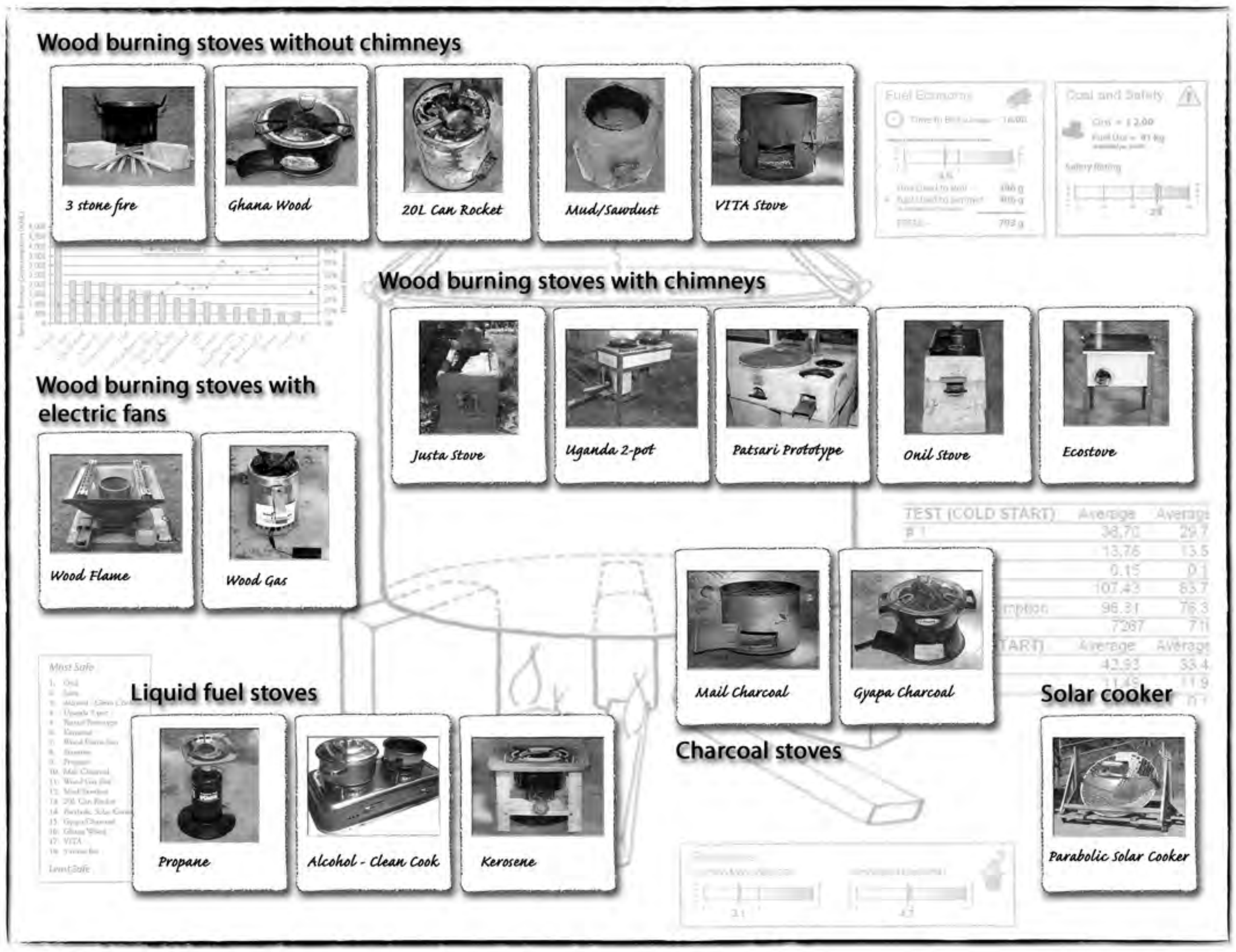
Partnership for Clean Indoor Air

Test Results of Cook Stove Performance



Aprovecho Research Center
Shell Foundation
United States Environmental Protection Agency

The Partnership for Clean Indoor Air was launched by the U.S. Environmental Protection Agency (EPA) and other leading partners at the World Summit on Sustainable Development in Johannesburg in September 2002. Its mission is to improve health, livelihood and quality of life in developing countries by reducing people's exposure to indoor air pollution from household energy use. More than 460 organizations are working together to increase the use of clean, reliable, affordable, efficient and safe home cooking and heating practices. For more information, or to join the Partnership, visit www.PCIAonline.org.

This document was developed by Aprovecho Research Center under a grant from the Shell Foundation to provide technical support to household energy and health projects and to ensure that the projects' designs represent the best available technical practices. The emissions testing equipment used to evaluate the stoves in this book was provided by a generous grant from the M.J. Murdock Charitable Trust. Additional financial support was provided by The Woodard Family Trust Foundation. The principal authors of this publication are Dean Still, Nordica MacCarty, Damon Ogle, Dr. Tami Bond and Dr. Mark Bryden. The participation of Dr. Bond and graduate student Christoph Roden was made possible by the U.S. National Science Foundation and the University of Illinois. The journal article "Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks"[1] adds to Aprovecho's survey of household stove performance.

Aprovecho is a center for research, experimentation and education on alternative technologies that are ecologically sustainable and culturally responsive. The Advanced Studies in Appropriate Technology Laboratory at Aprovecho works to develop energy-efficient, nonpolluting, renewable technologies that reflect current research and can be made in almost any country. For more information on Aprovecho, visit www.Aprovecho.org.

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[1] MacCarty, N., Still, D., and Ogle, D. (2010). Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks. Energy for Sustainable Development 14. 161-171.

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Preface

Cooking fires and cook stoves are some of the earliest technologies. Therefore, it is often assumed that we thoroughly understand cook stoves and there is little improvement to be made in cook stove design. Yet we continue to learn about how to build cook stoves. There are no internationally accepted design standards for stoves burning biomass.

Users of this guide are encouraged to think of it not as the final answer, but as a step in a journey towards better, safer and more functional cooking systems. We encourage them to contribute ideas, thoughts and experiences at any of the many forums for sharing experiences with stoves, including Internet-based lists, websites, and conferences.

We hope that our work with stoves is helping to develop a model for how technology can be improved and implemented in a way that can change people's lives.

Household technologies are essential. By thinking beyond stoves we can have an even greater impact on the world around us. We can and we will change the world in the same way that we are changing stoves, by investigating what works in the lab and what works in the kitchen.

Test Results of Cook Stove Performance

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Introduction

More than half of the world's population cook their food and heat their homes by burning coal and biomass, including wood, dung, and crop residues, over open fires or in rudimentary stoves. Besides releasing greenhouse gases into the air, indoor burning of these solid fuels releases dangerous particulate matter (PM), carbon monoxide (CO), and other toxic pollutants and leads to indoor air pollution levels that are often 20 to 100 times great than the air quality guidelines of the World Health Organization (WHO). Unfortunately, the health risks and threats to the environment are on the rise: the International Energy Agency estimates that 200 million more people will use these fuels by 2030.

Exposure to smoke is associated with chronic obstructive lung diseases and acute lower respiratory infections. WHO estimates that about 1.6 million people die prematurely each year due to breathing smoke. Although breathing CO is dangerous, especially for pregnant women, the elderly, and people with heart or respiratory disease, PM is probably the single most important health-related risk in breathing wood smoke.[2]

Breathing in even small amounts of PM can lead to increased mortality. The increase in rates of mortality caused by inhaling very high levels of PM has yet to be determined. However, a national study in the U.S. concluded that there is a 0.5 percent increase in the relative rate of death from all causes for each increase in the PM_{10} (particles up to 10 micrometers in diameter) level of 10 µg per cubic meter. The estimated increase in the relative rate of death from cardiovascular and respiratory causes was 0.68 percent for each increase in the PM_{10} level of 10 µg per cubic meter.[3]

In 2002, the World Summit on Sustainable Development identified the inhalation of smoke as a major health hazard in countries where solid fuel is used for cooking, heating and illumination. Their resolution to reduce indoor air pollution has focused greater attention on the clean combustion of biomass fuels. Researchers have realized that both improved fuel efficiency and cleaner combustion can be achieved in improved cooking stoves.

The goal of reducing indoor air pollution is met by many interventions (increasing kitchen ventilation, using a chimney, etc.) that protect the health of a family. Cleaner burning stoves have many other benefits beyond improving health including time savings, cleaner kitchens, reduced effort to gather fuel and more sustainable use of a diminished energy resource. Stoves that use less wood and make less smoke are the result of the efforts of hundreds of people who have developed solutions over the years.

Over the past 30 years, awareness of the environmental and social costs of using traditional fuels and stoves has grown, as has understanding about how to reduce emissions from these stoves. Yet the improved stoves currently available do not always represent best practice or an understanding of design based on modern engineering. The authors of this guide intend to provide all stakeholders—people with an interest in stove design and dissemination—with information about certain consequences of their stove choices.

The challenge of cook stove design is that it is not only a technical issue, but also a human issue. How and what we cook is tightly coupled to our culture, lifestyle and resources. Cook stoves are used extensively and continually. They need to be able to boil water quickly, simmer food, and cook an almost infinite variety of foods in different ways depending on the culture. Cook stoves need to be easy to use, require little attention and respond quickly when needed. They need to be safe, efficient and nonpolluting. Cook stoves need to be pleasing to the eye.

[2] Naeher, L., Smith, K., Brauer, M., Chowdhury, Z., Simpson, C., Koenig, J., Lipsett, M., and Zelikoff, J. (2005). Critical review of the health effects of woodsmoke. Air Health Effects Division, Health Canada, Ottawa.

[3] Samet, J., Dominici, F., Curriero, F., Coursac, I., and Zenger, S. (2000). Fine particulate air pollution and mortality in 20 U.S. cities, 1987-1994. The New England Journal of Medicine 2000; 343: 1742-1749.

These multiple and sometimes conflicting goals obviously require an integrated approach to cook stove design an implementation. The cook and the engineer are both "experts."

Test Results of Cook Stove Performance represents a major step forward in developing an integrated approach to cook stove design. For the first time, a variety of stoves from across the world have been tested in a variety of ways and the results presented here for all to review. One stove is more efficient, another heats quicker, others are safer, and each of these stoves pollutes more or less than others. Stove designers can pick and choose stove design options to create stoves that serve local needs.

Reducing fuel use and lowering emissions

One of the major motivations for the "first wave" of improved stove dissemination was to reduce fuel use and thereby affect the rate of deforestation. Stoves were designed with fuel efficiency as a major goal. Improved wood-burning stoves probably saved between 30% and 50% of the fuel used to cook with the 3 Stone Fire.[4] Unfortunately, the first-generation improved stoves were not always designed to also reduce emissions. Most early stove researchers did not have the equipment to measure harmful pollutants. In fact, researchers found that some of the fuel-efficient designs could actually increase emissions.

Reducing deforestation proved to be a difficult goal for the first wave of stove projects to achieve. Studies showed that to have an effect on deforestation, the projects would have to make fuel-efficient stoves available to a much larger percentage of the wood-using population. Even when stoves were shown to be cost effective, the need to distribute millions of stoves was daunting.

Between 1970 and 1980 many cooking stoves were developed, some were more fuel efficient than others. The thermal efficiency of stoves was studied by researchers, and books were written that have helped create a general consensus about how to improve cooking stoves. The improved understanding of the thermodynamics of cooking with wood has been useful for the various stove-building projects around the world in their efforts to manufacture and distribute a new generation of fuel-efficient and cleaner burning stoves.

Learning from the 3 Stone Fire

As with any tool, the skill of the operator determines how well the work is accomplished. The 3 Stone Fire can be operated cleanly, or it can be very dirty and wasteful. Open fires tend to go out easily, however, and it is a natural inclination to make an overly large fire or leave smoking wood under a simmering pot while attending to other work. The fact that the 3 Stone Fire can be operated with very different results was confusing to early investigators.

In some kitchens, large fires made for cooking use a lot of wood and make a great deal of smoke. Small fires are also made that cook food relatively cleanly. Watching indigenous experts in the field cook with fire has led to a better understanding of effective biomass fuel use. Cooks who are trying to conserve wood tend to meter fuel by pushing wood into the fire, slowly burning the wood at the tip of the stick. Knowledgeable cooks only need a small, hot fire close to the pot to quickly boil water. Improving upon a well-made 3 Stone Fire was more difficult than the first generation of designers had expected. Learning from expert users helped teach engineers how to make better stoves.

Testing cook stoves

The emission collection system provides real-time data, is relatively inexpensive and has been used by other researchers. (See page 94 for emission hood details.)

The research staff at Aprovecho decided that it would be valuable to test a variety of cooking stoves from around the world. The intention was

[4] Appropriate Technology Sourcebook, 1997.

to provide all stakeholders with information about how to make the best stove choice.
Eighteen stoves were tested in three ways:

1. Boiling 5 liters (L) of water in a standard 7-liter pot (cold and hot start), simmering the hot water for 45 minutes and carefully weighing the water remaining and the wood used for high power (bringing to boil) and low power (simmering) stove operation. The revised University of California Berkeley (UCB) Water Boiling Test (WBT) protocols were used (three repetitions per stove). The revised UCB/WBT protocols can be found in Appendix C and at *www.aprovecho.org.*
2. The stoves were tested three times again, using the revised UCB Water Boiling Test under the emissions hood, which measures the levels of CO, carbon dioxide (CO_2), PM and hydrocarbons. The data are displayed as they are being measured in real time. Due to technical problems, data from only one of the three Water Boiling Tests accurately measured PM.
3. The stoves were also tested three times boiling water and then simmering the hot water for 30 minutes in a 15 m^3 test kitchen with approximately three air exchanges per hour. Portable emission equipment was used to measure the levels of CO, CO_2, and PM.

Testing methods are explained in detail in Appendix B on page 93.

The results of testing are presented in this book. The following chapter describes how each stove performed at high and low power in the following categories:

- **Time to boil**
- **Fuel used to cook**
- **Energy used to cook**
- **CO emissions**
- **PM emissions**
- **Safety ratings**
- **Cost to purchase**
- **Monthly fuel use**

Chapter 2 ranks each stove on eight important performance indicators. The stoves are frequently compared to the 3 Stone Fire. These comparisons point out what modifications can reduce emissions and fuel use.

Chapter 3 of this book attempts to answer frequently asked questions, such as:

- **Why do some stoves boil water faster?**
- **Why do some stoves use less fuel?**
- **Why do some stoves make less CO?**
- **How do wood- and charcoal-burning stoves compare?**
- **What is the effect of adding a chimney to the stove?**
- **How can stoves be improved?**

The 3 Stone Fire in the laboratory and in the field

It is important to remember that in the Aprovecho lab testing the 3 Stone Fire used less wood and made less pollution than cooking fires in the field. All of the fires in these tests were carefully made using dry and uniform sticks of Douglas fir fed into the fire in a controlled way to optimize the performance of all stoves.

Well-constructed 3 Stone Fires protected from wind and tended with care scored between 20% and 30% thermal efficiency. Open fires made with moister wood and operated with less attention to the wind can score as low as 5%. The operator and the conditions of use largely determine the effectiveness of operation. Stoves must be tested with careful repetition in order to minimize variables in test results.

Because there are so many differences between laboratory and field results, it is difficult to use the results of laboratory testing to predict how stoves will perform in the real world. However, side-by-side comparisons can be used to estimate performance. An automobile that gets 40 miles per gallon on a dynamometer is more likely to use less gas on the highway than a car that only gets 20 miles per gallon in the same test. A cooking stove that used less fuel or made less pollution in a standardized test will, one hopes, translate into reductions in the field, but only field surveys can establish the actual performance.

Many good stoves

Several types of stoves were significantly better than the 3 Stone Fire on most tests, which indicates that biomass-burning stoves can be both more fuel efficient and cleaner burning. Stoves equipped with chimneys can be used safely indoors. Adding a lightweight rocket-type combustion chamber to a stove reduces CO by approximately 75% and PM by about 50% compared to an open fire. Adding a fan to a wood-burning stove dramatically reduces emissions.

The 18 stoves covered in this book embody effective solutions that are now in use in countries around the world. Having options will enable interested people to create appropriate solutions tailored to their needs. There are various successful approaches to cooking and cooks have the opportunity to choose their favorites.

Perhaps most important to a cook is how a stove prepares his or her favorite foods. This factor can outweigh the advantages of less emissions and decreased fuel consumption. Stove choice is often based on far more subjective variables. Reducing harmful emissions and fuel use will help the cook and family, but if a stove does not please the cook, it may not be used.

Improving stoves

Engineers have been studying fire for many generations, and there is general agreement that certain modifications will improve the effectiveness of biomass fuel stoves. The following suggestions will improve intermittently fed stoves that are designed to achieve more complete initial combustion and improved heat transfer efficiency to the pot or griddle.

1. **A hotter fire burns cleaner.** Insulating around a fire helps it burn hotter. Insulation should be made from lightweight materials, because heavy materials such as sand, clay or cement placed around a fire absorbs heat that could be used for cooking.
2. **Burning too much wood at once creates smoke.** Wood burns cleanly when it is fed slowly into the fire. Wood gets hot and makes gases that can be more completely burned if the gas and air are mixed into flame.
3. **The right amount of incoming air helps the fire burn cleanly.** Increasing the velocity of the right amount of air helps the fire burn hotter and helps to improve the mixing of fuel, air and spark.
4. **A grate lifts wood above the floor of the combustion chamber.** This allows air to flow up through the fire. Air can enter the fire from underneath, which is beneficial.
5. **Insulating the path of the hot flue gases (except around the pot or griddle) delivers more heat to the cooking surface.** That is because the heat is not lost into the body of the stove.
6. **Get more heat into the pot.** Most of the inefficiency in cooking occurs because heat is not effectively transferred to the pot. Heat transfer can be increased by directing the hot gases in a narrow channel parallel to the cooking surface. Gases should be kept as hot as possible and flowing at the highest possible velocity without decreasing gas temperatures. More detailed information can be found in *Design Principles for Wood Burning Cookstoves* (EPA 402-K-05-004) available at www.PCIAonline.org/resources.
7. **Increasing the surface area of the cooking surface is helpful.** On the other hand, decreasing the surface area of exposed water in pots helps to reduce steam production.
8. **An insulated space above the fire improves the mixing of hot gases, air and flame.** This significantly reduces emissions, especially if the gas is well mixed.

Chapter 1

Stove Descriptions and Performance

Wood-burning stoves without chimneys


3 Stone Fire


Ghana Wood


20L Can Rocket


Mud/Sawdust


VITA Stove

Wood-burning stoves with chimneys


Justa Stove


Uganda 2-pot


Patsari Prototype


Onil Stove


Ecostove

Wood-burning stoves with electric fans


Wood Flame


Wood Gas

Charcoal stoves


Mali Charcoal


Gyapa Charcoal

Liquid-fuel stoves


Propane


Alcohol - Clean Cook


Kerosene

Solar cooker


Parabolic Solar Cooker

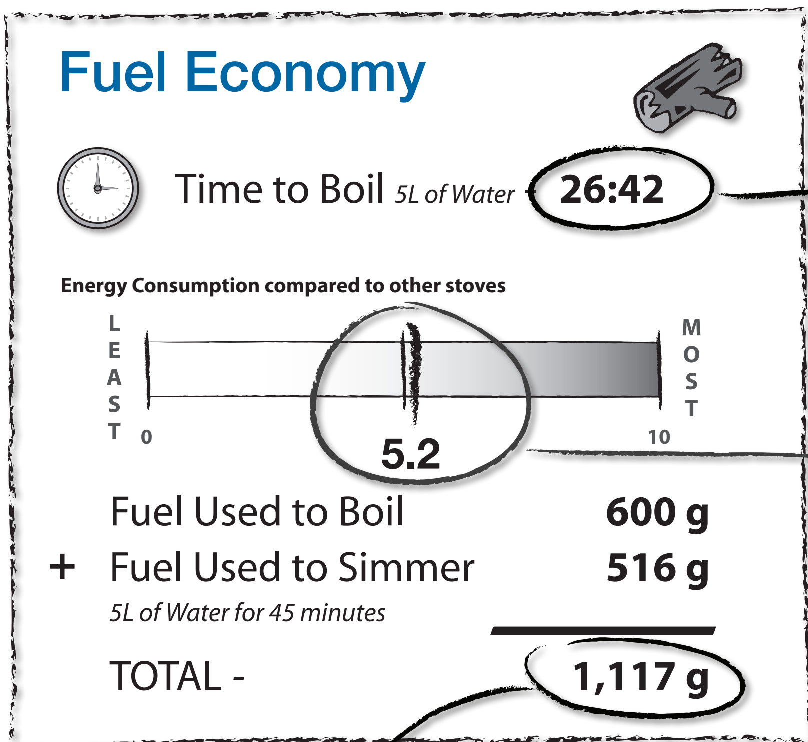
This chapter describes how the individual stoves performed in three major categories:

- Fuel Economy
- Cost and Safety
- Emissions

Included are the following:

- Description of the stoves
- Stove origins
- Specifications
- Comments on performance
- Pictures and drawings of each stove

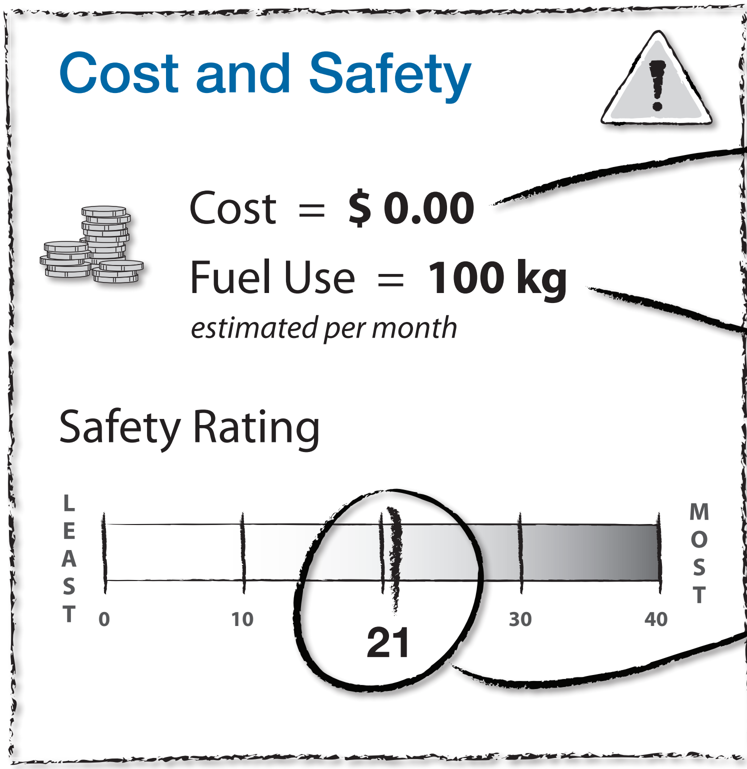
Use the following key to understand what the various numbers and the different categories mean. More detailed information on each stove and the testing methods can be found in the appendix.



Time to Boil *5 L of water (expressed in minutes:seconds). The total time is an average of the cold and hot start phases of the Water Boiling Test.*

Energy Consumption *rating is how much energy is used to complete a cooking task. Different fuels can be compared on the basis of energy used. A rating of 1 would mean the stove used less energy compared to a stove that received a higher rating.*

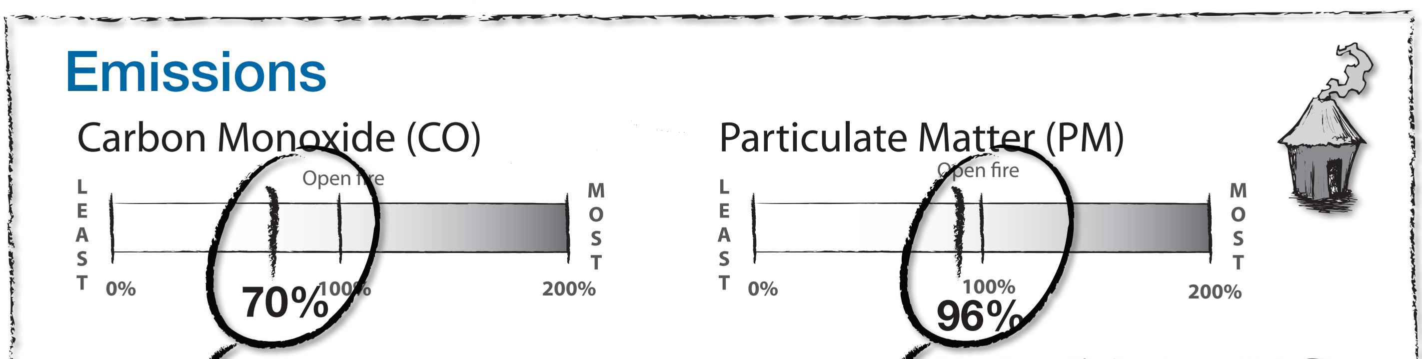
Total *amount of fuel used to bring 5L of water to a rolling boil and then to simmer the water for 45 minutes. The fuel is weighed before and after each test phase to determine the amount of fuel used for each task.*



*The **Cost** of buying or building the stove is shown in U.S. dollars.*

***Fuel Use** is the amount of fuel used to bring 5 L of water to a rolling boil and simmer it for 45 minutes twice a day for one month (30 days). This number can be used to compare the monthly costs of operating the stoves based on local fuel costs.*

*The **Safety Rating** is determined by evaluating the stove in multiple categories such as the likelihood of tipping, burns, fire spreading and sharp edges on a scale of zero to 40 points. Appendix C includes the detailed safety evaluation methods.*



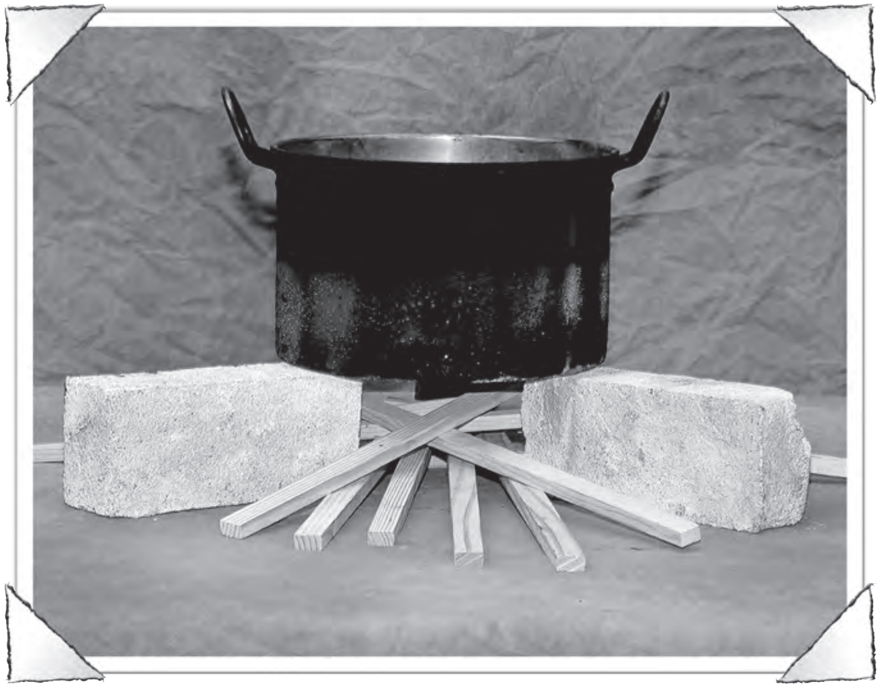
*The **Carbon Monoxide (CO)** and **Particulate Matter (PM)** ratings show the average relation between stoves based on pollution-level data collected from the test kitchen. The CO and PM averages are based on three tests done in the test kitchen. Percentages were calculated relative to an open fire.*

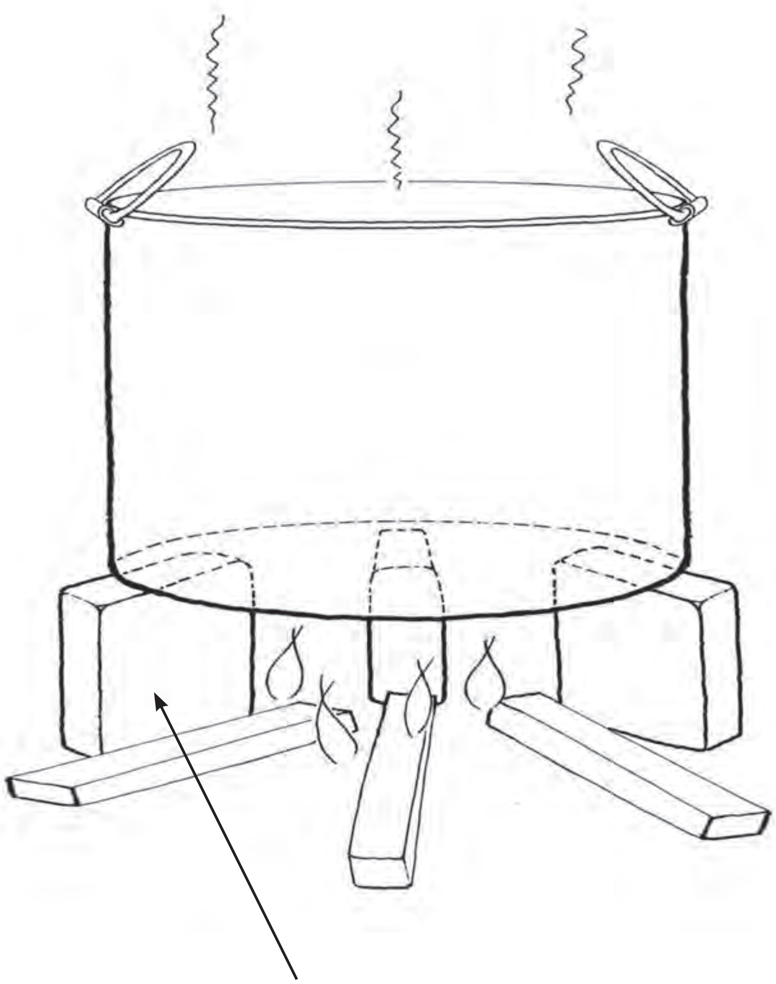
3 Stone Fire

Origin: Traditional

Weight: 5.1 kilos

Fuel Type: Wood





The 3 stones or bricks (20 x 6.5 x 9.5 cm) hold the pot over the flames of an open fire.

Description:

Open fires are used every day by a large percentage of the world's population. The 3 Stone Fire can be used more or less successfully, depending on the care and skill of the operator. If the sticks of wood are burnt at the tips and pushed into the center as the wood is consumed, the fire can be hot and relatively clean burning. If too much of the stick is smoldering, a lot of smoke can be made. If the pot is closer to the fire, more of the heat enters the pot.

In this case, the pot was placed 12 cm above the ground on three bricks. Dry wood was used. The fire was indoors and care was taken to make the fire as effective as possible. The 3 Stone Fires are usually made less carefully and can be expected to use more wood and make more smoke and harmful emissions than the fires in these tests.

3 Stone Fire

Performance:

It is difficult to keep the 3 Stone Fire burning. The sticks of wood are often touching the ground, and the fire can die out fairly easily. The temptation is to make a big fire, so it won't go out.

A lot of smoke was made when lighting the fire and when it wasn't burning well. When the fire was large and hot, there was less smoke.

The 3 Stone Fire was hard to start. If it had been outside in the wind, lighting the fire and cooking would have been much more difficult.

3 Stone Fire

Test Results

Fuel Economy

Time to Boil *5L of Water* - **26:42**

Energy Consumption compared to other stoves

5.2

	Fuel Used to Boil	**601 g**
+	Fuel Used to Simmer *5L of Water for 45 minutes*	**517 g**
	TOTAL -	**1,118 g**

Cost and Safety

Cost = **$ 0.00**

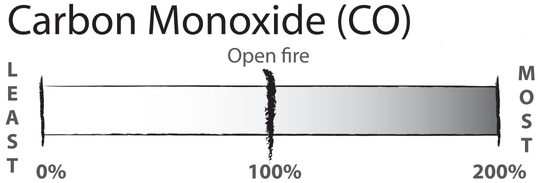
Fuel Use = **67 kg**
estimated per month

Safety Rating

21

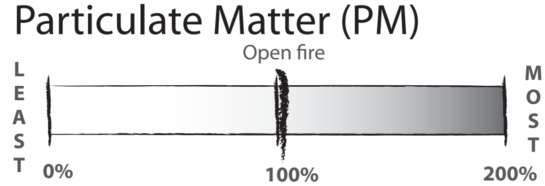
Emissions

Carbon Monoxide (CO)



100%

Particulate Matter (PM)



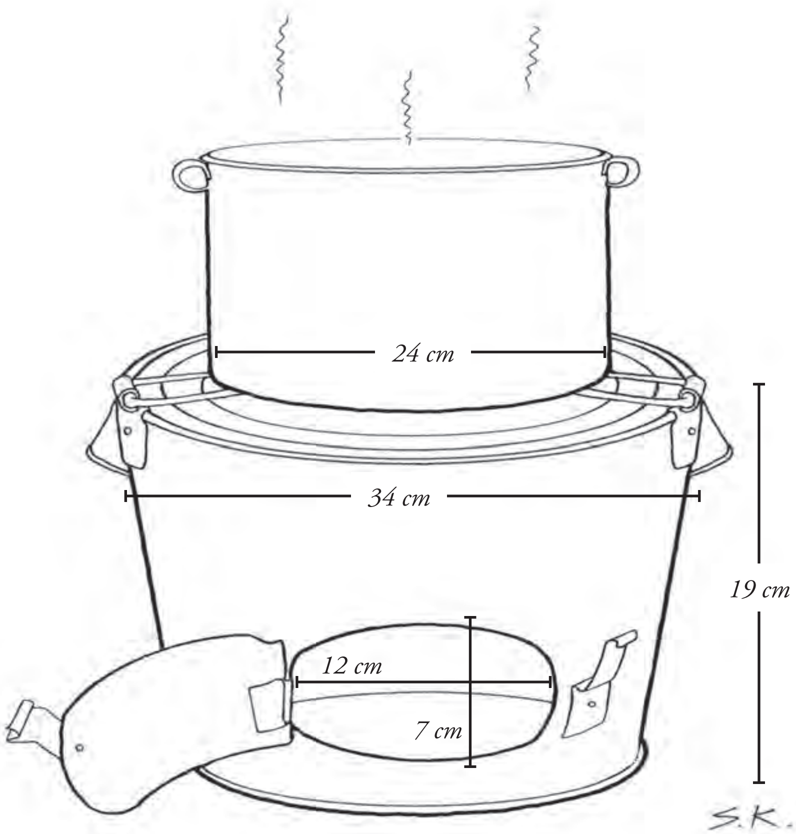
100%

Ghana Wood

Origin: Ghana, Africa

Weight: 8 Kilos

Fuel Type: Wood



Description:

The Ghana stove surrounds the fire with a thick ceramic liner inside a sturdy sheet metal body. The pot sits on three supports about 20 cm above the stove floor. Fuel is pushed into the fire through a door that can be closed.

This is a durable and safe stove. The walls protect the fire from the wind, and the opening is large enough to freely feed the fire. Closing the door helps leftover wood simmer food efficiently.

Once the stove body is hot, the walls surrounding the fire help keep the fire from cooling. Radiant heat from the fire directly contacts the pot. Sturdy handles help the cook move the stove as needed.

Ghana Wood

Ghana Wood

Performance:

Although the Ghana stove uses slightly less fuel than the 3 Stone Fire, it pollutes more. Enclosing a fire inside a cylinder of heavy ceramic and sheet metal does not help the fire burn more cleanly. Instead, the walls may cool the fire initially and cause the fire to smoke a bit more.

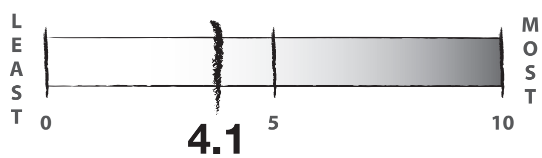
On the other hand, the stove is faster to boil than the 3 Stone Fire and works better in windy conditions. As mentioned, closing the door helps conserve wood, which is very useful when simmering food.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **21:48**

Energy Consumption compared to other stoves



Fuel Used to Boil	**422 g**
+ Fuel Used to Simmer *5L of Water for 45 minutes*	**574 g**
TOTAL -	**996 g**

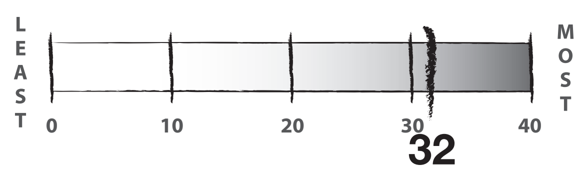
Cost and Safety

Cost = **$ 5.00**

Fuel Use = **60 kg**

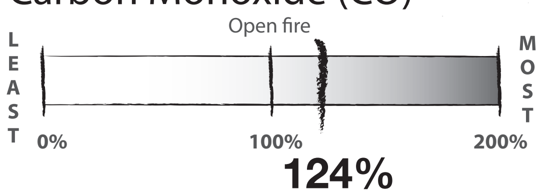
estimated per month

Safety Rating

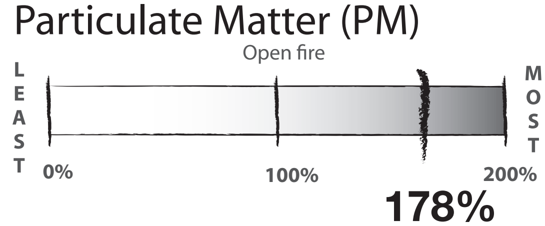


Emissions

Carbon Monoxide (CO)



Particulate Matter (PM)



20 L Can Rocket

Origin: Prototype

Weight: 6.6 kilos

Fuel Type: Wood

Contact:
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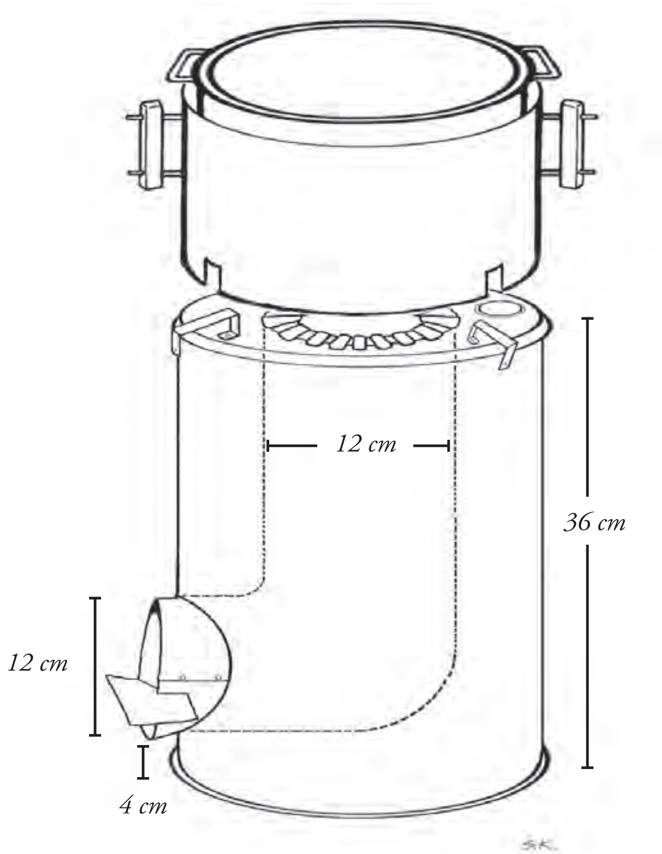


Description:

Relief agencies such as the World Food Program distribute food in 20 L metal cans all around the world. Rwandan refugees made stoves from these cans in the Mgunga camps in Tanzania.

A rocket-type combustion chamber is inserted in the can. Three supports made from folded metal hold up the pot. Wood ash fills the space inside the stove between the combustion chamber and the stove body. A metal cylinder (not shown) surrounds the pot, increasing heat transfer efficiency by forcing hot flue gasses to scrape against the pot.

The high temperatures in the combustion chamber deteriorate the metal, which has to be replaced in two to three months. Making the combustion chamber from ceramic or preferably lightweight firebrick makes this stove much longer lasting. Ligthweight ceramic weighs less than 0.8 grams/cubic centimeter.

20 L Can Rocket

20 L Can Rocket

Performance:

The lightweight, well-insulated combustion chamber in the 20 L can stove reduces both CO and PM compared to the 3 Stone Fire. Both heat transfer and combustion efficiency are improved, which means that fuel use and emissions are reduced.

The CO produced is about one-third of that made by the 3 Stone Fire, and the PM is about half. The higher temperatures and improved mixing of flame, gases and air above the fire result in more complete combustion.

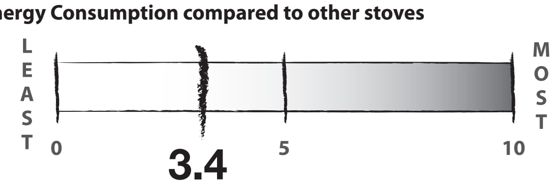
Since metal does not last at the high temperatures in the combustion chamber, it is preferable to replace it with insulative refractory ceramics when possible.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **22:18**

Energy Consumption compared to other stoves



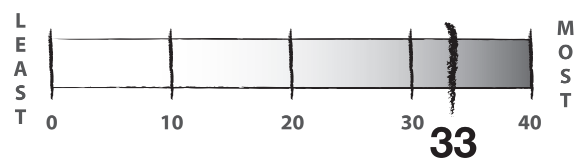
Fuel Used to Boil	**361 g**
+ Fuel Used to Simmer *5 L of Water for 45 minutes*	**372 g**
TOTAL -	**733 g**

Cost and Safety

Cost = **$ 0.00***

Fuel Use = **44 kg**
estimated per month

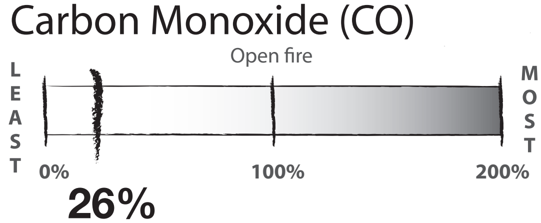
Safety Rating



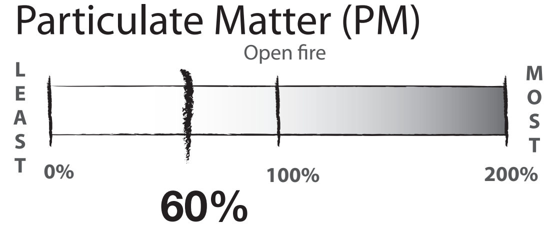
**When cans and sheet metal are available for free.*

Emissions

Carbon Monoxide (CO)



Particulate Matter (PM)

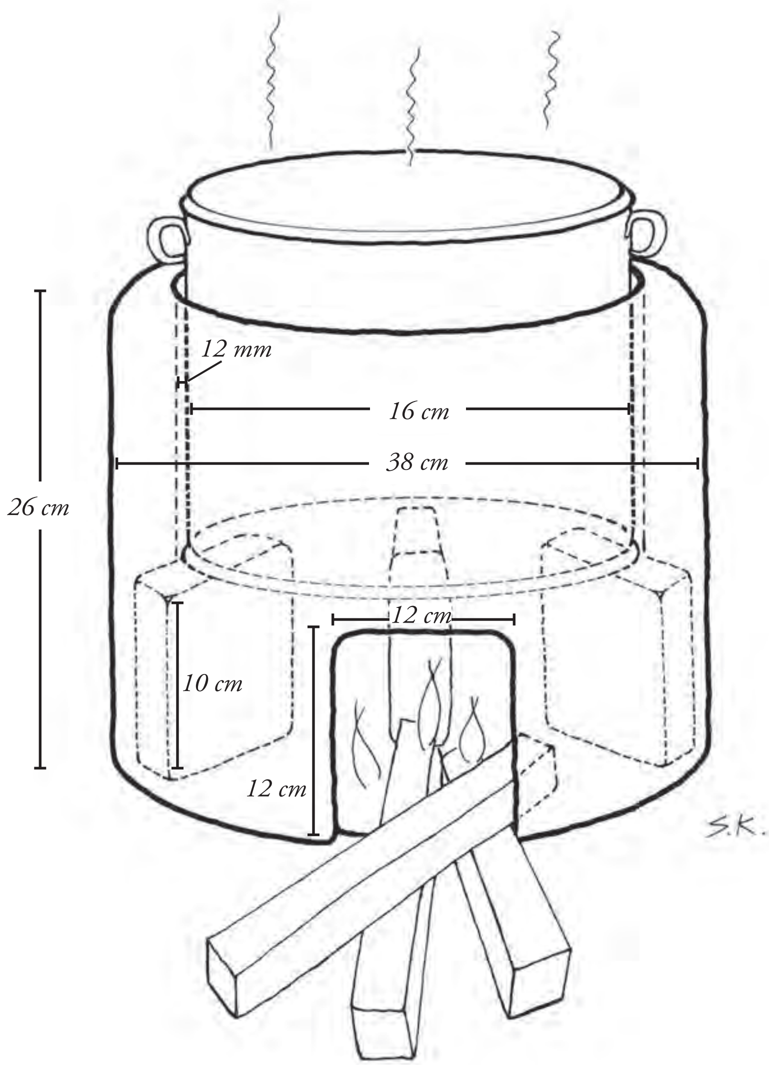


Mud/Sawdust Stove

Origin: Africa

Weight: 18 kilos

Fuel Type: Wood



Description:

This stove is made from 60% sand and 40% clay. Then equal amounts of sawdust are added to the earthen mixture. The sawdust lightens the sand/clay material.

Eventually the sawdust nearest the inside of the wall burns away, creating small pockets of air which help to insulate the fire.

The gap between the earthen cylinder and the pot was 12mm. The small channel forces the hot flue gases to scrape against the sides of the pot after touching its bottom. The scraping of heat against the side of the pot increases heat transfer efficiency, which decreases wood use compared to the 3 Stone Fire.

Emissions are higher than an insulated stove with a combustion chamber that effectively increases the mixing of the flame and smoke. However, this type of stove can be built with found materials and provides improved fuel use and protection of the fire from wind. The stove might be suitable for refugees, especially when used in well-ventilated areas.

Mud/Sawdust Stove

Performance:

Just as with the 3 Stone Fire, it is difficult to keep the fire going in this stove. A grate under the fire would be a big help. It is tempting to make an overly large fire that will not easily die out.

The small channel is filled with flame at times, and it is easy to see why more heat enters the pot through the sides. It is nice to see that a potentially zero-cost wall of earth and sawdust can boil water faster while using less fuel than a 3 Stone Fire.

Unfortunately, the stove only works well with the pot for which it was designed.

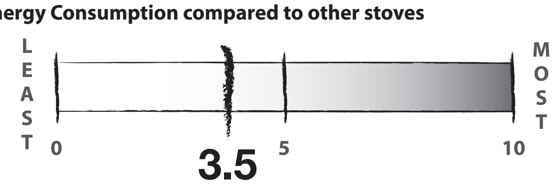
Mud/ Sawdust Stove

Test Results

Fuel Economy

Time to Boil *5L of Water* - **16:00**

Energy Consumption compared to other stoves



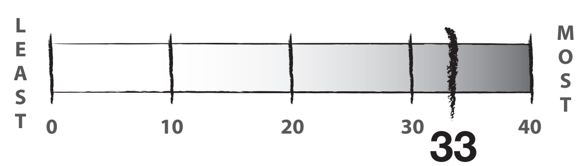
	Fuel Used to Boil	**386 g**
+	Fuel Used to Simmer *5L of Water for 45 minutes*	**406 g**
	TOTAL -	**793 g**

Cost and Safety

Cost = **$ 0.00**

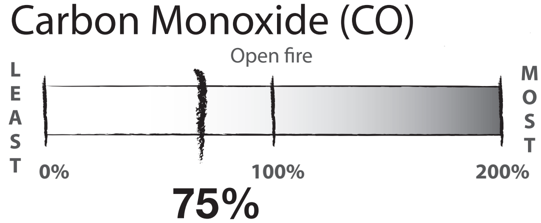
Fuel Use = **48 kg**
estimated per month

Safety Rating

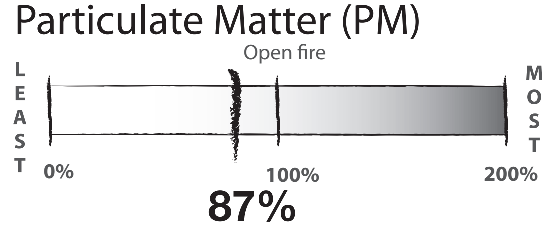


Emissions

Carbon Monoxide (CO)



Particulate Matter (PM)



VITA Stove

Origin: West Africa

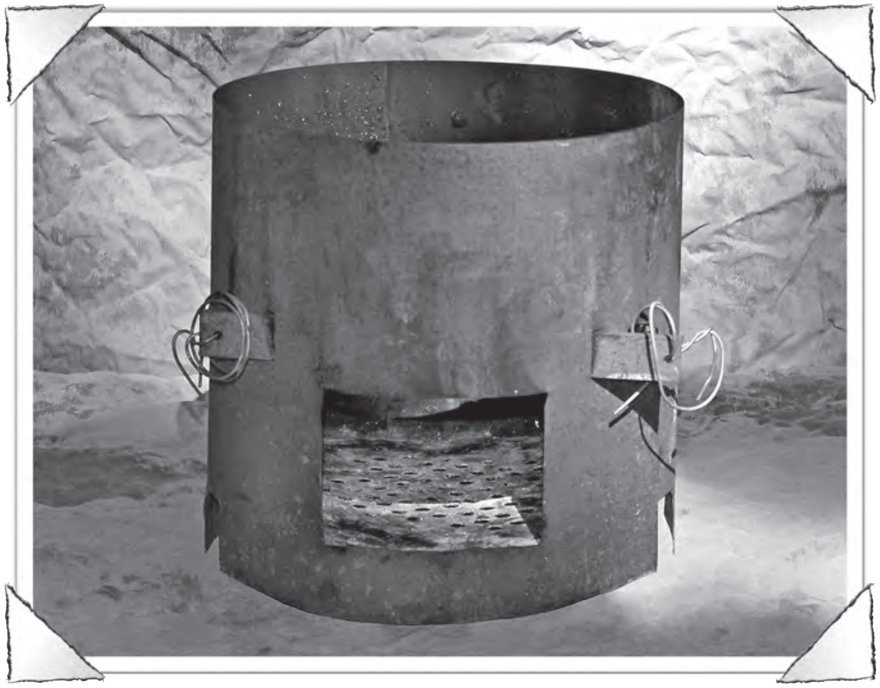
Weight: 2.2 kilos

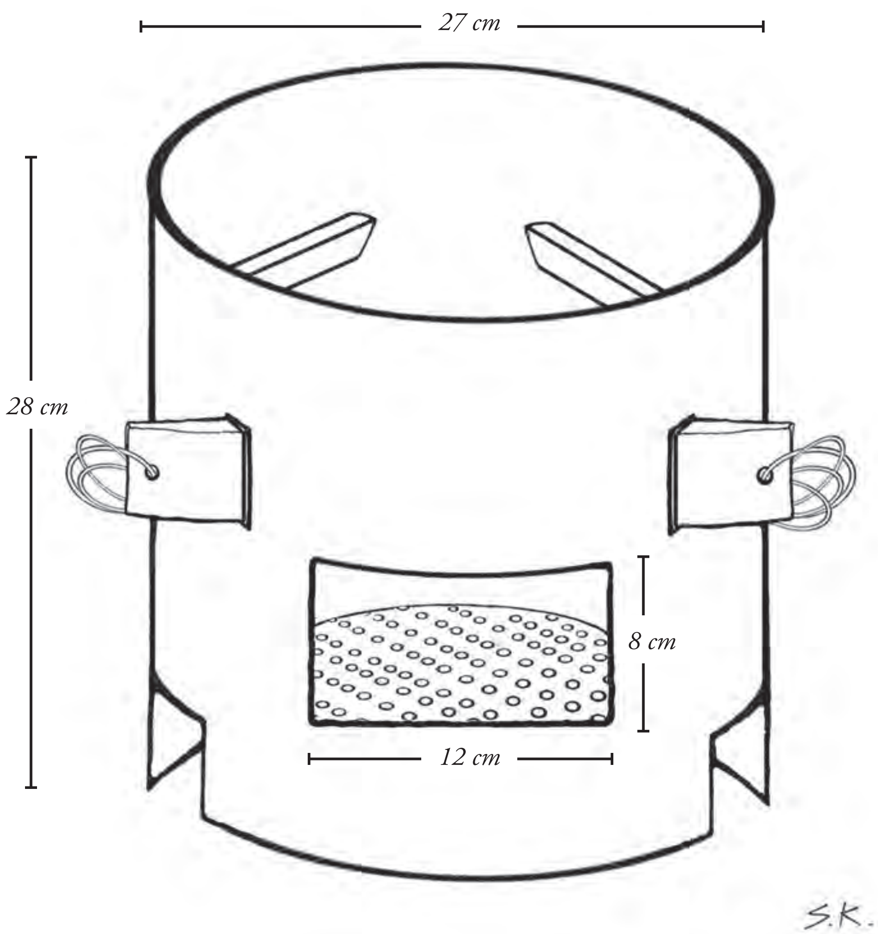
Fuel Type: Wood

Contact:
Relief International/
EnterpriseWorks-VITA

1100 H Street NW, Suite 1200
Washington, DC 20005
www.enterpriseworks.org

info@enterpriseworks.org
tel: (202) 639-8660
fax: (202) 639-8664





Description:

The VITA stove was designed by Dr. Sam Baldwin. It is the result of a great deal of study to inexpensively reduce the fuel used to cook food.

Dr. Baldwin's book *Biomass Stoves: Engineering Design, Development, and Dissemination* is an important work that describes practical methods to improve heat transfer and decrease the wood used for cooking.

The VITA stove is made from sheet metal that creates an appropriately sized gap between the pot and stove body. A grate holds the wood up over the floor, allowing air to pass through the fire. The pot is held up by three sturdy supports. Plans to build the stove are included in *Biomass Stoves*.

Since the pot is contained within the cylinder of sheet metal, both it and fire are protected from the wind. The stove will work well only with the intended pot. The stove is durable, lightweight and portable.

VITA Stove

Performance:

VITA Stove

The simple VITA stove is one of the most fuel-efficient stoves tested. The fire is close to the pot, and hot flue gases contact both the bottom and sides of the pot. It can boil water quickly.

Since the stove does not have a combustion chamber, merely an open space for the fire, and because the fire is close to the pot, emissions are rather high.

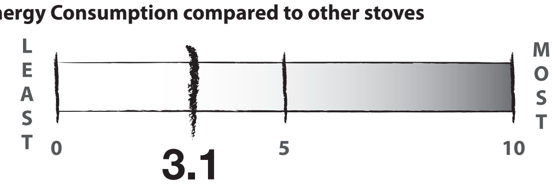
The VITA stove features ease of construction, low cost and decreased fuel use. This type of stove seems well-suited to emergencies and where cooking occurs outdoors in well-ventilated areas.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **14:00**

Energy Consumption compared to other stoves



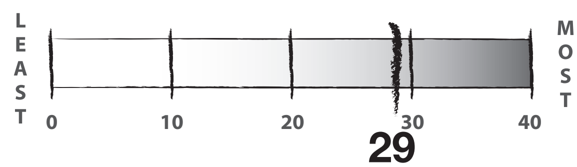
Fuel Used to Boil	**352 g**
+ Fuel Used to Simmer *5L of Water for 45 minutes*	**338 g**
TOTAL -	**689 g**

Cost and Safety

Cost = **$ 2.00**

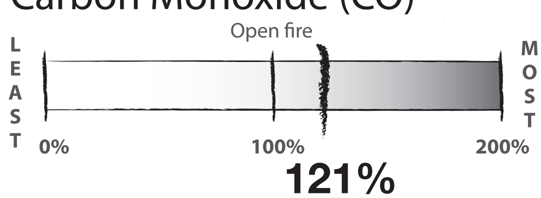
Fuel Use = **41 kg**
estimated per month

Safety Rating

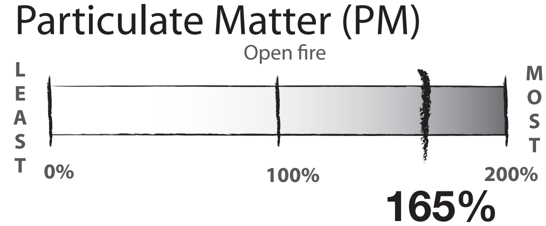


Emissions

Carbon Monoxide (CO)



Particulate Matter (PM)



Justa Stove

Origin: Central America

Weight: 175 kilos

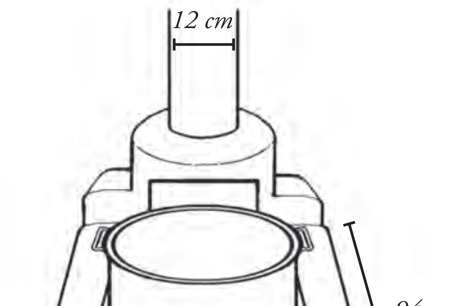
Fuel Type: Wood

Contact:
Trees, Water & People

633 Remington Street
Fort Collins, CO 80524

twp@treeswaterpeople.org

tel: (970) 484-3678
toll free: (877) 606-4897



Description:

The Justa stove body is constructed from bricks enclosing a rocket-type combustion chamber. The combustion chamber is made from "baldosa," a widely available and inexpensive ceramic floor tile.

Wood ash is deposited between the combustion chamber and the stove body. The wood ash almost fills the interior leaving a 2 cm channel between the ash and the griddle. Hot flue gases flow in this space to the chimney.

A constant cross-sectional area is maintained throughout the stove from the fuel entrance, up the combustion chamber, under the griddle, to the chimney. Heat transfer is increased because the hot gases are forced to scrape against the underside of the griddle. The wood ash insulation helps to keep the gases hot, while the constant cross-sectional area of the spaces inside the stove reduce friction that would slow the gases. Heat has to pass through the griddle to the pots on top of it.

Justa Stove

Performance:

Justa Stove

The Justa stove can heat two or three pots of food at once. It is designed for Central America, where the griddle is used for making tortillas. Since heat has to pass through the griddle to the pots of food, the stove uses more fuel than a single-pot stove to boil and simmer water.

However, the sealed stove body takes almost all pollution out of the room through the chimney. This type of stove, with a functional chimney, can solve the problem of indoor air pollution. The solid body also protects the occupants from burns.

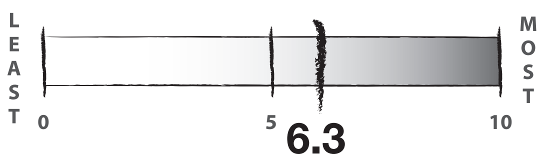
The griddle-type stove provides the cook with many advantages: clean pots, clean kitchen, greater convenience, and potentially reduced fuel use for a variety of cooking tasks. In field tests, the Justa stove saved approximately 70% of the wood typically used for cooking.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **46:42**

Energy Consumption compared to other stoves



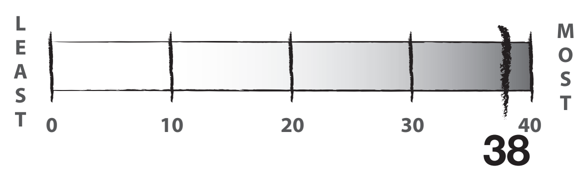
	Fuel Used to Boil	**662 g**
+	Fuel Used to Simmer *5L of Water for 45 minutes*	**704 g**
	TOTAL -	**1,367 g**

Cost and Safety

Cost = **$ 60.00**

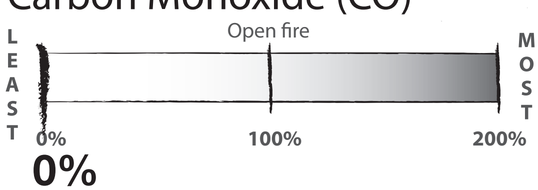
Fuel Use = **82 kg**
estimated per month

Safety Rating

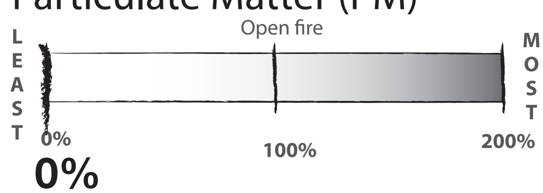


Emissions (in Test Kitchen)

Carbon Monoxide (CO)



Particulate Matter (PM)



The Justa stove and Patsari Prototype were not tested in the test kitchen since they are stationary stoves. However, like the other stoves with chimneys, they can be expected to produce close to 0.0 CO and PM because the chimney removes pollution from the room.

Uganda 2-pot

Origin: Uganda

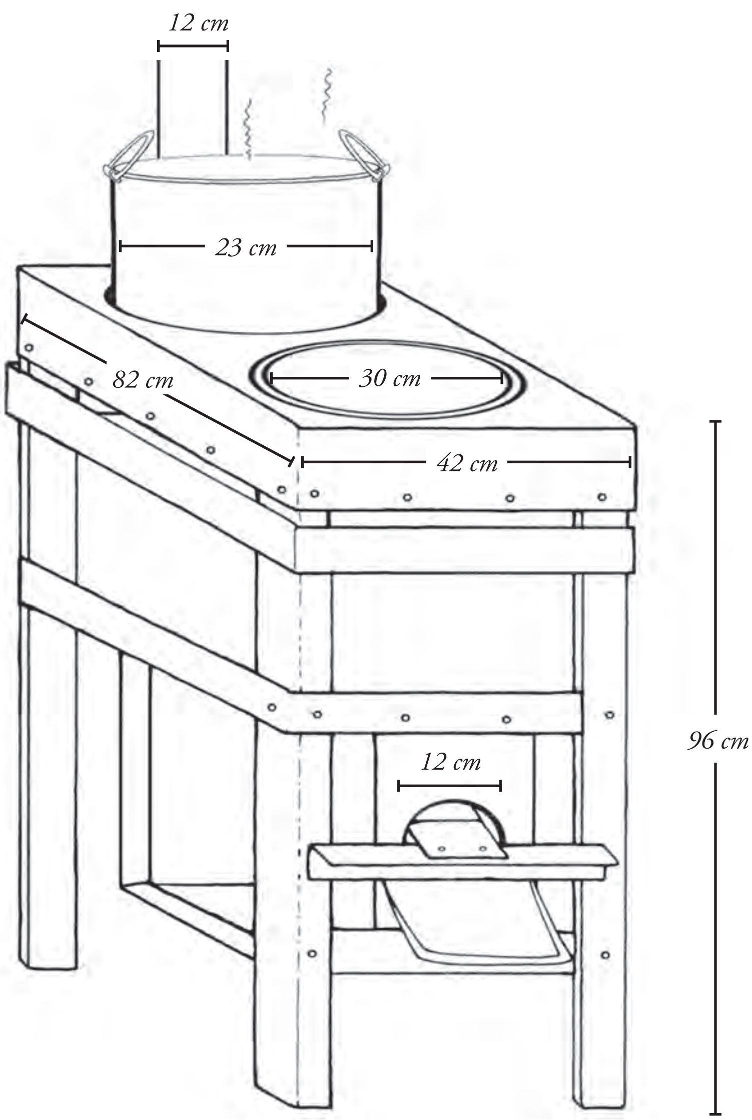
Weight: 36 kilos

Fuel Type: Wood

Contact:
Aprovecho Research Center

PO Box 1175
Cottage Grove, Oregon 97424

www.aprovecho.org
tel: 541 767-0287



Description:

The Uganda 2-pot stove has a rocket-type combustion chamber made from lightweight insulative fire brick. The hot gases made by the fire pass through narrow, insulated channels around the first pot, which is deeply sunk into the stove. The gases then pass through an insulated tunnel and are forced into narrow channels around the second pot before exiting the chimney. The pots fit tightly into holes in the sheet metal top, preventing smoke from escaping into the kitchen.

Like the VITA and Mud/Sawdust stoves, this stove only works well with the pots that come with it. Sinking pots into cylinders that force hot gases to scrape against the sides of the pots increases efficiency and decreases wood use. However, this technique requires the use of specified pots.

Uganda 2-pot

Uganda 2-pot

Performance:

This stove is fast to boil and uses less wood than most stoves with chimneys. Sunken pots help to dramatically improve fuel use and time to boil in stoves with chimneys. Smoke exits the room up the chimney.

The first pot is 30 cm in diameter, which uses up most of the heat from the fire. The smaller 23 cm pot will not boil but instead is designed to simmer sauce while corn porridge is being prepared in the larger pot. For both pots to boil, the first pot needs to be smaller than 25 cm, or the firepower has to be increased.

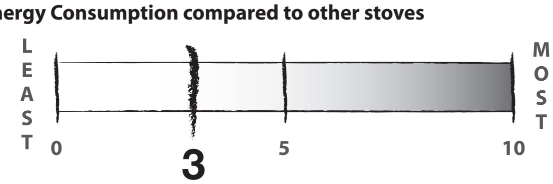
The fire brick insulates the stove body, which does not get very hot, making this a safer stove.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **16:12**

Energy Consumption compared to other stoves



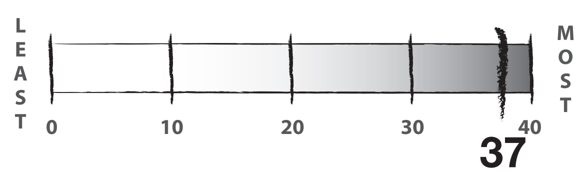
Fuel Used to Boil	**262 g**
+ Fuel Used to Simmer *5L of Water for 45 minutes*	**459 g**
TOTAL -	**720 g**

Cost and Safety

Cost = **$ 40.00**

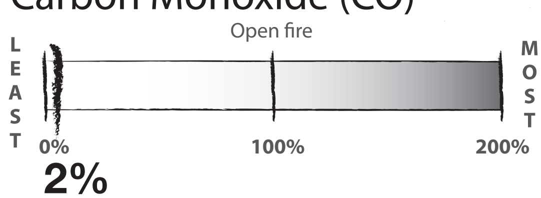
Fuel Use = **43 kg**
estimated per month

Safety Rating

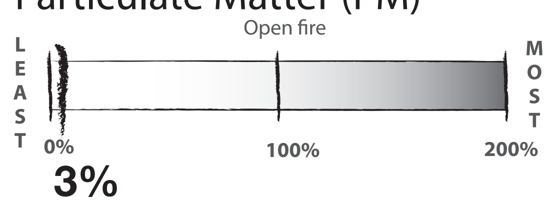


Emissions (in Test Kitchen)

Carbon Monoxide (CO)



Particulate Matter (PM)



Patsari Prototype

Origin: Pátzcuaro, Michoacán, Mexico

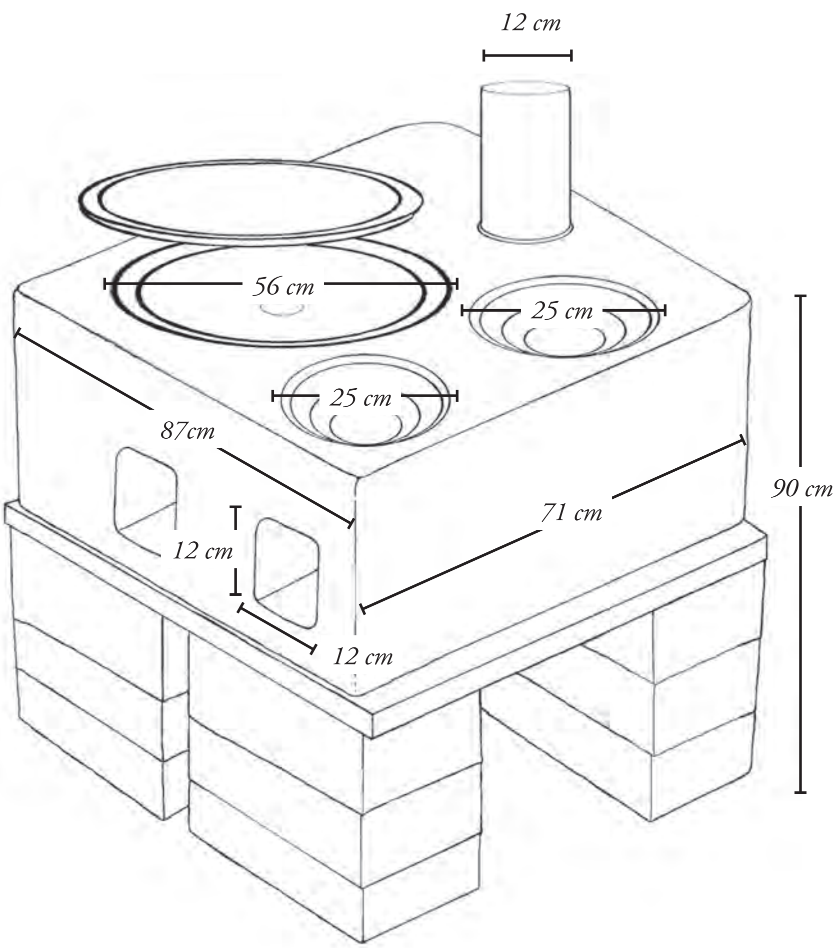
Weight: 280 kilos

Fuel Type: Wood

Contact: GIRA

Centro Comercial El Parián
Interior 17, Col. Morelos, A.P. 158, CP. 61609, Pátzcuaro, Michoacán, México

giraac@gira.org.mx
Tel: (+0052) (434) 342.32.16



Description:

The GIRA team developed the Patsari stove with indigenous people in the high-altitude, hilly regions of Mexico. This version has two hollow cylinders of insulative brick inside the spaces under the two pots. The fire directly hits the bottoms of both pots.

A second fire inside another insulated combustion chamber is used to cook tortillas on a large circular comal or griddle.

The stove is made from a Lorena-type earthen mixture of approximately 60% sand and 40% clay. Molds are used to ensure uniformity. The lightweight ceramic insulation near the fire, with the Lorena mix surrounding it, creates a composite material which is inexpensive and beautiful.

A chimney stove made mostly from sand and clay provides a family with a clean, pleasant cooking stove that removes harmful pollution from the kitchen.

Patsari Prototype

Patsari Prototype

Performance:

The stove with chimney removes essentially all of the harmful emissions from the room. The draft is sufficient to draw the smoke into the stove and up the chimney.

Since the pots in this version are directly contacted by the fire, the Patsari is more fuel efficient than other stoves with griddles.

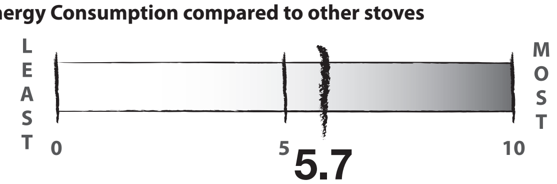
This is a safe stove which keeps heat inside and does not overly warm the exterior.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **34:48**

Energy Consumption compared to other stoves



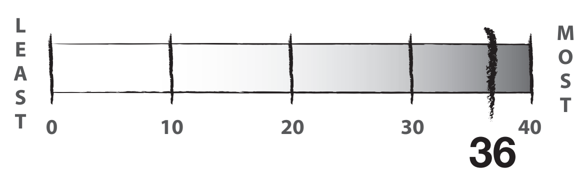
Fuel Used to Boil	**558 g**
+ Fuel Used to Simmer *5L of Water for 45 minutes*	**720 g**
TOTAL -	**1,277 g**

Cost and Safety

Cost = **$ 35.00**

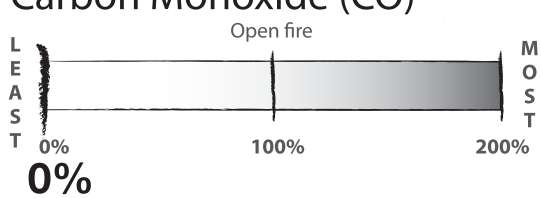
Fuel Use = **77 kg**
estimated per month

Safety Rating

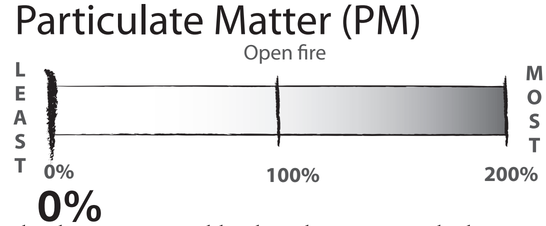


Emissions (in Test Kitchen)

Carbon Monoxide (CO)



Particulate Matter (PM)



The Patsari Prototype and the Justa stoves were not tested in the test kitchen. However, like the other stoves with chimneys, they can be expected to produce close to 0.0 CO and PM because the chimney removes pollution from the room.

Onil Stove

Origin: Guatemala

Weight: 280 kilos

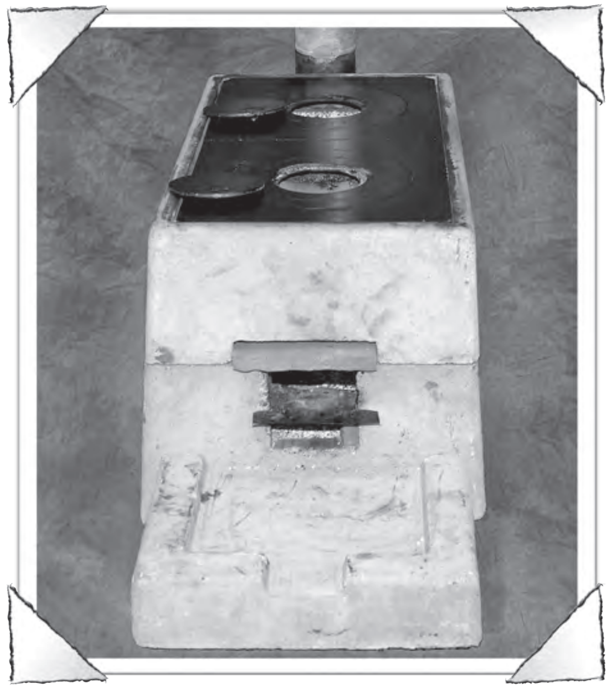
Fuel Type: Wood

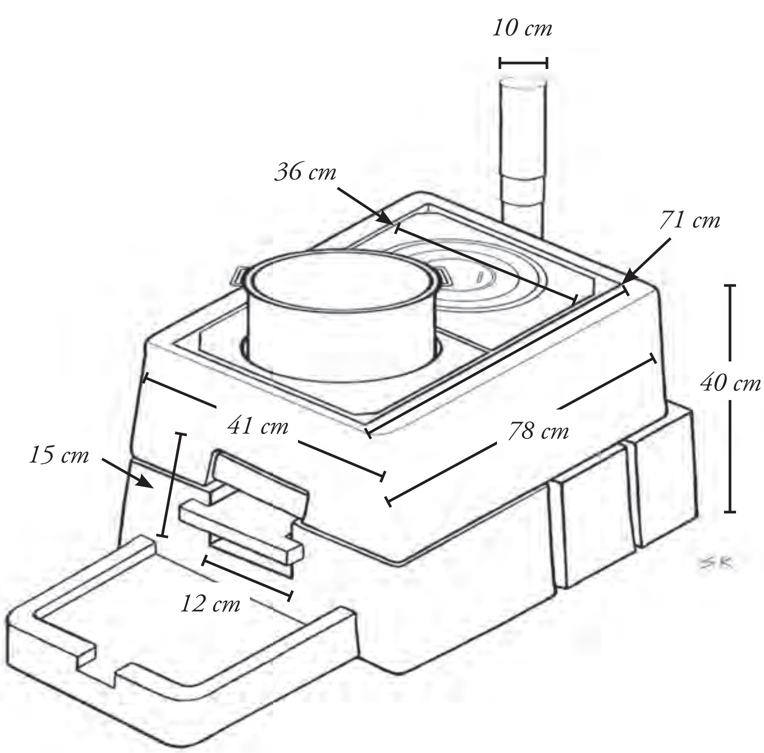
Contact:
HELPS International

15301 Dallas Pkwy. Suite 200
Addison, TX 75001

info@helpsinternational.com

tel: (972) 386-2901
toll free: (800) 414-3577





Description:

Don O'Neal developed this molded-cement griddle stove with the help of indigenous women in Guatemala. The three-part stove is made in a factory using molds.

A rocket combustion chamber made from ceramic floor tile material (molded baldosa) is surrounded by loose pumice used as insulation. The pumice fills the stove within 2 cm of the griddle, creating a wide channel that forces the hot flue gases to scrape against the underside of the griddle.

The griddle has removable inserts so flame can contact the bottom of the pots. A protected fence around the chimney (not pictured) guards the users from burns.

The Onil stove is made in a factory and looks professionally made. The molded-cement body is strong and very long lasting.

Onil Stove

Performance:

Onil Stove

The Onil is a well-thought-out stove that can boil two pots of water exposed to flame and hot gases. The removable inserts are well made and fit large and small pots.

Fuel use is similar to the Justa. Smoke is removed from the kitchen through the functional chimney.

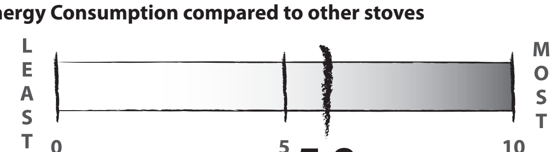
The Onil ranks high on safety and is a fine example of an improved griddle-type stove. Field surveys found that the Onil stove uses approximately 70% less wood than traditional cooking methods in Guatemala.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **28:00**

Energy Consumption compared to other stoves



5.8

Fuel Used to Boil **584 g**

\+ Fuel Used to Simmer **802 g**

5L of Water for 45 minutes

TOTAL - **1,386 g**

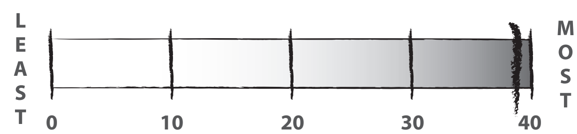
Cost and Safety

Cost = **$ 72.00**

Fuel Use = **83 kg**

estimated per month

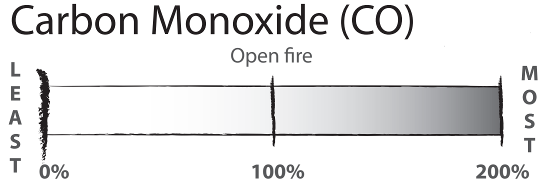
Safety Rating



39

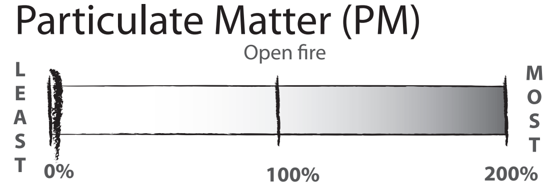
Emissions (in Test Kitchen)

Carbon Monoxide (CO)



0%

Particulate Matter (PM)



1%

Ecostove

Origin: Brazil, Nicaragua, Honduras

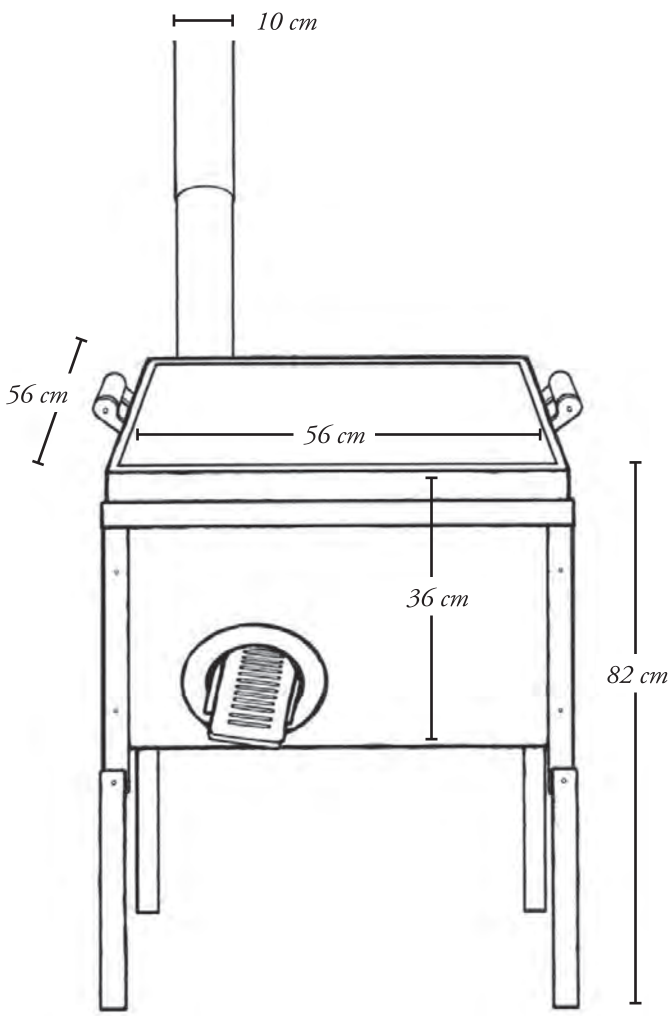
Weight: 45 kilos

Fuel Type: Wood

Contact: Brazil: ECOFOGAO Ltda, Rogerio Miranda ecofogao@ecofogao.com.br

Nicaragua: PROLEÑA Marlyng Buitrago; mbprolena@hotmail.com

Honduras: AHDESA, Ignacio Osorto Núñez; ignacio.osorto@ahdesa.org
tel: (504) 226-4527



Description:

The Ecostove was developed by Rogerio Carneiro de Miranda in Nicaragua and Brazil. PROLEÑA has made thousands of stoves of this type in Nicaragua.

The Brazilian Ecostove has a heavy cast iron griddle that provides an excellent cooking surface. A handmade ceramic rocket combustion chamber is surrounded by lightweight cement insulation made from Aerated Autoclaved Cement. A channel under the griddle ensures improved heat transfer. Baffles direct hot flue gases to more evenly heat the griddle before exiting the chimney.

The body of the Ecostove is made from painted sheet metal and angle iron. The cooking surface is at waist height. The stove seems very well suited for making tortillas or for any type of grilling. Furthermore, it can be equipped with a coil to heat piped-in water.

Ecostove

Performance:

Ecostove

Like other griddle stoves, the Ecostove is designed to cook tortillas. Large amounts of grilled food can be prepared at the same time. Once the griddle is warm, the stove can boil water in about 30 minutes. However, it can use more fuel than an open fire to boil water from a cold start. This stove was a favorite of cooks at Aprovecho since large amounts of fried food can be prepared at the same time.

The heavy griddle takes time and fuel to heat initially, but once warm, the stove had about the same fuel economy as other griddle stoves.

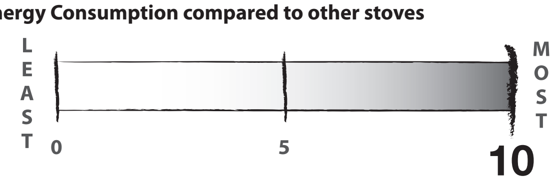
The Ecostove chimney removed almost all the smoke from the test kitchen, creating a much safer and cleaner living space.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **38:36**

Energy Consumption compared to other stoves



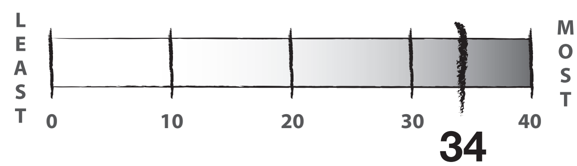
Fuel Used to Boil	**1,171 g**
+ Fuel Used to Simmer *5L of Water for 45 minutes*	**843 g**
TOTAL -	**2,014 g**

Cost and Safety

Cost = **$ 60.00**

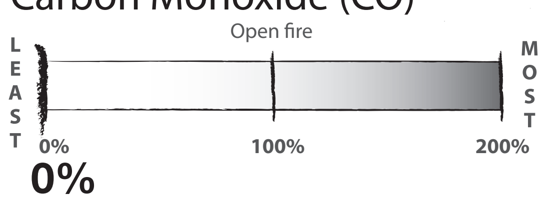
Fuel Use = **121 kg**
estimated per month

Safety Rating

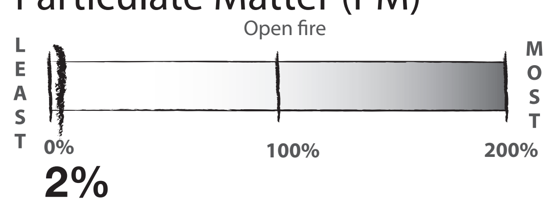


Emissions (in Test Kitchen)

Carbon Monoxide (CO)



Particulate Matter (PM)



Wood Flame

Origin: Canada

Weight: 6 kilos

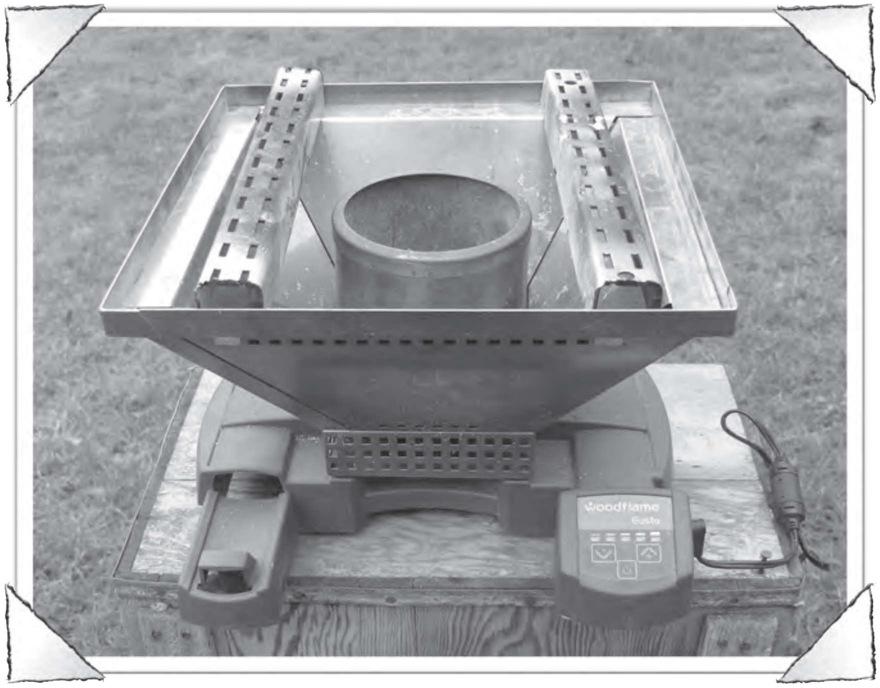
Fuel Type: Wood

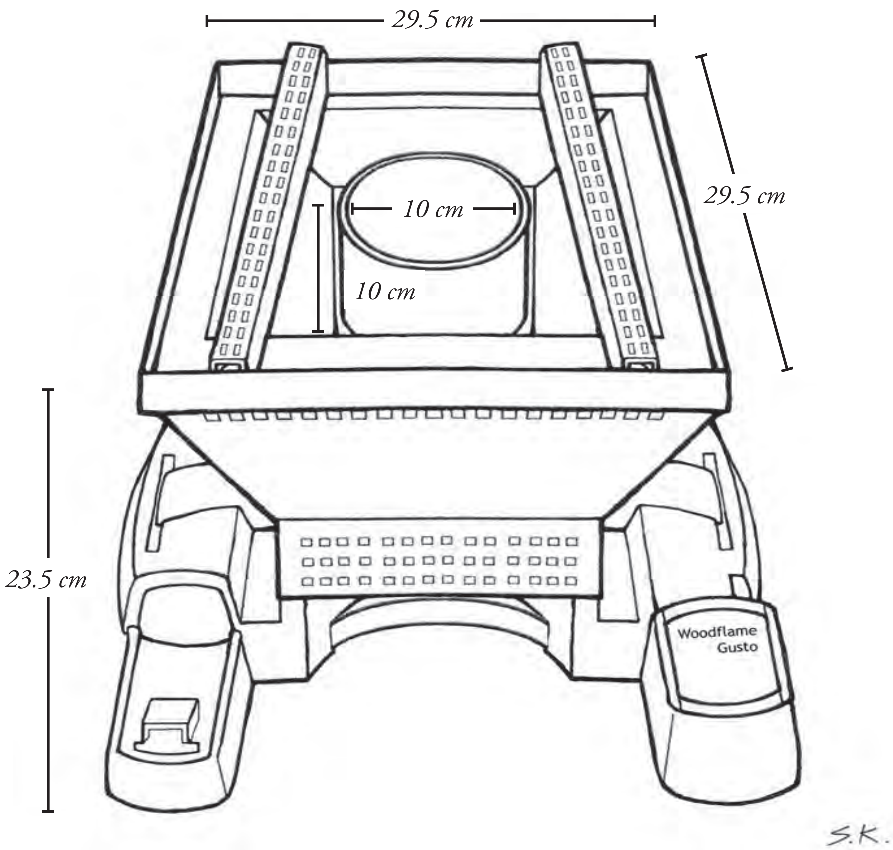
Contact: Woodflame

6155 Des Grandes-Prairies
Blvd. Montreal (Québec),
Canada H1P 1A5

info@woodflame.com

tel: (514) 328-2929
toll free: (888) 664-6966





Description:

The Wood Flame stove uses a small, externally powered electric fan to mix wood gases, air and flame to clean up combustion. In the bottom of the metal combustion chamber are many very small holes which send strong jets of air up through the burning wood.

A griddle used for grilling comes with the stove. When tested, the griddle was removed and supports were made to hold up the pot.

The combustion chamber is filled with small pieces of wood and lit. As the fire grows larger, the speed of the fan is increased manually, creating a small blast furnace. Wood is added to the combustion chamber by sliding it under the pot.

Blowing air up into the fire causes the fire to look very "jumpy" and frenzied. Flames turn from yellow to reddish to blue at various stages of burning.

Wood Flame


Wood Flame

Performance:

The Wood Flame stove uses a batch of wood to grill foods. In these tests, the grill is removed so a full Water Boiling Test can be performed.

This is an interesting stove to use, with nine fan speeds. The amount of air is matched to the size of the fire. The stove is amazingly clean burning and uses a reduced amount of fuel. Feeding the stove under the pot is challenging, however.

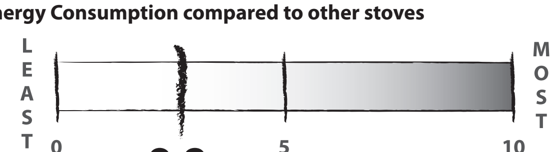
The stove uses much less wood than the 3 Stone Fire and makes only 16% the CO and 2% of the PM made by the 3 Stone Fire.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **19:30**

Energy Consumption compared to other stoves



2.8

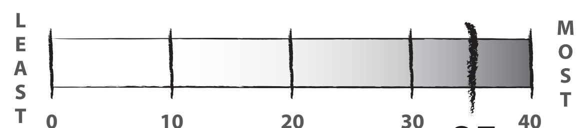
Fuel Used to Boil	**249 g**
+ Fuel Used to Simmer *5L of Water for 45 minutes*	**377 g**
TOTAL -	**626 g**

Cost and Safety

Cost = **$ 229.00**

Fuel Use = **38 kg**
estimated per month

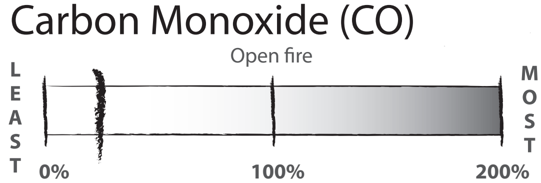
Safety Rating



35

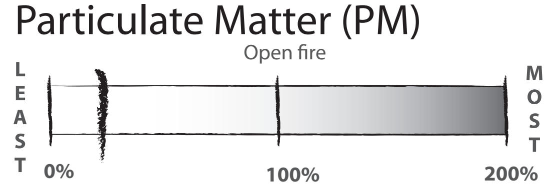
Emissions

Carbon Monoxide (CO)



24%

Particulate Matter (PM)



14%

Wood Gas

Origin: Prototype

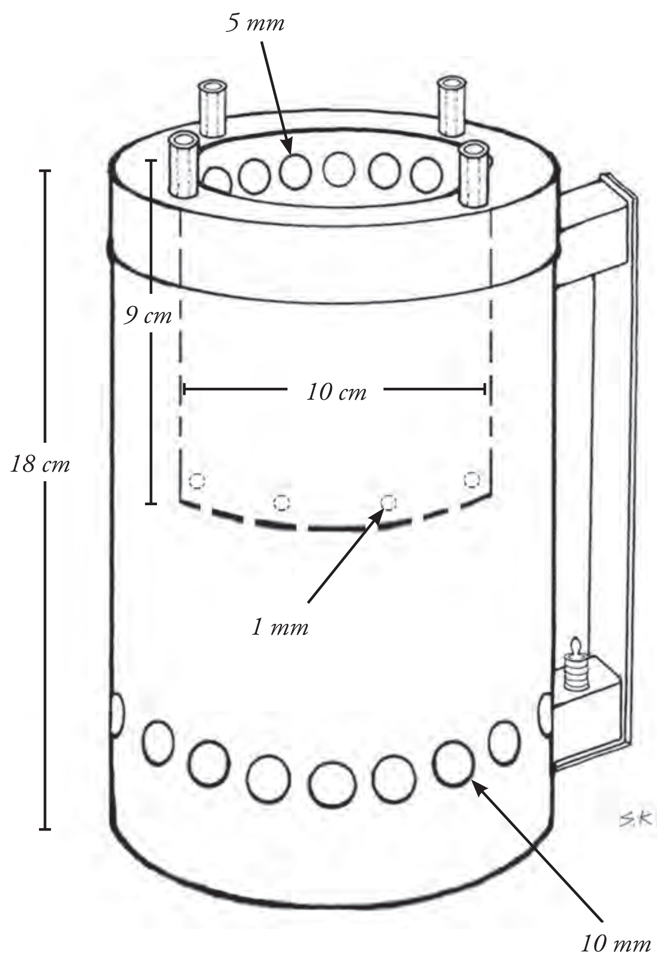
Weight: 1 kilo

Fuel Type: Wood

Contact: Dr. Paul Anderson
Biomass Energy Foundation

227 South Orr Drive
Normal, IL 61761
www.biomassenergyfoundation.org

tombreed2009@gmail.com
tel: (309) 452-7072



Description:

Dr. Tom Reed has spent decades studying and designing stoves in which wood gases are burned in two stages. This stove is started by top-lighting a batch of fuel that burns gases rising up into the fire zone.

The Wood Gas stove is made from sheet metal. The combustion chamber has holes near the bottom and larger holes near the top. A fan powered by an external battery blows jets of air into the fire. The fan is located under the fire.

This very lightweight stove could fit into a backpack. The handle makes moving the stove easy, even when lit.

Wood Gas

Performance:

The Wood Gas stove is very clean burning and uses less fuel than other stoves to boil and simmer water. Like the Wood Flame stove, it shows the ability of a fan to dramatically lower emissions.

This is a small camping stove, so to complete the Water Boiling Test, fuel must be added piece by piece to the fire under the pot. This manouver is a bit difficult.

Wood Gas

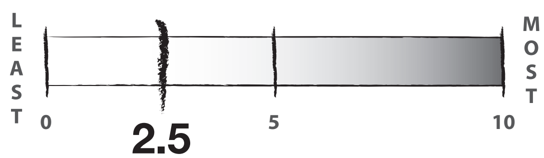
How the stove burns wood seems almost miraculous. There is no smoke after starting the fire; fan stoves operate almost as cleanly as liquid-fueled stoves.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **23:42**

Energy Consumption compared to other stoves



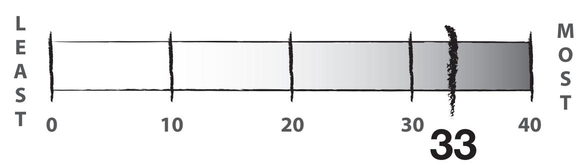
Fuel Used to Boil	**235 g**
+ Fuel Used to Simmer *5L of Water for 45 minutes*	**224 g**
TOTAL -	**459 g**

Cost and Safety

Cost = **$ 55.00**

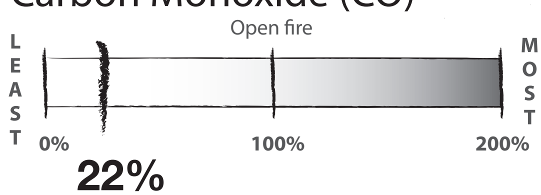
Fuel Use = **28 kg**
estimated per month

Safety Rating

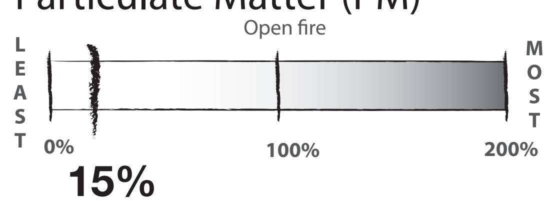


Emissions

Carbon Monoxide (CO)



Particulate Matter (PM)

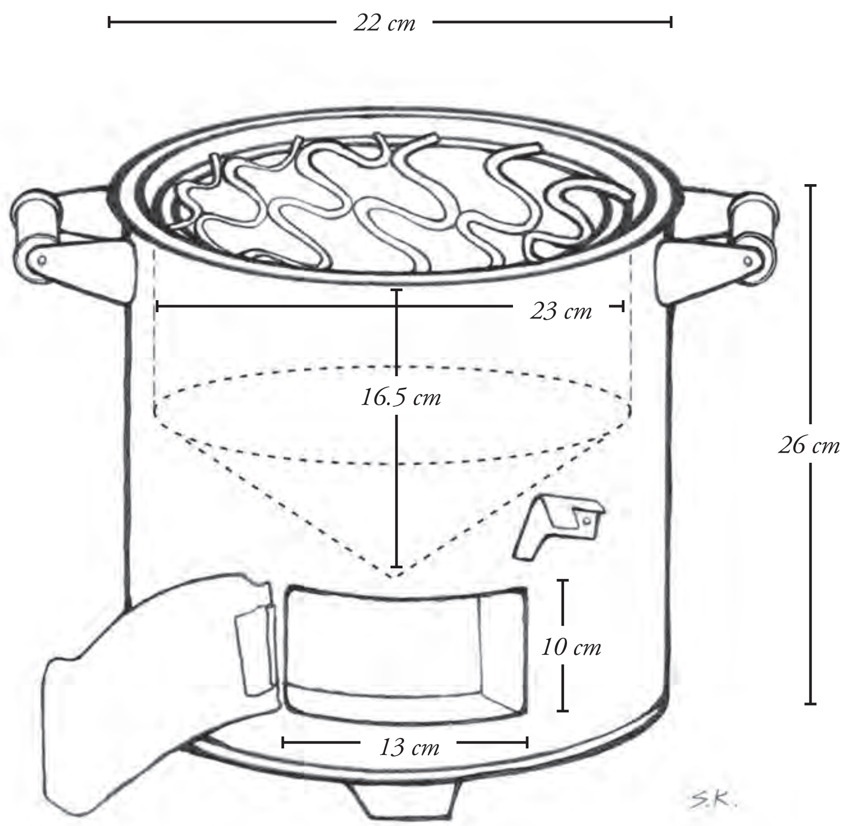


Mali Charcoal

Origin: Mali

Weight: 4.2 kilos

Fuel Type: Charcoal



Description:

The Mali charcoal stove is made from silver-painted sheet metal. A door controls the amount of air entering underneath the charcoal. Controlling the air saves charcoal, especially during simmering, when less heat is needed. A ring can be removed to lower the pot when smaller amounts of charcoal are used.

An air gap between the conical combustion chamber and the outside of the stove helps reduce external temperatures. The conical combustion chamber helps the charcoal slide into the center as it is consumed.

A draft is created that pulls air up through the fire, increasing the heat available for boiling. This increased draft takes the place of blowing on the charcoal to increase firepower.

Mali Charcoal

Mali Charcoal

Performance:

Opening the door increases the draft, which speeds combustion. Closing the door saves fuel and provides the reduced heat needed for efficient simmering.

It's easy to see why people like charcoal. Once the fire is lit, cooking with charcoal is almost as convenient as liquid fuel.

However, burning charcoal can emit high levels of CO. Especially at high power, the levels of CO emitted were dangerous.

On the other hand, emissions of PM were lower than from most wood-burning stoves.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **38:36**

Energy Consumption compared to other stoves

5.3

Fuel Used to Boil	**406 g**
+ Fuel Used to Simmer *5L of Water for 45 minutes*	**268 g**
TOTAL -	**674 g**

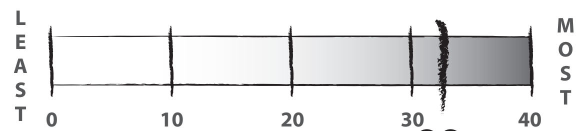
Cost and Safety

Cost = **$ 5.00**

Fuel Use = **40 kg**

estimated per month

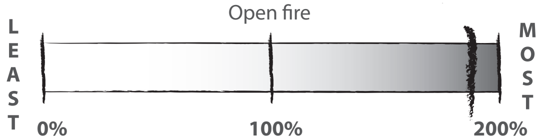
Safety Rating



33

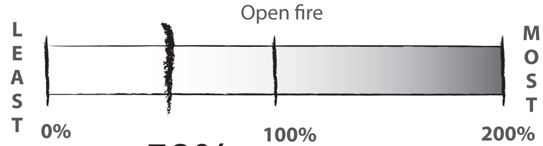
Emissions

Carbon Monoxide (CO)



194%

Particulate Matter (PM)



56%

Gyapa Charcoal

Origin: Ghana

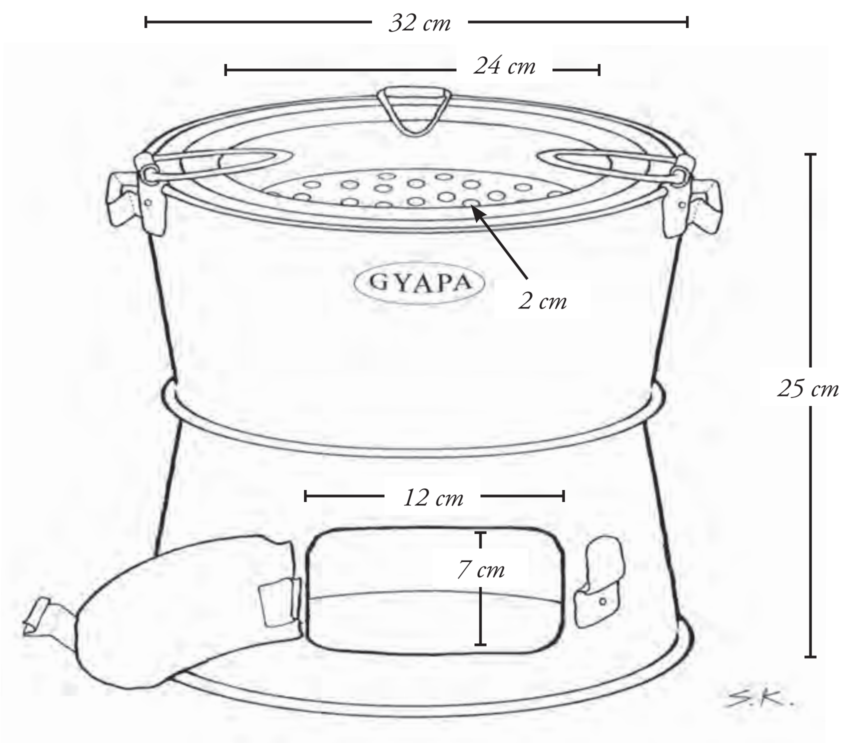
Weight: 9 kilos

Fuel Type: Charcoal

Contact:
Relief International/
EnterpriseWorks-VITA

1100 H Street NW, Suite 1200
Washington, DC 20005
www.enterpriseworks.org

tel: (202) 639-8660
fax: (202) 639-8664



Description:

The Gyapa charcoal-burning stove is produced by Enterprise Works/VITA in Ghana. The stove has a ceramic liner bonded to the sheet metal body by an insulative, cement-like adhesive. The charcoal sits on a ceramic grate.

The door under the grate allows varying amounts of air to pass up into the fire, which raises and lowers firepower. Having a door on the opening under the fire seems to be an important feature in an improved charcoal-burning stove.

Three supports made from bent steel bars hold the pot close to the fire. Sturdy handles facilitate portability of the stove.

Gyapa Charcoal

Performance:

Gyapa Charcoal

The Gyapa is somewhat faster to boil than the Mali stove while using less fuel. However, fuel use for both boiling and simmering is approximately the same for the two stoves.

The ceramic liner in the Gyapa may help to lower the temperature of the external stove body.

The stove boils water relatively quickly with the door open and simmers nicely with the door closed or mostly shut. Again, the amount of CO emitted was high while PM was reduced, compared to the 3 Stone Fire.

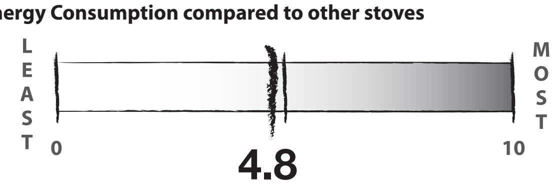
Closing the door lowers the firepower and reduces the emissions of CO. For this reason, charcoal stoves seem to be safer when simmering.

Test Results

Fuel Economy

Time to Boil *5L of Water* - **28:24**

Energy Consumption compared to other stoves



Fuel Used to Boil	**342 g**
+ Fuel Used to Simmer	**353 g**
5L of Water for 45 minutes	
TOTAL -	**694 g**

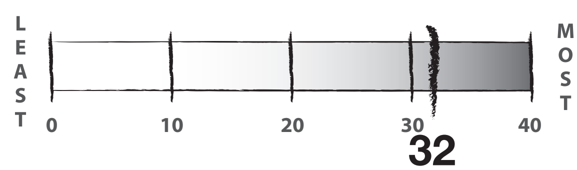
Cost and Safety

Cost = **$ 5.90**

Fuel Use = **42 kg**

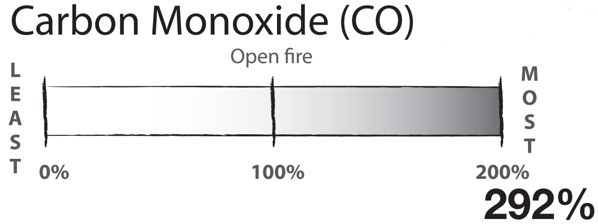
estimated per month

Safety Rating

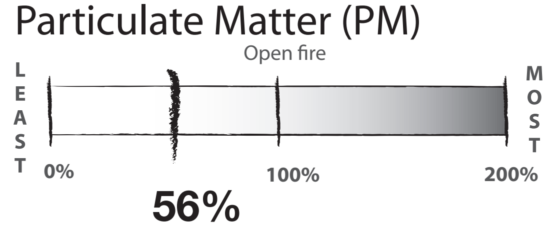


Emissions

Carbon Monoxide (CO)



Particulate Matter (PM)



Propane

Origin: USA

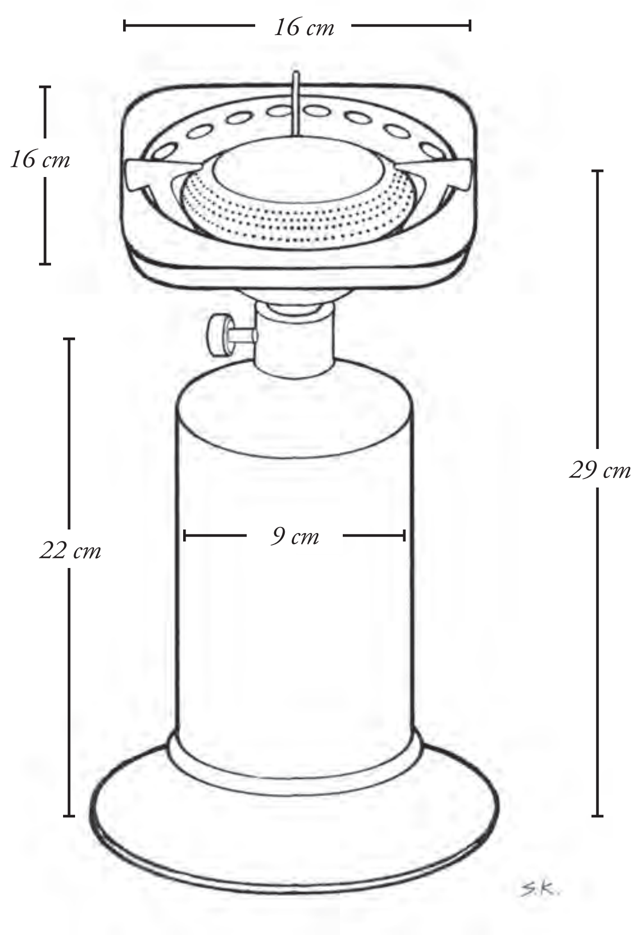
Weight: 1.8 kilos

Fuel Type: Propane

Contact:
Century Tool & Manufacturing

1462 US Route 20 Bypass
P.O. Box 188
Cherry Valley, Illinois 61016

tel: (800) 435-4525



Description:

The stove consists of a single burner that screws onto a propane cylinder. A knob under the burner adjusts the rate of burn. It is very pleasant to go so easily from high to low power with the twist of a knob.

The stove burns with a hot blue flame, created by precise mixing of gas, air and flame. The gas exits under pressure, which aids the superior mixing. The stove sits on top of a wider stand that makes it more stable.

A propane stove delivers controllable, clean heat that is appreciated by cooks around the world.