Aprovecho Research Center
80574 Hazelton Road, Cottage Grove, OR 97424-9747, USA
phone: (541) 942-8198 fax: (541) 942-8198
e-mail: apro@efn.org webpage: http://www.efn.org/~apro

Stove Design and Performance Training

Dhaka Bangladesh

November 30-December 2 2011

Mike Hatfield – Aprovecho Reserch Center, USA

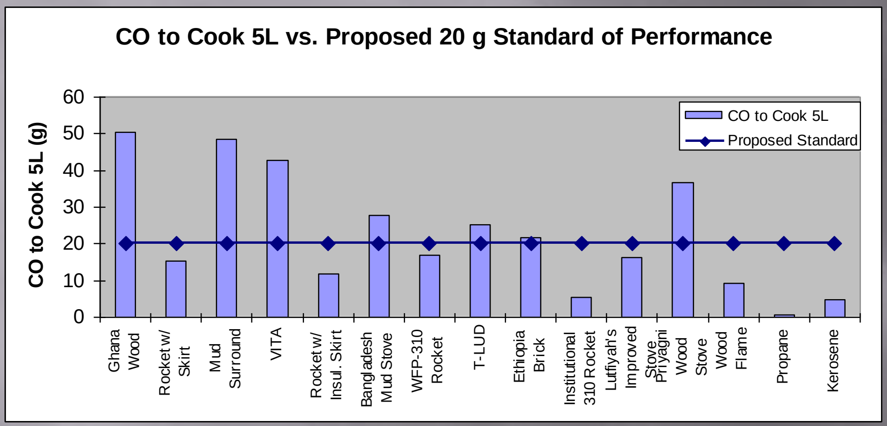
Aprovecho Research Center
80574 Hazelton Road, Cottage Grove, OR 97424-9747, USA
phone: (541) 942-8198 fax: (541) 942-8198
e-mail: apro@efn.org webpage: http://www.efn.org/~apro

Aprovecho Research Center

Started in 1976 with invention of Lorena Stove

A failure!!!!

Aprovecho Research Center
80574 Hazelton Road, Cottage Grove, OR 97424-9747, USA
phone: (541) 942-8198 fax: (541) 942-8198
e-mail: apro@efn.org webpage: http://www.efn.org/~apro



Two focuses

1 - In Field Projects

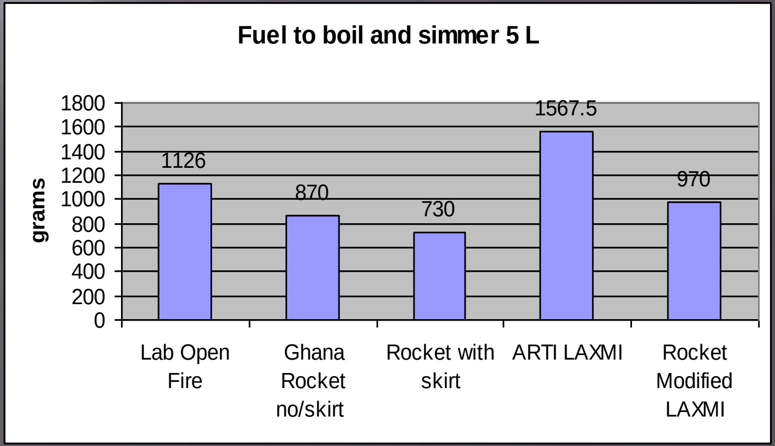
2 - Monitoring and Evaluation

Aprovecho Stove Projects and Trainings

Active Stove Projects in over 20 countries – Trainings in 30 countries with participants from over 60 countries – Tested and evaluated over 100 stoves

Aprovecho Research Center
80574 Hazelton Road, Cottage Grove, OR 97424-9747, USA
phone: (541) 942-8198 fax: (541) 942-8198
e-mail: apro@efn.org webpage: http://www.efn.org/~apro

Lab Work



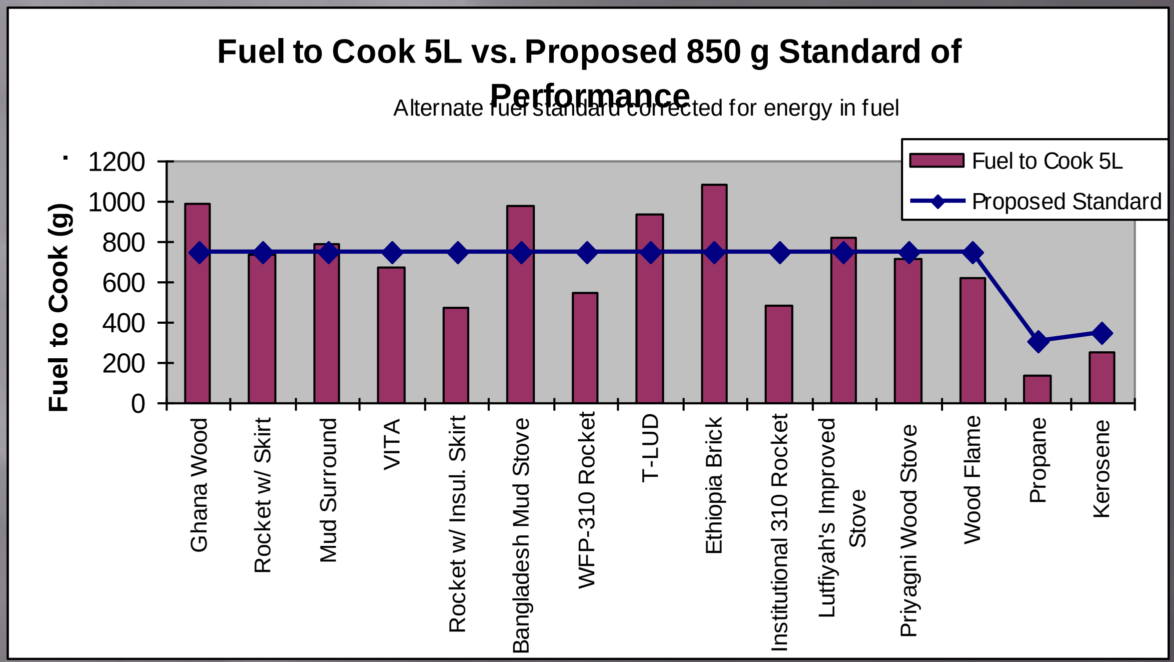
International Testing Center

Creation of Regional Testing Centers

Aprovecho Research Center

80574 Hazelton Road, Cottage Grove, OR 97424-9747, USA
phone: (541) 942-8198 fax: (541) 942-8198
e-mail: apro@efn.org webpage: http://www.efn.org/~apro

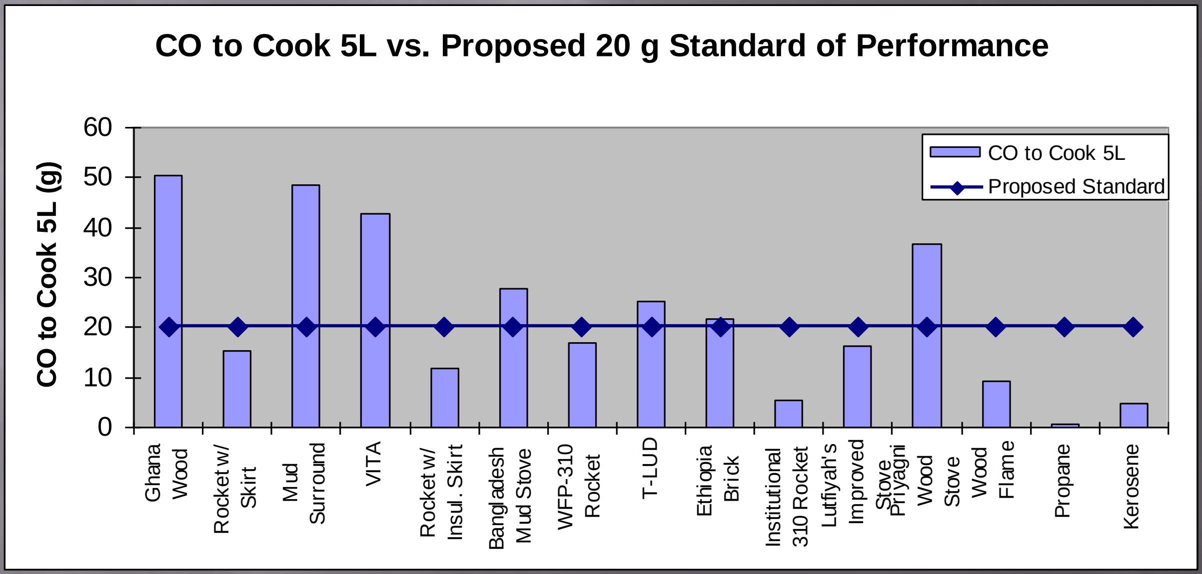
Lab Work



Creating International Standards of Performance

Aprovecho Research Center
80574 Hazelton Road, Cottage Grove, OR 97424-9747, USA
phone: (541) 942-8198 fax: (541) 942-8198
e-mail: apro@efn.org webpage: http://www.efn.org/~apro

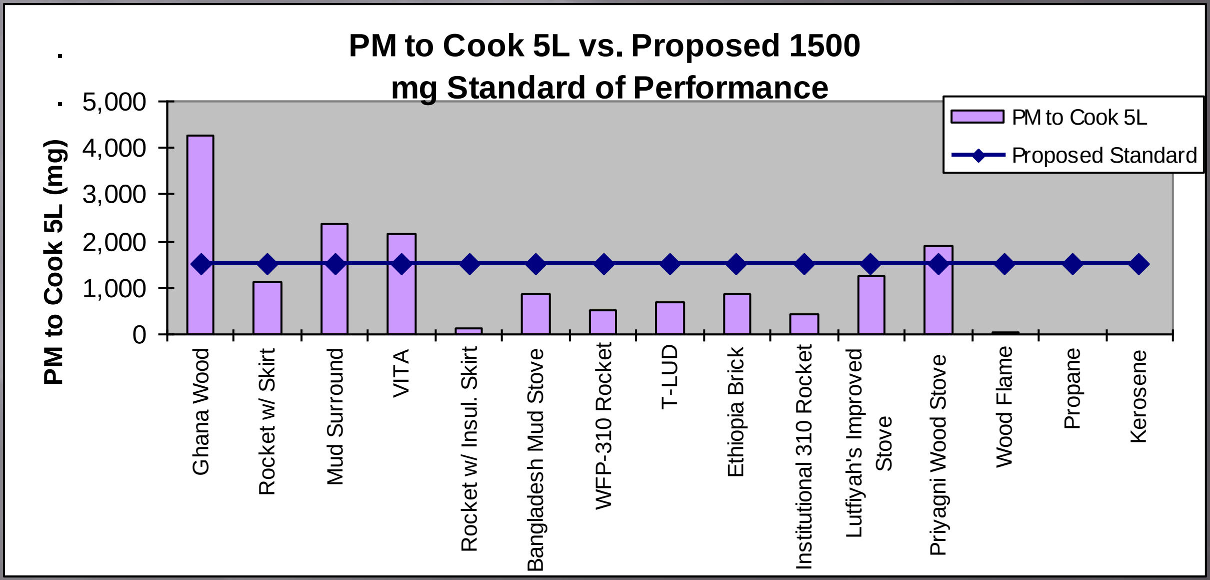
Lab Work



Creating International Standards of Performance

Aprovecho Research Center
80574 Hazelton Road, Cottage Grove, OR 97424-9747, USA
phone: (541) 942-8198 fax: (541) 942-8198
e-mail: apro@efn.org webpage: http://www.efn.org/~apro

Lab Work



Creating International Standards of Performance

Elements of an improved stove (ICS)

There are four goals we need to meet when designing a stove –

1- The stove cooks food as well or better than the traditional method

2- The stove eliminates or reduces the amount of smoke in the kitchen

3- It uses less fuel to cook food

4- Is producible at a cost that is acceptable to users

Elements of an improved stove

1 - The stove cooks food as well or better than the traditional method

- Use local cooks throughout design process
- Form a stove committee
- Perform tests using local cooks (CCT and KPT)
- Follow up by independent organizations

Elements of an improved stove

2 - The stove eliminates or reduces the amount of smoke in the kitchen

- Worldwide 1.6 million people, mostly women and young children, die each year from breathing wood smoke!!
- By cleaning up combustion as best we can and then making sure cooks are not exposed to what smoke is produced we reduce health risks of biomass cooking.
- Chimneys

Elements of an improved stove

3 - It uses less fuel to cook food

- Often meeting goals one and two will be in direct conflict with fuel savings
- Requires testing (WBT,CCT, KPT) to determine if fuel is in truth being saved

Elements of an improved stove

4 - Is producible at a cost that is acceptable to users

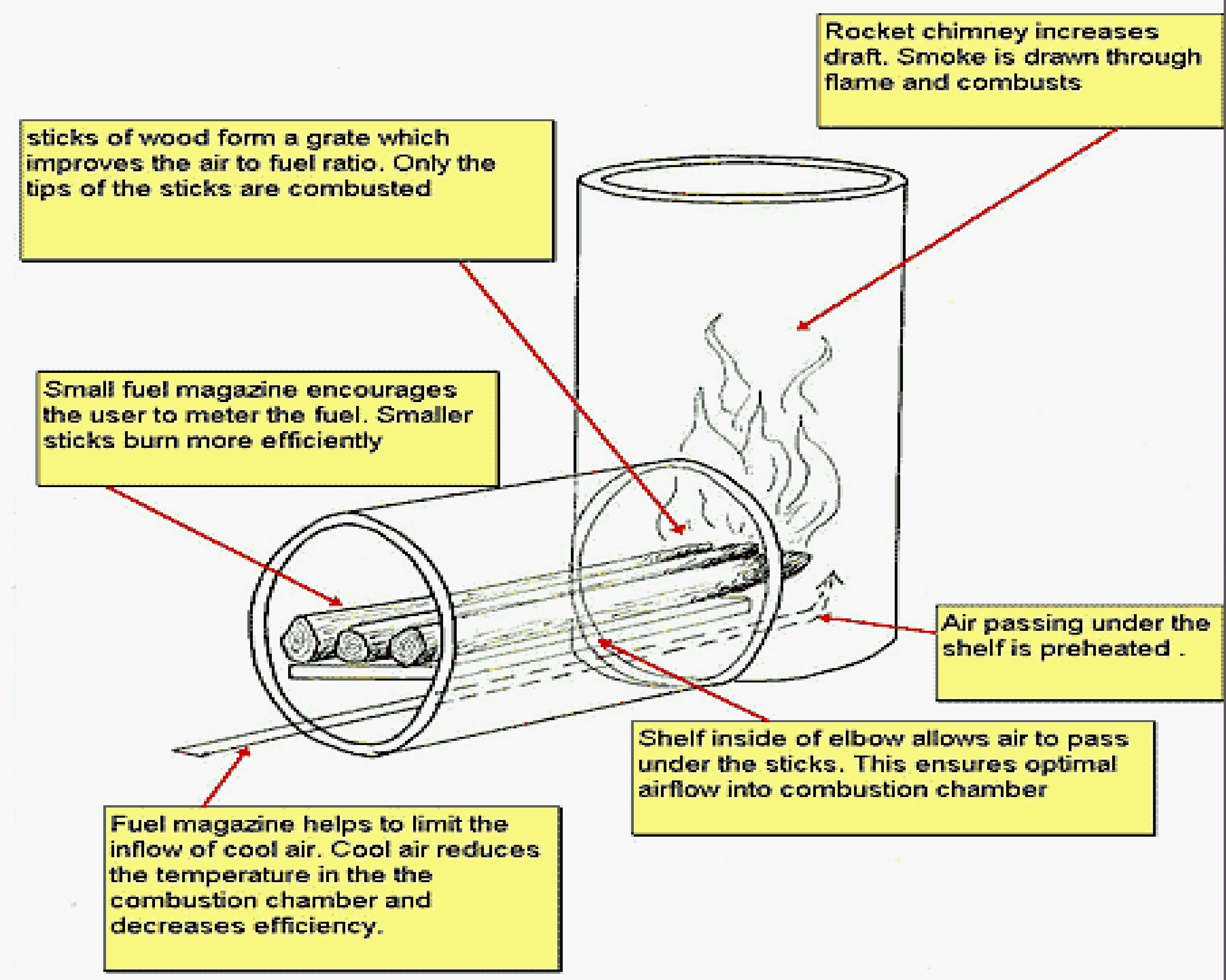
- Given enough money almost any stove can be made
- To reach the majority of the some 3 billion people who cook on biomass we need to have a stove that sells for as little as $5
- Other options – Micro Finance, Carbon Credits…?

Simplified Designing of an Improved Stove

1 – Improved Combustion and/or chimney

2 - Improved Heat Transfer

There are many ways to achieve our goals



Simplified combustion theory review

- Wood doesn't burn
- Wood gets hot and releases volatile gases that then combust
- If wood is heated to 650 degrees Celsius (and sufficient oxygen is mixed with the volatile gases) the result is complete combustion. The products of clean combustion are CO_2 , water vapour and heat.
- For this to happen we need to have sufficient **Time, Temperature and Turbulence**
- A lot of heat, roughly speaking, dry wood has **half** the energy per kg as gasoline
- Smoke is wasted energy

What are limiting factors to high temperatures and achieving complete combustion ?

Challenge # 1

- **Cool stove body**
- **Cool earth**
- The body of the stove or of the earth **robs** heat from the fire
- Which lowers combustion temperature, decreases efficiency, and increases smoke

Aprovecho Research Center
80574 Hazelton Road, Cottage Grove, OR 97424-9747, USA
phone: (541) 942-8198 fax: (541) 942-8198
e-mail: apro@efn.org webpage: http://www.efn.org/~apro

Lorena Stove

1 m x 1 m x 1 m = 1,000,000 cc
Density of 1.5 g/cc – 1,500 KG
-Tunnels = about 1,000 KG

1 kg clay raised 1 deg C = 1.38 KJ

1.38 KJ x 100 deg x 1,000 KG
= 138 MJ or 7KG dry wood
Plus thermal conductivity losses

What are limiting factors to high temperatures and achieving complete combustion ?

Challenge # 1

- **Cool stove body**
- **Cool earth**
- The body of the stove or of the earth **robs** heat from the fire
- Which lowers combustion temperature, decreases efficiency, and increases smoke

Solution?

- Insulate the stove with low mass, heat resistant materials in order to keep the fire as hot as possible
- Remember mass is the opposite of insulation
- Effective stove insulators are pumice, vermiculite, and wood ash
- Dense things such as earth, sand, cement, water and cast iron are poor insulators

Maximizing combustion efficiency

- <u>Challenge #2</u>
- Cool wood
- Which lowers combustion temperatures…which decreases efficiency…And increases smoke

Maximizing combustion efficiency

- Challenge #2
- Cool wood
- Which lowers combustion temperatures…which decreases efficiency…And increases smoke

- Solution?
- Meter the fuel!
- Use small sticks whenever possible
- Maximize the surface area of the wood exposed to coals
- Heat only the fuel that is burning
- Burn the tips of sticks only as they enter the combustion chamber

Maximizing combustion efficiency

- Challenge # 3
- Cool air/ Too much air
- Which lowers combustion temperature, decreases efficiency, and increases smoke
- Note: an open fire can draw 20 times more than is required for stochiometric (chemically ideal) combustion

Maximizing combustion efficiency

- Challenge # 3
- Cool air/ Too much air
- Which lowers combustion temperature, decreases efficiency, and increases smoke
- Note: an open fire can draw 20 times more than is required for stochiometric (chemically ideal) combustion

- Solution ?
- Do not allow too much or too little air to enter the combustion chamber.
- There should be a minimum excess of air supporting clean burning.

Maximizing combustion efficiency

- Challenge # 4
- Cool cooking pot
- The cooking pot is generally no more than a 100 –200 degrees Celsius
- Flames touching the pot?
- **Soot and smoke!**

Maximizing combustion efficiency

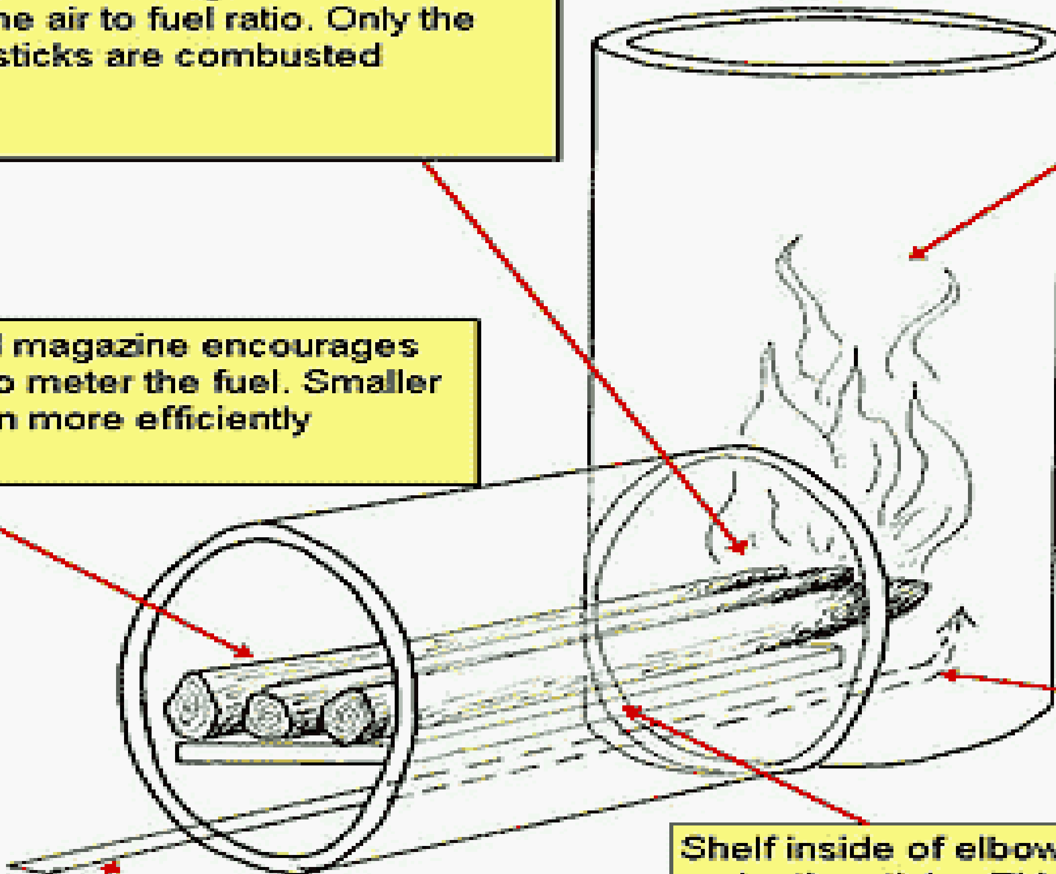
- Challenge # 4
- Cool cooking pot
- The cooking pot is generally no more than a 100 –200 degrees Celsius
- Flames touching the pot?
- **Soot and smoke**!

Solution?

- Elevate the pot above the height of the flames
- This creates an internal ‘chimney’ which increases draft
- And gives time for improved air/ fuel mixing

Aprovecho Research Center
80574 Hazelton Road, Cottage Grove, OR 97424-9747, USA
phone: (541) 942-8198 fax: (541) 942-8198
e-mail: apro@efn.org webpage: http://www.efn.org/~apro

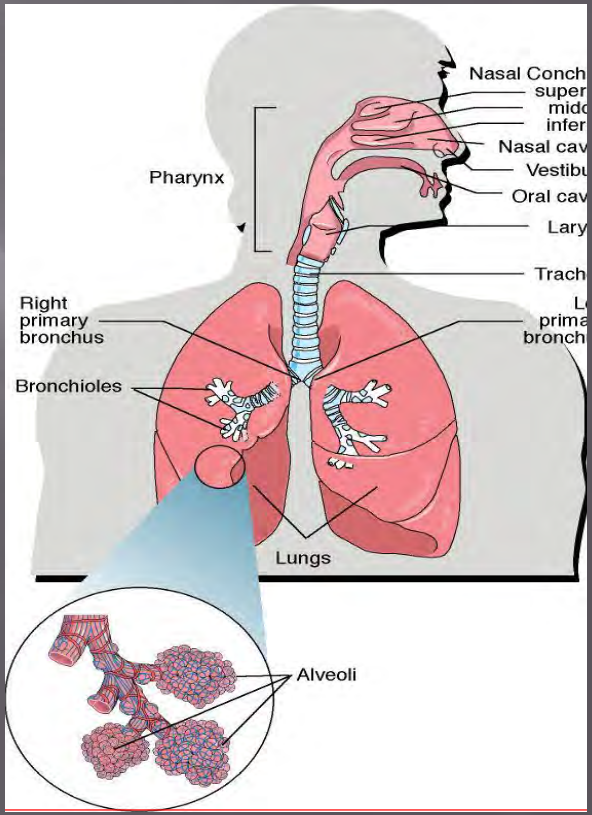
Stove Wood Air Pot



Complete combustion

Carbon Monoxide (CO) - Odorless and invisible

Particulate Matter (PM) – Visible Smoke



A Few of the Chemicals in Woodsmoke (~g/kg emission factors)

Carbon Monoxide	80-370
Methane	14-25
VOCs (C2-C7)	7-27
Aldehydes	0.65.4
Formaldehyde	0.1-0.7
Acrolein	0.02-0.1
Propionaldehyde	0.1-0.3
Butryaldehyde	0.01-1.7
Acetaldehyde	0.03-0.6
Furfural	0.2-1.6 1.6
Substituted Furans	0.15-1.7
Benzene	0.6-4.0
Alkyl Benzenes	1-6
Toluene	0.15-1.0
Acetic Acid	1.8-2.4
Formic Acid	0.06-0.08
Nitrogen Oxides (NO,NO2)	0.2-0.9
Sulfur Dioxide	0.16-0.24
Methyl chloride	0.01-0.04
Napthalene	0.24-1.6
Substituted Napthalenes	0.3-2.1
Oxygenated Monoaromatics	1 - 7
Guaiacol (and derivatives)	0.4-1.6
Phenol (and derivatives)	0.2-0.8
Syringol (and derivatives)	0.7-2.7
Catechol (and denvatives)	0.2-0.8
Particulate Organic Carbon	2-20
Chlorinated dioxins	1xl0-5 - 4x10-5
Particulate Acidity .	7x10-3 - 7x10-2
Normal alkanes (C24-C30)	1x10-3 - 6x10-3

Oxygenated PAHs	0.15-1
Polycyclic Aromatic Hydrocarbons (PAH)	
Fluorene	10-5 - 1.7x10-2
Phenanthrene	2x10-5 - 3.4x10-2
Anthracene	5x10-5 - 2.1x10-5
Methylanthracenes	7xl0-5 - 8x10-5
Fluoranthene	7xl0-4- 4.2xl0-2
Pyrene	8x10-4 - 3.1x10-2
Benzo(a)anthracene	4x10-4 - 2x10-3
Chrysene	5x104- 1x10-2
Benzofluoranthenes	6x10-4- 5x10-3
Benzo(e)pyrene	2x104 - 4x10-3
Benzo(a)pyrene	3x104- 5x10-3
Perylene	5x10-5 - 3x10-3
Ideno(1,2,3-cd)pyrene	2xl0-4- 1.3x10-2
Benz(ghi)perylene	3x10-5- 1.1x10-2
Coronene	8x10-4- 3x10-3
Dibenzo(a,h)pyrene	3x104- lx10-3
Retene	7x10-3 - 3x10-2
Dibenz(a,h)anthracene	2x10-5 - 2xl0-3
Trace Elements	
Cr	2x10-5 - 3x10-3
Mn	7xl0-5 - 4x10-3
Fe	3x10-4 - 5x10-3
Ni	lxl0-6 - lx10-3
Cu	2x10-4 - 9x10-4
Zn	7xl0-4 - 8x10-3
Br	7x10-5 - 9x10-4
Pb	lx10-4 -3x10-3
Elemental Carbon	0.3 - 5
Cyclic di-and triterpenoids	
Dehydroabietic acid	0.01 - 0.05
Isopimaric acid	0.02 - 0.10
Lupenone	2x10-3 - 8x10-3
Friedelin	4x10-6 - 2x10-5

USEPA

Optimising heat transfer

Baldwin found that even a smoky fire can be as high as 92% Combustion Efficiency

The second half of the equation

The true efficiency or fuel saving potential of a stove comes from two factors:

- Combustion Efficiency
- Heat Transfer Efficiency

Total efficiency = CE x HTE

The second half of the equation

Total efficiency = CE x HTE

The simplest of rocket stoves, the insulated elbow alone, can be said to have an overall efficiency of about 18%

If we are getting above 90% CE, what is the HTE?

18% = 90% x HTE -- HTE = 20%

The second half of the equation

Total Eff = 18% = 90% x 20%

What happens if we work to get CE up to 100% (a difficult 10% increase)?

Total E = 100% x 20% = 20%

But instead what happens if we work to raise HTE by 10% (a much easier increase)?

Total E = 90% x 30% = 27%

Always work on the weakest link!!!

The second half of the equation

Total Eff = 18% = 90% x 20%

What happens if we work to get CE up to 100% (a difficult 10% increase)?

Total E = 100% x 20% = 20%

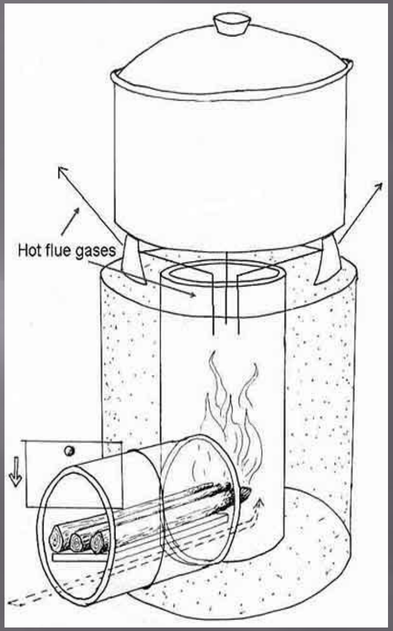
But instead what happens if we work to raise HTE by 10% (a much easier increase)?

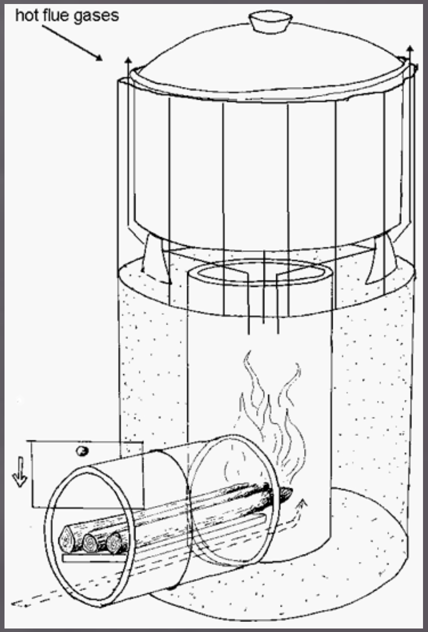
Total E = 90% x 30% = 27%

Always work on the weekest link!!!

Optimising heat transfer

- Maximize radiation to Pot if it does not increase exposure
- Maximize **surface area** of pot that is exposed to hot flue gases
- Keep cross sectional area constant throughout flow path of hot gasses
- Insulate wherever heat is being lost





With a heat exchanger, overall efficiency can be improved by 50% or more

heat exchanger/skirt

Clean burning and fuel efficient stoves

Complete Combustion

- Insulated combustion chamber
- Metered Fuel
- Metered/Preheated air
- Pot kept away from Combustion zone

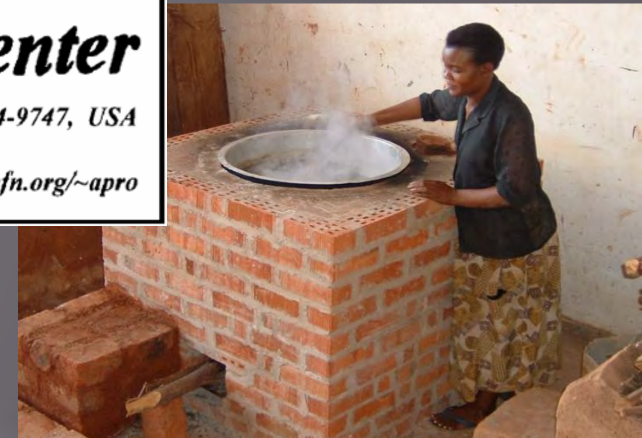
Clean burning and fuel efficient stoves

Improved Heat Transfer

- Radiation if it does not hurt combustion!
- Maximize **surface area**
- Radiation if it does not hurt combustion!
- Constant cross sectional area
- Maximize temp difference between hot gases and pot (insulate against losses)
- Maximize **velocity** of hot flue gases

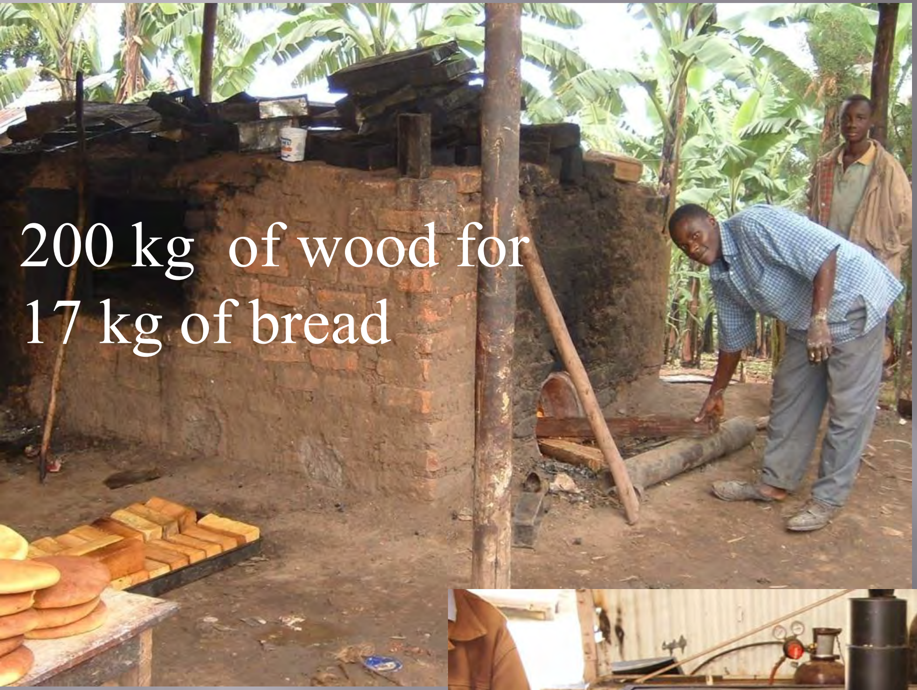
Aprovecho Research Center

80574 Hazelton Road, Cottage Grove, OR 97424-9747, USA
phone: (541) 942-8198 fax: (541) 942-8198
e-mail: apro@efn.org webpage: http://www.efn.org/~apro

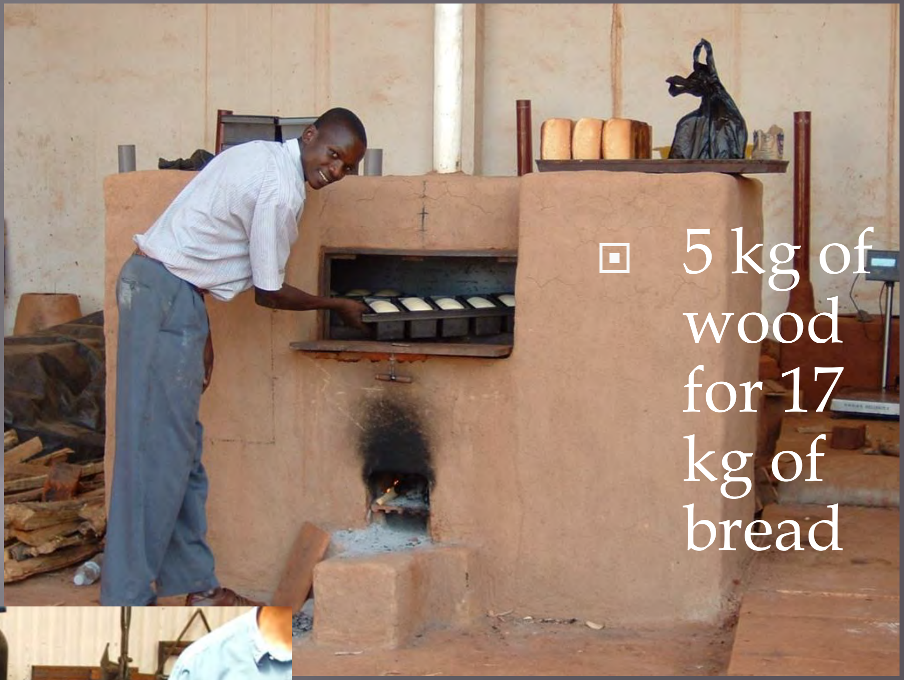


A few rocket stove design possibilities

Rocket Bread Oven



200 kg of wood for 17 kg of bread



- 5 kg of wood for 17 kg of bread

Central American Griddle Stove

In Central America where tortillas are a major part of the cooking task our griddle stove has been found to save up to 70% or the fuel use

Tea Estates in Africa

In Southern Africa we have institutional sized rocket stoves at tea plantations that are cooking for 40,000 people

A visual comparison between the quantity of wood used (170kg) for the open fire vs. the amount of wood used (13kg) by the 100L Rocket stove. Independently tested by EP Lauderdale Tea Estates (Malawi)

Many other stoves

Many other stoves

Using the shielded fire stove

Many other stoves

Using the rocket – lorena stove

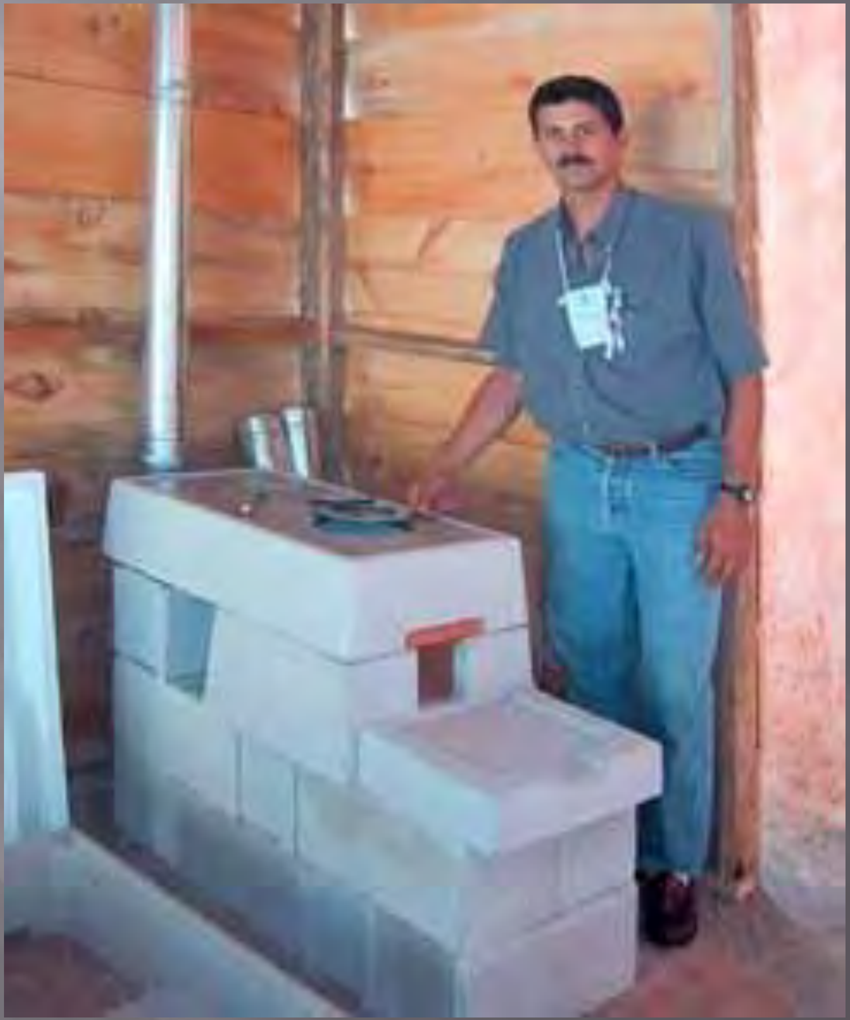
Many other stoves

Many other stoves

Many other stoves

Many other stoves

Many other stoves



Many other stoves