Down Feed Rocket Stove

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Objective Statement

Design and build a family-size stove that is clean; can burn wood of a variety of types, sizes, and moisture contents; and can be used with multiple pot sizes for use in third world countries.

Background

- 2.5-3 billion people still use biomass fires to cook[1]
- Current cooking methods:
    - Three stone method
    - Traditional stove
- 600,000 people die as a result of indoor air pollution each year, in India alone.[2]
- What are people doing about it?
    - Industrialized stoves for one pot size
    - Designed only for ideal conditions
        - dry, specially cut lumber

Stove Tiers: Crisis in 3rd World

- Tier 0 - Open Fire / Poor Stove, Smoky, & Inefficient (<15%)
- Tier 1 - Measurable Improvement
- Tier 2 - Substantial Improvement
- Tier 3 - Clean and Efficient
- Tier 4 - Very Clean & Very Efficient (>45%), Often Impractical

Design Process

1. Determine design objectives
2. Review current down feed stove designs
3. Brainstorm potential ideas
4. Build Prototype
5. Test and analyze
6. Modify prototype
7. Repeat Steps 4-6 to determine ideal parameters

Design Objectives

Clean burning (pass eye-nose test, IAP meter)

Capable of supporting any pot shape or size (within reason)

Able to burn wet wood (30-35% moisture)

Quick boil time (20 min)

Inexpensive (less than current model by InStove)

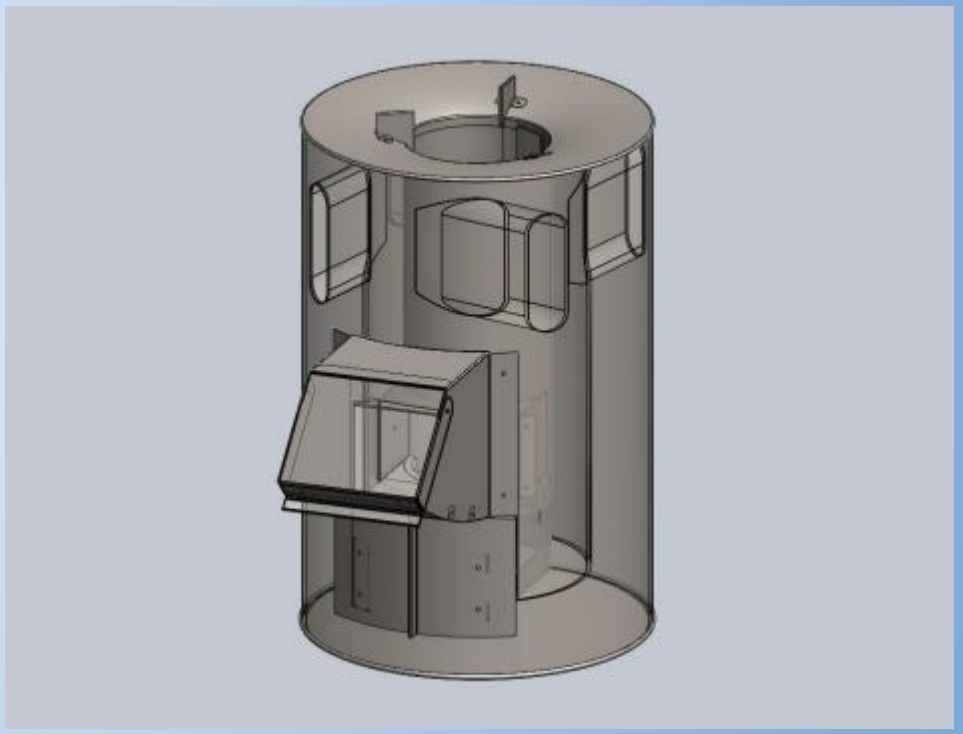
Efficient (> 30%)

Burn wood up to 2.5” in diameter & 3’ in length

Self Feeding

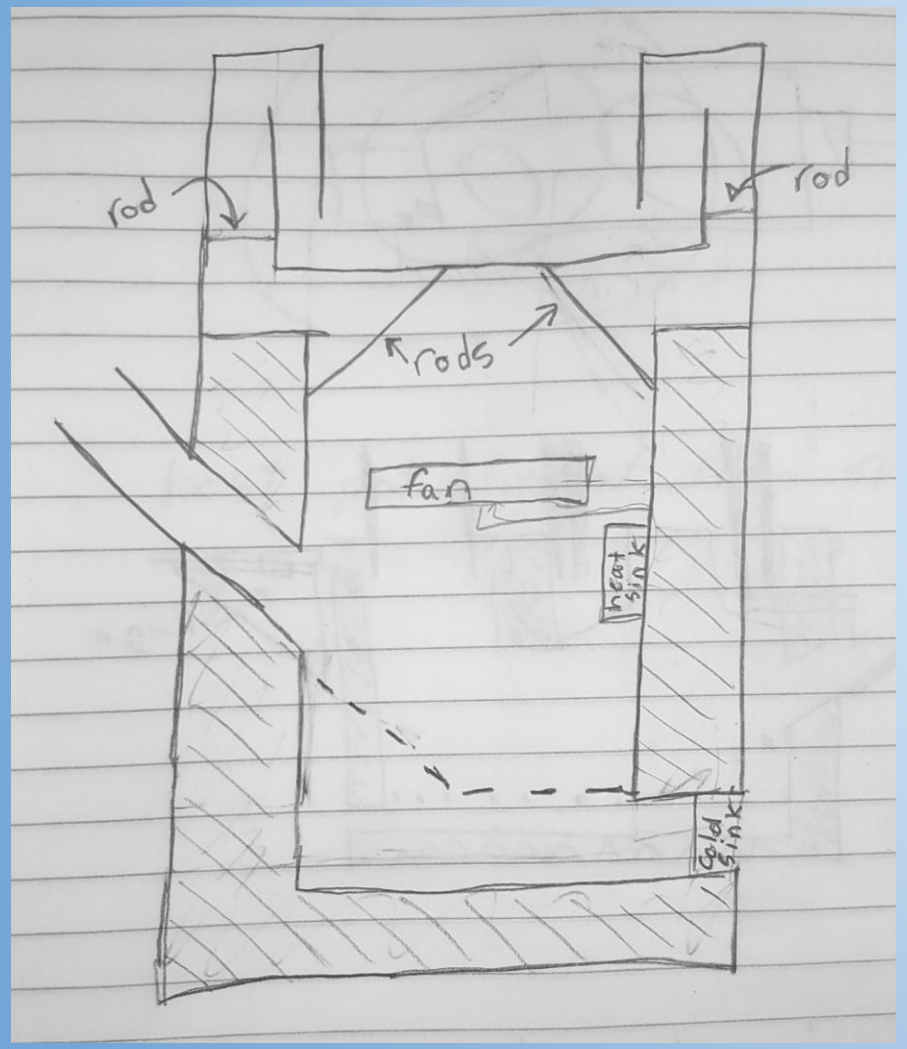
Review of Current Downfeed Designs

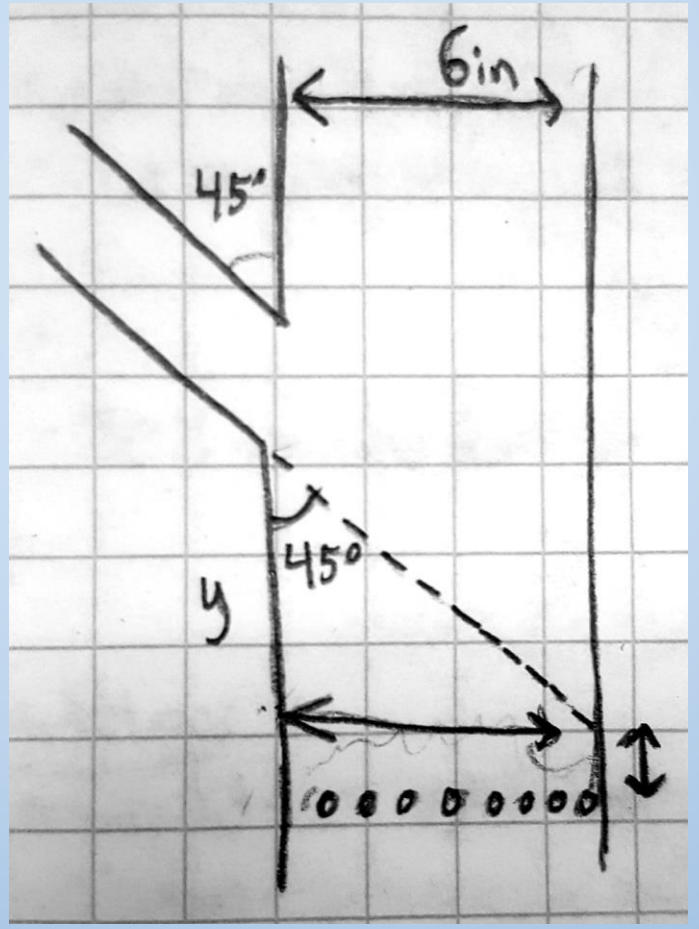
Instove's 20L Downfeed Stove

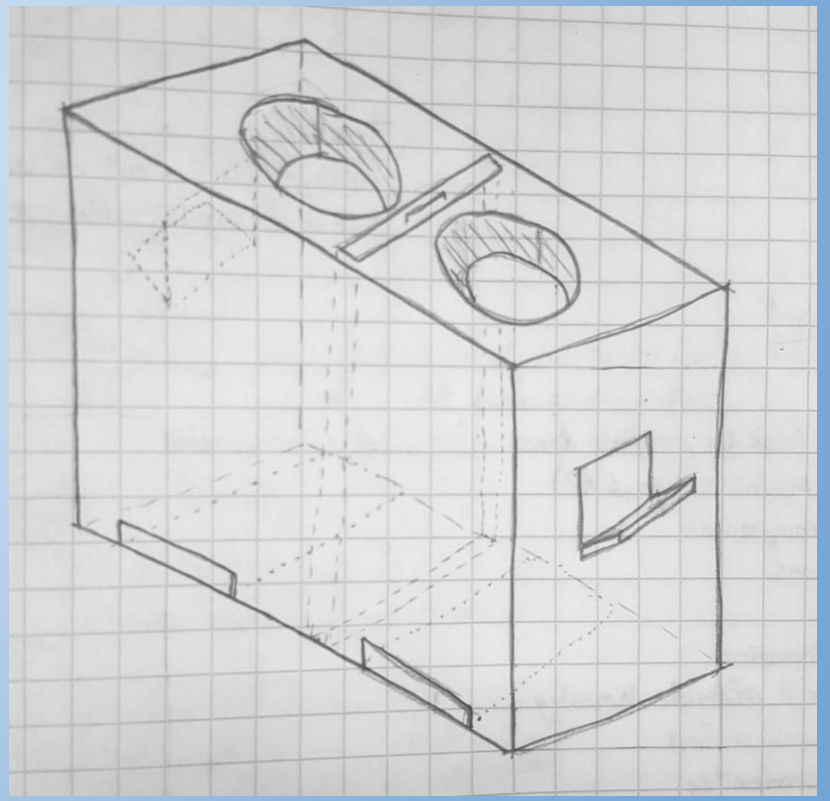


Northern Arizona University Clean Burning Stove Team

Brainstorming Potential Ideas







Test Process: High Power

High Power Phase: Heat Water to a Boil

- Time to boil
- Smoke evaluation (IAP meter or Eye-Nose Test)
- Mass of water evaporated
- Mass of fuel burned
- Temperature change of water
- 4 types of wood used:
  - Dry standard lumber
  - Dry sticks
  - Dry large sticks
  - Wet wood

Test Process: Low Power

Low Power Phase: Simmer for 45 minutes

- Mass of water evaporated
- Mass of fuel burned
- Number of times fire was tended
- Smoke evaluation (IAP meter or Eye-Nose Test)

Efficiency Calculations

- Determine energy extracted from wood.
- Determine energy absorbed by water.
- Calculate efficiency by dividing energy in water by energy in wood.
- Time to boil is corrected to be comparable between tests
  - Standardizes test to 5kg of water with initial and boil temperatures of 20°C and 100°C

$$H_{LHV} = (20634 - C_{moisture} \times 23000)[J/g]$$

$$E_{wood,HP} = wood_{consumed,HP} \times H_{LHV}[J]$$

$$E_{wood,LP} = wood_{consumed,LP} \times H_{LHV}[J]$$

$$TTB_{corrected} = \frac{TTB_{measured} \times 5000 \times 80}{m_{water}(T_{boil} - T_{initial})}[s]$$

$$E_{water,HP} = m_{water} \times 4.186(T_{boil} - T_{initial})[J]$$

$$E_{water,LP} = 2260(m_{initial} - m_{final})[J]$$

$$\eta_{HP} = \frac{E_{water,HP}}{E_{wood}}$$

$$\eta_{LP} = \frac{E_{water,LP}}{E_{wood,LP}}$$

$$\eta_{total} = \frac{E_{water,HP} + E_{water,LP}}{E_{wood,HP} + E_{wood,LP}}$$

Initial Prototype: Beal

Design Goal: Balance of power and efficiency
Purpose: Gain experience with testing a stove
Build Method: Stock part to build stove

- 6” diameter chamber
- 16” chamber height
- Metal ductwork for chamber
- 2 layers of tin foil insulation

Results: Beal

High Power Efficiency: 17.6%

Low Power Efficiency: 13.0%

Overall Efficiency: 15.1%

Corrected Time to Boil: 17:45min

Second Prototype: Seal

Design Goal: Easily Modifiable
Purpose: Test how parameters affect efficiency
Build Method: Sheet metal rolled and welded

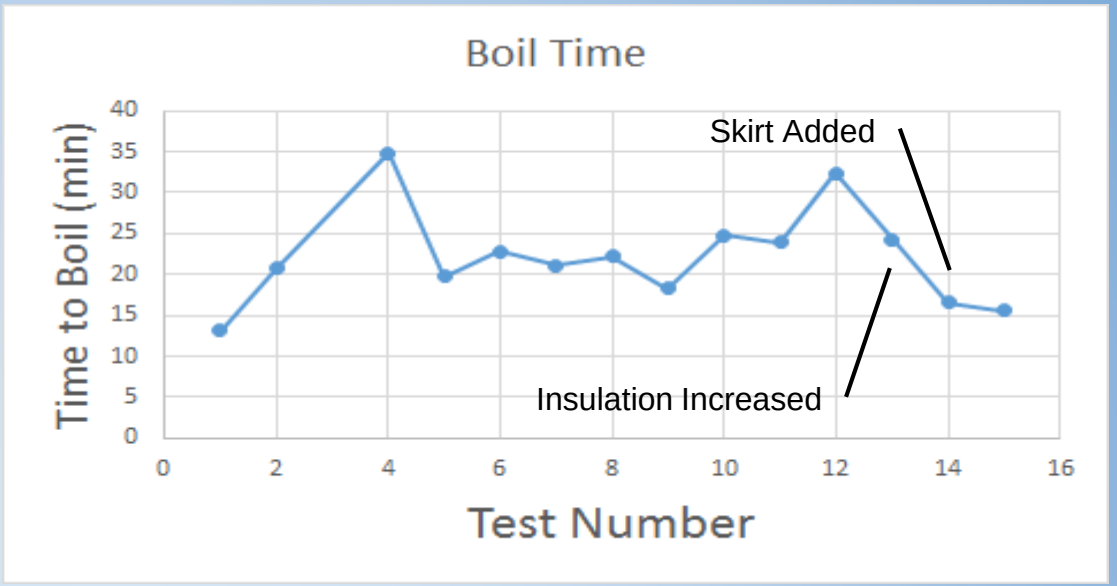
- 6” diameter combustion chamber
- 24” (initial) chamber height
- Burner plate and cone for pot support
- Chamber and chute were welded
- 1” air holes at base (n=6)
- Tin foil insulation

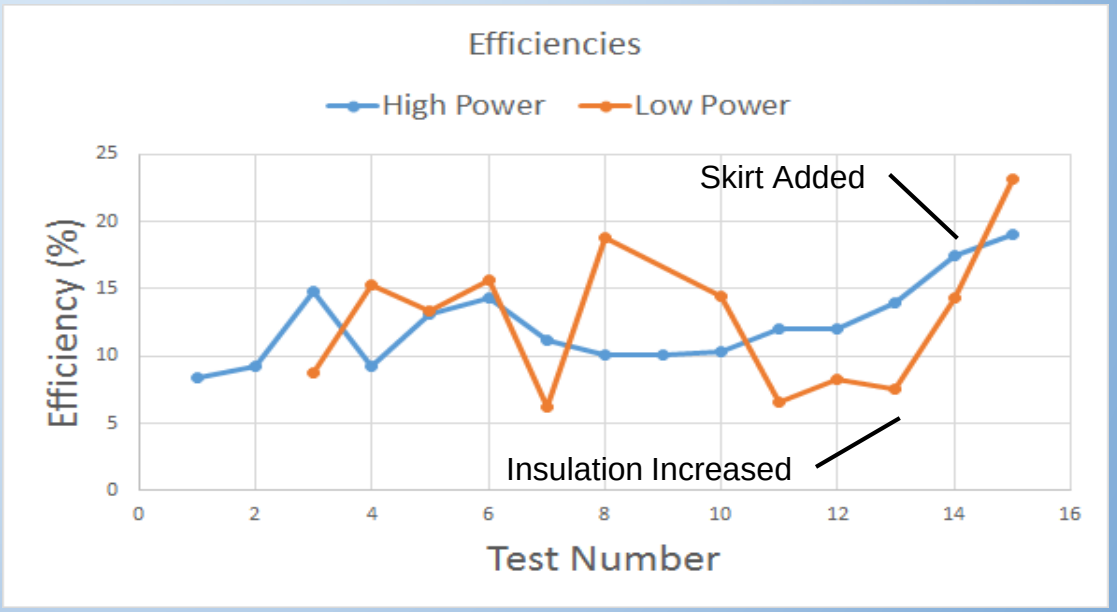
Seal: Design Continued

Results: Seal

Modified Parameters:

- Chamber Height
- Grate Height
- Airflow
- Pot Support Type
- Skirt



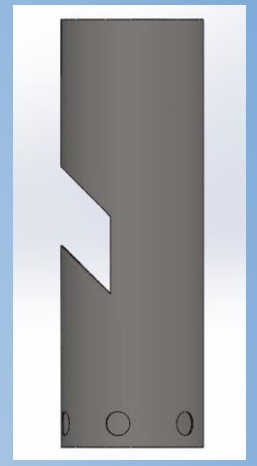


Results Continued

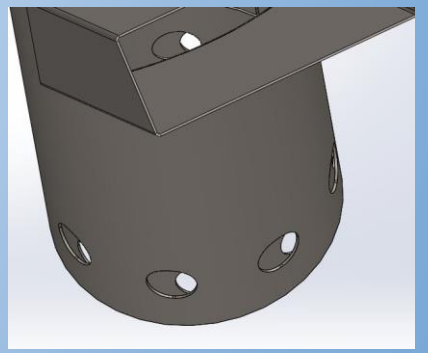
Conclusions:

- 5” grate height much better
- Air had negligible effect
- Higher pot support led to increased cleanliness
- Shorter chamber height better efficiency, but smokier
- Skirt improved efficiency and cleanliness

Chamber Height (in)	Average Overall Efficiency
24	13.07
22	10.74
20	10.56
18	18.50



Air Openings	Average Overall Efficiency
Less than 50%	12.69
More than 50%	12.25



Results Continued

Pot Support Type	Average Overall Efficiency
3 1/16th	11.31
5 1/16th	11.17
Cone	13.35

Skirt	Average Overall Efficiency
None	11.69
6"	18.50

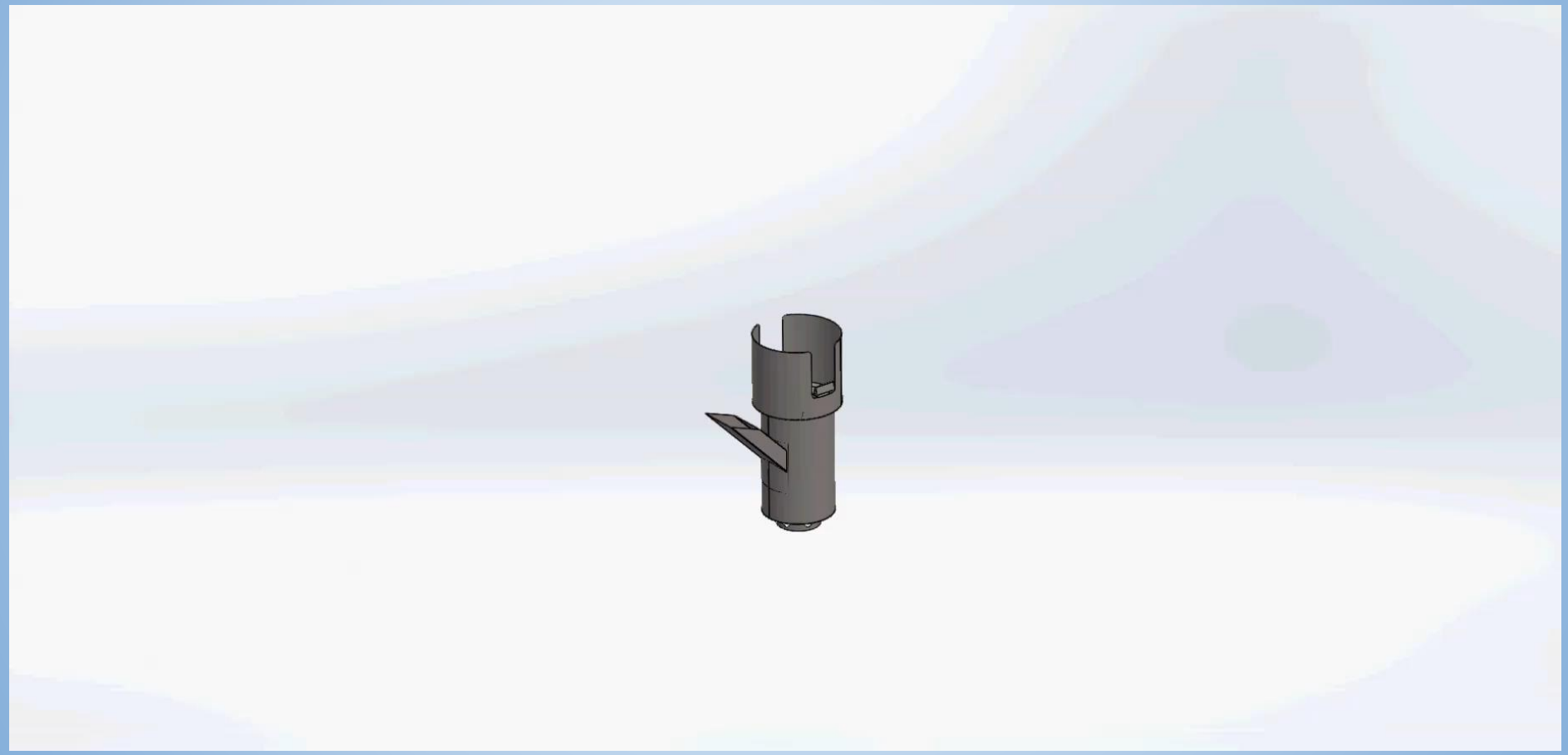
Grate Height (in)	Average Overall Efficiency
3	8.83
5	13.32

Feal: Design

Design Goal: Mass Production Ready Stove
Purpose: Combine optimal parameters determined from Seal into a single design
Build Method: Sheet metal rolled and welded

- 6” diameter chamber
- 10” diameter outer wall
- 18” chamber height
- 1” air holes at base (n=5)
- 2” vermiculite insulation
- 12” diameter heat skirt (10” tall)

Feal: Design Continued



Feal: Design Continued

Feal: Building Process

Materials:

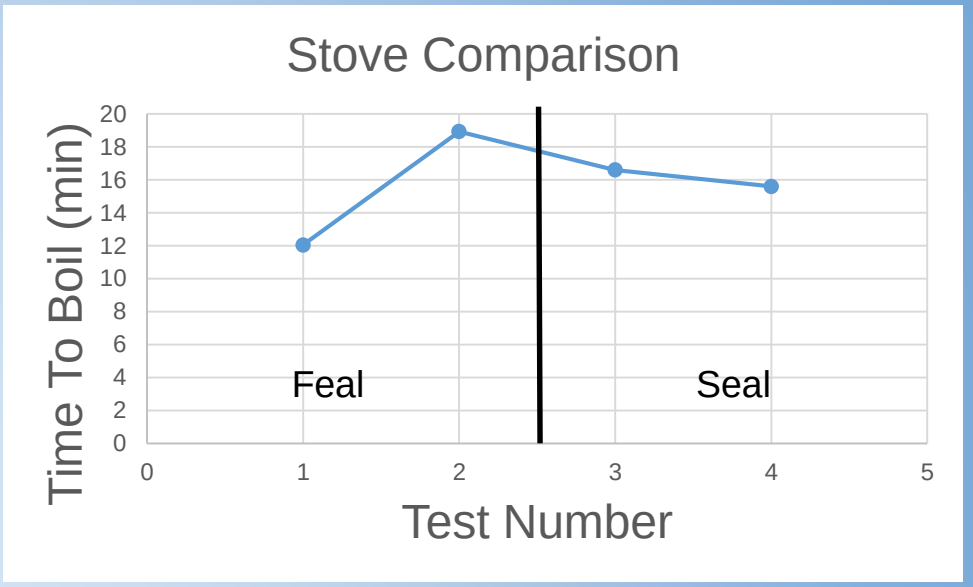
- 24”x48” 22-gage steel (n=3)
- Vermiculite (12 quarts)
- 6” diameter expanded metal grate
- 5” bolts (n=4)
- Nuts and washers (n=8)
- Furnace Putty

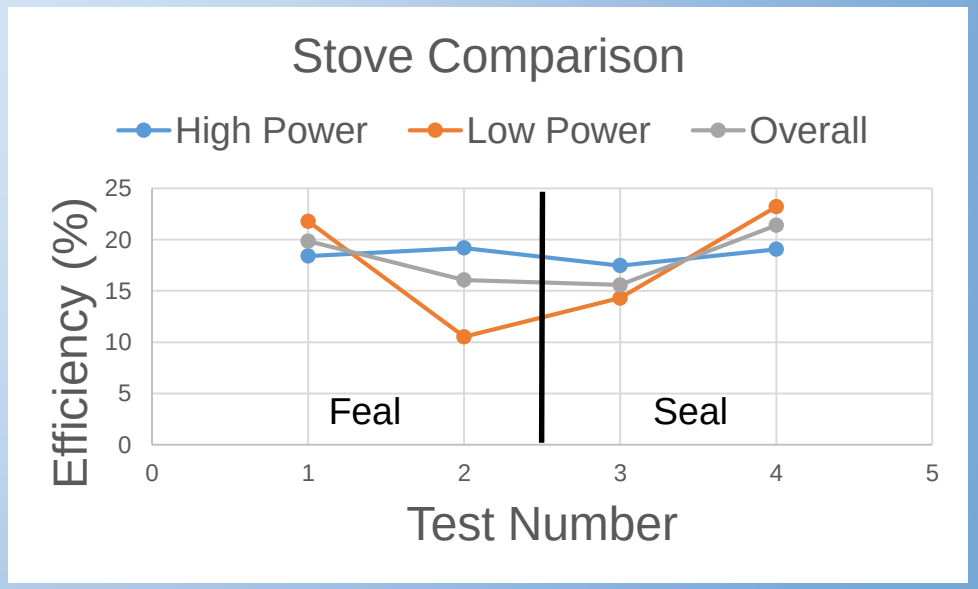
Building:

- Create Parts in SolidWorks
- Cut steel to size
- Roll and bend steel
- Weld chambers and chute
- Fill outer chamber with vermiculite
- Attach top plate, risers, and heat skirt with putty

Feal: Dry Lumber Testing

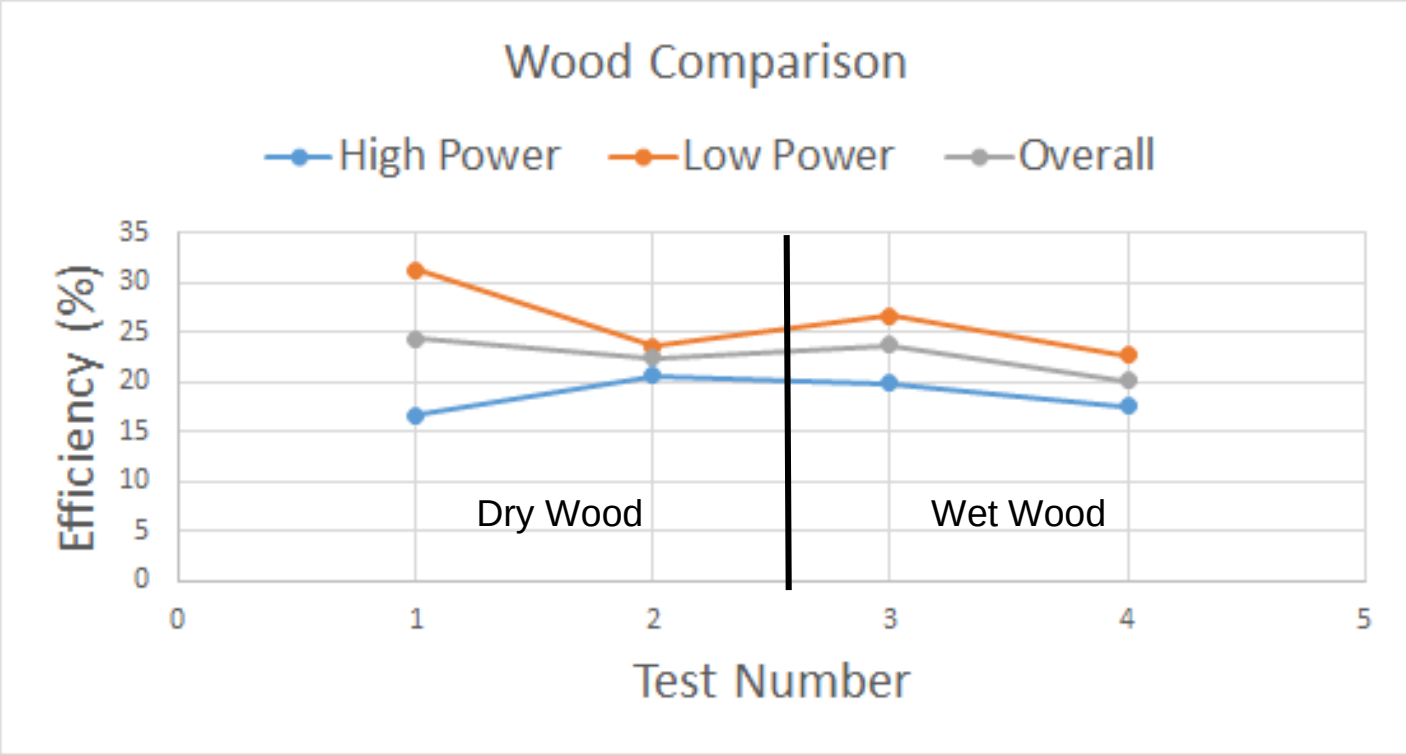
Standard wood for comparison tests





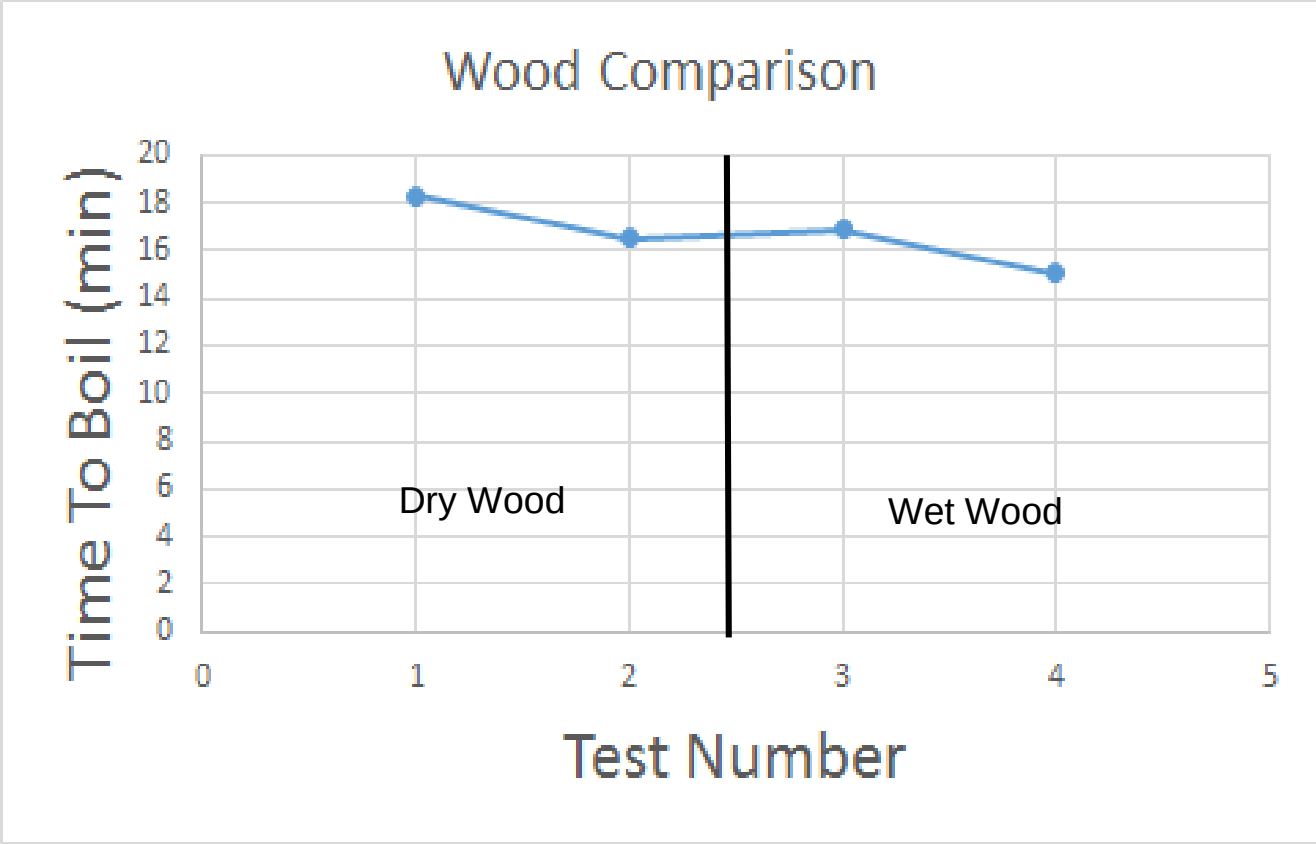
Feal: Wet Wood Testing

Can the stove burn sticks of around 35% moisture?



Feal: Wet Wood Testing Cont.

Does moisture affect boil time?



Feal: Large Wood Testing

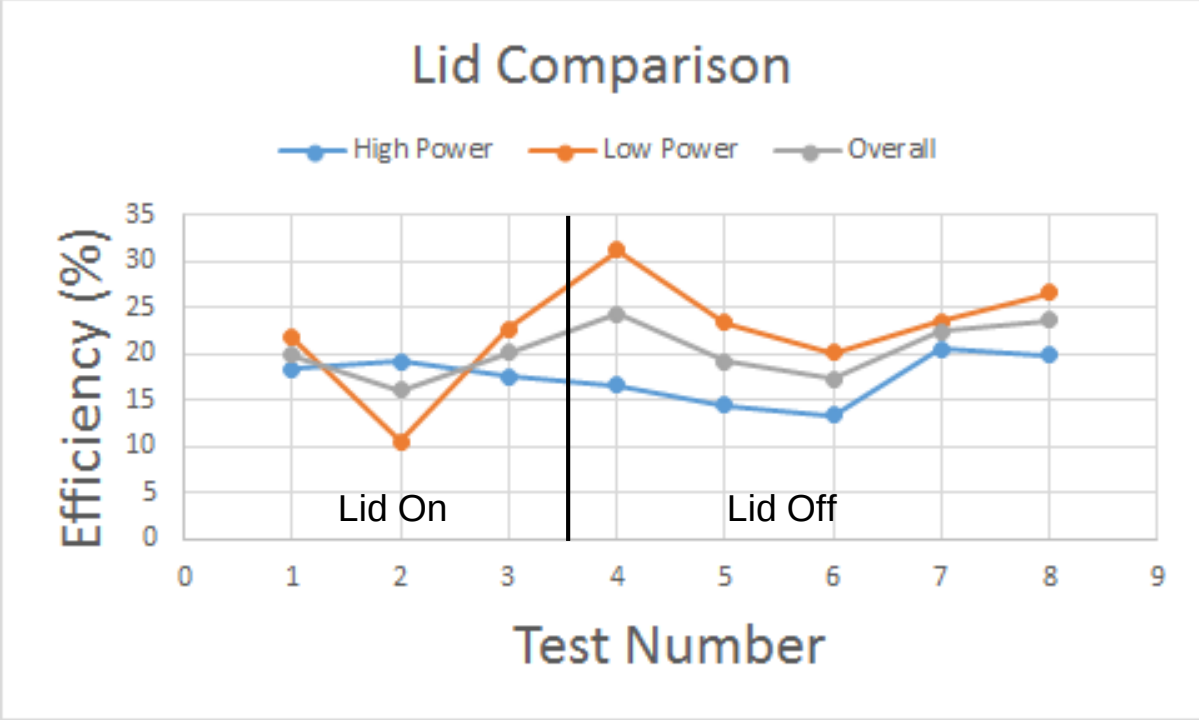
Can the stove burn natural wood of 3’ in length and 2.5” diameter?

Feal: Large Wood Testing Cont.

Does wood size affect boil time?

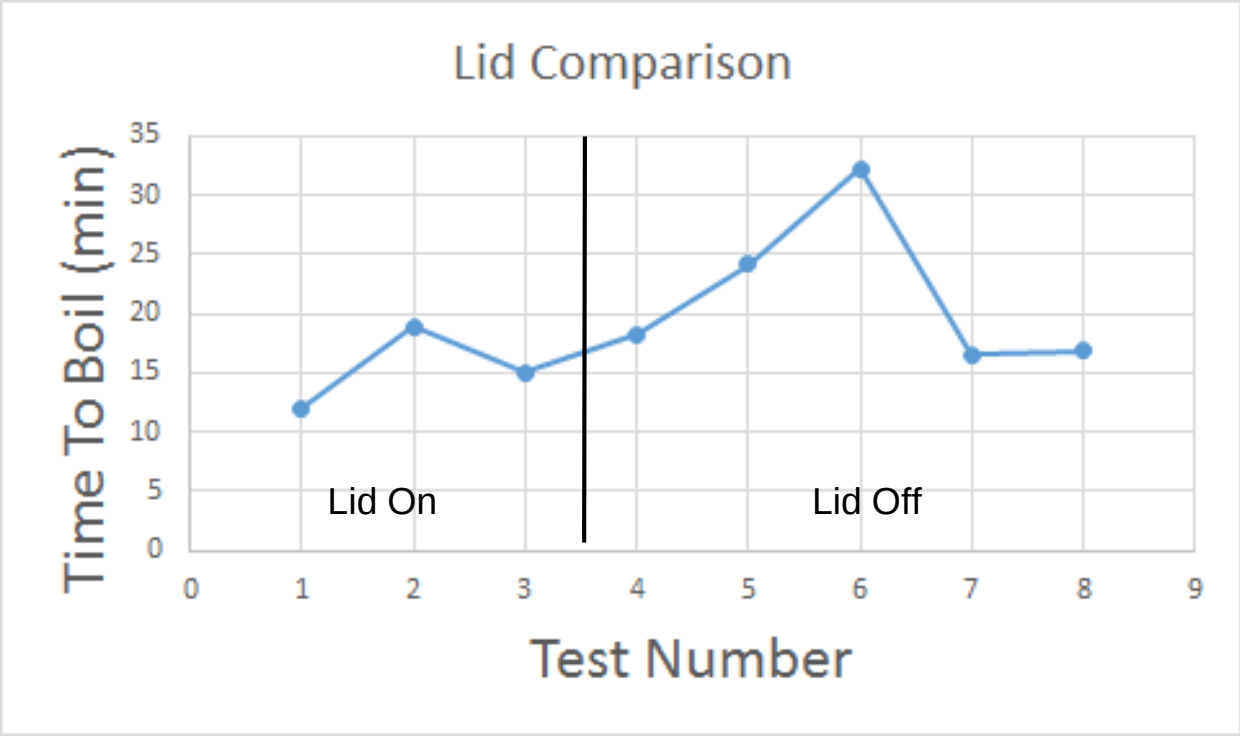
Feal: No Lid Testing

Can the stove boil and maintain an efficient boil with no lid on the pot?



Feal: No Lid Testing Cont.

Can the stove boil quickly with no lid on the pot?



Feal: Results

		Fuel Type			
		Stock Lumber, Dry	Natural, Dry	Natural, Wet	Large Natural, Dry
Efficiency (%)	High-Power	17.15	18.59	18.7	13.92
	Low-Power	13.24	27.39	24.73	21.77
	Overall	**15.66**	**23.38**	**21.96**	**18.26**
Time to Boil (min.)	Measured	18.75	16.5	15.38	28.25
	Corrected	20.07	17.38	15.94	28.18

- Clean burning with minimal smoke when fresh wood is added
- Average Overall Efficiency: 19.8%
- Average Corrected Time to Boil: 20.4 min

Indoor Air Pollution (IAP) Meter

- Measures the amount air particulates and carbon dioxide in the smoke
- Built a custom fume hood to capture all of the smoke
- Air at IAP meter proved too hot (~110°C) and IAP meter use was abandoned

Conclusions

	Objective	Actual
Cost	< $445	$315
Efficiency	> 30%	~20%
Clean	Eyes Nose Test	Yes
Wood Moisture	30-35%	32%
Boil Time	< 20 min	20.4 min
Large Wood	2.5" dia; 3' length	Yes
Self Feeding	Yes	Yes
Multiple Pots Sizes	Yes	Yes

Lessons Learned

- Standardized testing conditions
  - Multiple of same test is required
  - Use consistent ground (not open-air concrete)
  - Use standard wood, wood mass, and water mass

- Insulation and airflow under pot are vital
  - Add radiation shield inside vermiculite and increase insulation width

- Simplified stove construction
  - Crimp metal more, weld less
  - Labor costs are >50% of the total cost of the stove

Acknowledgments

Dale Andreatta

Nick Moses and Fred Colgan from InStove

Sources

Dale Andreatta

Nick Moses and Fred Colgan from InStove

[1]https://www.iea.org/publications/freepublications/publication/cooking.pdf

[2] http://web.mit.edu/adnane/www/adnan/portfolio/idd/stove.html

Questions?