The Evolution of Cooking Stoves

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Evolution of Stoves

- The Open Fire: Hard to Beat!
- A simplified history:
  - 1970’s: Any stove must be better than the 3-stone?
    - Lorena story
  - 1980’s: We need stoves to **save fuel**
    - Great but emissions were often increased
  - 1990’s: We need stoves to also **reduce IAP!**
    - Combustion chambers, high mass chimney stoves increased fuel use, hard to make by hand, etc.
  - 2000’s: Stoves need to address **climate change!**
    - Low fuel and emissions, close tolerances, costly
  - 2010+: Stoves that reduce 1.) fuel 2.) emissions, and are 3.) *effective* and 4.) *accessible* !
  - Better think about it!

The Three-Stone Fire

- The open fire (out of the wind) has many advantages:
  - Low mass
  - Radiation helps cook food
  - Careful tending equals good heat transfer efficiency
    - Tami Bond made a 30% efficient fire in her lab
  - Hot flames touch bottom of pot
  - No heat is lost into the stove body
  - Free, traditional, and portable!

Yikes, There are Lots of Bad Stoves in 2007!!!

- USAID study in Uganda of stoves made using local earthen designs.

Table 2: Results of Water Boiling Tests: Average Stove Efficiencies

Stove type	No. of tests conducted	Thermal Efficiency			
		Cold start	Hot start	Simmering	*Average*
6-brick stove (NGO D)	8 tests, 4 stoves	13.6%	14.3%	15.4%	*14.4%*
Open fire	6 tests, 2 fires	13.7%	12.5%	15.5%	*13.9%*
Traditional mud stove	7 tests, 3 stoves	10.9%	9.3%	15.8%	*12.0%*
Trench stove	8 tests, 2 stoves	8.5%	10.1%	17.4%	*12.0%*
Lorena 2-pot (NGO B)	6 tests, 2 stoves	8.8%	7.5%	10.8%	*9.0%*
Lorena 2-pot (NGO A)	6 tests, 2 stoves	4.8%	4.5%	10.3%	*6.5%*

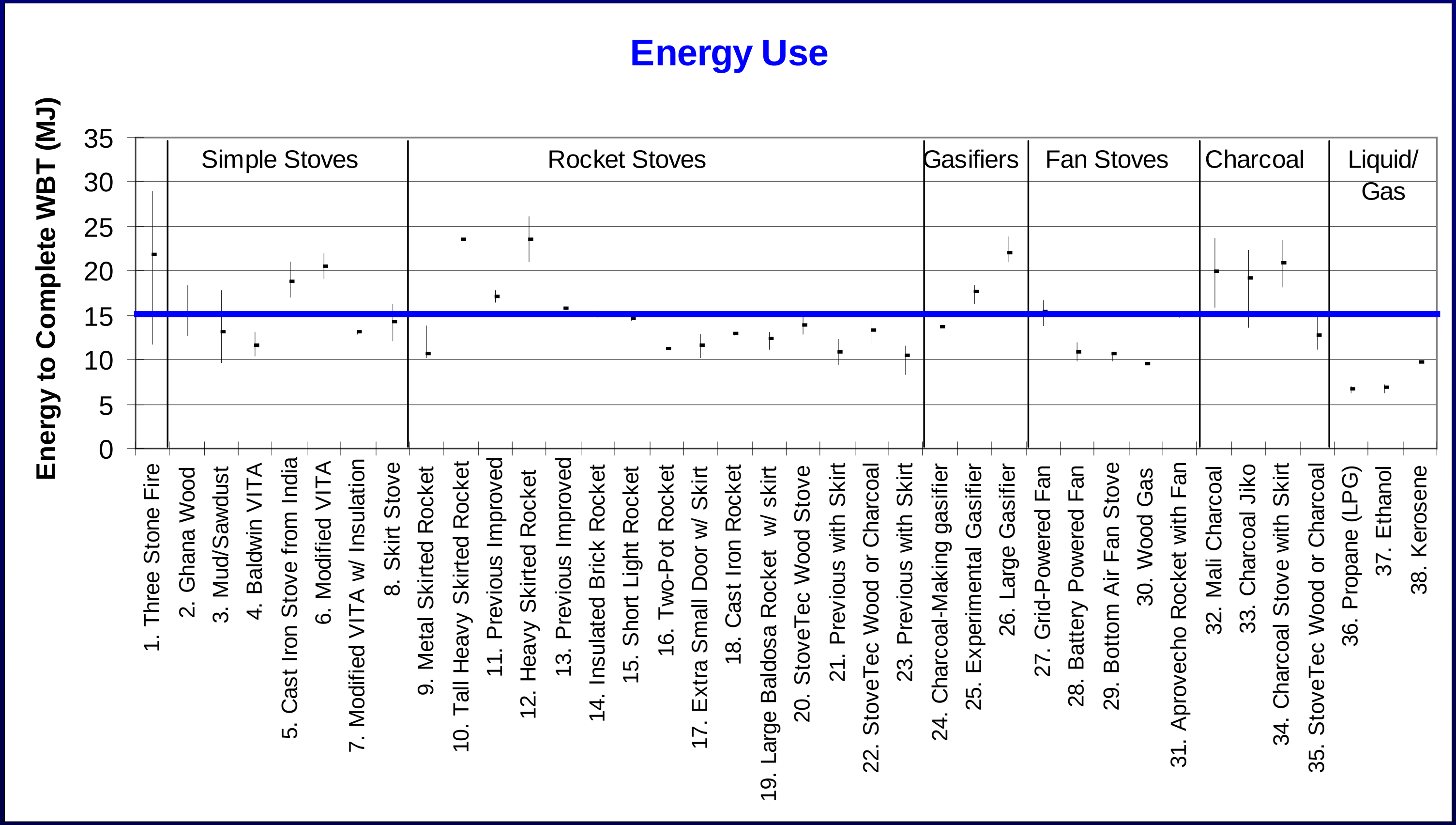
Note: Stoves are ranked by average efficiency over the three test phases.

Only one stove just barely beat the three-stone fire in both WBTs and CCTs.

What is an improved stove?

- The 2005+ definition includes the Aprovecho/Shell Foundation benchmarks of fuel use and emissions performance: 850g, 20g, 1500mg
  - Adopted and modified by World Bank, Philips, ARECOP, GTZ,…
- The 2009 definition in the Waxman-Markey Bill is:
  - Reduces fuel by 50%
  - Reduces black carbon by 60%
  - Reduces childhood pneumonia by 30%
- To meet these requirements, stoves must be carefully engineered, quality manufactured, and consistently tested.

Benchmarks of Improved Stoves



Hundreds of stoves have been tested in relation to the Shell Foundation benchmarks
More on these Wednesday....

Knowing if a Stove is Improved: Testing

- Our field has been (is) characterized by little testing and minimal engineering in stoves
  - Testing in the field of cook stoves has been sporadic and usually not third-party
  - How many times have we heard "Our stove saves 75% of fuel"?
- Even today, in third-party evaluations, many stoves do not use less fuel compared to the open fire.
- Eindhoven, Aprovecho, Philips, UIUC, CSU, Iowa State, USAID and other organizations have studied stoves by testing them
- Standard testing protocols have been written and refined, and are starting to take root at organizations around the world.
- Still, when ICS are mentioned in the UN we hear undisguised groans of "Not again"…

How is a stove improved?

- By improving both heat transfer and combustion efficiencies
  - Good heat transfer requires:
    - High Delta T
    - High velocity
    - High radiation
    - Thin boundary layer by use of small channels near pot (griddle, etc.)
    - Increase area of exposed surface (pot skirt, etc.)
  - Good combustion has:
    - High temperature
    - Thorough Mixing
    - Fuel Metering and/or preparation

Improved Stoves Today

- There have been stove "visionaries" who have created existing solutions:
- Dr. Samuel Baldwin
- Dr. Tom Reed
- Dr. Larry Winiarski
- Dr. Alexis Belonio

Dr. Samuel Baldwin

- **Dr. Sam Baldwin** showed how to increase heat transfer efficiency in 1987 in Biomass Stoves: Engineering Design, Development, and Dissemination
- The use of narrow channels under the pot and near the side of the pot without restricting draft resulted in Sam's VITA stove. Dr. Baldwin explored the effects of mass, materials, etc. in his wonderful book.

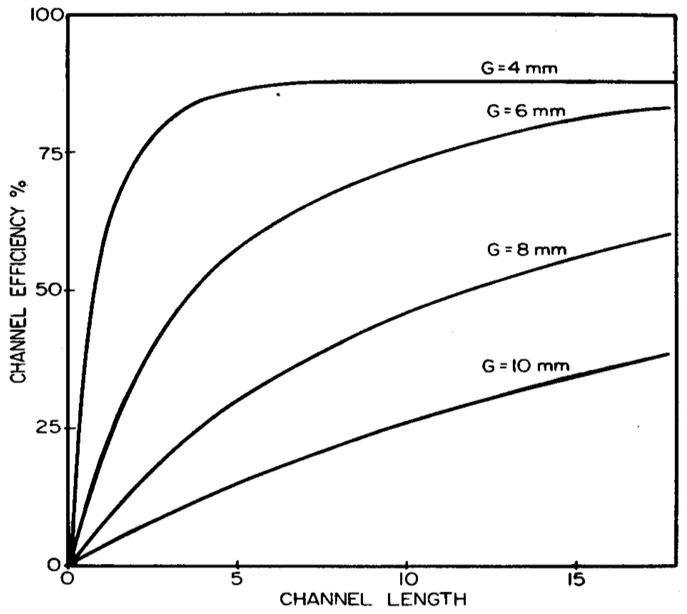


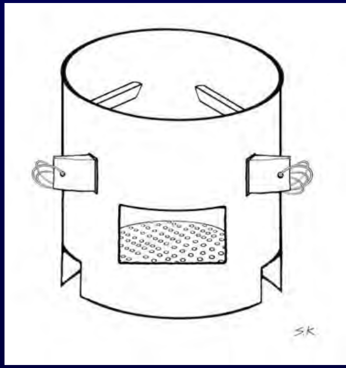
FIGURE 9B: Channel efficiency as a function of channel length for various channel widths. Parameters are given in Appendix B.

Baldwin's VITA Stove

- A simple cylinder of shiny sheet metal around the pot creating a 10mm gap reduced fuel used to cook dramatically.
- This successfully reduces fuel, but, as Kirk said, emissions are not necessarily decreased.
- A grate is also used under the fire, lifting the coals and making fire tending easier.

Performance of VITA Stove

Forcing the hot gases to pass closely to the sides of the pot reduces fuel use. Adding a grate under the fire reduces CO emissions.



	Time to Boil	Fuel Use	CO Emission	PM Emission
3-Stone	38	1253	65	2363
VITA	14	668	43	2150

64% Reduction

46% Reduction

44% Reduction

9% Reduction

COST: $4

Dr. Larry Winiarski

- Larry worked with gasification for a decade before deciding that it was too finicky for cooks so he invented the 10 Rocket Stove Design Principles
- Committed to doing something good for the world, Larry's idea was to clean up combustion then to force hot gases in narrow insulated channels close to the pot(s)

TEN DESIGN PRINCIPLES FOR WOOD BURNING STOVES

Aprovecho Research Center
Advanced Studies in Appropriate Technology

By Dr. Larry Winiarski

1. ***Insulate around the fire*** *using lightweight, heat-resistant materials.*
2. *Place an insulated short* ***chimney right above the fire*** *to burn up the smoke and speed up the draft.*
3. *Heat and burn the* ***tips of the sticks*** *as they enter the fire to make flame, not smoke.*
4. *High and low heat are created by* ***how many sticks*** *are pushed into the fire.*
5. *Maintain a* ***good fast draft from under the fire****, up through the coals. Avoid allowing too much extra air in above the fire to cool it.*
6. ***Too little draft*** *being pulled into the fire* ***will result in smoke and excess charcoal****.*
7. ***Keep unrestricted airflow*** *by maintaining constant cross sectional area through the stove. The opening into the fire, the size of the spaces within the stove through which hot air flows, and the chimney should all be about the same size.*
8. *Use a* ***grate*** *under the fire.*
9. ***Insulate the heat flow path****, from the fire, to and around the pot(s) or griddle.*
10. *Maximize heat transfer to the pot with* ***properly sized gaps****.*

Winiarski's Rocket Stove

- The Rocket has been studied and tested more than other ICS designs. More than one million "Rocket" stoves have been disseminated over 3 decades, although not all have been great rocket stoves.
- The StoveTec stove is an optimized Rocket stove
  - 90,000 have been sold from Shengzhou Stove Manufacturer since March 2008.
  - Third party **field** tests have shown 40% fuel reduction without a skirt and reductions of between 50% to 70% of CO and PM emissions. This agrees with in-house lab and field tests.
  - StoveTec stoves come with a skirt. Will people use a skirt to achieve 50% fuel reduction?
  - Both StoveTec and Envirofit sell the same stove made by Shengzhou Stove Manufacturer. One is green, one is black.

Performance of StoveTec Rocket

Higher temperatures, mixing, metering and then forcing the gases against the bottom of the pot reduces both fuel use and emissions

	Time to Boil	Fuel Use	CO Emission	PM Emission
3-Stone	38	1253	65	2363
Rocket	38	830	20	783

0% Reduction

33% Reduction No Skirt

70% Reduction

64% Reduction

COST: $8

Dr.'s Reed, Larson, & Anderson

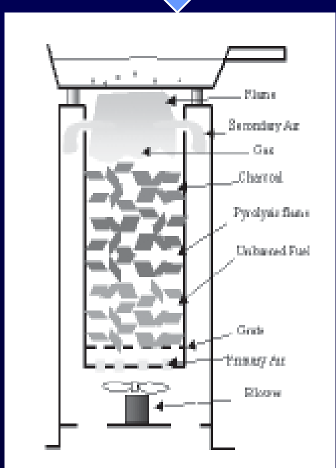
- Dr Tom Reed and Ron Larson are two folks in the US who for decades have been experimenting and making "gasifying" stoves.
- Many other people are experimenting with gasification from small to large scale.
- Dr. Paul Anderson and has been promoting natural draft TLUD stoves.
- Gasification can be making the gas in one place and burning it in another place.

TLUD Stoves

- Generally top lit up draft burning involves limiting the bottom air to a batch loaded fuel supply so that wood burns only on top of the pile with more top air.
- A TLUD (Top Lit Up Draft) stove is:
  - batch loaded with dried small pieces of fuel
  - The wood pile in the can is top lit so the surface of the pile is all on fire
  - The gases from below must pass through the flame, like a candle, so emissions are reduced.
- Gasifiers can be very clean burning when operated properly
- Our lab has tuned a TLUD made by Paal Wendelbo. When the heat transfer and draft were adjusted, three tests using wood pellets resulted in the following:

Performance of TLUD Stoves

TLUD results in very little particulate matter emissions



	Time to Boil	Fuel Use	CO Emission	PM Emission
3-Stone	38	1253	65	2363
TLUD	27	737	18	255

30% Reduction

40% Reduction

72% Reduction

89% Reduction

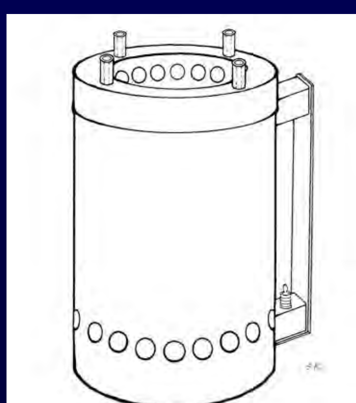
COST: $8

Dr. Tom Reed

- Dr Tom Reed has also pioneered the use of forced air in cooking stoves
- His design has been closely followed by Philips and many other organizations
- A 1-3 watt battery driven fan adds a small amount of air under the batch loaded fuel and also creates superior mixing above the burning fuel
- Fuel must be prepared/pelletized before use
- A forced air stove can also shoot jets of air into the fuel only from below, as seen in the commercial Canadian fan stove which plugs into the wall. It costs $225.

Performance of Fan Stoves

Burning the pellets of fuel with forced air jets at the bottom and/or top of the combustion chamber creates high velocity mixing which dramatically decreases fuel use & emissions.



	Time to Boil	Fuel Use	CO Emission	PM Emission
3-Stone	38	1253	65	2363
Fan	14	614	6	293

64% Reduction

50% Reduction

91% Reduction

88% Reduction

COST: $55

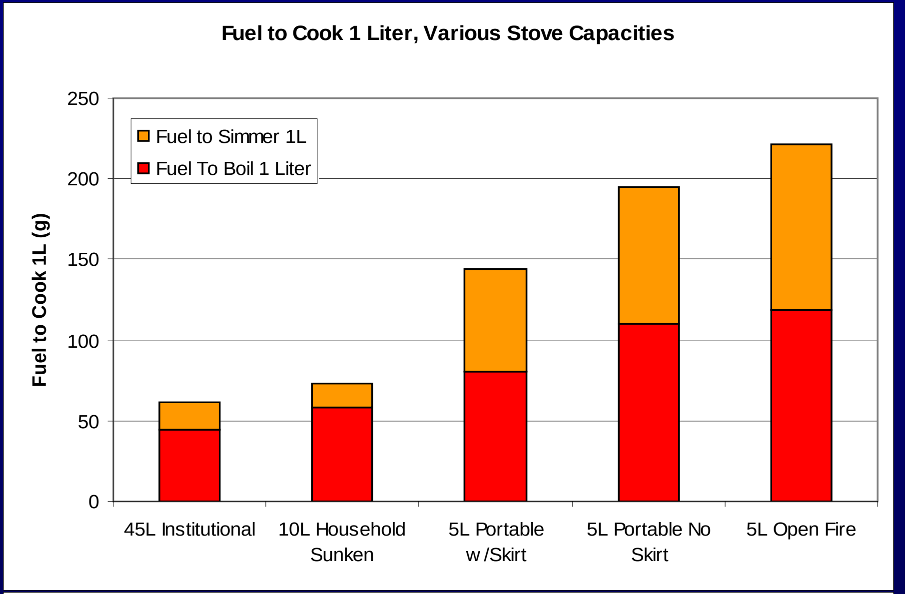
Fan Stove: Aprovecho Thermoelectric Side-Feed

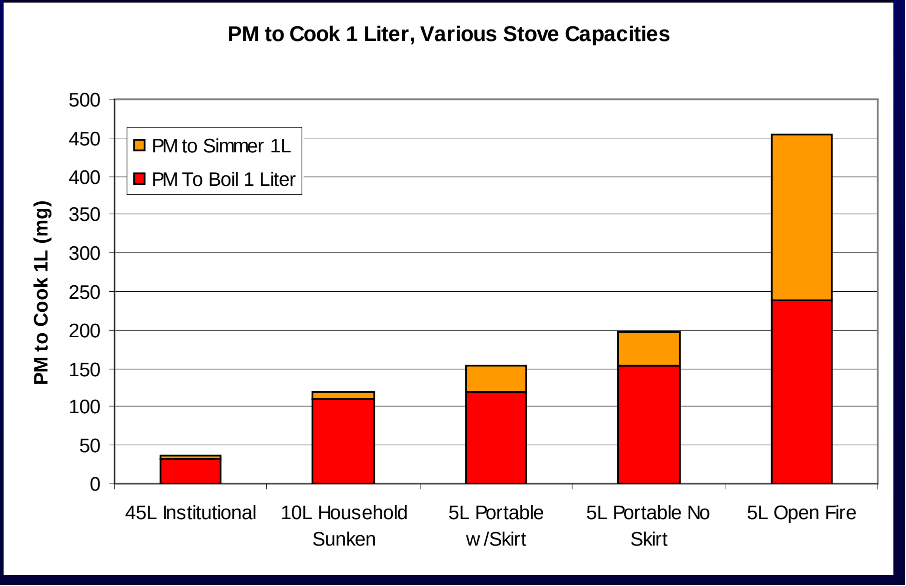
- The Thermoelectric Side Feed Rocket Stove (prototype in development) is a simple forced air stove using long sticks as fuel.
- The stove uses a low volume, high velocity, preheated jet of air to increase mixing above the fire. A $10 thermoelectric generator and fan accessory is attached to the standard StoveTec wood/charcoal stove.
- Fuel = 722 g, CO = 5.6 g, PM = 150 mg
- COST: ~$25 FOB Ningbo, China

!

Dr. Winiarski's Institutional Stoves

- Heat transfer to a large pot when using a skirt is so powerful that specific emissions for an institutional stove rival forced air stoves
- Cooking large amounts of food can be an extremely clean and fuel efficient operation in institutional settings





Performance of Institutional Stoves

Transferring heat to the bottom and sides of a very large pot efficiently uses the heat from the fire and emits fewer emissions.

	Time to Boil	Fuel Use	CO Emission	PM Emission
3-Stone	38	1253	65	2363
60L Stove	32	305	7	181

(Data Normalized for 5L)

16% Reduction

75% Reduction

90% Reduction

92% Reduction

COST: $400

Is My Cool Stove Useful ???

- Cooks don't know about the Waxman-Markey bill!
- Consumer testing is one half of prototype development
  - Must be consumer tested to ensure appeal and effectiveness before dissemination
- Hard lessons have been learned from worldwide experience: The fact that inventors love their stoves doesn't mean that cooks share their passion
- WBT for design, CCT to check with cooks, then KPT if you can afford it

Making Stoves Accessible

- How are a billion stoves disseminated?
  - Artisan approach vs. mass production
  - Commercial vs. philanthropy
  - Open source vs. trade secrets
  - Big bank carbon credit financing vs. paying for and ownership of verified credits
  - Government programs

In my opinion, price is a determining factor in dissemination

- $10 or less can be directly sold to poor people?
- Then need subsidy: governments, philanthropy, microfinance or carbon credits
- Carbon credit projects favor $10 stoves if they save fuel.
- Substantial difference between Gold Standard and Waxman-Markey.
- Optimistic future!