MINISTRY OF ENERGY AND MINERAL DEVELOPMENT
ENERGY ADVISORY PROJECT

DEVELOPMENT AND TESTING OF BIOMASS ENERGY EFFICIENT TECHNOLOGIES

Terms of Reference

1. BACKGROUND

In Uganda over 94% of the energy consumed is obtained from biomass. Most of the biomass energy consumed is utilized in households for cooking and currently, acres of valuable ecological resource are going up in smoke at the rate of 240 million tones per year (NEMA 2001) and the traditional 3 stone fire (characterized by a very low efficiency) is the main cooking device used. Therefore it is of great urgency to focus attention and promote more efficient cooking devices in order to minimize losses hence reducing the rapidly increasing biomass energy demand.

For this reason, one of the specific objectives of the Energy Policy for Uganda is to improve the efficiency in the use of biomass resources recognizing that biomass will remain a dominant source of energy for the foreseeable future. To achieve this effectively, the Ministry of Energy and Mineral Development intends to develop and carry out scientific testing of various cookstove and kiln designs in order to come up with the most efficient ones to be recommended for dissemination to the communities.

This exercise is to be carried out in collaboration with the Uganda Industrial research Institute which among other things will provide the space where the experiments will be conducted.

2. SCOPE OF WORK FOR THE BIOMASS TECHNOLOGY EXPERT

a) To design, produce and test a single pot metal rocket stove
b) To design, produce and test a two pots clay rocket stove (rocket Lorena)
c) To design, build and test an efficient bread oven using woodfuel
d) To design, build and test an efficient institutional stove using woodfuel
e) To draft and draw stove/oven technical diagrams
f) To produce a general brief mission report and one detailed technical report for each stove/oven (rocket stove, Lorena, bread oven, institutional stove) developed including plans, technical production details…

3. TIMING

The length of contract will be for 3 weeks, from Aug 15th to Sept 7th.

Week 1:

To fire insulated bricks with Pumice/clay and vermiculite/clay and sawdust/clay, develop a number of prototypes with fired and unfired mixtures for the market rocket stove, and meet with local stove-building partners.

At the end of the first week, the stoves will be demonstrated to a group of women with the help of NGO partners. The stoves will then be placed in people's homes in the peri-urban areas around Kampala, preferably in places where people are using a mixture of charcoal and wood. These stoves will then be monitored.

Week 2:

To improve the bread oven, the institutional stove and the single pot commercial Rocket.

- Improve the market stove (per the women's recommendations from the demonstration) and the insulative mix.
- Visit an existing wood fired bread oven site to see their cooking methodology
- Build and test an improved bread oven (see RETAP-Kenya model)
- Visit institutional stoves in schools built by Mr George Sizoomu and Mr Kawere Muhammad and improve them.
- Based on the new Aprovecho prototype of an improved (insulative) Lorena stove, improve the existing one and build an improved one at the research center and then one in the field.
- Meet with the women who are beta testing the stove to garner their further impressions and find out if the stove is suitable to their cooking task. If not the stove can be modified and then returned to them ASAP.

Week 3:

Monitor field tests and develop a monitoring plan for the 4 stoves/oven

- Controlled cooking tests against the open fire in the center
- Monitoring in the field
- Prepare reports

Abbreviated Draft Report

Introduction of Rocket Stove Cooking Devices in Uganda

Prepared by Peter Scott/Aprovecho
GTZ-EAP Consultant

Sept 12,2003

Kampala, Uganda

From August 12th to Sept 12th, Peter Scott, working in concert with GTZ-EAP staff, independent stove producers, and members of the local community developed a number of cooking devices that were unique to Central Africa

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1.0 Material Outputs

1.1
One **100 L fixed institutional stove made with insulated ceramic (**VIC) and Kajansi firebrick was constructed at UIRI. This stove can be built with or with out chimney. Chimneyless model is shown here. Note the absence of smoke above the pot or large amounts of wood in the combustion chamber

1.2
One **2-pot Sunken Rocket stove** with built in skirt.

1.3
Five 200L **institutional stoves were constructed** at Musa Body University of Technology. These stoves, which will be constructed by Kawere Muhammad, were the first of thirty that were ordered by the UPDF.

1.4
Two **100**L **portable metal and insulated brick institutional stoves were constructed**. One of these was an initial prototype constructed at George Sizoomu shop at Kirinya-Bweyogerere as part of a one-day training. The second (shown here) was built at Musa's university of technology in cooperation with Kawere Muhammad.

1.5
One **75-loaf bread oven** was designed and constructed. At the end of the contract only cosmetic finishing touches were necessary for full completion of the oven.

1.5
Before arrival, the consultant produced **plans for a Rocket bread oven** that was then built and tested by GTZ/UIRI.

1.7
Over **50 insulated test bricks were fired** in Cooperation with George Sizoomu and Francis Sebabi at the Department of Industrial Ceramic / Uganda Polytechnic Kyambogo/ Kyambogo University.

1.8
An **adjustable skirt for a single pot stove** was produced by JICA

1.9
Four **single pot Rocket stoves** were produced using **Vernacular Insulative Ceramic** (**VIC).**

1.10
One **metal mould** was made for firing 30cm by 30 cm by 5cm VIC tiles

1.11
20 wooden moulds were made for firing the 6 brick VIC stove

2.0 Trainings

Three women were selected to use the stoves for a week. GTZ-EAP's telephone number was given to the selected women and it was explained that they could contact us toll free at anytime if they were faced with problems with their demonstration stove.

- One sunken pot stove that was fabricated by Sizoomu's artisans; ,
- One VIC rocket stove that was constructed in March of 2003 in partnership with Kawere Muhammad
- And one Rocket stove that was constructed by the participants during the NGO training of the previous week

4.0 Household Stove Assessment (Kasubi, Kampala)

On Sept 10th, 2003 we visited the three houses where the stoves had been placed during the previous week.

Unfortunately, we were not able to connect with Frank Ssentongo so we couldn't plan the visits ahead of time so we ended up arriving a few days later than scheduled. Although a surprise visit is a good way of assessing if the stove is being used (Quick! light the fire, the mzungus are coming!) it is not ideal for eliciting coherent information from the participants.

4.1
Household #1**Betty Mutaisa (tel#077 417 133)**

The participant that was selected during the workshop, Mrs. Mutaisa, was not at home so we interviewed the maid instead. She seemed a little uncertain, or perhaps a little shy, in regards to discussing the cooking situation.

The Rocket stove was not in use when we arrived but the maid of the house assured us that the stove was being used frequently. She said that she was only now using charcoal today because she had run out of wood. Under normal circumstances she said that she would use about 150 shillings worth of wood per day (for approx 8 people) compared to approx. 300 Ush per day for charcoal.

At the end of the visit we took the stove to a local metal shop to make some adjustments to the skirt and the pot stand. The stove was then returned to the house.

As mentioned earlier, the women responsible for the stove was not present during our visit so another visit would be highly recommended.

4.2
Household #2 (Name not available)

At the second house that we visited the participant that was selected during the workshop was also not at home but we found the stove in use outside of the house. It was explained to us that the recipient was sharing the stove. The woman

who was cooking was very pleased with the stove. In fact when we suggested that we take the stove for the day – to make a few changes – she appeared very unhappy.

Both the stove and the skirt were being used. The cook said that she always used the skirt and noted that food took longer to cook without the skirt. We educated her about the need to maintain the proper gap between the pot and the skirt. We explained that the skirt should be no more than the thickness of a pinky finger. (See the Design Guide for more info on gaps)

She commented that the stove was cooking food very quickly and saving a considerable amount of fuel - roughly 60-80% less than the traditional stove. She said that her fuel costs had been reduced from 500 Ush /day to approx 100 Ush/day. This, however, is only when she buys firewood, which is not everyday). She said that there was nothing that she would change about the stove and that it was a great to benefit to her family.

4.3

Household #3 Nalongo Jastine Kanyike (telephone # 075 818 334)

This is the only woman who faced serious problems with her stove. After cooking at her house for a few days, she was convinced that the stove could not cook traditional foods such as Matooke. When we went to her house we realized that the stove was still wet from the mortar. The insulative bricks absorb a lot of moisture during the construction process and take some time to dry. We explained this to her and donated some firewood to her for the purpose of drying out the stove.

A few days later she traveled to UIRI to tell us how pleased she was about the effectiveness of the stove. It was able to cook a 35 cm diameter saucepan full of Matooke in only 35 minutes. She also said that the stove was able to cook a large pot of dry unsoaked beans in 2 hours and 45 minutes with only 2 pieces of wood (approx 6cm in diameter by 60cm in length). She said that this was about 20% of the wood that she would normally use to accomplish such a task.

Below is a visual comparison of the amount of fuel that she used to cook one pot of unsoaked dry beans before and after the introduction of the single pot sunken rocket stove.

Before Sunken Pot Rocket Stove

After Sunken Pot Rocket Stove

On the day of our surprise visit, when we went to visit her house, we found that she was away on a trip and that her daughter was in charge of the kitchen. She was using charcoal and explained that she personally wasn't using the stove because she didn't like having to push in the firewood and that charcoal was much more convenient. This is not surprising as it would be hard for a wood stove to compete with a charcoal stove in terms of user convenience, or that her daughter would choose to use the most expensive method as she was not paying for the fuel.

4.3.1
Perspective

These brief visits suggest that **women who are aware of fuel costs or a faced with severe fuel shortages** due to cost or availability are open to switching from charcoal to wood.

Any commercial cookstove program should be targeting these people, as they will see the greatest benefit of the stove.

4.4
1.

5.0 Rocket Bread Oven

The rocket bread oven features a 120 cm by 120cm by 30 cm baking compartment made from 2.5 and 1.5 mm sheet metal. The combustion chamber and the area that encompasses the baking compartment were constructed with VIC bricks (see ceramic section for more details) and cut pumice brick.

5.1
The first model was designed by Peter Scott and built by GTZ and UIRI in May 2003.
UIRI staff tested the bread oven and found that it was able to cook **17 kg of bread with only 5 kg of dry wood.**

5.2
This was a considerable reduction in wood consumption as compared to the **traditional wood fired bread oven that consumed 200 kg** to bake the same quantity of bread.

Even though this first prototype was built around Rocket principles there were a few deviations from the original design. UIRI staff constructed the combustion chamber **before** the final plans arrived so they were forced to improvise some of the construction details. This led to a couple of small problems that could cause problems in the long term.

As can be seen from photo 5.1, the area between the combustion chamber and the baking compartment is blackened with soot. This is a result from fire and smoke spilling out of the front of the stove. In a properly functioning stove, this area should be free of soot. (Obviously over time it is possible that careless cooks might allow fire to occasionally creep out of the front of the stove by leaving it unattended for long periods of time. This was obviously not the case as the stove was only fired a few times.

The reason for this 'back-firing' was that the gap between the top of the combustion chamber and the baking compartment was not sufficient. The builders created a 3cm gap between the **bottom, the sides, and the top** of the baking compartment. A 3 cm gap along the sides and the top of the compartment is sufficient, **but directly above the combustion chamber, a larger gap is needed (10-15 cm).**

5.3
<u>The insufficient 3m gap **under** the baking chamber leads to</u>

Insufficient air entering the stove: this creates a 'lazy' looking fire in the combustion chamber that creeps back along the fuel and eventually travels out the front of the stove. In a Rocket Stove with proper draft the fire is 'pulled' up the combustion chamber.

Increased smoke production The 'lazy' fire is a symbol that the combustion is not at a stochiometric optimum, which means more smoke is visible out of the chimney. Smoke coming out of a Rocket stove chimney is a symptom of a incorrectly functioning rocket stove.

Not surprisingly, both of these situations were apparent when I observed the stove operating. The fire crept out of the front of the stove and a large amount of smoke was emitted from the chimney at the beginning of the fire. Eventually, as the oven heated up, more draft was created inside the stove, which increased the air flow into the combustion chamber closer to the stoichiometric rate, which led to a decrease in smoke production.

One could argue (albeit erroneously) that the oven eventually functions effectively – smoke production decreases, the fire is pulled up the chamber and the fire begins to burn more vigorously.

5.4

This is an incorrect conclusion for two reasons:

First, the poor combustion of the initial fire leads to increase soot production. This soot is then deposited around the baking compartment. This decreases heat transfer and means that maintenance and cleaning of the baking compartment must be performed more frequently. Cleaning the oven is time consuming and difficult.

Secondly, placing the combustion chamber too close to the baking compartment creates a hot spot directly above the combustion chamber that burns the bread and eventually degrades the sheet metal.

For this reason, the 2nd model features a combustion chamber that is 12 cm below the baking compartment

5.5

The 2nd prototype also features these advantages

- **Easier access around the baking compartment for cleaning**

The entire baking compartment is now designed to be removed for maintenance, alteration and repair without damaging the structure of the oven.

- **A hollow pipe connecting the baking compartment to the external environment to release excess steam**.

This pipe connects the baking compartment to the external environment. This can be opened and closed by the baker as needed.

- **A slightly wider feed chamber (20cm tall by 25 cm wide) to accommodate the larger diameter pieces of wood that are used by traditional artisans.**

- **Insulated bricks and whole pumice block are used to insulate the combustion chamber and around the entire baking compartment.**

The oven body of the earlier design required more materials.

Multiple layers of metal, wood ash, and brick were required. Here is a cross section of the original prototype

Brick	Wood ash	Metal jacket	Hot flue gases	Baking compartment	Hot flue gases	Metal jacket	Wood ash	Brick

As the cross section of the new prototype shows, the new model now only requires VIC and common brick for insulation. These insulated bricks should last indefinitely unlike the metal jacket that would have to be replaced periodically.

Brick	Insulated brick	Hot flue gases	Baking compartment	Hot flue gases	Insulated brick	Brick

If desired, the new design can also utilize the original brick- wood ash-metal matrix to insulate the oven.

5.6

<u>Materials used</u>	<u>Cost</u>
Approx 350 common bricks	24,500
Approx 10 insulating bricks/pumice blocks	30,000
Two - 122.5 by 245 cm sheet of 1.5 mm steel	42,000
One -122.5 by 245 cm sheet of 2.5 mm steel	70,000
Three 20mm by 1.2 square pipe	21,000
Angle iron 25 mm by 3	9,000
Chimney	30,000
Fiberglass	15,000
Welding Rods	10,000
Hinges	5,000
Flat bar	7,000
Mica	50,000
Cement	17,500
Vermiculite	2,000
Total Exclusive of labour	**333,000**

5.7

5.8





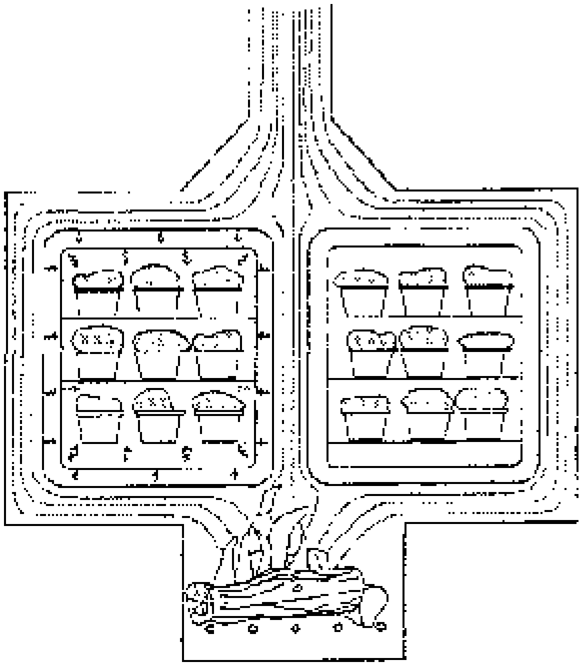

5.9
The way forward
<u>The bread oven</u>

I would estimate that there is sufficient energy within the present combustion chamber to build a double layer-baking chamber. The existing **oven body** can be used and in fact the existing **baking compartment** can be used, as it only needs to be extended vertically by 15-30cm or enough to support a second tray of bread. The top can be cut off, raised up, and supported with three15-30 cm panels attached to the sides of the oven. Then a second baking door could be fitted on to the newly extended chamber. Tests should then be run to determine its new baking capacity.

If the stove is extended vertically again, I would recommend that the baking compartment be split in two along the vertical axis, so as to create two baking compartments of equal volume sitting next to each other(see picture below)

With this layout for the baking compartments, some modification of the gap between the baking compartments and the oven body will be necessary.

The cross sectional area gap (1080cm2) between the baking compartment and the oven body is actually greater than necessary (see calculating pot gaps in the General design guide for more info). Because the feed chamber has a perimeter of 90 cm and a cross sectional area of 500cm^2 we actually have more than twice the cross sectional area than is necessary. If these 3 cm gaps were maintained between and around the two baking compartments than the cross sectional area would be greatly increased which would lead to a diminished heat flux to the ovens. For this reason the gap will have to be narrowed between the baking compartment (perhaps 1cm wide) and 1.5 cm around the baking compartments



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This drawing is not to scale but is shown to give a sense of the proportions between the midpoint and exterior gaps

6.0 100L Institutional Brick Rocket Store

W/ chimney

Here is the rocket stove maintaining a rolling boil with only a few sticks

W/out chimney

This stove was built in cooperation with Kawere Muhammad and his stove mason Mande.

6.1
Cost and materials

Kajansi rectangular fire bricks	110,000
Kajansi curved fire bricks	70,000

VIC bricks	30,000
Chimney (optional)	30,000
2 mm top ring and angle iron frame	20,000
<u>Mortar</u>	
Cement	17,500
Vermiculite	<u>5,000</u>
Total	**285.500Ush***

*This accounting of the material costs shows that the majority of the cost of the stove (180,000 Ush) was for the purchase of high-fired Kajansi bricks.

These bricks are valued for their strength and durability, which is important for those who are building institutional stoves commercially. However, their cost might put the stove out of reach for poorer institutions that want to build stoves on their own. These stoves could be replaced with cheaper **local mud bricks**. I recommend that plans be drawn up to substitute cheaper local bricks that cost only 70 shillings each. The total cost for these bricks would be only 13,300USh **thus lowering the cost of the stove by over 166,700 Ush**. .

6.2
<u>Mortar For the external (square) body</u>

- a common **cement /sand mixture** was used**.** Common anthill **soil/sand** mixture could also be used if cement is not available. Note: This part of the stove will not be exposed to high temperatures so a special mortar is not necessary

6.3

<u>Mortar For the circular curved brick skirt and combustion chamber</u>

- Four options are available for this mortar:

1 part Mica 2 parts high temp clay 1 part low temp clay	2 parts mica 1 part sand 1 part cement	2 parts mica 1 part clay	2 parts sand 1part **true expanded** vermiculite 1 part cement

6.4
<u>Time to construct</u>
The initial prototype took 3 days to construct but this could most likely be reduced to 2 days

6.5

The 100L institutional brick stove features:

6.6
High heat transfer efficiency:
The saucepan is sunken into the stove - only 3 cm (of the 36cm total saucepan height) is exposed above the edge of the stove.

6.7
Note: Submerging the pot is extremely important for increasing the surface area exposed to the hot flue gases and maximizing heat transfer. The sides of this pot (height 35cm / diameter 63.5) have twice the surface area of the bottom of the saucepan.

6.8
Only exposing the bottom of the pot to the hot flue gases (as shown in these so-called improved stoves from Masindi) decreases heat transfer and over all efficiency by 50%.

6.9
- **An insulated Rocket Stove combustion chamber.**

6.10
The rocket combustion chamber was constructed with an insulated ceramic brick produced by George Sizoomu This mixture contains equal parts by weight of Kaolin, stone dust, sawdust and bowl clay. It is fired at 1300C. This particular mixture, while effective is more than is actually needed for the Rocket stove. The Rocket stove does not normally produce temperatures in excess of 900C. Other types of VIC brick or cut pumice blocks can be used instead.

- **Insulation under the pot (with VIC brick)**

Note the white insulated bricks that are encircled by the curved (non insulated) Kajansi Bricks. Ideally these curved bricks would be insulative as well but strength is a more important consideration than insulation in the circular bricks

6.11
<u>Stove Efficiency</u>

The efficiency of the stove varies depending on how the stove was configured and the type of wood that was used. (Leonard can you update these figures?)

Stove	Chimney	Wood type	Efficiency	Time to boil (min)
100 L Brick	no chimney	dry wood	49.5	52
100L Brick	With chimney	dry wood	36%	58
100L Brick	No chimney	Wet wood		100?
100L Brick	With chimney	Wet wood		

The above table demonstrates that the chimney decreases efficiency of the stove and that wet wood greatly decreases the time to boil. It should be noted that, as with all Water Boiling Tests, no lids were used. Obviously in a real cooking situation, where a lid should be used, the time to boil would be greatly reduced.

6.12

6.13
Finishing the 100L fixed stove

- We need to build the angle iron structure/top ring around the stove. We have already paid Kawere Muhammad for a properly sized metal top ring that rests on the brick skirt. We will need to hire someone to build the angle iron enclosure. I would recommend making it removable so that we can demonstrate the stove with and without the chimney.

- Put pot stabilizers in place.

- Repeat tests for dry/wet wood and chimney/no chimney. Due to the leak in the old pot the stove might still be wet so I would recommend giving it a good firing to dry it out the day before the testing. Remember that it is difficult to dry out that brick. Also if you buy a new pot remember to use it once, to soot it up, before you do tests on it. Or, conversely, clean it each time you do the test

- More research needs to be done on the insulator around the skirt. The stove presently has raw sawdust around it. This should be periodically monitored to see how it responds to the heat of the bricks. In the future I would recommend using vermiculite where applicable

Once these tasks are completed, build a prototype in a local school

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7.0 100L Portable Institutional Rocket Stove

This stove is built around the same design as the fixed 100L version. The metal version, however offers an insulated double walled skirt so higher efficiencies would be expected

7.1
Material cost

One 1225 by 2450mm sheet of 2mm sheet steel	60,000
Two 1225 by 2450mm sheets of 1.5 mm sheet steel	82,000

40 insulated bricks or cut pumice blocks	40,000
Vermiculite	5,000
45 kg cement	17,000
Tiles (for shelf)	2,000
Angle iron 40mm by 6m	10,000
Cost (excluding labour)	**216,000**

7.2
Mortar for the combustion chamber

- Four options are available for this mortar

1 part Mica 2 parts high temp clay 1 part low temp clay	2 parts mica 1 part sand 1 part cement	2 parts mica 1 part clay	2 parts sand 1part **true** vermiculite 1 part cement

The area between the bottom of the saucepan and the stove body is insulated with pumice or VIC bricks. This increases the heat transfer to the pot and increases the longevity of the stove (any metal exposed to the hot flue gases or flames is in danger of degradation

7.3
The way forward
The 100L portable institutional stove

The chimney stove *can* achieve higher efficiencies but to do so the gap must be very narrow and tightly controlled. More research needs to be done on the impact of shrinking the gap between the pot and the stove body. See attached Baldwin notes

A chimney stove is, by nature, more difficult to build and maintain. For example, to accommodate the handles and allow for the easy removal of the saucepan it is necessary to leave a small gap between the skirt and the saucepan. This means that it is difficult to completely seal the top of the stove. Cool air can leak through this gap and this can decrease the effectiveness of the chimney.

8.0 Vernacular Insulated Ceramic

Finding a locally produced insulated brick is the cornerstone of any Rocket stove program. Attempting to copy the Rocket stove geometry without following the principles of insulation will result in a stove that could **actually increase wood consumption** compared to traditional or other improved stove designs.
Emphasis must be placed on locating suitable materials before production of stoves begins in any region. Otherwise people might adopt the technology and use whatever materials are available regardless of their suitability.

Some basic points regarding insulating bricks:

Thin walled, yet higher mass materials (such as clay tiles) that are surrounded by insulation are acceptable but not as effective as a combustion chamber that is itself built with insulating materials (such as the fired sawdust/clay or charcoal/ clay or vermiculite/clay bricks

Insulation is not just important for increasing efficiency.
Highly insulated combustion chambers - as opposed to those only nominally insulated - increase efficiency, but more importantly, they reduce smoke production in the stove. This is illustrates by the difference between the three improved LoRocket stoves. The difference in efficiency between the sawdust stove and the pumice stove is only approximately 2% but there is a significant reduction in visible smoke (as noted by Leonard) This focus on combustion is especially important when building stoves that do not have a chimney. The extra efficiency points that are noted are a result in an increase in Nominal combustion efficiency and this will have a profound effect on the users long-term health.

This contradicts the school of thought that says its better to build 100,000 stoves at 20% then 30,000 stoves at 33% as the increase will not just increase fuel efficiency but will , more importantly, reduce IAP.

8.1 Material choice

During the contract period we focused on constructing charcoal and saw dust bricks (see attached appendix for brick densities and characteristics). The **charcoal bricks** *were* **our first material choice** because charcoal fines were thought to be a waste product and they formed a light and strong brick when fired. This Charcoal/clay brick (shown here) was artificially dried for 2 days at 250C and then fired for 24 hours in the electric kiln at 950C. This brick still has a large portion of charcoal remaining in the brick. The charcoal from the outer layer of the brick has been burnt away which has created a sufficient 3cm insulative barrier. The remaining charcoal has a low conductivity and improves the strength of the brick.

Unfortunately this unburned charcoal clay adds considerable weight to the brick. It would obviously take a longer period of time (and more energy) in the kiln to burn all of the charcoal out of the bricks. More research has to be done on the effectiveness of longer fired charcoal bricks before they were introduced as a liner into a stove.

The longer firing times, combined with the extra effort and energy to grind the charcoal into a fine powder make charcoal bricks a less than perfect option for VIC.

Sifted sawdust bricks – while still needing more research- seem to offer the best solution in the short term.

I would recommend focusing on **sawdust bricks for the single pot stove** and **vermiculite bricks for the institutional stove**. The bricks that we are using in Lesotho are about 80% medium vermiculite by volume and about 20% clay.

Some of the test bricks that we fired in Uganda were with fine Vermiculite because we had not located the coarser vermiculite. This fine vermiculite has a very limited insulative aspect and is not recommended for the VIC brick.

The above photo shows three different kinds of mica. Starting at bottom left and moving clockwise the picture shows medium or coarse vermiculite, fine vermiculite and finally unprocessed mica.

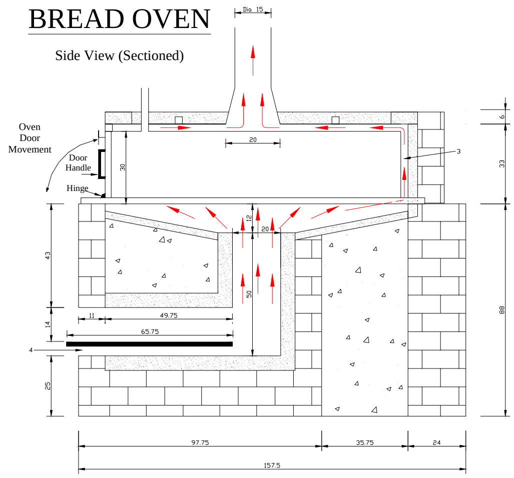
8.2 Design points

- The ideal density of the bricks should be between .4 and .7 grams/cc.
- Longer drying periods without the use of the artificial drier will produce a stronger and lighter brick
- All bricks should be dried in the shade for at least 5 days and then fired in an electric or wood kiln for one day. Artificial drying is not necessary if sufficient natural drying is possible.

9.0 Auto CAD drawings

BREAD OVEN

Side View (Sectioned)

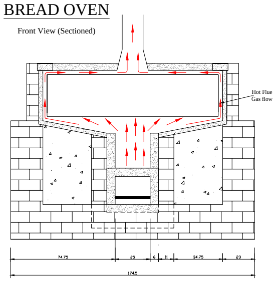


Dimensions: cm

Designed by: Aprovecho/GTZ-EAP, Date September 2003

BREAD OVEN

Front View (Sectioned)



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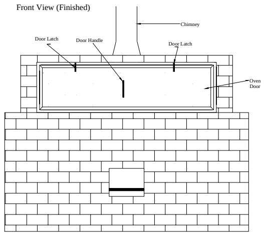
BREAD OVEN

Front View (Finished)



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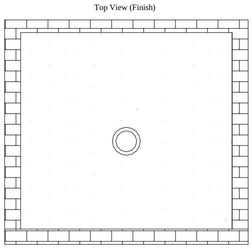
Designed by: Aprovecho/GTZ-EAP, Date September 2003

BREAD OVEN

Top View (Finish)



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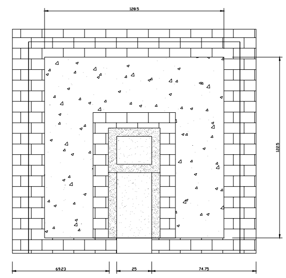
Designed by: Aprovecho/GTZ-EAP, Date September 2003

BREAD OVEN

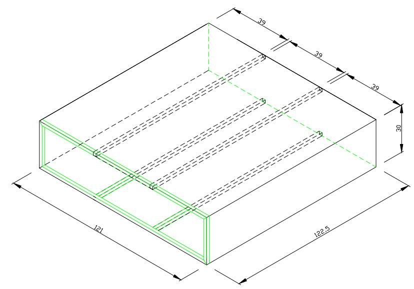
Top View (Initial stage)



Dimensions: cm

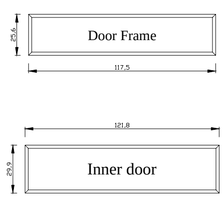
Designed by: Aprovecho/GTZ-EAP, Date September 2003

Metal Box for Bread Oven



Dimensions cm

Designed by Aprovecho/GTZ-EAP, Date September 2003

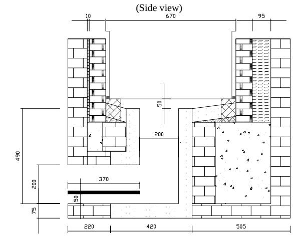


Dimensions cm

Designed by Aprovecho/GTZ-EAP, Date September 2003

100-LITRE FIXED STOVE

(Side view)



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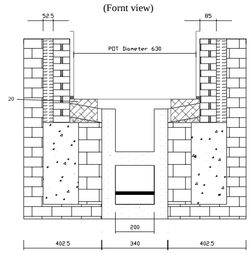
100-LITRE FIXED STOVE

(Fornt view)



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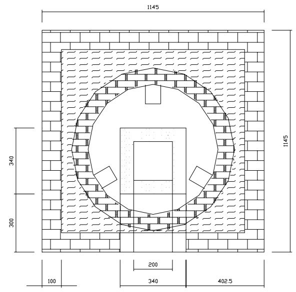
100-LITRE FIXED STOVE

(Top view)



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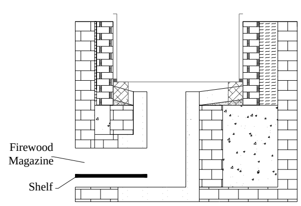
100-LITRE FIXED STOVE

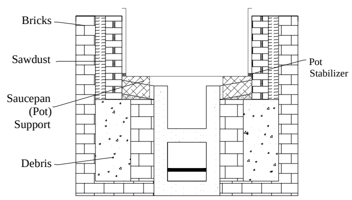
(Side view)



Designed by Aprovecho/EAP-GTZ

100-LITRE FIXED STOVE

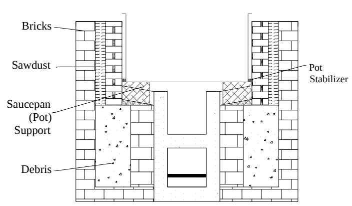
(Front view)



Designed by Aprovecho/EAP-GTZ

100-LITRE FIXED STOVE

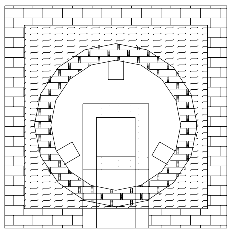
(Front view)



Designed by Aprovecho/EAP-GTZ

100-LITRE FIXED STOVE

(Top view)



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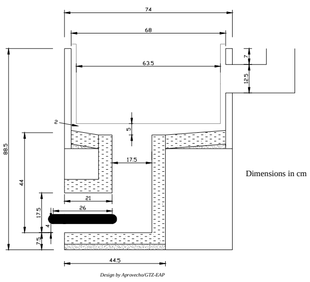
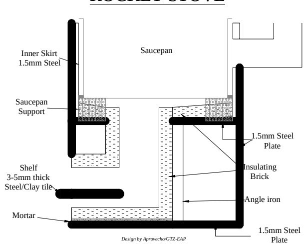
100LITRE INSTITUTIONAL ROCKET-STOVE

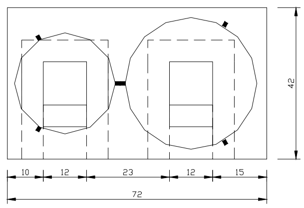


100LITRE INSTITUTIONAL ROCKET-STOVE



PORTABLE 2 POT STOVE

Top view (sectioned)



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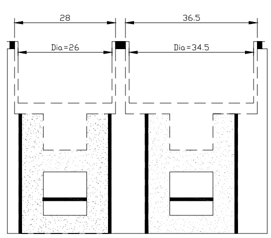
PORTABLE 2 POT STOVE

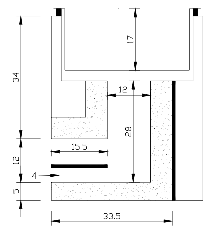
Front view (sectioned)



Designed by: Aprovecho/EAP-GTZ

PORTABLE 2 POT STOVE

Side view (sectioned)



Designed by: Aprovecho/EAP-GTZ

Appendix A Calculating the saucepan/stove gap

The correct gap will depend on the size of the combustion chamber and the size of the saucepan or baking compartment. We will use our 20cm by 20 cm combustion chamber and our 100L pot as an example.

First, calculate the cross sectional area of the opening of the combustion chamber. Assuming the combustion chamber is a 20 cm square then the total area is 20 cm *20cm or 400 $cm^{2.}$ This is the theoretical maximum cross sectional area that should always exist between the saucepan and the stove body. (Note: efficiencies can be increased by carefully **reducing** this gap. Conversely, construction limitations or cultural constraints might force the designer to **widen** this gap but knowing the "correct" gap is an important starting point).

Next calculate the perimeter (or circumference, if applicable) of the combustion chamber. The 20 cm by 20cm chamber has a perimeter of 80 cm (20cm +20cm+20cm+20cm= 80cm)

400 cm^2 of area is needed throughout the stove. So we need to calculate the correct gap at each point around the sides and under the bottom of the saucepan to maintain the correct cross sectional area. By using this equation for a square combustion chamber:

$\frac{A}{P}$ = "correct" gap

we can find the “correct” gap at any point between the saucepan and the stove body. Whereas A *is the cross sectional area* and P *is the perimeter of the combustion chamber*. In this case A=400 cm^2 and P = 80 cm

$$\frac{400\ cm^2}{80cm} = \mathbf{5cm}$$

So the “correct” gap between the saucepan and **directly above** the combustion chamber is 5 cm.

Now as the gasses flow out towards the **sides** of the pot, the **gap will shrink**. To calculate the correct gap at a wider point under the saucepan, imagine, for example, a circle with a diameter of 45 cm that sits **around** the combustion chamber. In this case we use the equation:

$$\frac{A}{C} = \text{“correct” gap}$$

Whereas A *is the cross sectional area* and C *is the circumference at a given point under the saucepan*

This 45 cm circle has a circumference of 141.3 cm (π * Diameter= C)

$$\frac{400\ cm^2}{141.3cm} = \mathbf{2.83cm}$$

2.83 cm is the correct gap between the saucepan and the stove body at any point 22.5 cm outward from the centre of the saucepan.

At the edge of our 100L saucepan (which is 63cm in diameter) we have a circle that has a circumference (π*Diameter) of 197.8 cm. Therefore:

$$\frac{400\ cm^2}{197.8\ cm} = 2.02\ cm$$

This is the “correct” gap between the saucepan and the stove body at the edge of the saucepan or any point that is 31.5 cm outward from the centre of saucepan.

This is also the correct gap between the **sides** of the saucepan and the stove body. Experience, however, shows us that for optimum performance the gap between the stove and the sides of the pot can **be reduced by 50%** to 1.01 cm

The three gap points under the saucepan (5cm, 2.83 cm, and 2.02cm) can be connected to form the “correct” slope under the saucepan.

Appendix B 25 quotes from Sam Baldwin

1.) The energy efficiency of a stove can be dramatically increased by making use of the energy in this hot flue gas through improved convective heat transfer to the pot. (Page 28)

2.) High power water boiling tests, for example, measure the thermal efficiency. High/low power water boiling tests and cooking tests measure the stove efficiency. (Page 31)

3.) …it is the surface resistance, not the resistance to heat transfer of the material itself, that primarily determines the rate of heat loss through the stove wall. (Page 34)

4.) In controlled cooking tests with aluminium pots, fuel savings were about 45% compared to using clay pots. (Page 35)

5.) Although a thick wall of dense high specific heat material may have slightly lower heat loss than a thinner wall after several hours… it takes many hours more for the eventual heat loss of the thick wall to compensate for its much greater absorption of heat to warm up to this state. Thus, it is always preferable to make the solid (non-insulator) portion of the wall as thin and light as possible. Additionally, the use of lightweight insulants such as fibreglass or double walled construction can dramatically lower heat loss…Materials such as sand-clay or concrete, which have a high specific heat and density, and which must be formed in thick sections to be sufficiently strong to support or resist the fire, should therefore be avoided. (Page 36)

6.) Water heating tests on hot massive stoves, however, have shown that only 0.6 to 1.3% of the energy released by the fire, of which perhaps one-third was stored in the massive wall, could be recuperated…heating the water by typically 18 to 19C…What is often thought to be heating or cooking by heat recuperation is actually done by the remaining coals of the fire. (Page 36)

7.) Similarly, using stored heat to complete cooking is an extremely inefficient technique compared to using a high efficiency lightweight stove and possibly a “haybox” cooker… (Page 36)

8.) Thus, lightweight walls have the intrinsic potential for much higher performance than massive walls due to their lower thermal inertia. This does not, however, necessarily mean that a lightweight stove will automatically save energy or that a massive stove cannot. For a lightweight stove to save energy its heat loss to the exterior must also be minimized and the convective and radiant heat transfer to its pot must be optimised. Conversely, massive stoves can and sometimes save energy if the convective and radiant heat transfer to the pot is carefully optimised. (Page 38)

9.) To increase the heat transfer to the pot there are, in principle, three things to do. First, the temperature of the hot gas can be increased…Second, as much of the area of the pot should be exposed to the hot gas as possible…The gas should be allowed to rise up around the pot and contact its entire surface…. Third, the convective heat transfer coefficient should be increased. This can be done by increasing the velocity of the hot gas as it flows past the pot...In convective heat transfer, the primary resistance to heat flow is not within the solid object (unless it is a very good insulator), nor within the flowing hot gas. Instead, the primary resistance is in the "“surface boundary layer” of very slowly moving gas immediately adjacent to a wall…It is this surface boundary layer of stagnant gas that primarily limits heat transfer from the flowing hot gas to the pot…To improve the thermal efficiency of a stove, the thermal resistance of this boundary layer must be reduced. This can be accomplished by (among others) increasing the flow velocity of the hot gas over the surface boundary layer and, thinner, the boundary layer of stagnant gas then offers less resistance to conductive heat transfer across it to the pot…(Page 41 to 42)

10.) The flow velocity of the hot gas over the pot is increased by narrowing the channel gap through which the gas must flow past the pot. (Page 42)

11.) For a 10cm long channel, the channel efficiency drops from 46% for an 8mm gap to 26% for a 10mm gap. (Page 45)

12.) For the 4mm gap, effectively all the energy in the gas can be recuperated in the first 2cm length of the channel. Channels longer than 5cm are useless. For the 6mm gap, the first 5cm length recuperates 57% of the energy in the gas, the next 5cm recuperates an additional 16%, the next 5cm an additional 8%, and so on. (Page 45)

13.) On page 48 Baldwin has two graphs that show optimum power of the stove matched to gap length and width. Stove efficiency is shown as dependent on these variables. “At powers greater than the optimum the combustion gases cannot all escape out the channel and instead must flow out the door or perhaps suffocate the fire and lower the combustion quality. At powers below the optimum, the gas flow through the channel will remain about the same but will be at a lower temperature due to more entrained air…In either case the efficiency drops. Experimental work has shown that for a variety of stoves the efficiency has a maximum at a particular fire power…”(Page 49)

14.) It is rather arbitrarily recommended that the pot to grate distance be no less than .4 times the pot diameter. (Page 54)

15.) …A metal wall with 2cm of fibreglass insulation can provide 50% more radiant heat flux to the pot than a bare metal wall…For example, insulating the exterior wall of a prototype channel stove increased the stove’s efficiency from about 33% to about 41% and increased its predicted fuel economy relative to the open fire from about 48% to about 57%…(Page 54)

16.) If a cold object, such as a pot, is placed close to the fire it will cool and stop the combustion of some of these volatiles, leaving a thick black smoke. (Page 59)

17.) The entire process uses about 5 meters cubed of air (at 20C and sea level pressure) to completely burn 1 kg of wood. To completely burn 1 kg of charcoal requires about 9 meters cubed of air. Thus, a wood fire burning at a power level of 1 kW burns .0556 grams of wood/second and requires about .278 litres of air per second. Additional, excess air is always present in open stoves and is important to ensure that the combustion process is

relatively complete. (Page 59)
18.) Using a grate will often increase efficiency and may reduce emissions as well…By injecting air below the fuel bed they provide better mixing of air with both the fuel bed and the diffusion flames above…Grates with a high density of holes (high fraction of open area) can also achieve high firepowers due to the improved mixing of air with the fuel bed. (Page 60)
19.) Controlling excess air can increase efficiency but may also increase emissions if too little oxygen enters the combustion chamber or if the mixing is poor. (Page 60)
20.) Injecting secondary air into the diffusion flame may, in some cases, allow more complete combustion than would otherwise be possible…Where an open firebox is used, however, secondary air may lower efficiency by cooling the hot gases. (Page 60)
21.) Preheating incoming air may also improve the quality of combustion and the efficiency by raising average combustion chamber temperatures. Preheating, however, can only be done in stoves where excess air is controlled; otherwise the air will bypass the preheating ducts and flow directly in the door. (Page 61)
22.) Optimising the shape of the combustion chamber may affect the combustion quality and stove efficiency in a number of ways. (Page 61)
23.) Insulating the combustion chamber raises interior temperatures and can reduce emissions. (Page 61)
24.) How well the fire is tended can strongly influence fuel use. Page 62)
25.) One of the most important factors determining field performance of a stove is the firepower it is run at during the simmering phase. Because simmering times tend to be long, quite modest increases in firepower above the minimum needed can greatly increase fuel consumption. (Page 63)

Things to remember for the best use and design of the Rocket Stove

- Use a small amount of wood cut into small diameter pieces
- Use dry wood.
- A larger pot filled to the top will give a higher efficiency as more of the heat will travel past a greater surface area
- Always use a skirt
- The feet of the shelf should never be less than 25 mm
- The rocket elbow is generally oversized, that means that even if you build a rocket for use with a larger pot you can usually use the same diameter of Rocket elbow
- Its not true that where there is smoke there is fire; in truth, **where there is smoke there is poor fire!**

Trouble shooting the Rocket Stove

Smoke coming out of the top of the stove?

Too much wood in the stove. Pull some of the sticks out of the combustion chamber.

The combustion chamber is over filled with coals. This results from pushing wood too quickly into the stove. Encourage users to push wood into the stove on a slower and more consistent basis

There is insufficient draft. **This is caused by the gap between the pot and the skirt *or* the pot and the combustion chamber being too small. This will result in increased smoke production, and a 'lazy' looking fire. Increase the gaps!**

The combustion chamber might be to short. Increase the height of the combustion chamber if you have altered it.

You are using wet wood. Encourage people to use dry wood

Fire coming out of the front of the stove/feed chamber?

Insufficient draft check pot /skirt gap and pot/combustion chamber gap

The combustion chamber is overfilled with coals instruct users to clean after each firing.

Here are the basic principles for designing any fuel-efficient cooking device

1) Insulate, particularly the combustion chamber, with low mass, heat resistant materials in order to keep the fire as hot as possible and not to heat the higher mass of the stove body.

2.) Within the stove body, above the combustion chamber, use an insulated, upright chimney that has a height that is 1.5 times higher than the diameter of the combustion chamber. In other words if the combustion chamber diameter is 100 mm than the height of the internal chimney should be 150 mm. The total height then of the entire combustion chamber and the chimney would then be 250mm.

This is the optimal height for overall stove efficiency. If you want to improve the combustion efficiency (ie reduce the amount of smoke) we recommend a combustion chamber that has a total height of 30 cm

3 .) Heat only the fuel that is burning Burn the tips of sticks only as they enter the combustion chamber. The object is NOT to produce more gasses or charcoal than can be cleanly burned at the power level desired.

4.) Maintain a good air velocity through the fuel. The primary Rocket stove principle feature is using a hot, insulated, vertical chimney within the stove body that increases draft.

5.) Do not allow too much or too little air to enter the combustion chamber. We strive to have stoichiometric (chemically ideal) combustion: in practice there should be the minimum excess of air supporting clean burning.

6.) The cross sectional area (perpendicular to the flow) of the combustion chamber should be sized within the range of power level of the stove. Experience has shown that roughly twenty-five square inches will suffice for home use (12 cm in diameter or 10 cm square). Commercial size is larger and depends on usage.

7.) Elevate the fuel and distribute airflow around the fuel surfaces. When burning sticks of wood, it is best to have several sticks close together, not touching, leaving air spaces between them. Particle fuels should be arranged on a grate.

8.) Arrange the fuel so that air largely flows through the glowing coals. Too much air passing above the coals cools the flames and condenses oil vapors.

9.) Throughout the stove, any place where hot gases flow, insulate from the higher mass of the stove body, only exposing pots, etc. to direct heat.

10.) Transfer the heat efficiently by making the gaps as narrow as possible between the insulation covering the stove body and surfaces to be heated but do this without choking the fire. Estimate the size of the gap by keeping the cross sectional area of the flow of hot flue gases constant. EXCEPTION: When using a external chimney or fan the gaps can be substantially reduced as long as adequate space has been left at the top of the internal short chimney for the gasses to turn smoothly and distribute evenly. This is tapering of the manifold. In a common domestic griddle stove with external chimney, the gap under the griddle can be reduced to about one 12mm for optimum heat transfer.