

Barrel on Fire, Charcoal Desire

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I. Abstract

Charcoal made from agricultural waste is a source of fuel that does not require deforestation and has an energy density that is comparable to other cooking fuels commonly used in developing countries. However, the process of making this charcoal provides some safety risks and uncomfortable exposure to heat. By placing the barrel of burning waste on a dugout with air channels rather than mounting it on bricks, the risk of the barrel toppling can be eliminated. To allow the waste to carbonize, the air channels can be sealed from a distance using metal sheets, which reduces heat exposure.

To maximize the metal seals' ease of usage, several designs were tested. Experiments were also conducted to ensure that high quality charcoal could still be produced with the dugout and metal seal solution. The possibility of insulating the barrel with different materials was investigated to provide suggestions for future work on heat reduction during the charcoal making process.

II. Problem Statement

From March 20, 2011 to March 26, 2011, we traveled to a small rural community in northern Nicaragua called Sabana Grande. We collaborated with Las Mujeres Solares de Totogalpa (Solar Women of Totogalpa), a cooperative dedicated to promoting the use of renewable energy technologies in the community. They operate in liaison with the Nicaraguan-based non-profit organization, Grupofenix, and the Alternative Energy Program of the National Engineering University of Nicaragua.

Our time spent working with these women was aimed at understanding the existing energy needs of the community in hopes of gaining perspective on how we could make a relevant contribution. As a team, we demonstrated the process of making agri-waste charcoal. The women have high hopes for the success of this charcoal in their community as an alternative to cooking over wood fires as well as a viable business tool for their up-and-coming "Solar Restaurant."

After two successful burns, the third burn was problematic. The Women did not coordinate when dismantling the barrel from the bricks. During this "tip-and-kick" method, one woman pushed the barrel in one direction and the second woman kicked the barrel out from under it directly making it fall on her (See Fig. 1).

We recognized the Women were still a long way from feeling comfortable enough with the charcoal burn to use it at high production levels for their restaurant. The Women told us that "The burn is the most difficult [part] especially covering the barrel. It gets so hot which means that we cannot bathe afterwards with the normal cold water, as it will make us sick." And, when asked what we focus our project on, they asked that we "work with the barrel, making some sort of insulation so that it wouldn't feel so hot."



Figure 1 – The barrel of burning biomass toppling over from poor coordination

With this feedback, we focused our attention on improving the safety risks and the heat exposure of the charcoal making process. After many iterative design cycles, our final design was sent to the Women for their testing and feedback. Ultimately, our design was a success with the women and has brought down the barriers of charcoal implementation they once had. Figure 2 depicts our involvement with charcoal making and the influence our work has had with the Women.

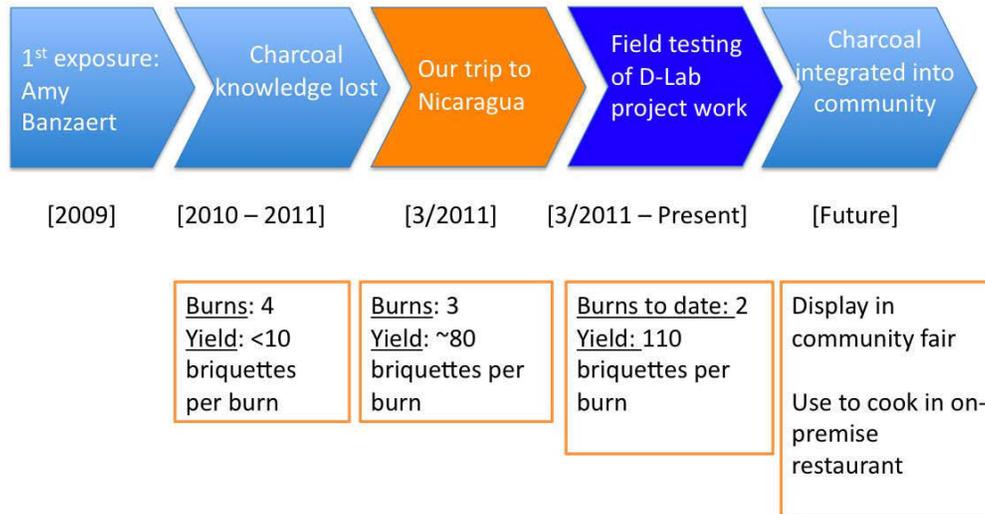


Figure 2 – Our team's involvement with charcoal and its influence on the Women of Totogalpa

III. Design Specifications

Our project scope was very dynamic, since this was the first anybody had tried to address these safety and heat issues in the charcoal making process. Although it was unclear what solution would solve both the safety and heat issues, there were certain design specifications that our solution would have to meet. The design specifications below in Table 1 were crafted as the qualities of a good solution. We considered these specifications at each stage of our design process to make sure to keep our designs aligned with our ultimate goals.

In drafting our design specifications, we had to be sensitive to the fact that the charcoal process is such a subjective one that requires qualitative measurements to produce the best charcoal. We were careful not to make the charcoal process scientifically more complex than it already is since most of the Women lack a technical background. Specifications like cost, maintained burn quality, and ease of use needed to be prioritized since they were already limited motivation for charcoal making before our solutions.

Table 1 – Design specifications

Customer Need	Product Attribute	Specs- Metric	Specs- Unit	Specs- Value
Decrease # of people needed to tend to drum	Less Manpower	Time	Man hours	< Current (1 Woman hour)
Cost	Cheap	Money	Cordoba	Profitable
Durable	Heat Resistant	Thermal resistance	K/m ²	>0
Can be left outside	Weather-resistant	Coated/rust-resistant	Binary	Yes
Ease of Use	All handling parts easy to use	Force	Newton	
Repairable	Local materials used & simple design	Distance to supplier	Km	<20
Needs to be safe	Childproof			
Equal or increased burn quality	Charcoal yield	Weight	Kg	>3.6
	Charcoal quality	Time to light/duration	Minutes	<5
Decrease exposure to heated barrel	Less manpower	Time	Man Hours	< Current

IV. Brief Review of Design Concepts Considered

Four categories of design concepts were considered to solve the issues of heat exposure and safety risks to the user:

1. Sheath

The concepts in this category of designs all entail type of sheath that seals off the airflow to the bottom of the barrel, which is still sitting on top of bricks a few inches above ground. One example is a sheath that encircles the entire barrel, sitting around the barrel while airflow is required and sliding down to the ground to seal the barrel once airflow is no longer required.

Problems: Too expensive to construct a large, barrel-encircling sheath out of sheet metal. It was too difficult to create an airtight seal using only the sheath.

2. Handles

These designs call for 2-3 handles that are attached to some part of the barrel through a gripping mechanism. The handles can then be used to more safely maneuver the barrel off the 3 supporting bricks when the airflow needs to be sealed, and the sealing process can be done at a distance. For instance, if two handles are located directly across from each other (180 deg.) on the outside of the barrel, then using two long sticks, two users could lift the barrel in between them (with the sticks lifting the handles), off the bricks, and onto a flat surface to seal it.

Problems: Metal for the handles is expensive. It was difficult to find an appropriate attachment mechanism to the barrel that can withstand multiple thermal cycles and possible rusting.

3. Rotating Disk

This concept involves having a sliding disk that covers the air holes punched out from the bottom of the barrel. The disk sits right up against the bottom of the barrel and has the same holes as the barrel so that air can flow through when the holes are aligned. Then, to seal the barrel, the user can turn a handle attached to the disk, sliding the solid portions of the disk over the barrel as the disk rotates in place. The disk is attached to the bottom of the barrel through some kind of clasping mechanism.

Problems: In order to seal the bottom of the barrel, the disk must be held up very close to the bottom of the barrel but still be able to rotate in place. This calls for a complicated attachment mechanism, which would be both costly and likely to break when the barrel is being handled.

4. Radiation Shields

This design concept grew out of our experimentation, which showed that most of the heat emanating from the burning barrel takes the form of thermal radiation and not convection. As such, we considered various radiation shields as a way of reducing heat exposure. Two shields that were considered were wrapping the barrel in multiple rolls of either aluminum window screening or steel mesh.

Problems: The two tested materials did not decrease radiation enough to justify their cost. Wrapping the barrel 6 times in either material only decreased radiation by 40% relative to the emittance of a naked radiation source.

V. Experimentation

Experimentation occurred across three areas that all contributed to our final design in crucial ways:

1. Dug-out Testing:

Before settling on the final dug-out design, we experimented with three designs and assessed each across four factors:

- Cost – is the design costly?
- Load Bearing Capacity – can the design hold the weight of a loaded barrel?
- Durability – is the design durable to multiple thermal cycles and constant removal and re-placement of the barrel?
- Other Factors

How each design measured up on each factors is not, strictly speaking, entirely the result of our own experimentation (for instance, cost). However, when experimenting with building and using these designs, we took all of these four factors into account at the same time, so they are all included here together.

Table 2 shows experimentation results and Fig. 3 shows pictures of all three designs.

Table 2 – Experimentation results

Design	Cost	Load-Bearing Capacity	Durability	Other Factors
Cross-shaped dug out	Low, no bricks required	Sufficient	Possible erosion of soil	Possibly sacrilegious design
Circular dug out with three dirt channels	Low, no bricks required	Sufficient	Possible erosion of soil	
Circular dug out with three brick-lined channels	Six bricks required, but cost still low relatively speaking	Sufficient	No worry of erosion because barrel is sitting on the bricks	



Figure 3 - Counter-clockwise from top right: Circular dugout with 3 dirt channels, Cross-shaped dugout, and circular dugout with 3 brick-lined channels

As a result of experimentation, we settled on the last design because we felt that the durability consideration was most important, and the cost of bricks was negligible.

2. Metal Seals Testing:

The metal seals for sealing the air channels varied in four ways, each of which we tested by assessing (1) the ease with which that design characteristic could be constructed and (2) the degree to which it affected the experience of using the plate to seal the barrel:

- Type of sheet metal
- Size of plate
- Type of handle
- Type of edge

The following table shows the qualitative results of experimenting with both the construction and usage of plates with the different design characteristics:

Table 3 – Design characteristics of Metal Plate Seals

Characteristic	Specific Design Choice	Construction Considerations	User Considerations
Type of sheet metal	Thin	Can be cut with just shears. Available in Sabana Grande.	Lightweight
	Thick	Cannot be cut with just shears; requires heavy machinery.	Heavy
Size of plate	10" length, 10" width	Can be cut with just shears. Available in Sabana Grande, Use less material	Too small to cover bricks and air channel
	13" length, 12" width	Can be cut with just shears. Available in Sabana Grande,	Could sacrifice width
	13" length, 14" width	Can be cut with just shears. Available in Sabana Grande,	Could Sacrifice width
	16" length, 14" width	Cannot be cut w/ shears	Too heavy
Type of handle	90 deg. to plate	Requires multiple spot welds	Impossible to lift; very difficult to maneuver
	45 deg. to plate	Requires multiple spot welds	Difficult to lift or maneuver
	45 deg. to plate + lipped handle	Requires multiple spot welds	Easiest to lift given the lips on the handle pieces, still hard to maneuver
	Cylindrical	Does not require welding, only riveting	Very easy to lift and maneuver
Type of edge	Triangular	Easy to cut	Same as semi-circular
	Semi-Circular	Hard to cut into exact semi-circle	Same as triangular

In Table 3, the specific design choices that are part of the final design are bolded.



Figure 4 - Plate with a spot-welded handle that sits 45 deg. to the plate, with a semi-circular edge.

3. Heat Insulation Testing

In order to test whether the heat from the barrel came from thermal radiation or convection, we covered part of the barrel with tin foil (a radiation shield) and felt around the barrel. The heat was greatly reduced relative to the un-covered barrel. Then, to test for convection, we lit a cigarette next to the bottom of the mounted barrel. The smoke from the cigarette flowed toward the barrel regardless of where we held it, indicating that cool air was being drawn into the barrel, away from the user, and no hot air was flowing out from underneath the barrel toward the user.

In order to test radiation shields, we set up an experiment with a thermopile. The details of the experimental set-up and the results (tabular and graphical) are below:

Experimental Set-up: Turned on a hot plate with a thermal mass over it. Measured the heat of the hot plate using a data logger and thermocouple; readings showed that the temperature of the hot plate was constant within a few degrees throughout the course of the experiment (95C – 106C). Attached a thermopile to a voltmeter, and taped the reader to the top of a brick. Experimenter placed the brick-thermopile apparatus in the same location on top of the thermal mass for each reading so that the thermopile was always reading in the same spot, regardless of the type or quantity of radiation shield being used. The brick-thermopile apparatus would sit on top of the radiation shields. The thermal was then recorded off the voltmeter in millivolts.

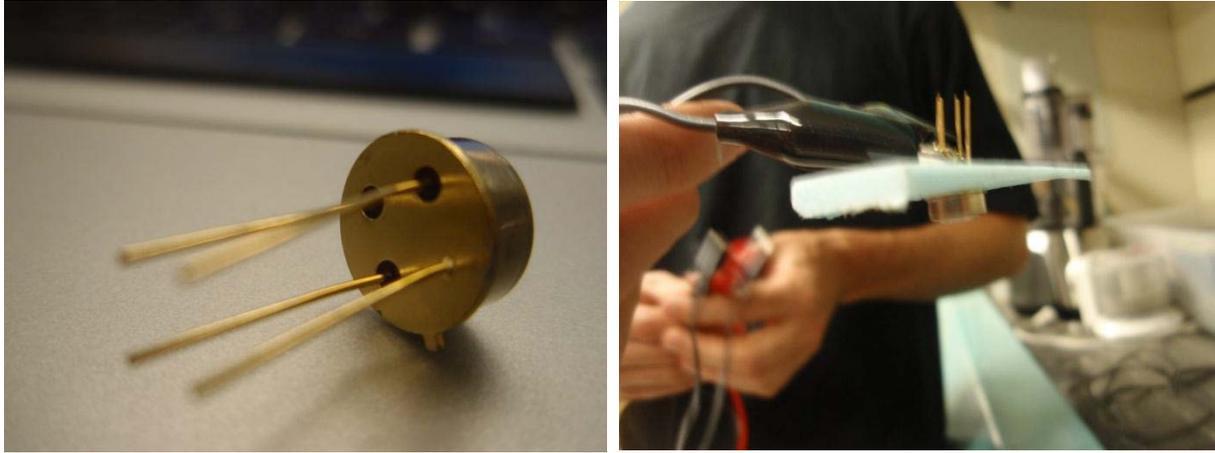


Figure 5 – Left: TPS 334 Thermopile; Right: Thermopile mounted on foam and connected to voltmeter



Figure 6 - Thermopile setup mounted to brick and set over very crinkled foil; entire setup on top of hotplate

Table 4 – Experimentation results

Radiation Shield	Thermopile reading	
	Trial #1 (mV)	Trial #2 (mV)
Nothing	20	21
Foil - slightly crinkled	0	0
Foil - very crinkled	0	0
Aluminum Screening - 1 layer	21	21
Aluminum Screening - 2 layers	19	19
Aluminum Screening - 3 layers	17	17
Aluminum Screening - 4 layers	15	16
Aluminum Screening - 5 layers	15	14
Aluminum Screening - 6 layers	14	13
Aluminum Screening - 7 layers	13	11
Metal Mesh (.25" holes) - 1 layer	19	21
Metal Mesh (.25" holes) - 2 layers	19	18
Metal Mesh (.25" holes) - 3 layers	17	17
Metal Mesh (.25" holes) - 4 layers	17	16

Metal Mesh (.25" holes) - 5 layer	14	14
Metal Mesh (.25" holes) - 6 layers	12	13

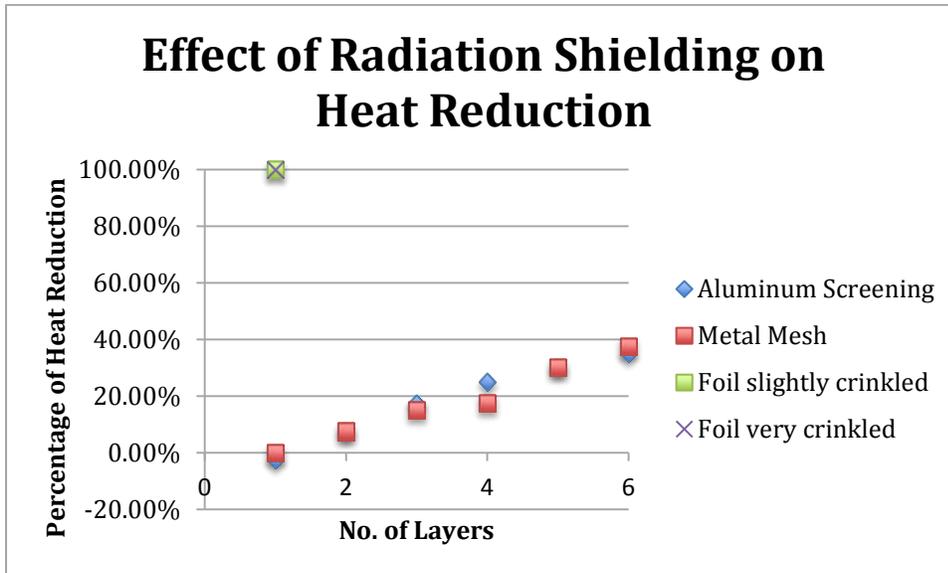


Figure 7

We concluded that if six layers of aluminum screening or steel mesh could not even reduce the heat by 40% (See Fig. 5), then it would not be worthwhile to use either material as a radiation shield.

VI. Design Description

In the charcoal making process, an alternative method can be used for the barrel setup. Rather than mounting the barrel on top of three bricks, this alternative method allows the barrel to rest at ground level and does not require the barrel to be dismantled during the burn. This alternative method involves a circular dugout with three air channels, as well as metal seals that are used to cover the air channels.

Circular dugout

The barrel sits at ground level above a circular dugout that is 4" deep with a slightly smaller circumference than the barrel. This allows the barrel to create a seal with the ground. There are three channels that extend from the dugout and two bricks are mounted in each channel to provide a level surface upon which the barrel stands. When the barrel is resting on top of the dugout, the area of channel exposed must be large enough to allow the necessary amount of airflow to reach the biomass through holes in bottom of barrel. The holes in the bottom of the barrel that we worked with had a total area of about 72 sq. in. Between the three air channels, each channel would have to expose 24 sq. in. It was

concluded that each channel needed to be roughly 6 in. measured radially from the barrel, and 4 in. across (see Figure 8).



Figure 8 – Circular dugout with (right) and without (left) the barrel on top

Metal Seals

Three separate metal seals are needed to seal the three air channels. Each seal is pentagon shaped (like a house). The bottom side measures 10", the sides adjacent to the bottom are both 6" and the last two sides are about 5.4". The handle is cylindrical and is attached to the bottom edge of the seal. The cylindrical handle has a height of 2" and a diameter of 2.5".

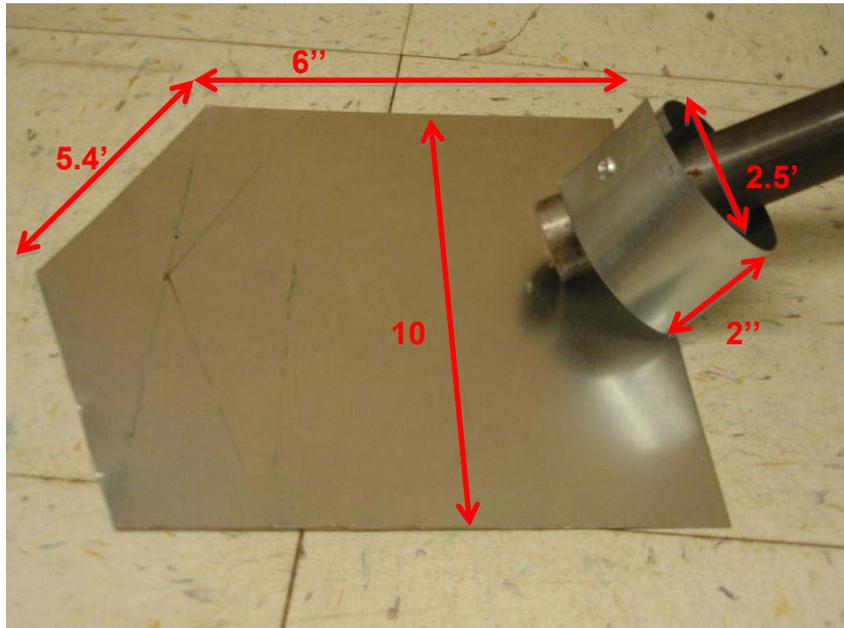


Figure 9 – Final product: pentagonal metal seal w/ cylindrical handle

Procedure for Making the Metal Seal

1. Cut out a 10" square out of sheet metal using metal shears, or any other method of cutting metal.
 - a. Mark 2" in from the edge of one side of the square and draw a line so that a 10" x 2" is allocated for the handle. Draw a 3.75" line from both edges, leaving a 2.5" section in the center unmarked, which will represent that point at which the handle and the seal are attached.
2. At the opposite end of the square, mark the midpoint. On the two adjacent sides of the square, measure 2" down and make a mark on the edge. Draw a line from the midpoint of the one end of the square to the mark made on each adjacent side. This should create the pointed end of the seal.
3. Cut along the lines marked for the pointed end of the seal. Also cut along the two 3.75" lines at the opposite end to create handle.

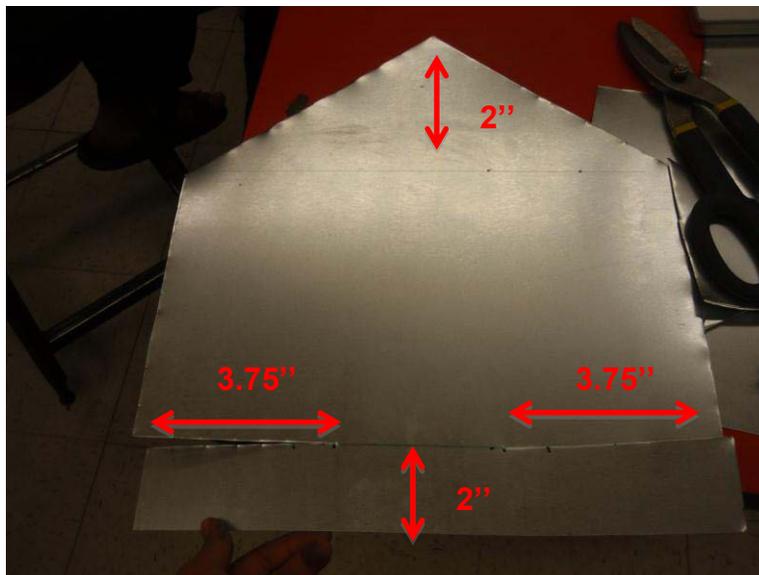


Figure 10 - Metal seal w/ measurements before handle is constructed

4. On the handle pieces, drill a hole 0.5" in from each side. Bend these two flaps around and rivet them together to create a circular handle.



Figure 11 – Bending and riveting the sheet metal to create the handle

5. Bend the entire handle up to form about a 45° angle with the plane of the seal.

When the barrel is ready to be cut off from airflow, the users can use the back of shovel, broom, or even the stick used to create the chimney in the biomass to move the metal seals into place. They are pushed right in between the barrel and the bricks, and then later sealed with sand for additional airtightness.



Figure 12 – Metal seals inserted between bricks/ground and the barrel

This design was chosen because the shape is simple enough to create with metal shears, assuming that the sheet metal is thin enough. Only one piece of sheet metal is needed, and there is no need to weld the metal. Many other developing communities in developing countries have the capabilities of riveting. The pointed edge allows for easier insertion into the air channel and the angled handle allows for a more natural movement for the user.

VII. Assessment

Our final design meets most of design specifications we set for our project in the beginning and actually improves the process in a few ways that we had not originally

considered. With the previous method, at least two people are required to dismount the barrel from the bricks. The dugout and metal seal solution only requires a single person to push all three metal seals under the barrel. This can be done in an amount of time that is comparable to the time it takes to dismount the barrel using the tip and kick method. This solution also meets the safety specification because there is no need to move or handle the barrel while the biomass is on fire. Heat exposure is also reduced because the seal can be made from about 1 meter away, and flames are no longer being emitted from the bottom of the barrel toward the users' feet.

The construction of the metal seals is feasible in developing countries, and particularly so for the Mujeres Solares. Sheet metal is readily available to them because it is a material that is also used in the construction of their solar ovens. It costs about \$8 for a 3 ft. x 12 ft. sheet. They are also able to rivet metal together, which is a technology that is neither bulky, complicated, nor does it require electricity.

Producing a similar quality of charcoal as the previous method is perhaps the most important specification for us to meet. In our experimentation, we were able to produce carbonized material that was not too ashy, and could make acceptable briquettes.

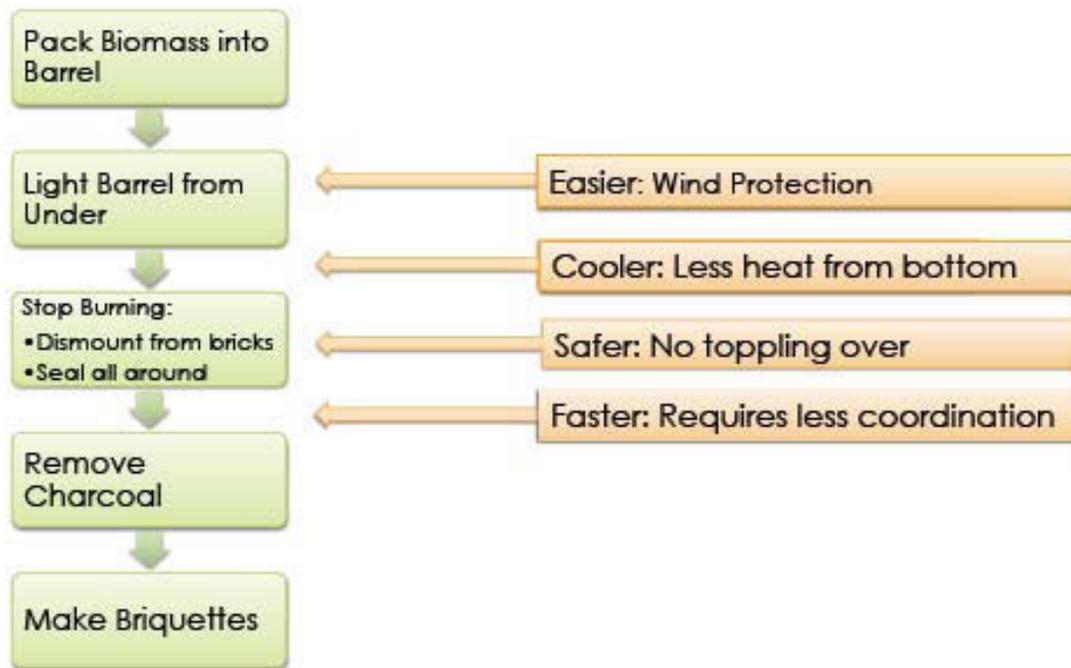


Figure 13 – Parts of the charcoal making process that we were able to improve

VIII. Community Partner Feedback

Our team was fortunate enough to maintain communication with the women constantly throughout our design process. We asked them for costs and descriptions of the

materials locally available to them in order to do a near-realistic cost analysis of barrel insulation options. We compiled a document of our final instructions with on how to make the dugout and the simple concept behind the sheet metal seals. We left out specific instructions on how to make the sheet metal seals in order to allow for their creativity of design. As expected, they designed a seal of sheet metal (Figure 14) different from ours and later mentioned they already had second designs in line for a second draft of sheet metals.



Figure 14 – The metal seal the Women used that did not include handles

They followed our instructions in making the dugout for the barrel and successfully carried out a charcoal burn. Their comments, below, were very encouraging to our design and marks of our success in addressing these issues for the Women.



Figure 15 – A charcoal burn that the women conducted after integrating our solutions

Direct Testimonials From the Mujeres

"I ate tortilla with the carbon we made!!! ...the tortillas were delicious!"

"It was really easy and fast to align the holes with the channels. We barely got any ashes or undercarbonized material, all the hearts were black"

"The burn went really well! This way is much better because there's no risk that it will fall, so now we don't get burn. Both things are important, but it's more important that the barrel is safer than that it's not as hot."

"I think the sheet metal design is easy. We made them almost just like yours, but we put a handle on the plate. But we don't feel as hot so it's fine to get close and then cover it with sand...very good work because now we don't feel the heat!"

"We have Big News: 17 of May we're gonna have a fair and sell charcoal that day! With [your] new technology we can make a lot of carbon and sell it at the fair! Our fear was that it would topple over, so we didn't feel as agitated when we did it this time. So we'll make charcoal this week and sell it at the fair. Now Elia really feels like a Charcoal Captain."

The women did run a second burn with our design solution, but this run did not proceed as flawlessly as the others. They had reported back to us through a phone call that they had done everything just as they had in the previous burn and left the biomass to carbonize for two hours. As they uncovered the top and the bottom seals, the biomass had suddenly erupted in flames again. The fire was safely put out with water. However, this devastated and confused the women. After careful consideration and consultation with our project mentors and professor, we were able to respond to their concerns. It was concluded that the seal must have not been completely airtight. This is the only way in which the flames could have been reignited. It is important to note that this situation was not particularly a fault of our design, and could have arisen in any other burn using any other method of sealing. We assured this to the women in hopes of restoring their confidence in the charcoal making process.

IX. Acknowledgements

We would like to give special thanks to our community partners at Grupofenix, the Alternative Energy Program, Las Mujeres Solares de Totogalpa and Lyndsey Chapman for continuously inspiring us and being receptive to our ideas. We'd also like to thank our project mentors, Amelia Servi and Steve Banzaert for guiding us through all aspects of our project; Ken McEnaney and Amy Banzaert for making significant contributions to our success; and Amit Gandhi, Gwyn Jones, Dennis Nagle, Dr. Barbara Hughey, Jonh DiFava, Daniel Caterino & Mike Tarkanian without whom this project would not have been possible.

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