99					
			$20.77	4/21/2011	Homco ACE Home Center	Yes	Chris
10 lbs 24 Gage Sheet steel, various cuts	x1	$50.20					
			$54.74	4/21/2011	Boyer Heating & Cooling	Yes	Chris
28 Gage 24" by 24" Steel	x1	$13.99					
			$15.31	4/22/2011	Homco ACE Home Center	Yes	Greg
Poster Print	x1	$79.80					
			$87.34	4/28/2011	AEC Reprographics and Design	Yes	Greg
Poster Mounting	x1	$66.88					
			$73.20	4/28/2011	Michaels Arts and Craft Store	Yes	Chris
		Total:	**$414.26**				









PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

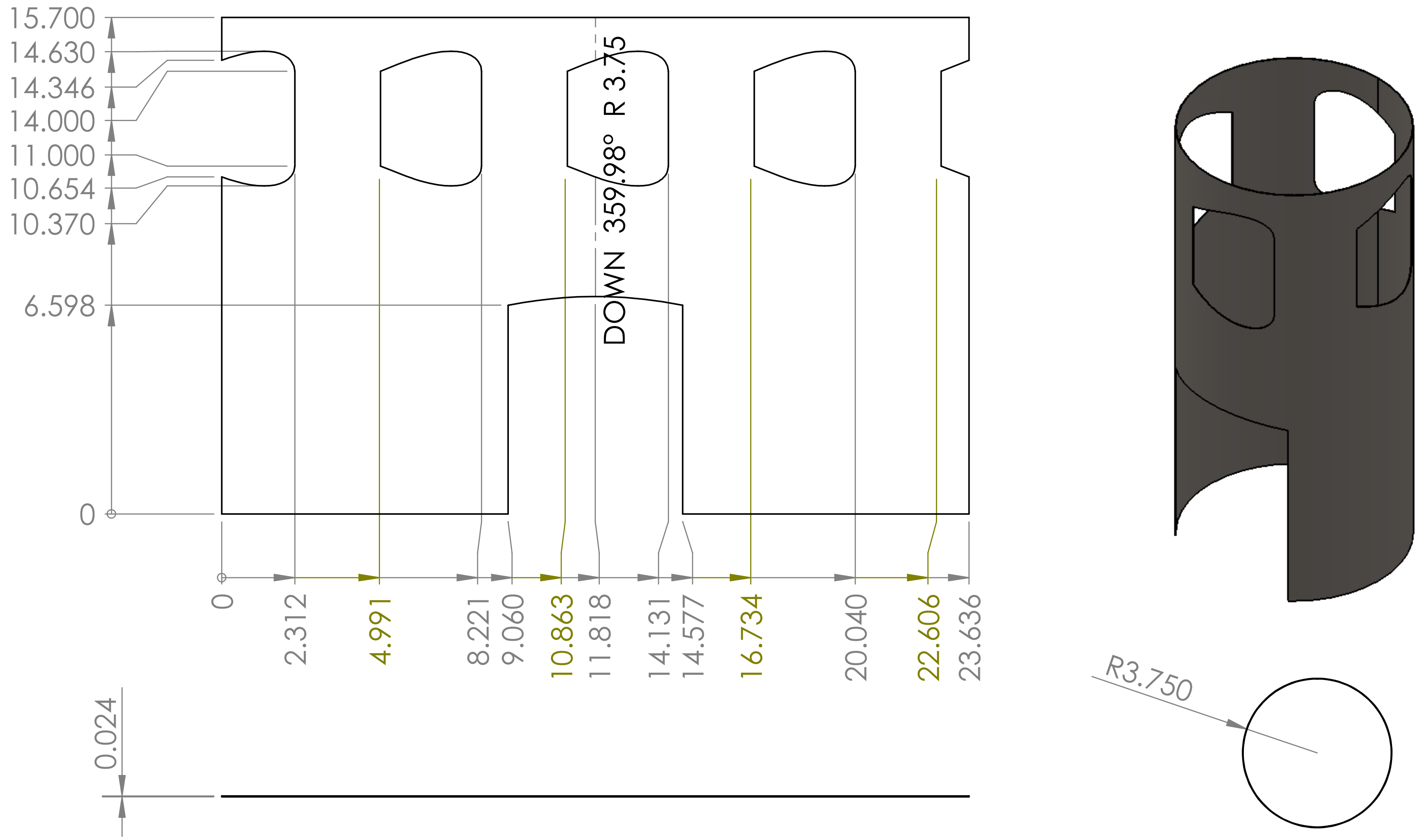
COMMENTS:

TITLE:

SIZE A DWG. NO. StoveShell REV

SCALE: 1:10 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



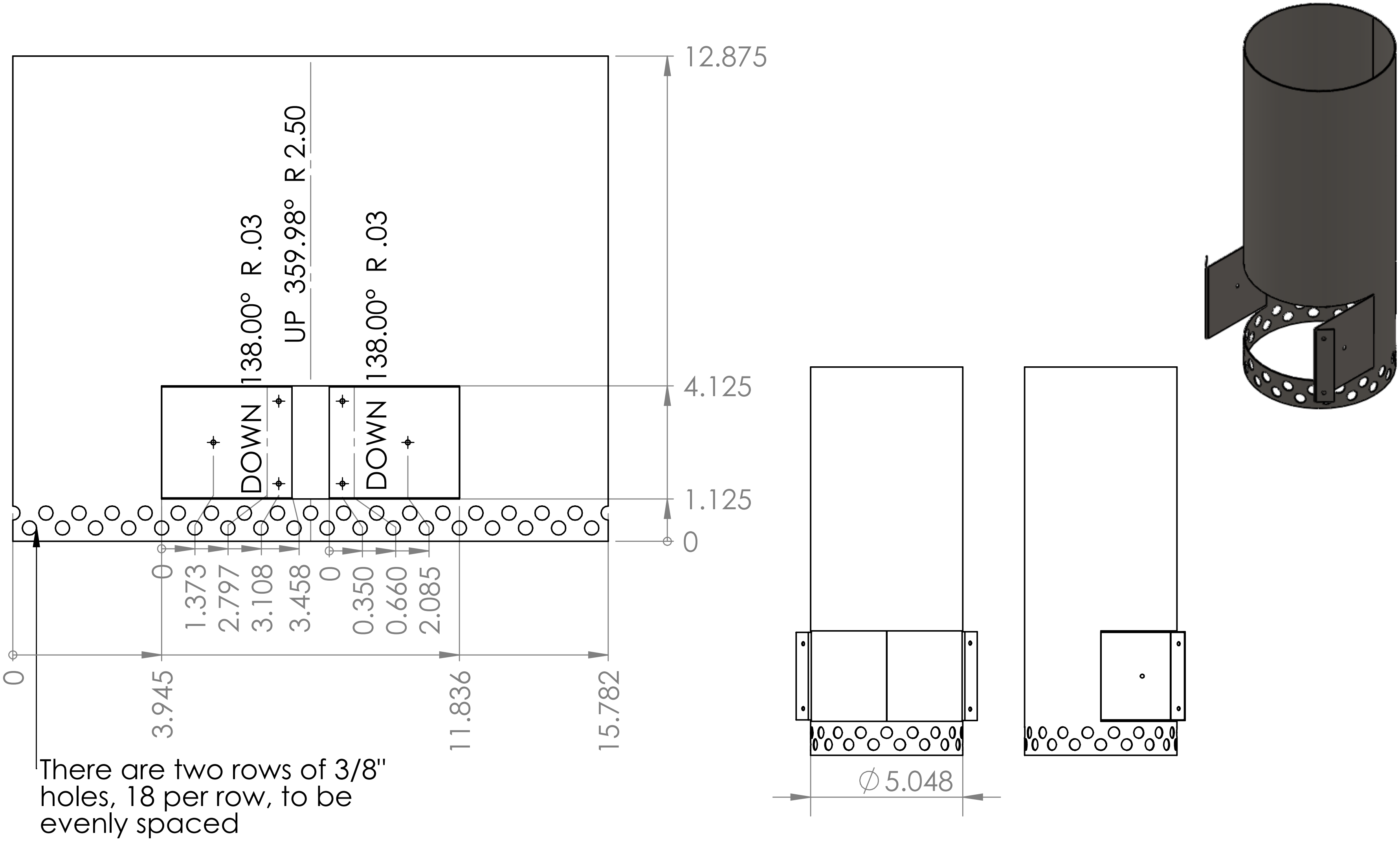
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE A | DWG. NO. HeatExchangerCylinder | REV

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

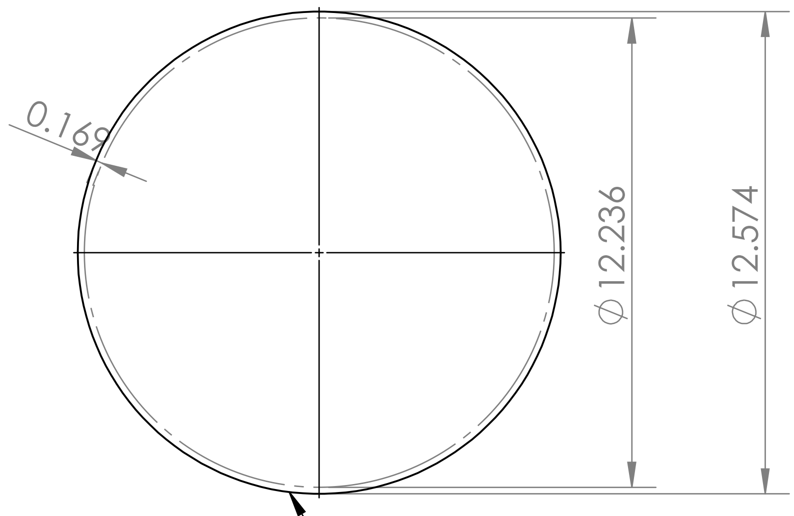
COMMENTS:

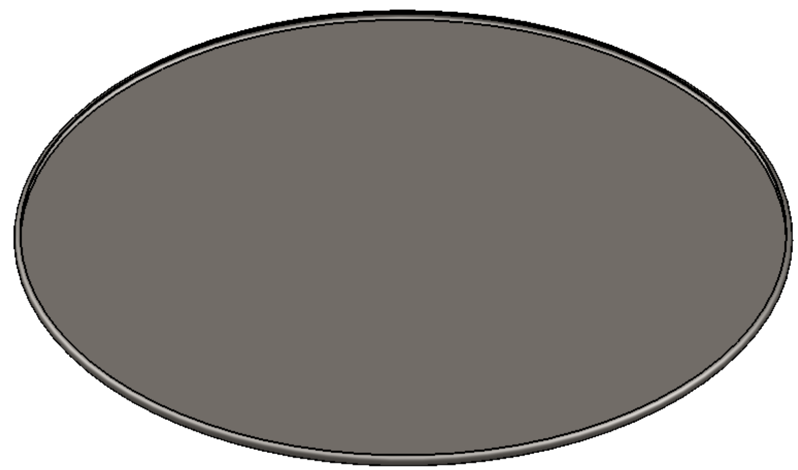
TITLE:

SIZE	DWG. NO.	REV
A	InnerChamber	

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

5 4 3 2 1





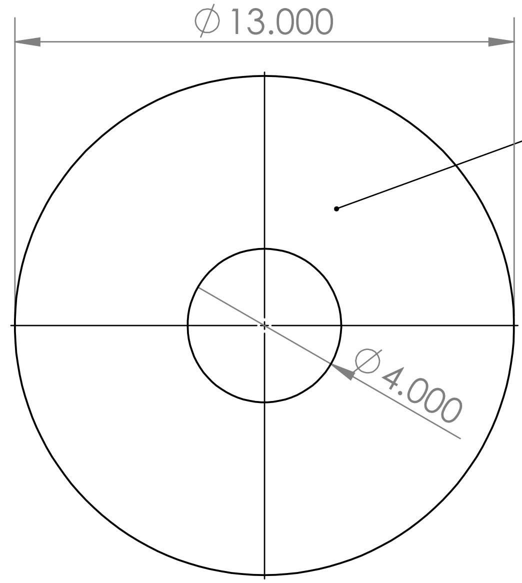
This seam is generated as a joining process with the outer body cylinder and should NOT be fabricated alone.

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			
			CHECKED			TITLE:
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A DWG. NO. StoveBottom REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:5 WEIGHT: SHEET 1 OF 1

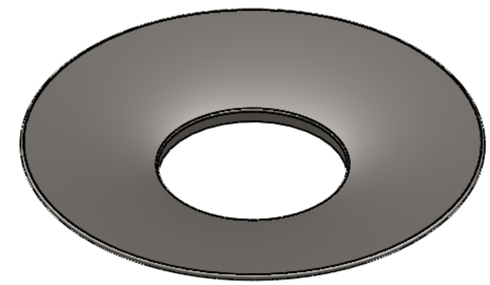
PROPRIETARY AND CONFIDENTIAL

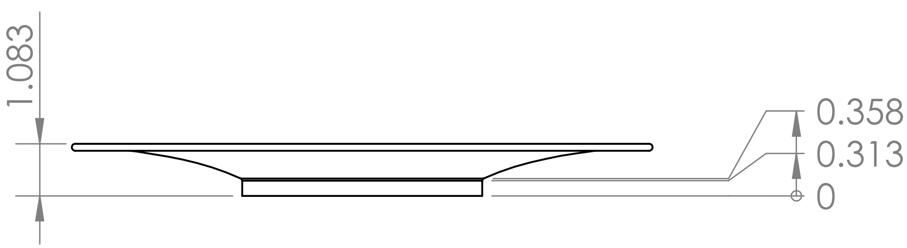
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

5 4 3 2 1



The dimensions of this flatented part are approximated to allow for the part to be drawn into the final shape (right) and to later be seamed with the stove body. These dimensions may need further refinement.





		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

PROPRIETARY AND CONFIDENTIAL

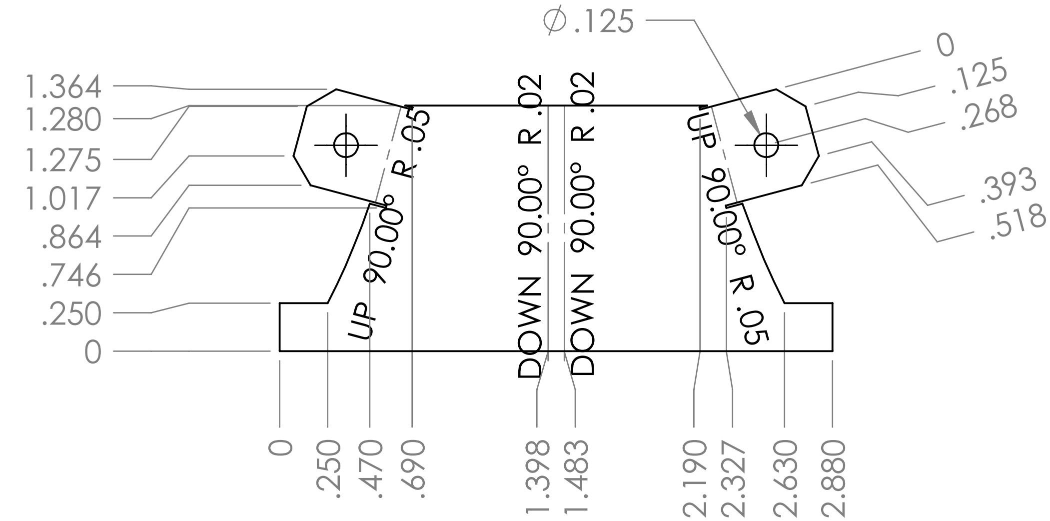
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

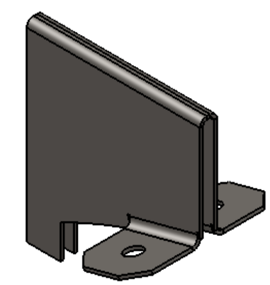
TITLE:

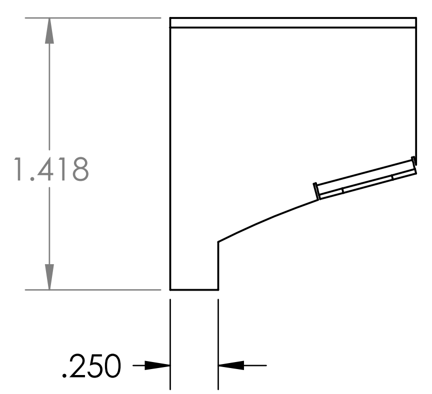
SIZE	DWG. NO.	REV
A	Stovetop-Drawn	

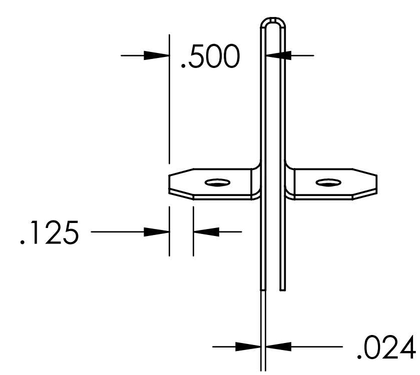
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



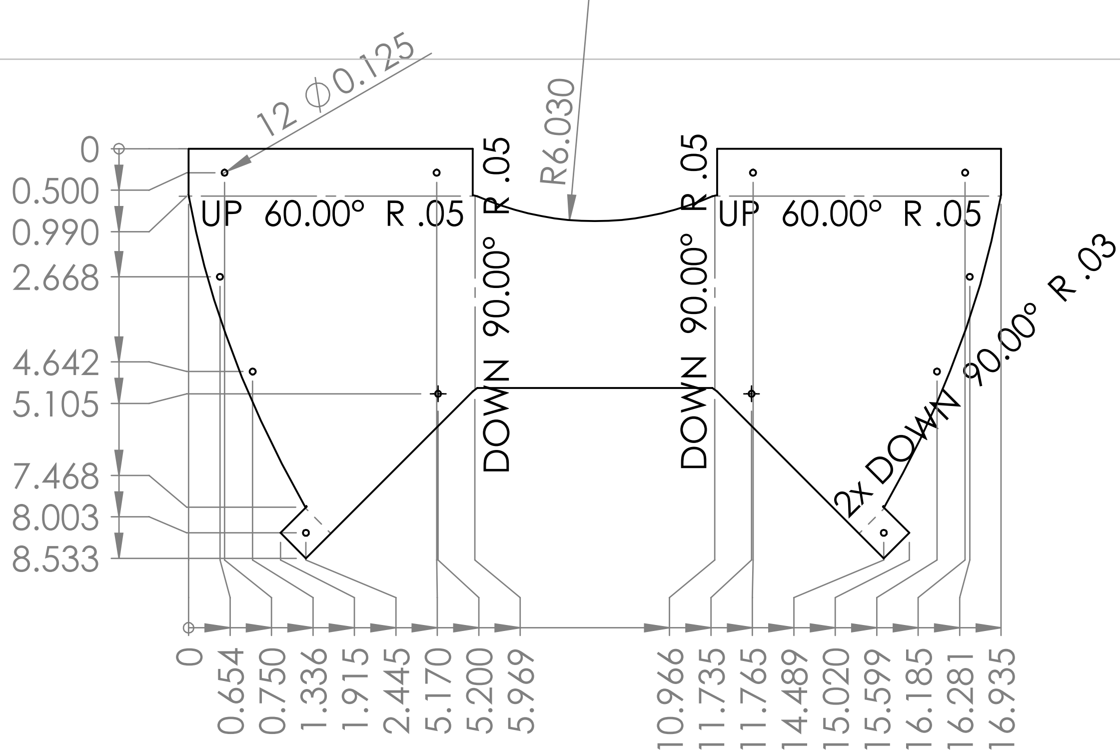


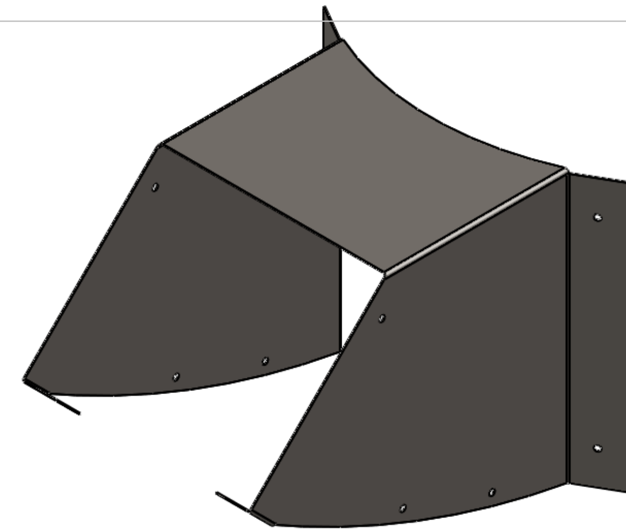


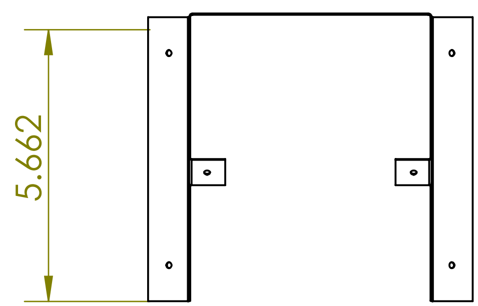


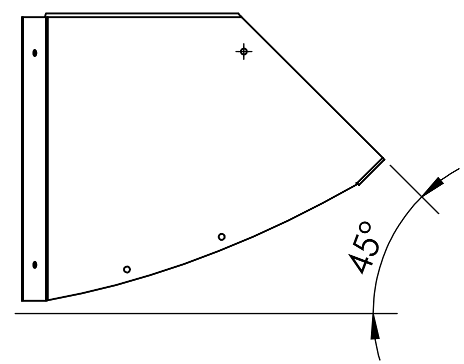
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			TITLE:
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.		MATERIAL	COMMENTS:			SIZE A DWG. NO. PotStands REV
	NEXT ASSY / USED ON	FINISH				
	APPLICATION	DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1









PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

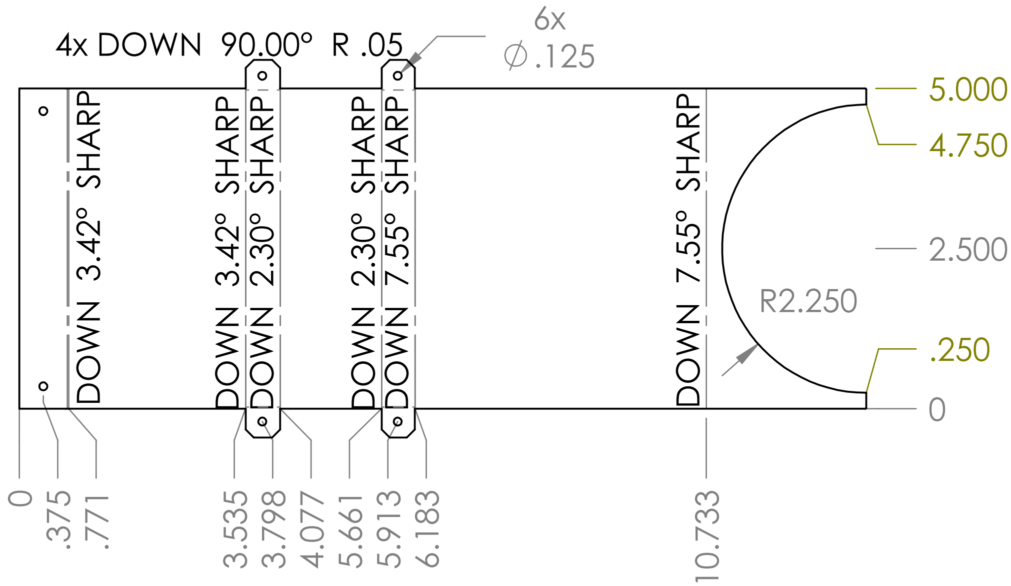
COMMENTS:

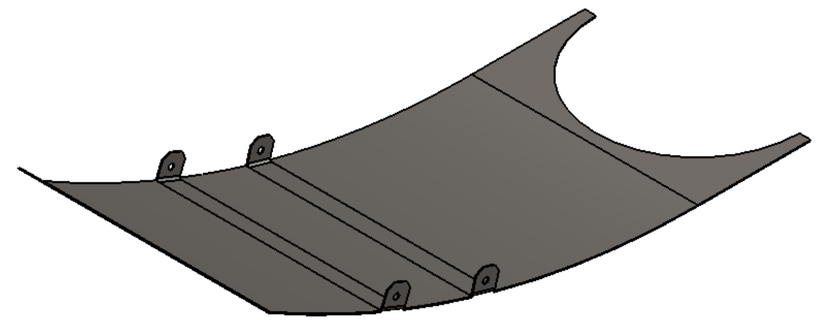
TITLE:

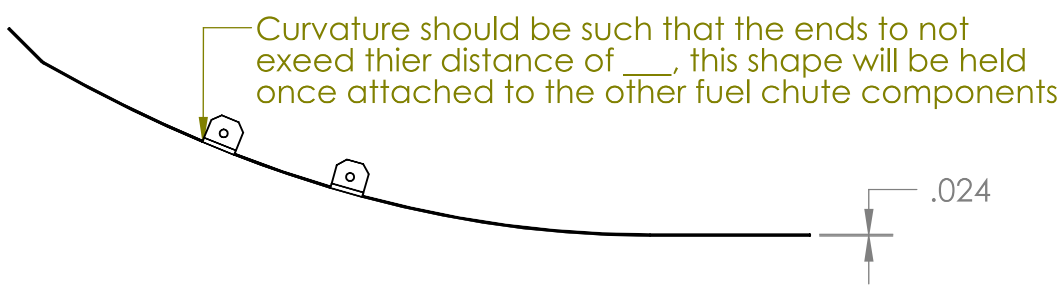
SIZE A | DWG. NO. FuelChuteSupport | REV

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1







PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

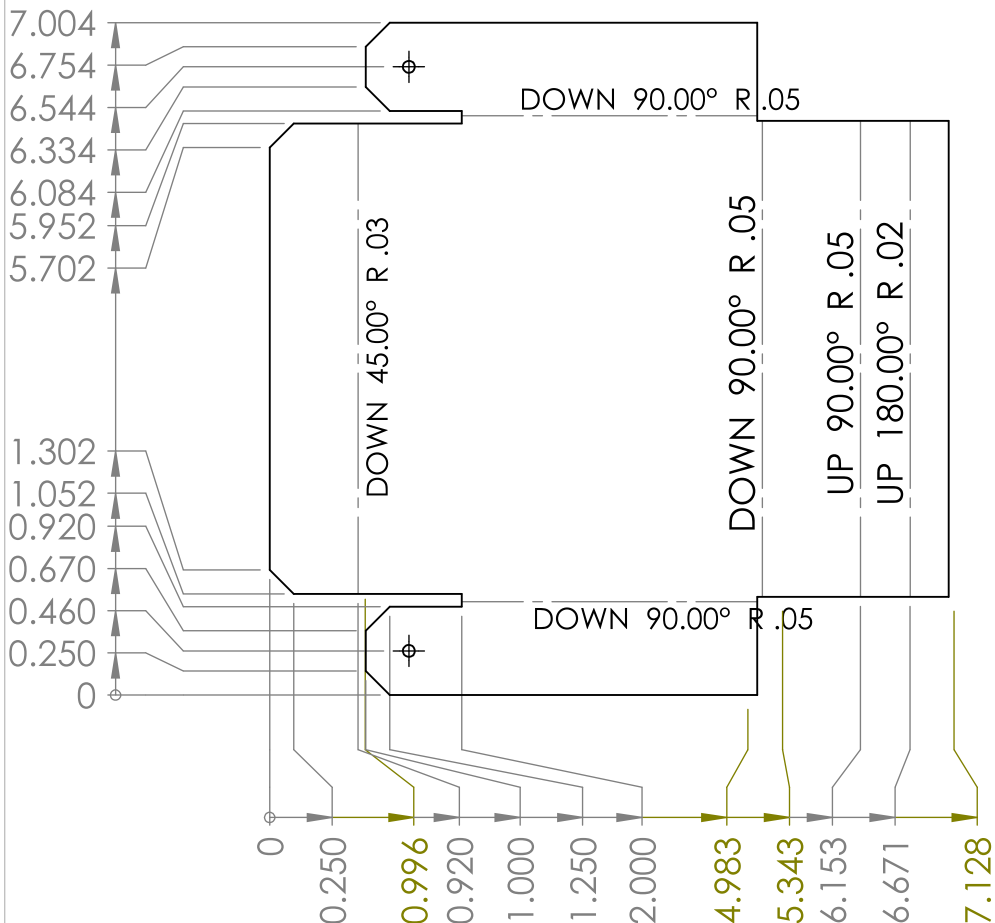
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

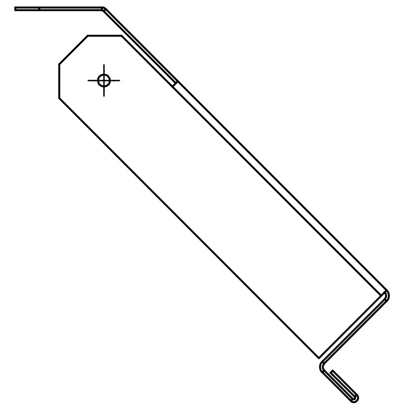
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

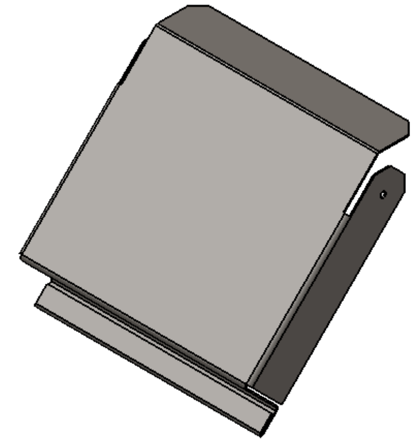
TITLE:

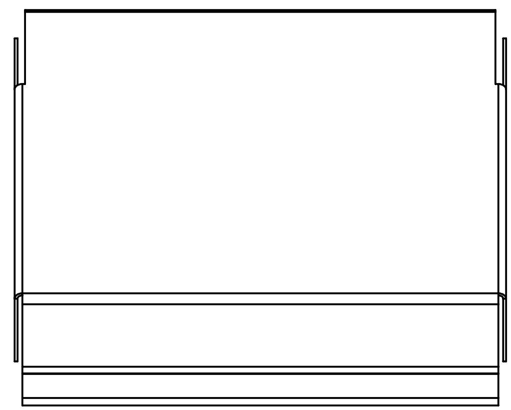
SIZE	DWG. NO.	REV
A	FuelChute	

SCALE: 1:5 WEIGHT: SHEET 1 OF 1









PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

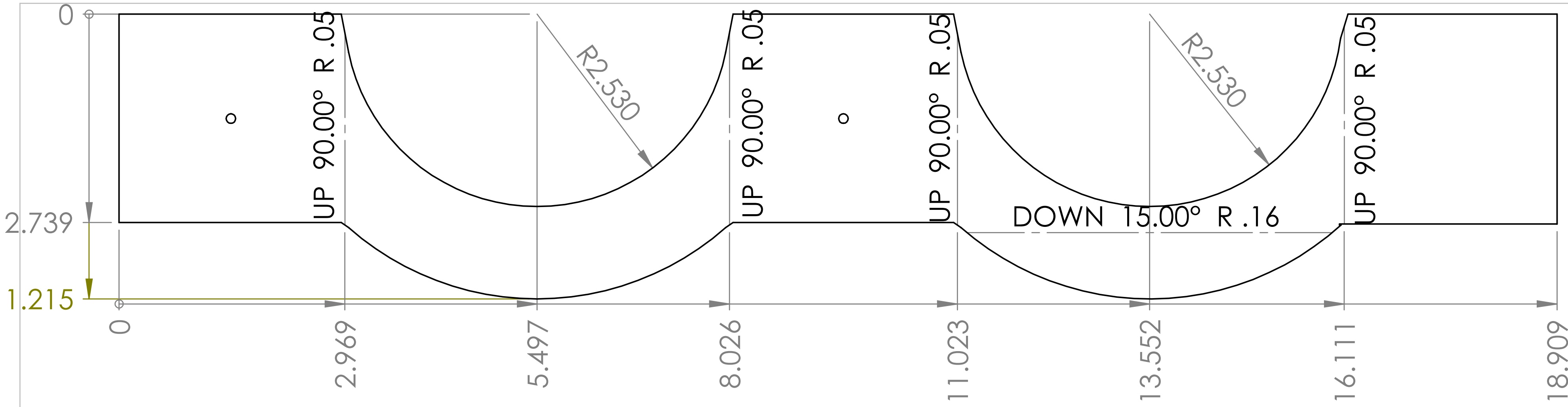
COMMENTS:

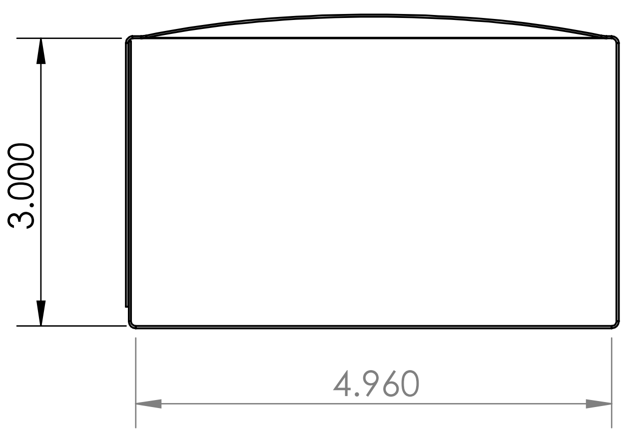
TITLE:

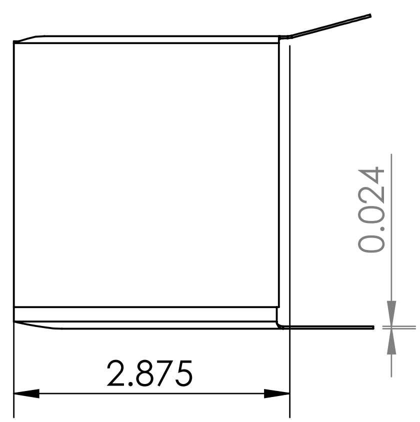
SIZE	DWG. NO.	REV
A	FuelChuteCap	

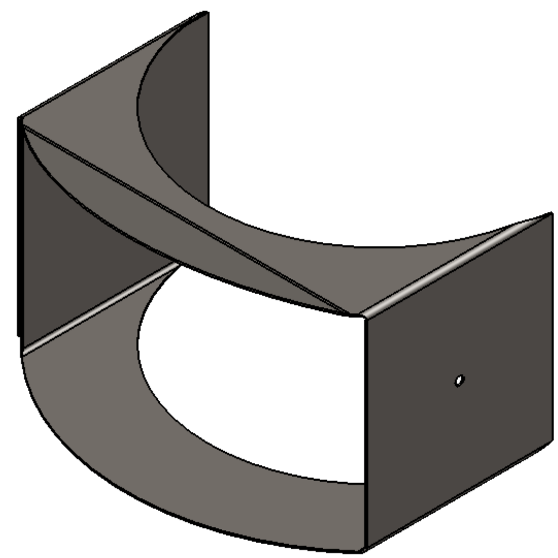
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1









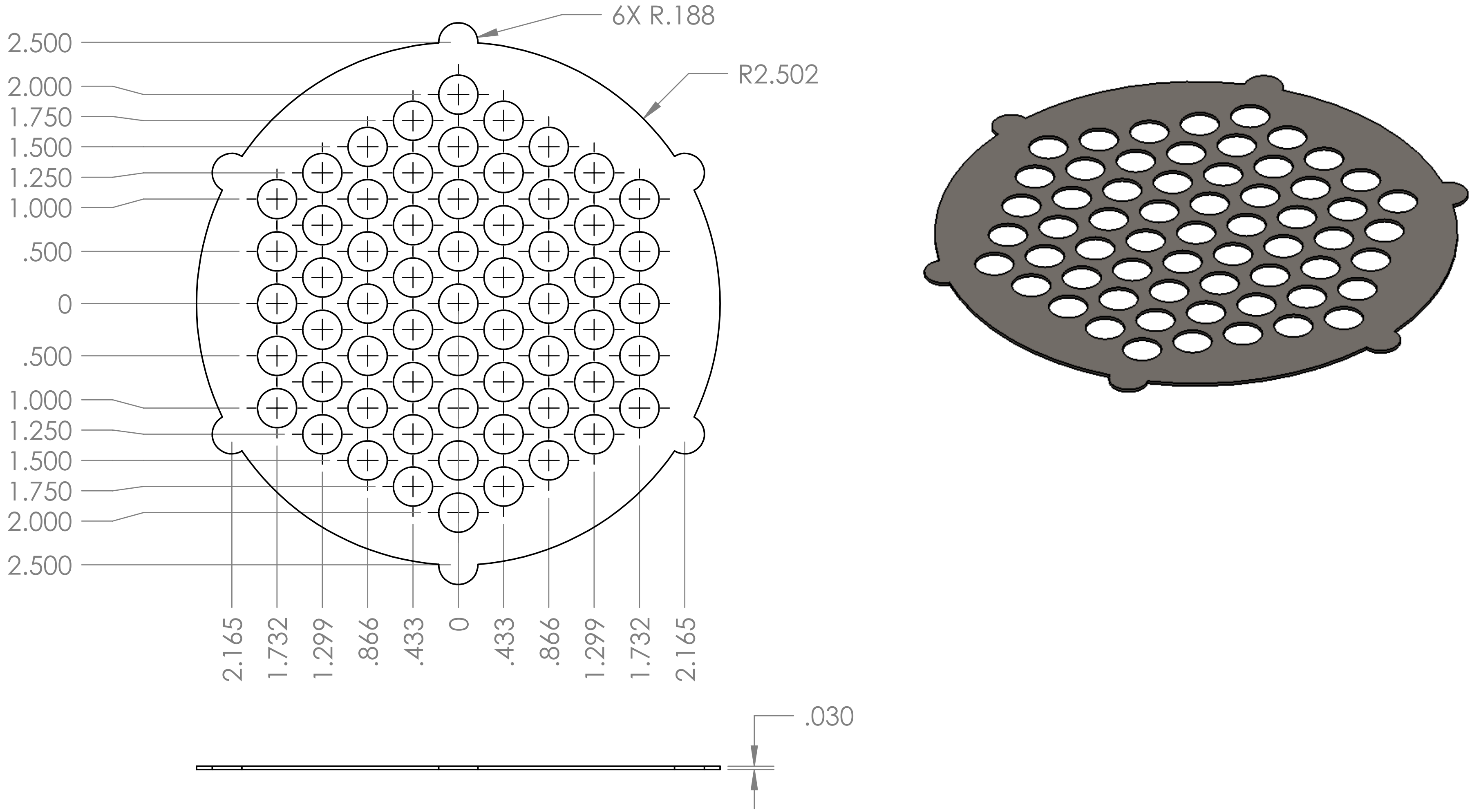
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE A | DWG. NO. InnerChamberSupport | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

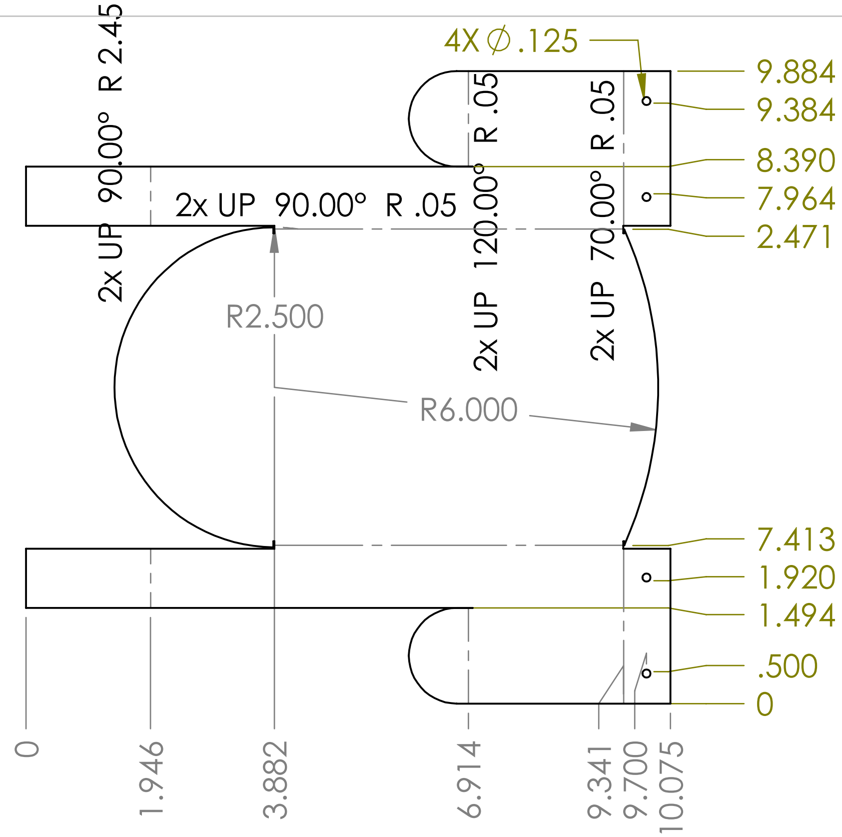
SIZE	DWG. NO.	REV
A	Grate	

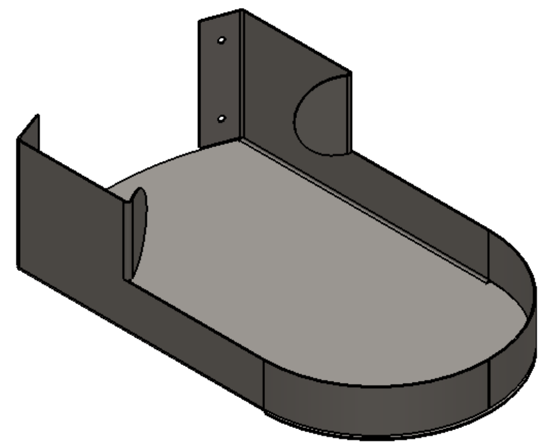
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

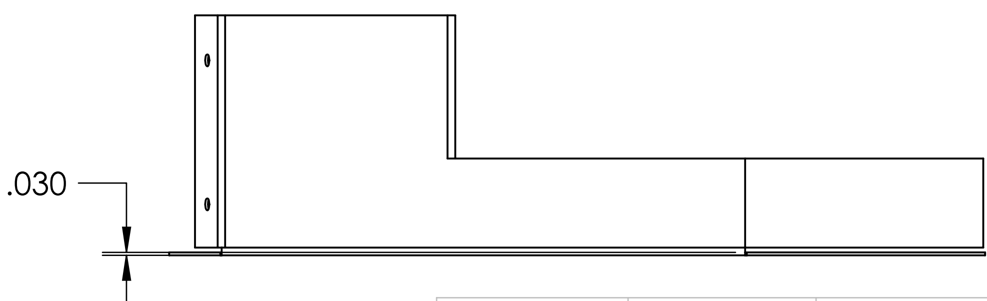
NEXT ASSY | USED ON

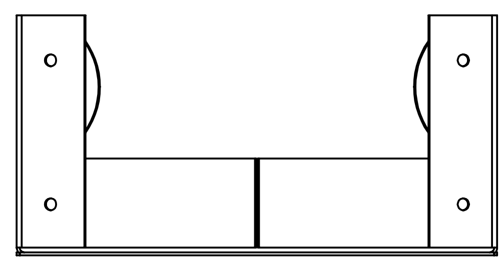
APPLICATION

5 4 3 2 1









UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

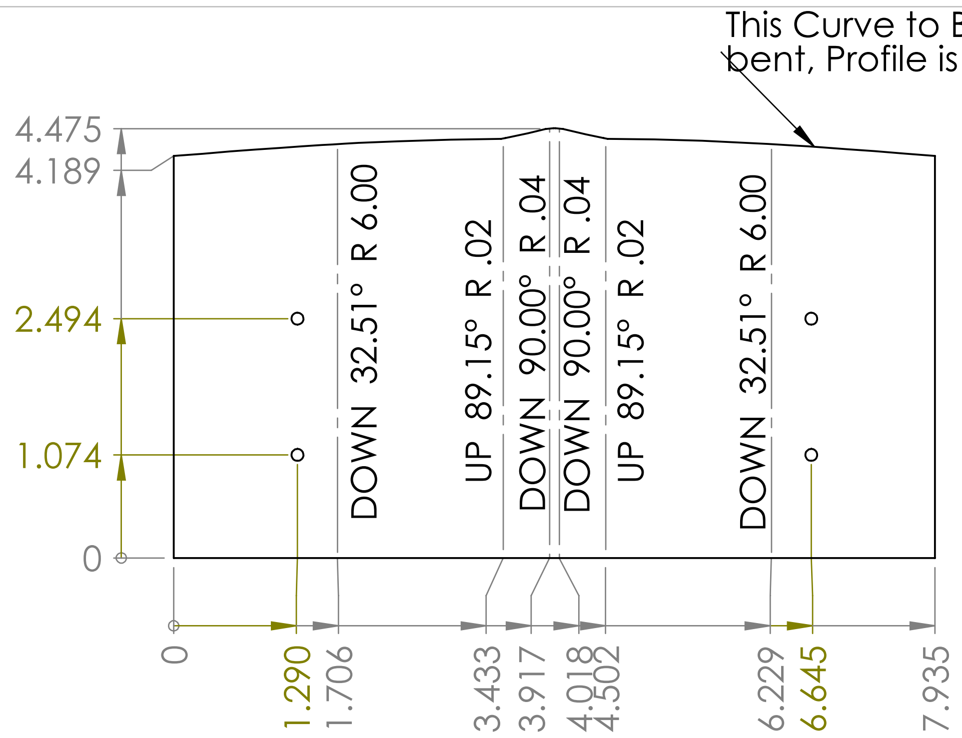
SIZE	DWG. NO.	REV
A	AshTray	

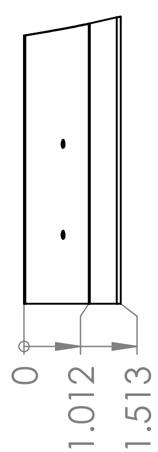
SCALE: 1:5 WEIGHT: SHEET 1 OF 1

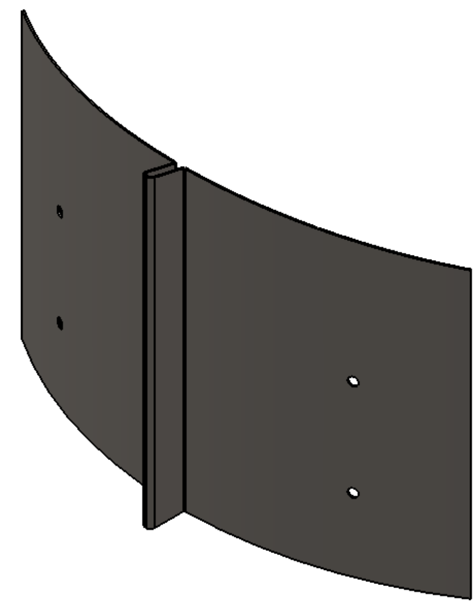
NEXT ASSY USED ON

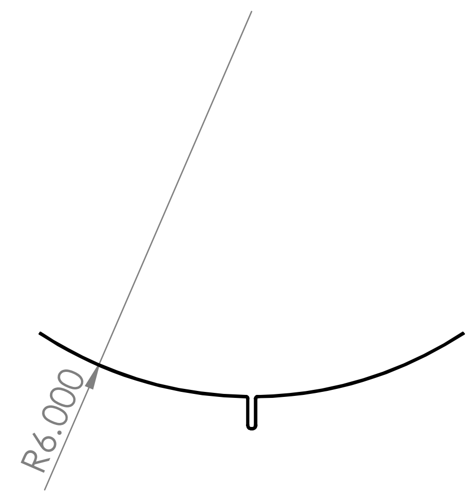
APPLICATION

5 4 3 2 1









NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

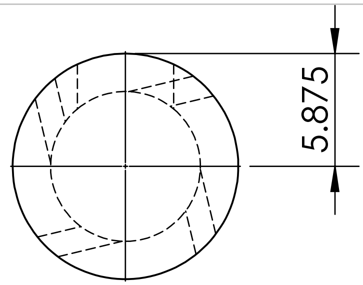
COMMENTS:

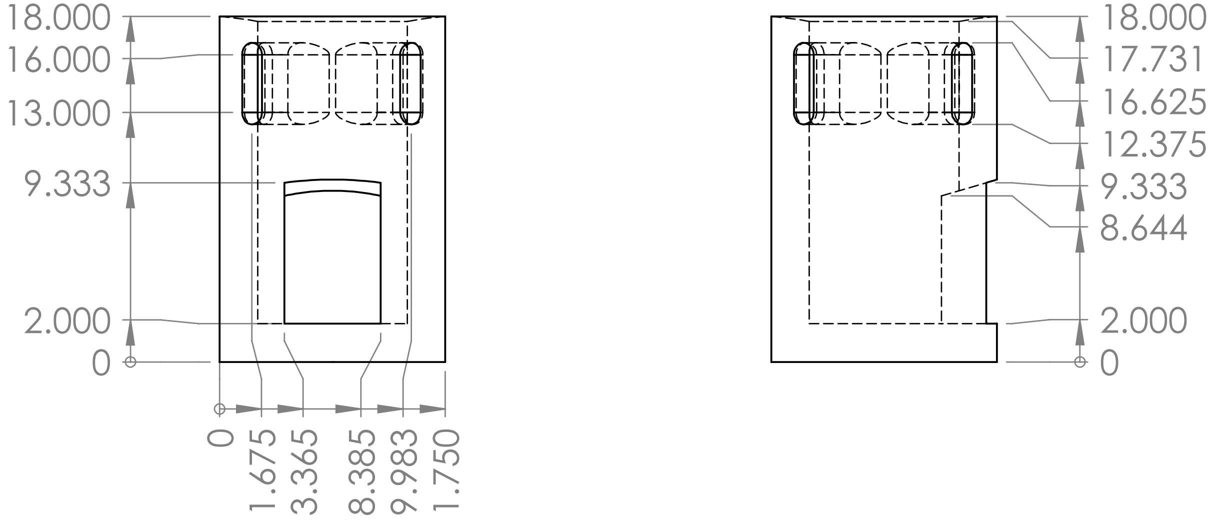
TITLE:

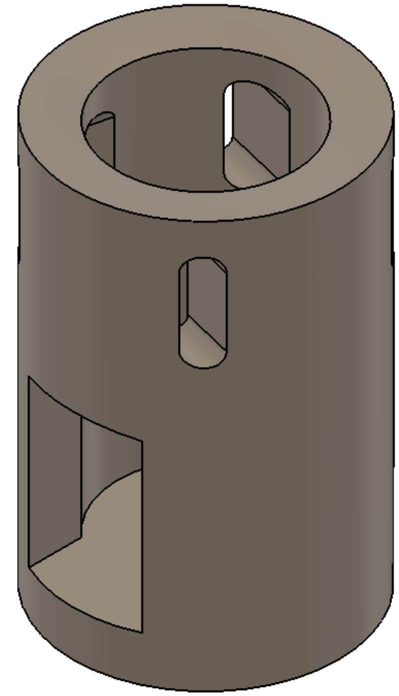
SIZE A DWG. NO. Ash Tray Cover REV

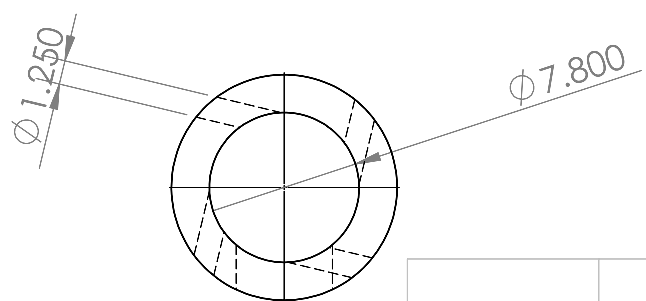
SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1









The Air inlet holes are best manufactured with the inner and outer cylinders on the part, to get the proper angle inward (all angles are 90 degrees to the centerline, and each other)

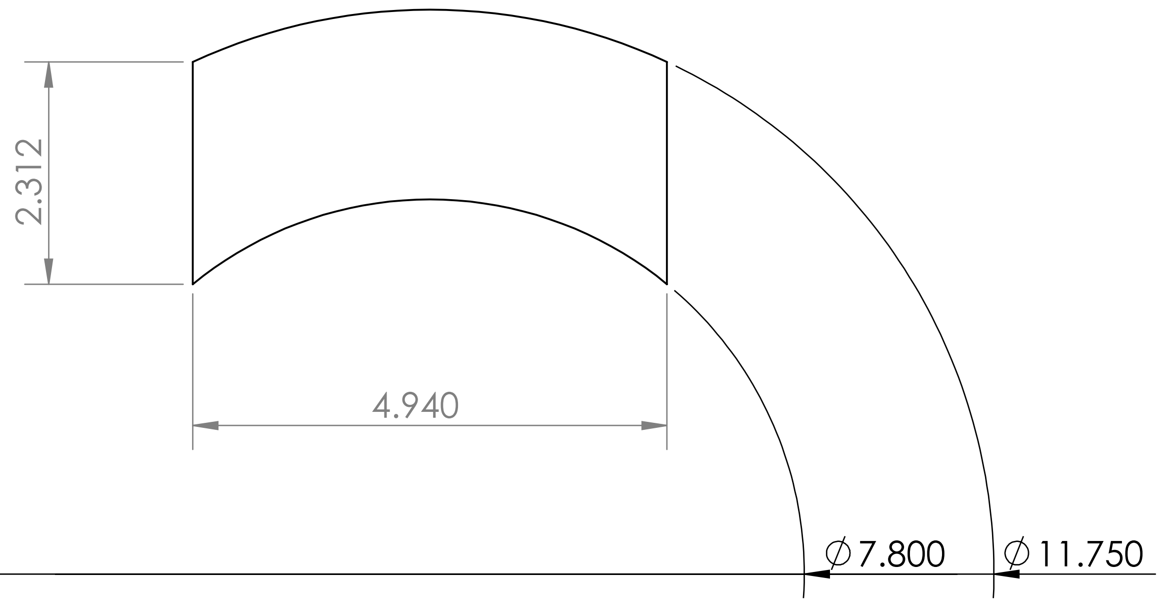
		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL
NEXT ASSY	USED ON	FINISH
APPLICATION		DO NOT SCALE DRAWING

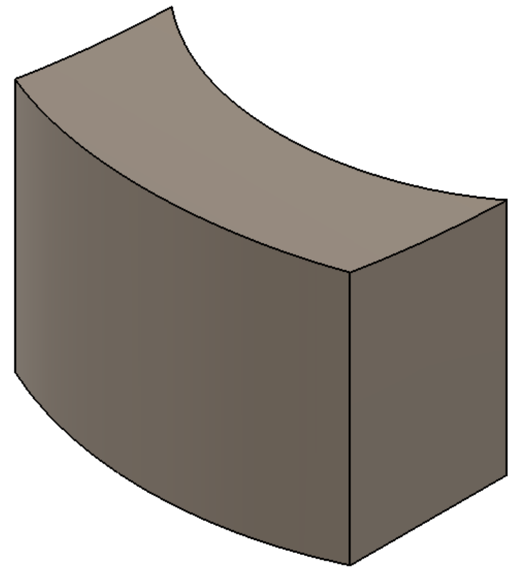
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

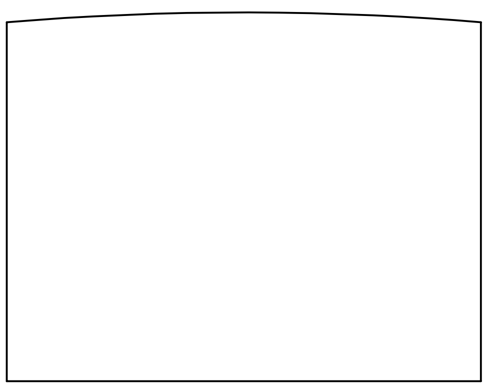
TITLE:

SIZE	DWG. NO.	REV
A	InsulationCore	
SCALE: 1:10	WEIGHT:	SHEET 1 OF 1

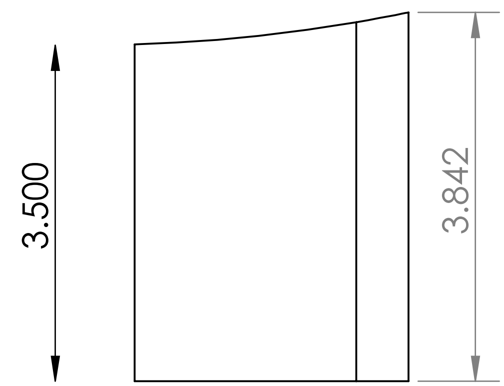
5 4 3 2 1







This portion is removed from the ceramic core. when the fuel chute cavity is removed, care must be taken to remove this peice as a whole, in order to use as the ash tray insulation



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

SIZE A | DWG. NO. InsulationBlock | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1