Future Generations University

Rocket Stove Sap Evaporator Manual

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March 2024

Supported by Northeast SARE Grant ONE19-347

Publication made possible by a grant from the U.S. Department of Agriculture (USDA), Forest Service, National Agroforestry Center, under the authority of the Cooperative Forestry Assistance Act of 1978.

The Rocket Stove Sap Evaporator Background

Rocket stoves have been utilized for decades in developing nations as a way to cook indoors with wood without the resulting smoke and particulate matter, improving community health. Rocket stoves create an efficient and focused heat source utilizing traditional tinder such as wood or charcoal. Based on these principles, the Rocket Sap Evaporator is a stove designed to provide a fast and vigorous sap boil with near complete combustion resulting in efficient wood use and little particulate matter. This sap evaporator was also designed to be to be inexpensive to build and capable of being fabricated by a local welder or others with machining experience. Although the cost is based on the volatile nature of the cost of goods of raw material, this evaporator should cost between $500-$700 in materials.

The Rocket Sap Evaporator is meant for small-scale or backyard syrup producers with 20-50 taps, however it can be utilized in larger syrup operations as long as there are enough individuals to continuously monitor and feed the fire. Developed by Future Generations University (FGU) in collaboration with the Robert C. Byrd Institute of Advanced Manufacturing (RCBI), these plans and instructions are meant as a guide for beginning syrup operations. Please read the document in its entirety before beginning fabrication.

Overview

Rocket Stove Physics

The basic physics principle behind a rocket stove incorporates an insulated chimney above a firebox in which wood gasses are ignited providing a fast, energy efficient burn. In typical home fireplaces and wood stoves, the fire is dampened down restricting the air flow to achieve a long and slow burn with unburned gasses drawn up through the chimney as smoke. Properly designed and constructed rocket stoves do not smoke because the wood gasses are burned in the chimney instead of escaping, and rocket stoves burn hot and fast.

Background

The advantage of putting a chimney above the fire to achieve complete combustion was discovered in 1780 by Aime Argand and first used in his patented Argand lamp. The complete combustion that resulted provided 6-10 candelas more of light than a standard wicked oil lamp, proving its efficiency. This increase in brightness led to the Argand lamp being used regularly in early North American lighthouses.

In the 1980's Dr. Larry Winiarski, director of the Aprovecho Research Center in Oregon, began engineering stoves for use in developing countries that would maximize energy efficiency, minimize the adverse health effects of a smokey kitchen full of particulate matter and noxious fumes, and maximize heat transfer to the cooking surface. Energy efficient wood cook stoves are also seen as one way of decreasing deforestation because they require less fuel to maintain constant temperatures.

In 2018, Future Generations University began working with colleagues at Virginia Tech to test the efficiencies of various backyard sap evaporators. One of the stoves looked at was an Aprovecho-designed rocket stove meant for cooking. The Aprovecho stove design burns hot and the temperature can be hard to control. This is an advantage for evaporating sap, where the user needs the heated

surface to be continuously very hot.

The Rocket Sap Evaporator is built based on Winiarski's engineering, as presented in the publication Design Principles for Wood Burning Cook Stoves, by the Aprovecho Research Center. Calculated chimney height and gap clearances are related to chimney cross sectional area and designed to maximize air flow through the stove and heat transfer to the pan. In this document, results of those calculations for an 8-inch square chimney are provided. The stove design presented here is a 4th generation sap evaporator. Each iteration of this design has improved evaporation rate and simplified the manufacturing process. This work is continuing, with users providing feedback for subsequent improvements.

Description of Key Components – Before You Build

The Combustion Chimney and Firebox

The internal components of a rocket stove are the firebox and an insulated chimney. Figure 1 shows the combustion chimney in this Rocket Sap Evaporator (RSE) design. This chimney will be wrapped in rock wool insulation to keep the heat in and ensure complete combustion. It is then set in a 55-gallon steel barrel.

The combustion chimney and firebox consist of:

- Wood feed that extends just through the wall of the barrel. The wood feed can then have an extender attached to make it easier and safer to feed the stove with kindling size wood tinder. Having the wood feed shoot at a 45-degree angle, helps the unburned wood drop into the firebox. The shoot has a wood shelf approximately ¼ of the distance from the bottom.
- Wood shelf which keeps the wood off the bottom of the combustion chamber and allows air flow under the wood for maximum combustion. The shelf meets the grate, allowing the wood to smoothy slide into the firebox and for air to enter below the grate and be drawn up through the firebox, burning any coals that may accumulate. The wood shelf should be tack-welded to the sides of the wood shoot before welding it on to the chimney.
- Air vent to allow ample air to flow under the fuel.
- Ash cleanout at the base of the chimney that has an extension box which is inserted once the chimney is in the barrel. Ash falls below the grate onto a metal plate welded to the bottom of the chimney. The plate provides stability to the combustion chimney, so it won't fall over, and protects the bottom of the barrel from the hot embers that fall through the grate. A cleanout box needs to be fabricated to remove ashes from outside the barrel. The cleanout needs a cap, so that air enters only through the wood shoot.
- Internal grate on which the wood is burned—it is important to not let ash buildup on the grate, which can cause overheating and warping of the fire box. The grate defines the bottom of the firebox. It is positioned by drilling two holes through the chimney and sliding two rods or bolts through for the grate to rest on or by building a stand-alone grate with rebar that stands on legs.
- Firebox where the fire is held.
- Combustion chimney where hot gasses swirl and mix with the incoming air resulting in maximum combustion and stove efficiency.

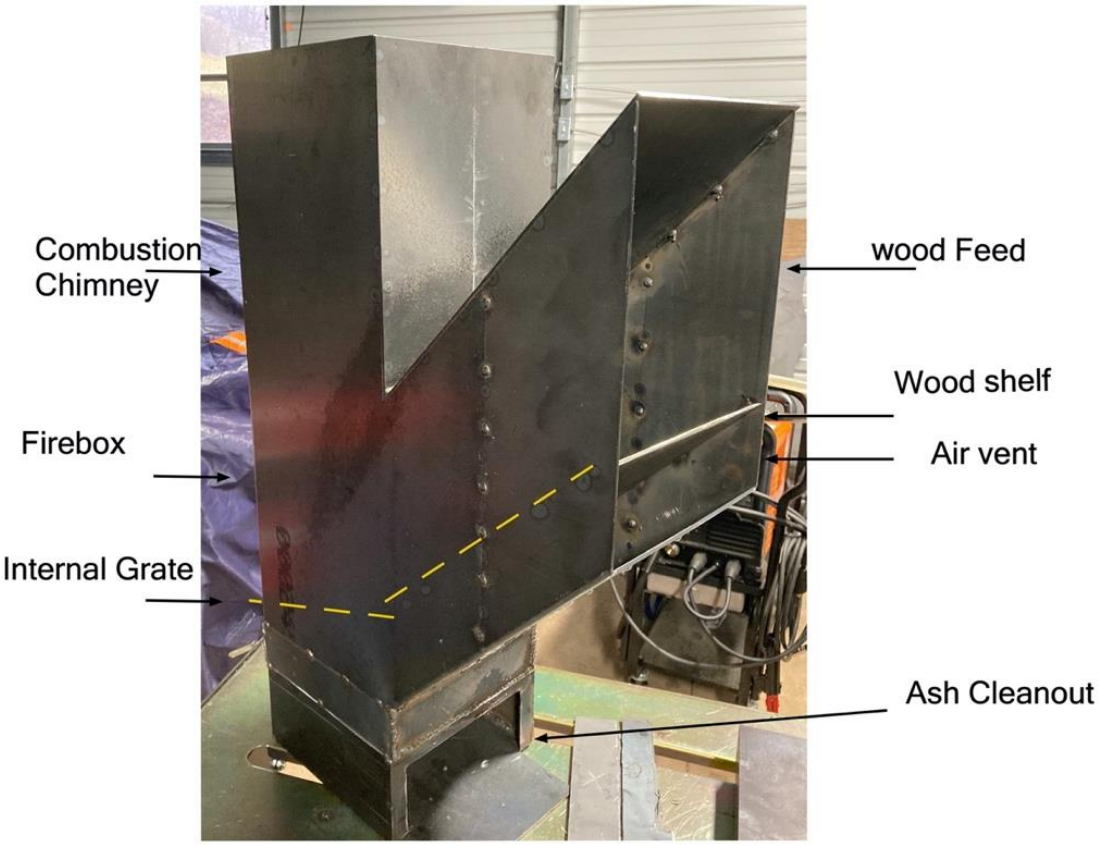

Figure 1 - Internal components of a Rocket Sap Evaporator. (Photo credit: Future Generations University)

The Smokestack

As air is drawn in through the wood feed, the heat of combustion expands those gasses, and they scrape under the pan transferring heat to the sap. Even though near complete combustion is achieved, those expanded hot gasses have to go somewhere. In many rocket stove designs they simply escape around the sides of the pan into the atmosphere, like a camp stove. However, in a rocket sap evaporator this would be a serious disadvantage as the producer would be working across the stream of exiting hot gasses. The solution is to draw the hot gasses back down the barrel and out a "smoke" stack. This stack should be attached low on the barrel so that both sides are drawn from equally.

To balance air flows, the stack diameter and cross-sectional area should be the same as the chimney and wood shoot. However, because of the positive draw of hot gasses rising up the smokestack, in the 8-inch chimney stove build, a 6-inch stack has been determined to be sufficient and is readily available at most local hardware stores.

The Flame Spreader

The flame spreader is the most complex component of the stove. It is determined as the distance from the plane of the top of the chimney to the edge of the pan decreasing at a rate that keeps the airspace volumes constant. If the distances are too small it restricts the airflow, resulting in incomplete combustion. If the distances are too large the hot gasses are not forced close to the pan, resulting in less-than-optimal heat transfer. The easiest way to do this is by welding together four independent plates, as shown in Figure 3.

When complete, the flame spreader should sit nicely on top of the chimney (weld on some taps to center it correctly) giving the proper distance to the pan on the edge (Gap B) and the proper spacing from the edge of the flame spreader to the side of the barrel (Gap C). There is no need to weld this on, as it sits on top of the chimney and is supported by the insulation.

Background Description of Calculations Used in Final Design

The combustion chimney is what makes a functioning rocket stove. The following calculations describe how it is made energy efficient and maximizes heat transfer to the pan. The Winiarski equations provided in Design Principles for Wood Burning Cook Stoves provide the height and gap dimensions shown in figure 2. These dimensions are critical to making an efficient stove. The Aprovecho stove has a chimney height that is approximately 3 times the width of the firebox (8 inches in this case). The cross-sectional area of the chimney is the same as the cross-sectional area of the wood and air feed, which is the same as Gaps A: between the top of the chimney and the bottom of the pot, B: between the bottom outer edge of the pot and the flame spreader, and C: between the edge of the flame spreader and the side of the barrel. This way there is nothing to restrict air flow and the distances utilized result in the hot gasses scraping along the bottom of the pan for maximum and consistent heat transfer.

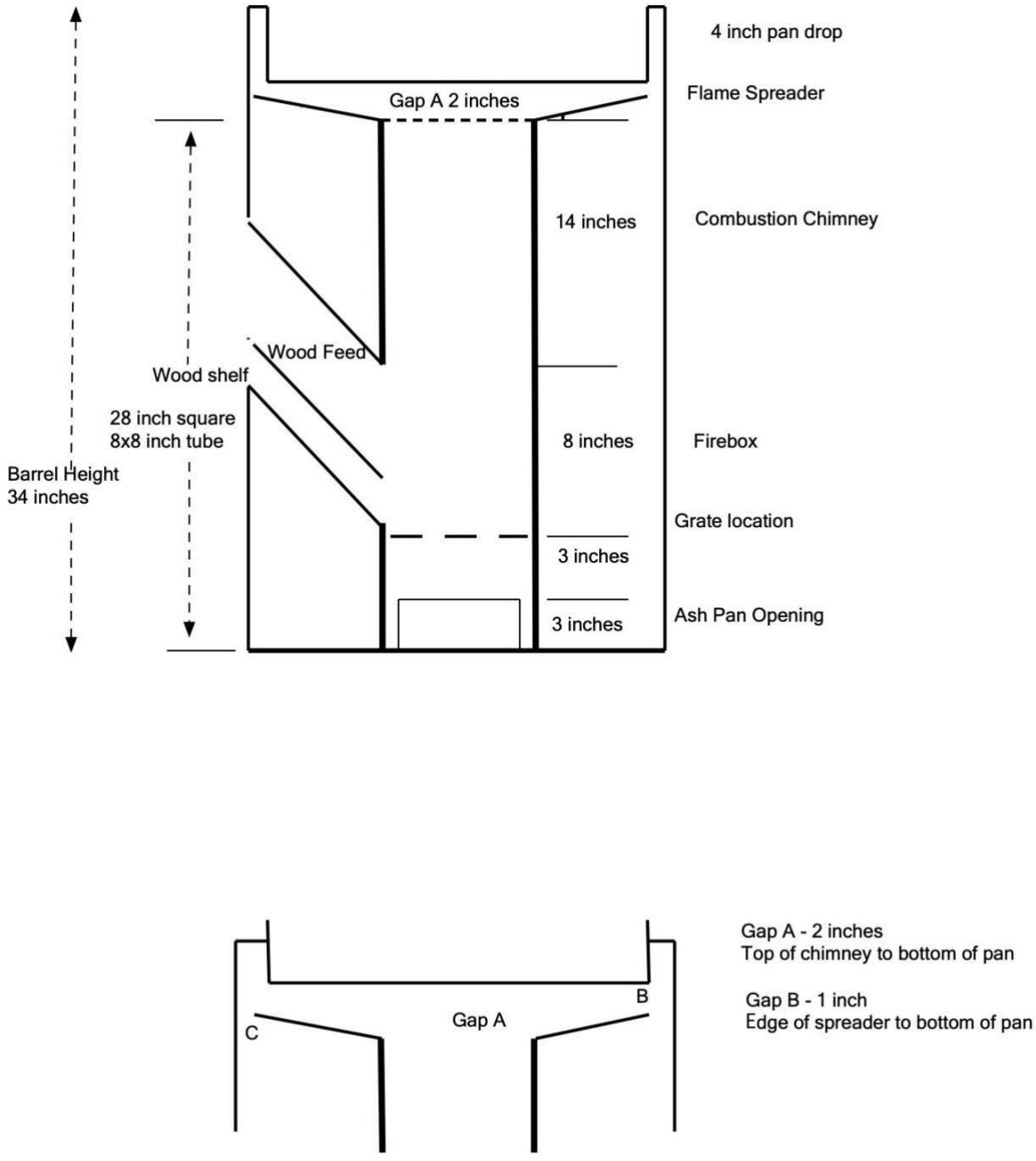

Figure 2 - Vertical dimension tolerances of the chimney as determined by rocket stove principles. (Image credit: Future Generations University)

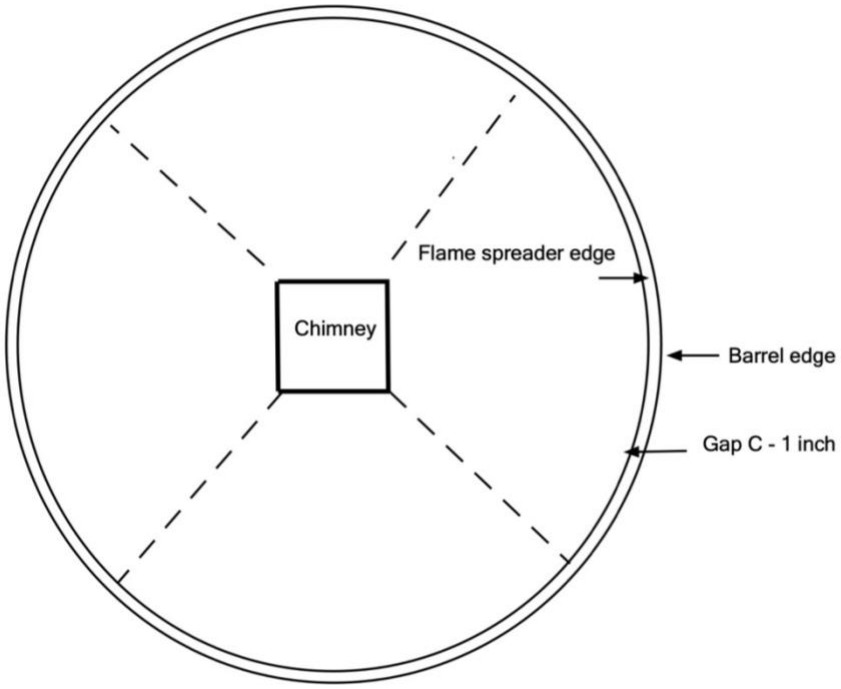

Figure 3 - Flame spreader. (Image credit: Future Generations University)

Summation of sizes and gaps for a stove with an 8-inch square chimney

ELEMENT	DIMENSION
55-Gal Barrel height	34 inches
Inside diameter	22 inches
Sap pan diameter	21 inches
Chimney total height	28 inches
Ash pan height	3 inches
Grate location	6 inches
Firebox	8 inches
Combustion chimney	14 inches
Gap A	2 inches
Gap B	1 inch
Gap C	1 inch
Wood shelf (from bottom)	2 inches
Wood chute	45 degrees

The Rocket Stove Sap Evaporator
Fabrication Instructions

The following instructions are easiest to use in conjunction with the Cut Pattern and Layout Diagrams available as a set of large-format printed plans directly from Future Generations University Appalachian Program or a digital file to have printed in large-format at your local print/copy shop. It is possible to draw the patterns directly on to the sheet steel based on the provided measurements with the exception of the flame spreader, which can be printed at home on two pieces of standard letter-size paper using the template located at the end of these instructions and then taped together to make a single template piece.

Minimum Materials List

- Standard 55 gal. steel drum
- 4' x 5' sheet 1/8" steel
- 4' x 18" sheet 1/16" steel
- One 2" or 3" hinge
- 3" tall piece 6" i.d. (inner diameter) well pipe
- 6" dia. stove pipe 90º elbow
- 6" dia. stove pipe, 4' length
- 7' of ½ inch steel rod to fabricate the fire grate, cut into 7 ½" long pieces
- Approx. 1' scrap of angle iron for "tuning" the evaporator pan height
- 30 qt. Stainless Steel Brazier Pan (Evaporator Pan) available here: https://www.webstaurantstore.com/vigor-30-qt-stainless-steel-aluminum-clad-heavy-weight-brazier-with-cover/473SSBRZR30.html

Tools Required

- Angle grinder with both diamond and polishing wheels
- Welder
- Silver sharpie or similar writing tool
- Ruler
- Plasma cutter (optional)

Fabrication Instructions

1. Cut out paper pattern template pieces (or begin with Step 3 if just measuring and drawing)
2. Trace all template pieces (EXCEPT the flame spreader) on to the 1/8" sheet steel (see Figure 1). Be sure to label your pieces. Proceed to Step 4.
   OR
3. Measure and draw patterns directly on to the 1/8" sheet steel (see Figure 1). Be sure to label your pieces. Proceed to Step 4.

HINT: Pieces can be drawn individually as you go to take advantage of shared edges and reduce the total number of cuts.

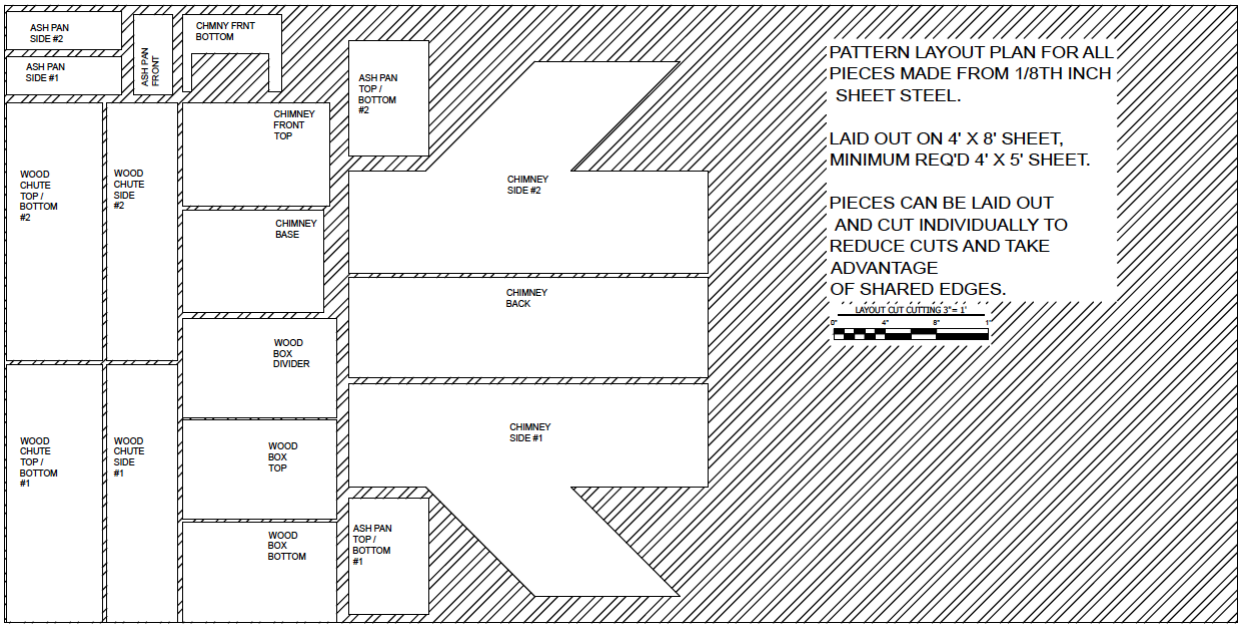

Figure 4 - Pattern Layout for 1/8th Inch sheet steel for most efficient use of steel. (Image credit: Future Generations University)

4. Cut pieces using angle grinder with a diamond wheel or a plasma cutter.
5. Using a polishing wheel on angle grinder, smooth the cut edges to prep for assembly.
6. Begin assembly by laying "Chimney Side #1" flat on the work surface, tack "Chimney Back" to the long straight edge of the chimney side using welder.
7. Tack the "Chimney Front Top" to the upper straight front edge and the "Chimney Front Bottom" to the lower straight front edge of the "Chimney Side #1. The "Chimney Front Top" should extend slightly past the angle that forms the wood box (see Figure 2) so that it creates a stop for the removable Wood Chute.

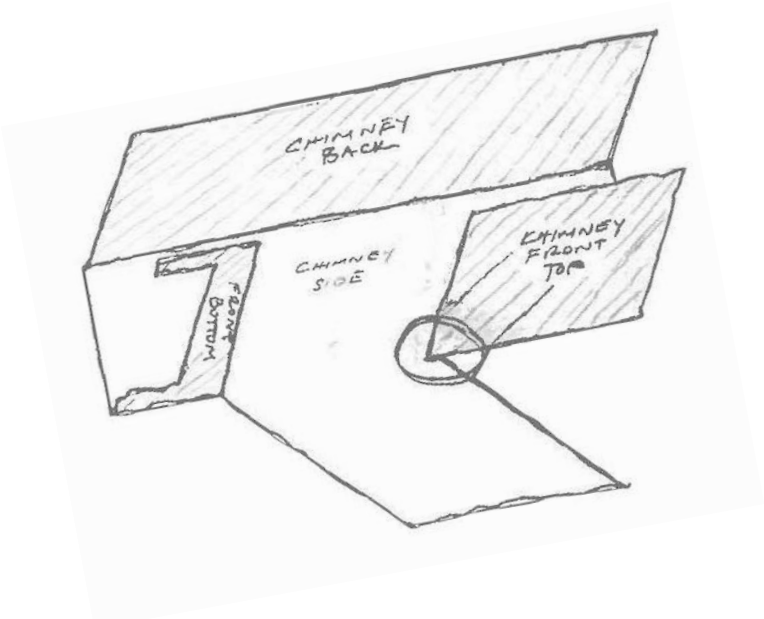

Figure 5 - Chimney Front Top extending past the Wood Box edge. (Image credit: Future Generations University)

8. Tack the “Wood Box Top” and “Wood Box Bottom” to the upper and lower angled edges of the “Chimney Side #1”.
9. With either the help of a second person or clamps to make sure the edges are tight, tack “Chimney Side #2” on top of the existing assembly (see Figure 3).

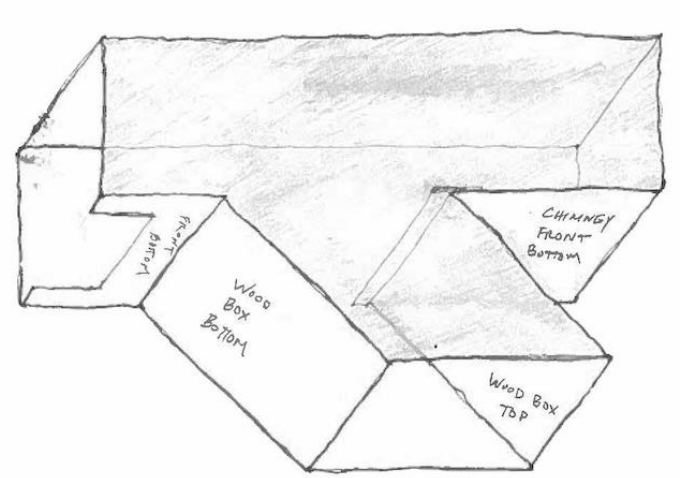

Figure 6 - Partially assembled Chimney, adding the Chimney Side #2. (Image credit: Future Generations University)

10. Tack the “Chimney Base” to the bottom of the chimney assembly. The “Chimney Base” will sit proud of the bottom of the chimney to help stabilize the structure (see Figure 4).

HINT: This is most easily accomplished by setting the assembly upside down on the work surface and placing the base on top.

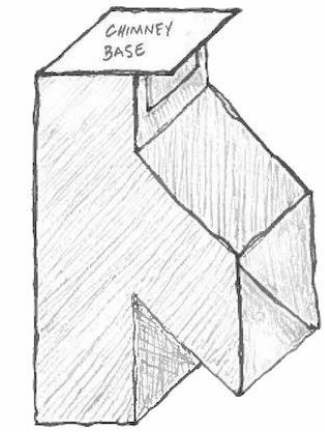

Figure 7 - Partially assembled Chimney, adding the Chimney Base. (Image credit: Future Generations University)

11. Fully weld the current assembly.
12. Tack the “Wood Box Divider” in place. It should be 2 inches up from the BOTTOM of the Wood Box section of the chimney.

HINT: This is most easily accomplished by using something to prop the “Wood Box Divider” at the proper spot, 2” above the “Wood Box Bottom.” Some of the best options for props are two scraps of 2” angle iron, a scrap 2” tubular steel, or a piece of lumber ripped to 2” tall.

13. Assemble the removable Wood Chute by tacking the two “Wood Chute Sides” to the “Wood Chute Bottom” and then adding the “Wood Chute Top” to make a rectangular box (see Figure 5). Weld this assembly together.

HINT: It makes the Wood Chute easier to add to and remove from the Wood Box if the welds are on the inside of the box.

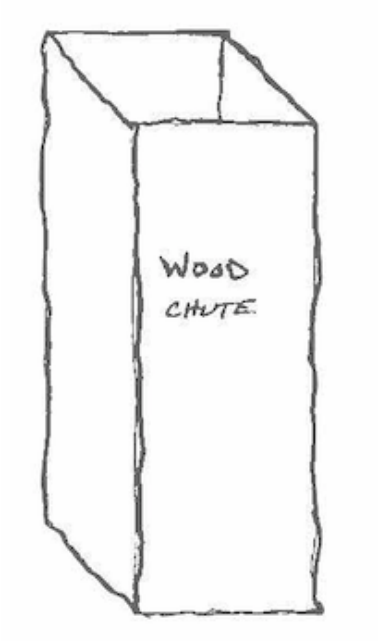

Figure 8 - Wood Chute Assembly. (Image credit: Future Generations University)

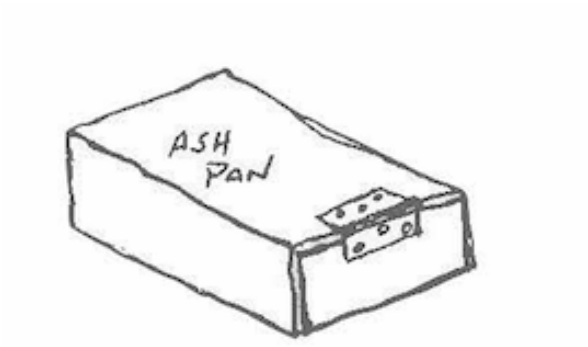

Figure 9 - Ash Pan with hinged door. (Image credit: Future Generations University)

14. Assemble the removeable Ash Pan by tacking the two “Ash Pan Sides” to the “Ash Pan Bottom” and then adding the “Ash Pan Top” to make a rectangular box (see Figure 6). Weld this assembly together. Add the “Ash Pan Front” using a hinge, so that it can be opened or closed to manage airflow when operating the RSE (see also Figure 6). The Ash Pan is a removable part that allows the Chimney structure to be more easily inserted into the barrel and more easily cleaned. It will simply nest tightly against the Chimney once it is in place in the barrel.

15. Cut out the “Flame Spreader”, “Flame Spreader Fabrication Stilt”, and the “Flame Spreader Fit Tab” templates and trace the template four times (for four pieces each) on 1/16” sheet steel.
16. Cut out the pieces using either angle grinder or plasma cutter.
17. Tack the “Flame Spreader Fabrication Stilt” pieces to “Flame Spreader” pieces referencing the proper location on the cut template.
18. Join the four “Flame Spreader” pieces together at the angled edges (see Figure 7).

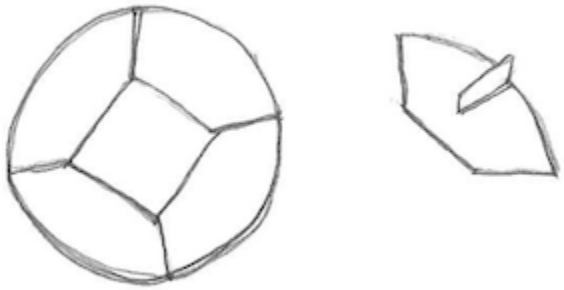

Figure 10 - Flame Spreader assembly. (Image credit: Future Generations University)

19. Tack the “Flame Spreader Fit Tabs” to the assembled Flame Spreader at the locations indicated on the pattern. The Flame Spreader will now sit on the top of the chimney and the Fit Tabs keep the Spreader in place, centered on top of the Chimney.
20. Time to modify the barrel! Referencing Figure 8 for measurements, use either a grinder with a cutting wheel or a plasma cutter to cut rectangular holes for the Wood Box and Ash Pan and opposite those cutouts (back of barrel), cut out a round hole for the stovepipe coupler.

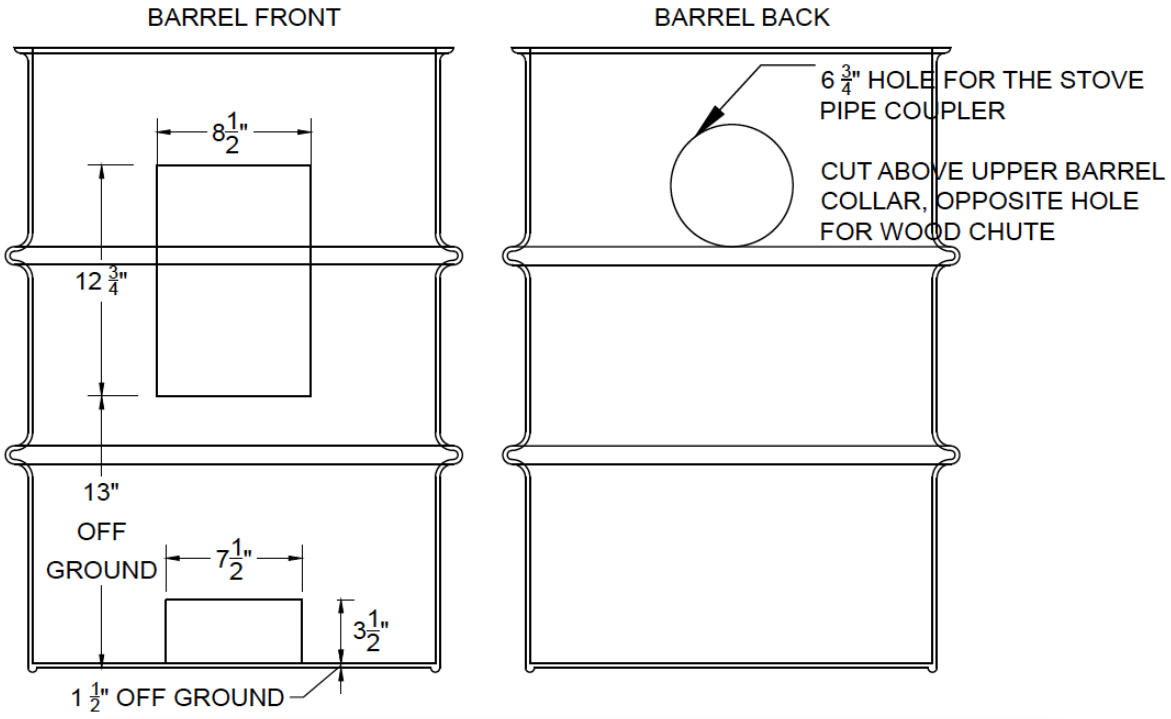

Figure 11 - Barrel cut-out dimensions. (Image credit: Future Generations University)

21. Weld the 6” i.d. well pipe to the barrel.
22. Insert the chimney into the barrel: Lift the chimney into the barrel, then tip it forward at an angle to get the Wood Box slip through the front opening so that the chimney is centered in the barrel. Small fit modifications may be necessary for the chimney to end up in the center.

HINT: Barrel steel tends to be thinner and softer, so minor modifications to improve chimney fit can easily be made using a grinder with a buffing wheel.

23. Modify the barrel lid to fit the evaporator (30 qt Brazier) pan by placing the pan on the barrel lid as centered as possible and tracing the outline. Cut out the outline and modify to fit with an angle grinder with a buffing wheel as necessary.
24. Cut ½” steel rod into 7 ½” long pieces, 11 pieces total. (See Figure 9) Using seven pieces, make a grid pattern with 4 pieces on top and 3 pieces on the bottom. Weld the grid together. Using the 4 remaining pieces, add legs to the grid. This fire grate will sit down in the bottom of the chimney to keep the coals above the air intake and ash pan area.

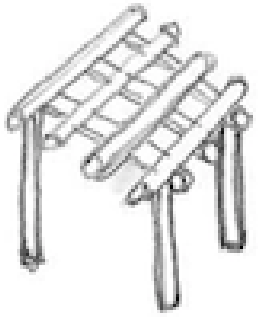

Figure 12 - Fire Grate assembly. (Image credit: Future Generations University)

CONGRATULATIONS! This completes the Rocket Stove Sap Evaporator construction. Please read the following Operation Instructions Manual, especially the section “Tuning your Rocket Stove.”

Rocket Stove Design to Rocket Sap Evaporator Use

Now that the rocket stove is constructed, it is time to learn about utilizing it specifically for sap evaporation. The longer sap is exposed to heat, the darker and more robust the flavor of the syrup. One reason so much "backyard" syrup is very dark is that it tends to be evaporated slowly and this takes a significant amount of time. Rocket stoves give a rapid boil—the goal is to evaporate 5 gallons of sap per hour. The Rocket Sap evaporator further increases the rate of evaporation by replacing a deep pot with a large shallow sap pan. The more surface area exposed to the hot gasses and the shallower the liquid in the pan, the greater the rate of evaporation. The 21-inch diameter commercially available sap pan rests on the top of the barrel with a 1-inch flange. The bottom of the pan sets 4-inches down in the barrel.

The Rocket Sap Evaporator should be run with a minimum of 2-inches of sap in the sap pan at all times. More is okay and safe, and less is also okay as long as the producer is paying close attention. If the pan runs out of sap, the sugars in the syrup burn, turning into a black and bubbly mess, and the pan may take an entire day to clean. When in doubt, more sap is better in this case.

When the evaporator is efficiently cooking, steam will be bellowing out and the sap level will drop. A few quarts of sap may be added at a time, but the cold sap kills the boil. A better solution is to purchase a bucket with a spigot, such as a brewer's bucket.

Figure 13 - a bucket with a spigot, such as a brewer's bucket. (Image credit: www.morebeer.com)

Mount this on a step ladder next to the evaporator, making sure it is secure. Set the drip such that the sap level in the pan stays constant. Sap dripping in should equal water being evaporated. You may need a bit of tubing attached to the spigot to direct the dripping sap into the sap pan.

Once the evaporator is constructed and all components are together, a dry run with water should be attempted to learn how to operate the Rocket Sap Evaporator.

The "Pre-ignition Checklist"

- Make sure the evaporator is level.
- Have a good supply of finely split and dry firewood.
- Make a cover (Figure 2). The stove will likely sit outside, and the internal insulation cannot get wet. A cover can easily be custom-sewn from a regular poly tarp available from the hardware store.
- Make sure all holes on the barrel are sealed. Air should only be drawn in only through the wood feed chute. Aluminum flashing and a pop rivet gun can seal it up if needed.
- The stove may need some minor adjustments to achieve optimum performance. When first lit, the smoke comes back out of the wood feed shoot. After the chimney has warmed, the air flow reverses, and smoke is drawn up into the stack. Stack emissions will turn clear as the system gets hot. If this reversal is not achieved, it could be that the gaps are too small, restricting air flow. A solution is to make risers to lift the sap pan the proper distances off the barrel rim and then seal the resulting gap with 1-inch rope gasket material (Figure 3). If a rolling boil on the bottom of the sap pan is not achievable, the distances may be too great and the chimney may need to be raised a bit.

Figure 14 - custom tarp cover. (Photo credit: Future Generations University)

Figure 15 - raised pan with rope gasket. (Photo credit: Future Generations University)

Operating Instructions

The Rocket Stove Sap Evaporator (RSE) is an energy efficient, and affordable evaporator designed for the hobbyist who wants to tap a few trees and make their own maple syrup. Tapping maple or walnut trees can be a fun family activity; it's almost as good as eating the pancakes smothered in your own homemade syrup. With this evaporator, you can make syrup from up to 20 maple trees (or up to 50 trees with the addition of a small Reverse Osmosis system, such as the RO Bucket) and up to 30 walnut trees.

Figure 16 - Rocket Stove Evaporator in action. (Photo Credit: Future Generations University)

Properly operated the RSE will:

- Get to a full boil in less than 15 minutes.
- Evaporate from 4-5 gallons of water per hour from your collected sap.

Starting the RSE:

1. With the pan removed, load a few sheets of crumpled newspaper down the chimney
2. Next put in some finely split, dry kindling.
3. Light the paper from the bottom through the wood feed chute.

Running the RSE:

1. Wait a few minutes until the kindling is burning well.
2. Place the sap pan on the top, sealing off the fire. Always put an inch of sap in the sap pan before placing it on the RSE. This eliminates any chance of the hot fire burning the pan before you get the sap in.
3. You will quickly see the smoke coming out of the chimney and hear the fire roar as the draft changes, drawing air in below the burning pile. The "rocket" is taking off.
4. Add more sap to the pan, up to 2-3 inches, and feed the fire through the wood chute.

5. From here on you will just be feeding more wood, arranging it with a poker (steel or wood), and monitoring the level of sap in the pan. You may need to occasionally clean out the ash pan throughout the boiling process.
6. You can evaporate down to 1 inch in the pan and then fill or develop a drip system that adds sap at the same rate as the water is evaporating.

Making syrup:

- You are not going to finish syrup on your RSE.
- Finished syrup has a density that equates to 7 degrees above the boiling point of water.
- Boil on the RSE until:
    - The sweetening sap in the pan has developed a deep brown color.
    - The bubbles start changing their character, from a rolling boil to smaller bubbles.
    - The temperature in the pan is elevated.
    - If you have a syrup hydrometer, it just starts to float.
    - Once you have reached the density of near-syrup,, or at the point you have run out of sap or run out of time to feed the fire, use welders' gloves to remove the pan from the RSE, and let the fire burn out.
    - You will then finish your syrup on a stove, turkey fryer (recommended) or barbecue grill until you reach 7 degrees above the boiling point of water for your area, or the syrup hydrometer floats to the HOT redline (66 brix).

Shutdown:

- Once cooled, clean out the ash pan.
- Cover your RSE with a custom tarp or similar covering.

Tuning The Rocket Sap Evaporator

The gaps in the stove design are critical:

- If they are too large, you lose efficiency in transferring heat to the pan.
- If the gap between the edge of the flame spreader and barrel is not relatively even (you can never get it exact,) the stove may boil better on one side than the other. It should be 1-inch around with this design.
- If the gap between the edge of the flame spreader and the bottom of the pan is too small, it will restrict the draft, resulting in smoke or flame coming out of the wood feed. It should also be 1-inch in this design.

Here is where you can tune your stove; because they are custom fabricated, each will be a little different:

- Be sure the flame spreader is large enough to only leave 1-inch between the edge and the barrel.
- If needed grind down the flame spreader to assure a relatively even gap. A quarter inch one way or the other should not be a problem.
- Measure from the top of the barrel to the edge of the flame spreader. Realizing this is not always uniform, measure to an average point.

- Measure the distance from the bottom of the handles on the pan, where it will rest on the barrel, to the bottom of the pan.
- Subtract these two measurements. The result should, on this stove design, be 1 inch.
- If less than 1- inch raise the pan by placing blocks (wood is okay, but using scrap angle iron is nice because it can be welded in place) under the handles to bring it up to the proper measurement.

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TACK
LOCATION
FOR STILT

FLAME
SPREADER
(CUT FOUR)

CUT FROM
1/16TH STEEL

TACK
LOCATION
FOR FIT TAB

FIT TAB

FABRICATION STILT