Practical Stoves-
Two Possible Designs

Dale Andreatta, Ph.D., P.E.
dandreatta@sealimited.com

With help from Paul Means, Christa Roth, Nick Moses, Damon Ogle, and students at The Ohio State University

ETHOS 2018, Northwest University, Kirkland

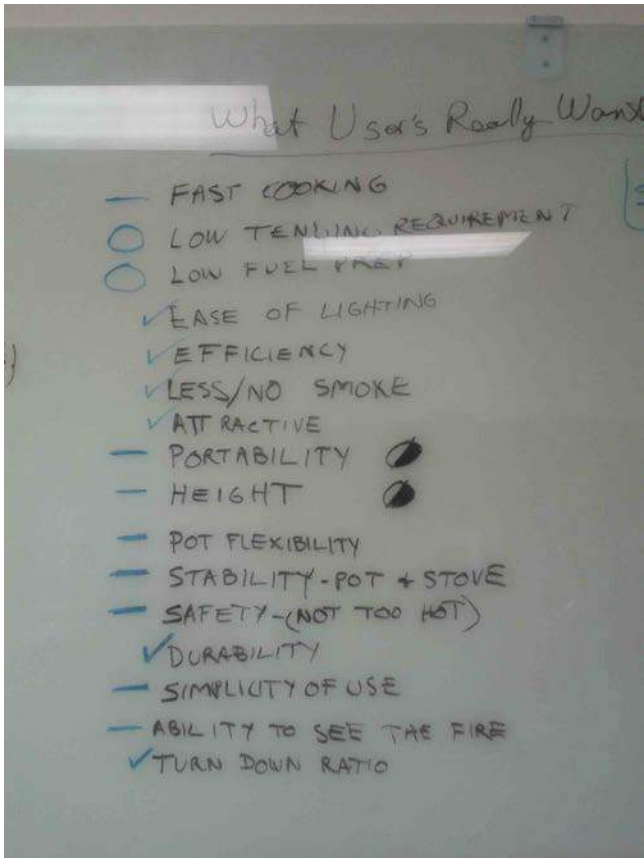
- Many slides in this presentation are not intended to be used in the live presentation.
- Rather, they are included so that more details can be read later by a larger audience.
- This is done instead of a lengthy separate report.
- If you are seeing this after the conference you are seeing a lot more information than the people at the conference.

Main Idea

- **Clean and efficient** stoves are fine, but users <u>will not sacrifice **practical features**</u>.
- In 2016 we did a brainstorming session about what people really want.
- In addition to clean and efficient some of the main items were…..

Practical Features that Users Want

- **High power, fast cooking.**
- Ability to burn any wood (big, small, wet, dry, branchy) with minimal processing.
- Stable pots, stable stove.
- Easy to see fire.
- Stove can go for 10-15 minutes without tending.
- Sometimes two pots.



Points picked from a list of features as a result of a brainstorming at Burn Design Lab after ETHOS 2016 with Amy Wickham, Christa Roth, Dale Andreatta and Paul Means

But the most important feature of all is so basic it wasn't on the list: **the stove must get the job done.**

- The stove must cook the food they have, **with the fuel they have!**
- Ideal lab fuel (usually small, straight, and dry) is fine for comparing stoves or determining best possible performance, but not for designing a stove for real people.

Reality snapshot (from Ghana November 2016)

From Malawi, about 10 cm

Malawi

Malawi

Data collected by Burn Design Lab in Kenya as an element of the development of the Kuniokoa cookstove under a USDOE grant with the University of Washington and Burn Design Lab showed that:

The Average Wood Size is 4 cm in Kenya.

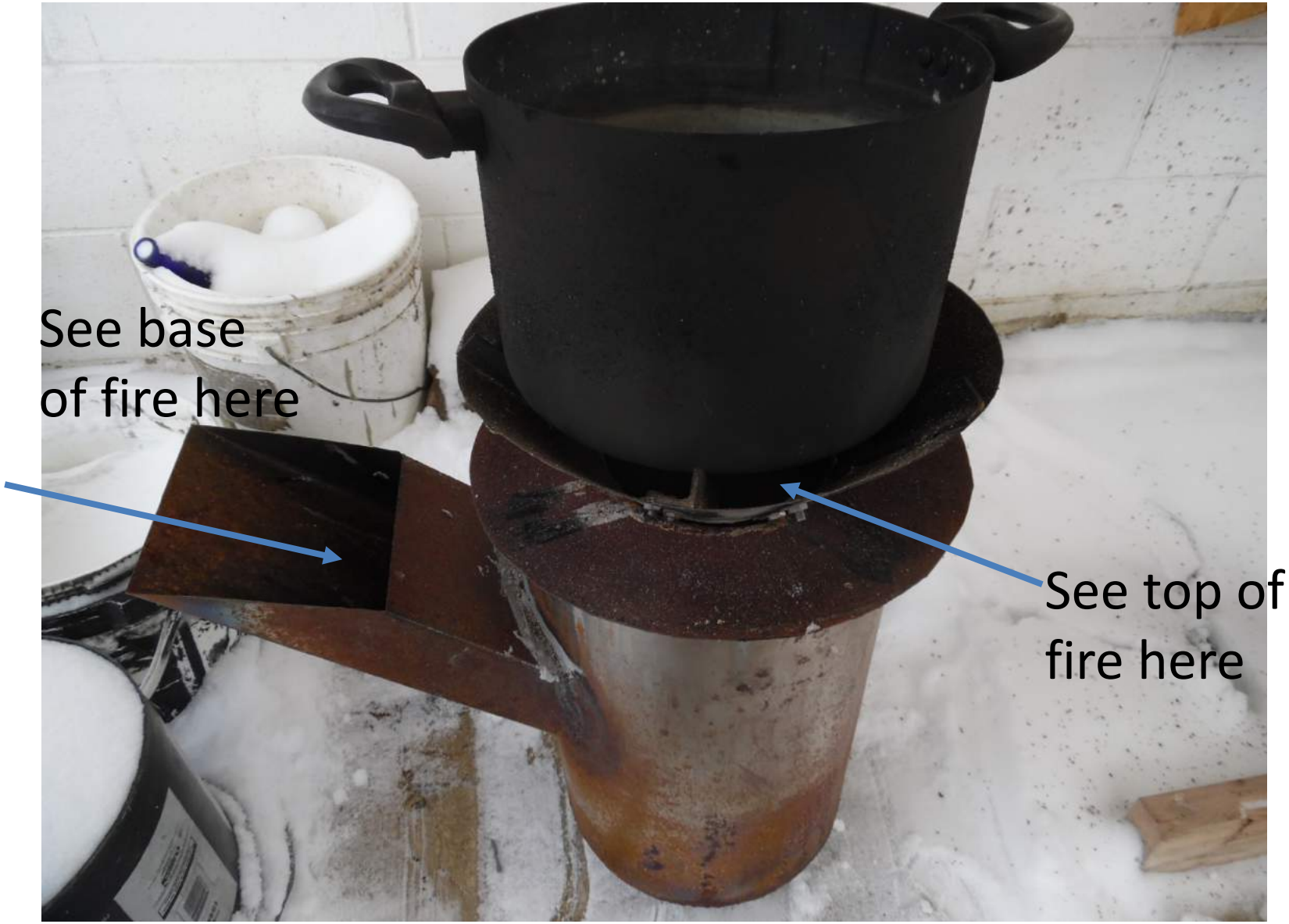
Introducing Two Stoves with Practical Features

- Downfeed Stove, designed by InStove in Cottage Grove, Oregon.
- Versatile Stove (or Large Combustion Chamber Stove) by me.

The Downfeed Rocket Stove

- Designed by InStove, further tested by students at The Ohio State University, then further tested by me.
- Similar to a rocket stove, but with a downward sloping fuel chute.
- Sometimes will self-feed, but not always, depending on size and shape of wood.

Downfeed Rocket Stove
(some insulation removed for clarity)


See base
of fire here
See top of
fire here


WARNING
COVERS
56 S
FOR JOINTS ABO

Put large pieces into riser for semi-batch burning mode

Practical Features

- Easy to see fire (I think the ability to see the fire and feel assured that it is burning strongly is a very important practical feature that we often overlook).
- Easy to tend fire.
- Easy to light.
- Up to 5 cm wood is handled well, possibly larger.
- Can put larger pieces in riser, giving semi-batch combustion mode. (See next slide.)
- Cone shaped pot support for single pot.

Pot Supports

- With the cone shaped pot supports the pot is very stable.
- Any size pot from 15 to 30 cm diameter with flat or round bottom can be used.
- You can see the top of the fire.
- Even bigger pots can rest on top of the pot rests (shown in a following slide).
- Heat transfer is not optimal, but reasonably good.
- Cone with 19 mm pot rests gives reasonable heat transfer and less smoke.
- With 13 mm pot supports get a little better efficiency with more smoke.

Small pot

Regular (about 7 liters) Pot

Very large pot, greater than 30 cm

Very large pot sits on tips of pot supports

Pot Stability Tests

Pot Stability Tests (pot weight 3.06 kg)

Stove/pull location	Force (kg)	Result
Regular stove top/Pull at top	2.1	Tip and slide
Regular stove top/Pull at middle	1.9	Slide
Regular stove top/Pull at bottom	1.8	Slide
45 degree cone/Pull at top	2.5	Tip
45 degree cone/Pull at middle	4.3	Tip
45 degree cone/Pull at bottom	>8	No movement
35 degree cone tested, not good		

How stable is the pot in the cone?

Downfeed Burner Video

- Short video of downfeed rocket is at: www.youtube.com/watch?v=VJcnp5lE_fg (the l is a lower case L)
- Thanks to the students, Sam McTurner, Matthew Gerding, Michael Haemmerle, Nathan Lackey, Cory Sharkey

Test Method-A Modified Water Boiling Test

- Many tests were done, most with either a 5-liter pot or a 5-liter pot and a 3-liter pot on the 2-burner stove.

- **Fire is tended as little as possible, as it would usually be in actual use.**

- Tests are done with and without lids.
- The 45-minute simmering phase has bubbles breaking the surface.
- Start stove with primitive methods, usually plastic bags and as little hydrocarbon fluid as possible (5-10 grams)

Rules for tending the fire:

- Don’t tend the fire unless:
  1. the fire is not covering most of the bottom of the pot (In the high power phase)
  2. simmer is lost (Usually the case when pot is not covered with a lid in the simmering phase)
  3. the fire is getting too small to easily rekindle (Usually the case with a lid in the simmering phase)

- Count number of times tending fire during test.
- Also measure time to achieve boiling and correct to standard conditions.

Wood Moisture Tests

- Weigh wood sample in normal state (100 g or more).
- Dry in oven for 12 hours at 220° F or 105° C.
- Weigh again, and assume no remaining moisture.
- Calculate original moisture content.
- Assume other similar wood is similar moisture.

Wet Wood Tests

- Take wood of known or approximately known moisture content. Weigh it.
- Dunk in water for some hours.
- Let drip, weigh again.
- Calculate the water gain, the initial water, and final moisture content.
- Use within an hour or so.

Downfeed Stove Achievements

- Self-feeds a significant amount of the time.
- Long burns with no attention, depending on the size of the wood. Once simmered a pot with a lid for 62 minutes with no attention.
- Can burn wet wood.
- Semi-batch method works well to extend burning time.

Wet Wood Test Results

(Dry portion about 16% moisture)

Date	% Wet / % Dry	Wet Wood Moisture Content
May 27, 2017	59% Wet / 41% Dry	33%
June 11, 2017	60% Wet / 40% Dry	32%
June 15, 2017	39% Wet / 61% Dry	30%
June 17, 2017	56% Wet / 44% Dry	30%
June 25, 2017	81% Wet / 19% Dry	30%
Nov. 2, 2017	76% Wet / 24% Dry	25%

For comparison, other types of wood are roughly:

- Lumber: 8%
- Summer wood in moderately humid climate (Ohio): 14%
- Winter wood in Ohio: 16-20%
- Summer wood in dry climate (Aprovecho): Not measured, but probably around 10%
- Green wood (fresh from tree): Over 30%

Different Burning Characteristics

- In theory, wet wood up to 25% moisture doesn’t have a lot less energy than dry wood.
- In theory, efficiency can be accurately measured and should be little affected by moisture.
- In practice, wet wood is a @#$%^ bitch to burn, efficiency drops, wood use goes way up, tending goes up, time to boil goes up.

Downfeed Stove Limitations

- Fuel chute is not that big, wood of 5 cm to 6 cm (if perfectly straight and smooth) is the maximum.
- Single pot.
- Limit on length of wood, otherwise you tip the stove (add a foot or brace to increase this limit).
- Not terribly efficient.

Other things that were tried on downfeed stove

- Add grate just above lower inlet holes-worked better, but made it hard to light through lower inlet holes.
- Add high grate, just below fuel chute-makes the combustion chamber effectively smaller and works well for dry wood.
- Lower pot supports to try to limit excess air and achieve greater efficiency-fire comes out of fuel chute.
- Different balance of dimensions-dimensions need to be balanced to keep fire from coming out fuel chute.

Introducing the **“Versatile Stove”**

- Major features are:
  - Very large combustion chamber
  - Cone shaped pot supports for very stable pot
  - Easy to see fire

Working title for the concept. So called because it gives the user lots of options for using it, and also has several design options.

- The following slide, with a lengthy quote from Johnson and Bryden, further suggests that stoves with larger combustion chambers are better from a users' perspective. Here, these authors are referring to the amount of attention that a stove requires, in other words, a high number of times tending the fire.

Clearing the Air Over Cookstoves, by Johnson and Bryden

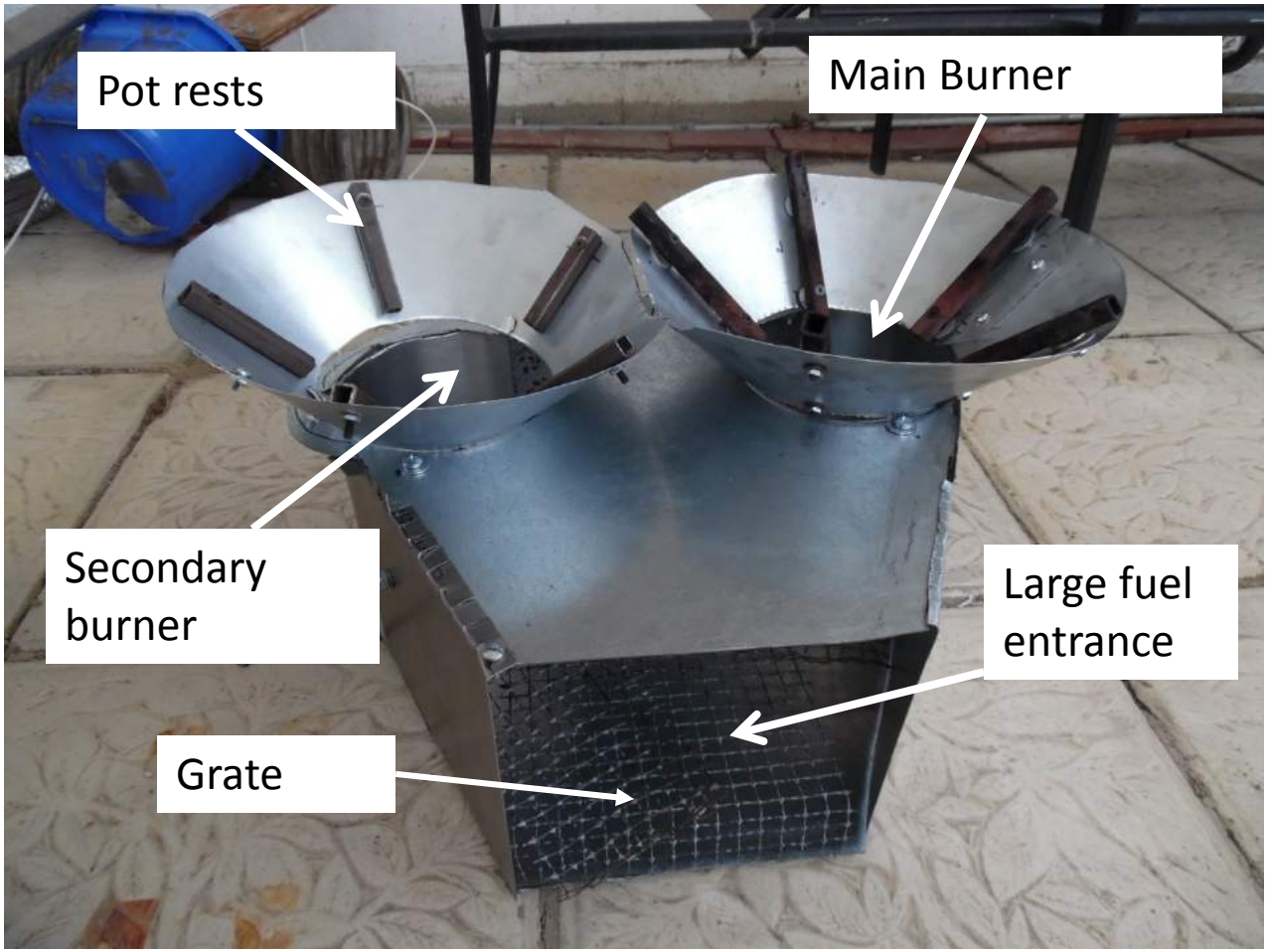
- Such parallel activities are often completed outside the kitchen, drawing the cook's attention away from the fire for periods as long as up to 15 minutes. To keep an unattended fire from smoldering, **women in the village prefer to stoke a fire with large amounts of wood. Improved cookstoves, however, don't allow for that**. Since they are engineered with an eye toward better performance and reduced emissions, improved cookstoves generally have small, well ventilated combustion chambers, meaning they require regular attention. Participant observations suggested that **the constant attention they require is part of the reason these ostensibly improved stoves were used infrequently** in the village.
- Reference, Clearing the Air Over Cookstoves, Nathan G. Johnson and Kenneth M. Bryden, Demand (American Society of Mechanical Engineers Global Development Review), Issue 1, pp. 8-13.

Versatile Stove Timeline

- Initial tests at Aprovecho (Stove Camp, August, 2016) with a T-shape stove (open at both ends with one pot in middle, see previous slide) showed great promise in limited tending of stove, high power. Probably, the limited tending was due to large dry wood in the dry climate of the Oregon summer.
- This led to end-feed stoves with a single pot, wide open at one end with a small air inlet in the other.
- This led to end-feed stove with two pots, but I could never get as much heat as I wanted to the pot closest to the fuel entrance.
- This led to the side-feed two-burner stove, which will be shown in detail.
- Smaller and larger combustion chambers were tried, with worse results.
- The end-option works well if you have a single pot, or are willing to have one weak burner.

Versatile Stove Two Pot Version

(Insulation removed for clarity)



End-feed One Pot Version

(Insulation removed for clarity)

Introducing *Big Moe*, the biggest piece of wood ever burned in a family size stove

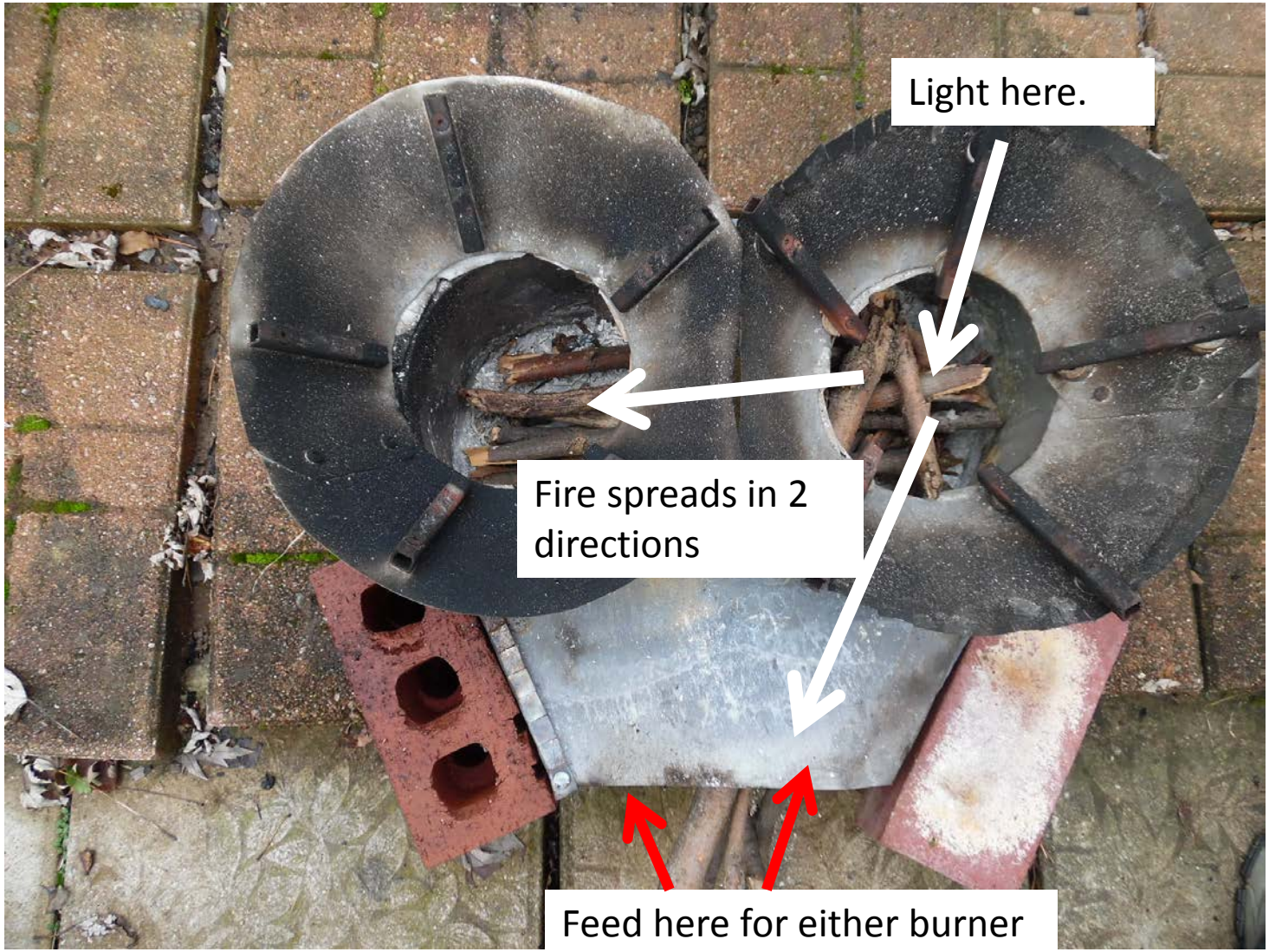
Spot the Similarity

Big Moe was 8 cm in diameter,
but is now fertilizing Dale's garden.

Several Options for Lighting Stove

- Stove can be kindled and then larger fuel added as the fire builds.
- Stove can be batch loaded with mixed small and large wood and will burn for a long time without attention.
- Stove can be batch loaded across stove chamber to light fire under both pots at once, as seen in following slide.

I prefer to batch light stove, such that fire burns under both pots without much attention.



Versatile Stove Results

- The stove is powerful, times to boil are typically 15-20 minutes for 5 liter main pot.

- Stove requires little tending, below 3 times if you have big dry wood, with or without lids on the pots. More tending needed for wet wood.

Test Results (continued)

- Two burner stove easily handles two pots, with <u>independent fire control under each pot</u>.
- You can also heat a pot of wash water if a second pot is not needed for cooking.
- Big and/or branchy wood can be burned.

Test Results (continued)

- Stove can burn some wet wood.
- 1/3 wood at 30% moisture has been burned along with 2/3 wood at 16% moisture.

Test Results (continued)

- Turndown ratios of 3-4 are possible with the right wood arrangement.
- fuel usage is to complete test is
  - For single burner stove
    1400 g with pot lid, 2000 g without.
  - For double burner,
    2000 g with lids, 2800 g without.
- Limited fire tending means fire is often larger than optimum (but this is reality in the field) thus burning more wood than with an ideal fire.

Limitations of Versatile Stove

- Big, and probably expensive.
- Not terribly efficient.

Other Things Tried on Versatile Stove

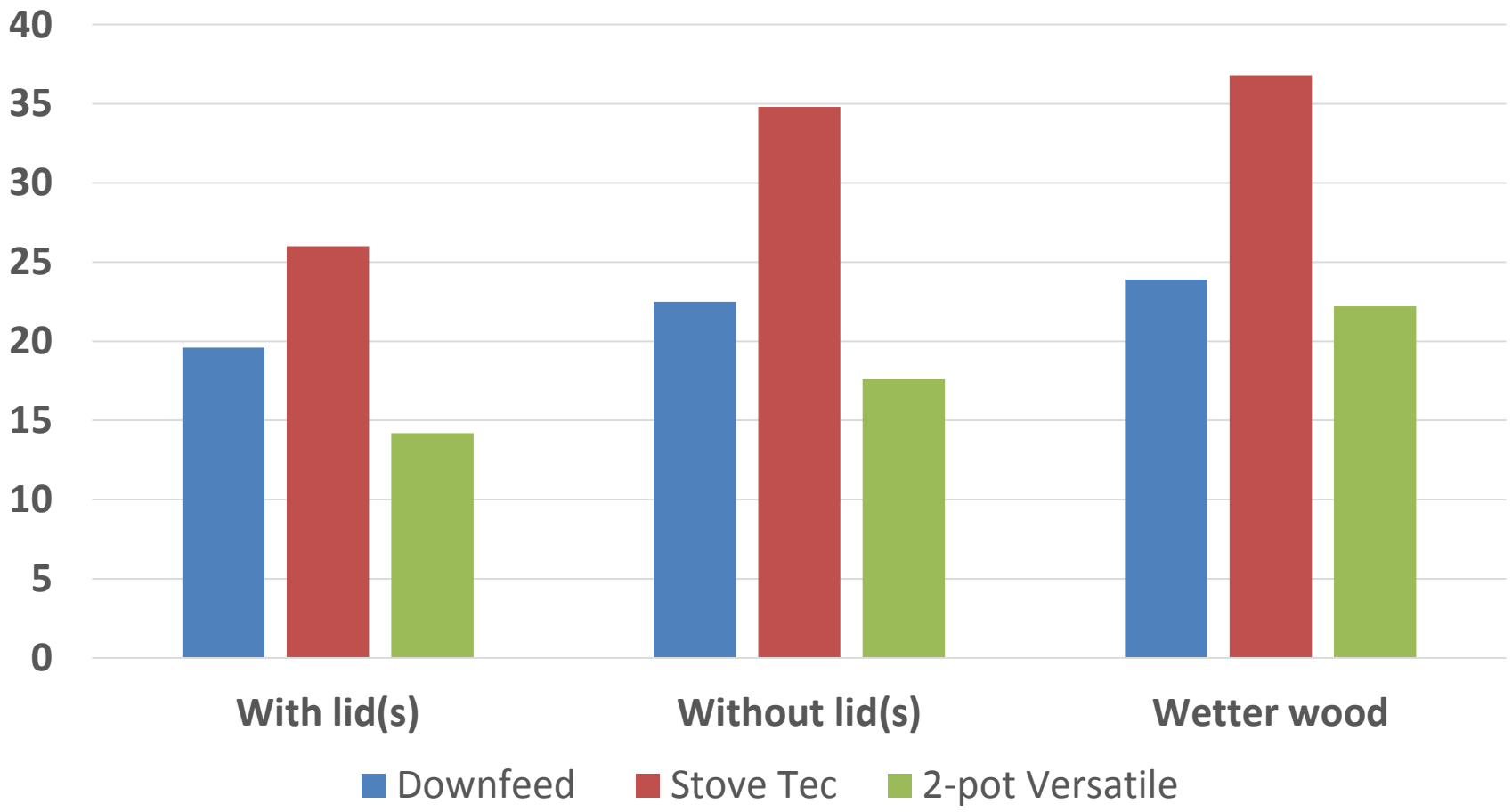
- Smaller combustion chamber, didn't work as well.
- Larger combustion chamber, barely worked at all.
- Curved lip at top of cone to redirect fire to the side of the pot, helped efficiency a little but not worth complexity.
- Cones made of perforated metal. Helped a little, but more complex.
- Shorter pot supports-improved efficiency but at the expense of visible smoke.
- Without grate-didn't burn as well, grates work better.
- For a single burner stove, the end feed option is better. For a 2-burner stove, the side feed is better.
- Two-burner end feed stoves have to heat to the back pot (at the closed end) but no design ever got much heat to the front pot. If a weak front pot heater is OK, some designs are available.
- For the 2-burner side feed, one can remove the weak side cone and just sit a small pot on the hole in the top of the box. This is not optimum, but could be adequate, and saves on cost.

Comparison Tests between Small Combustion Chamber Stove (Stove Tec), Downfeed, and Versatile Stove

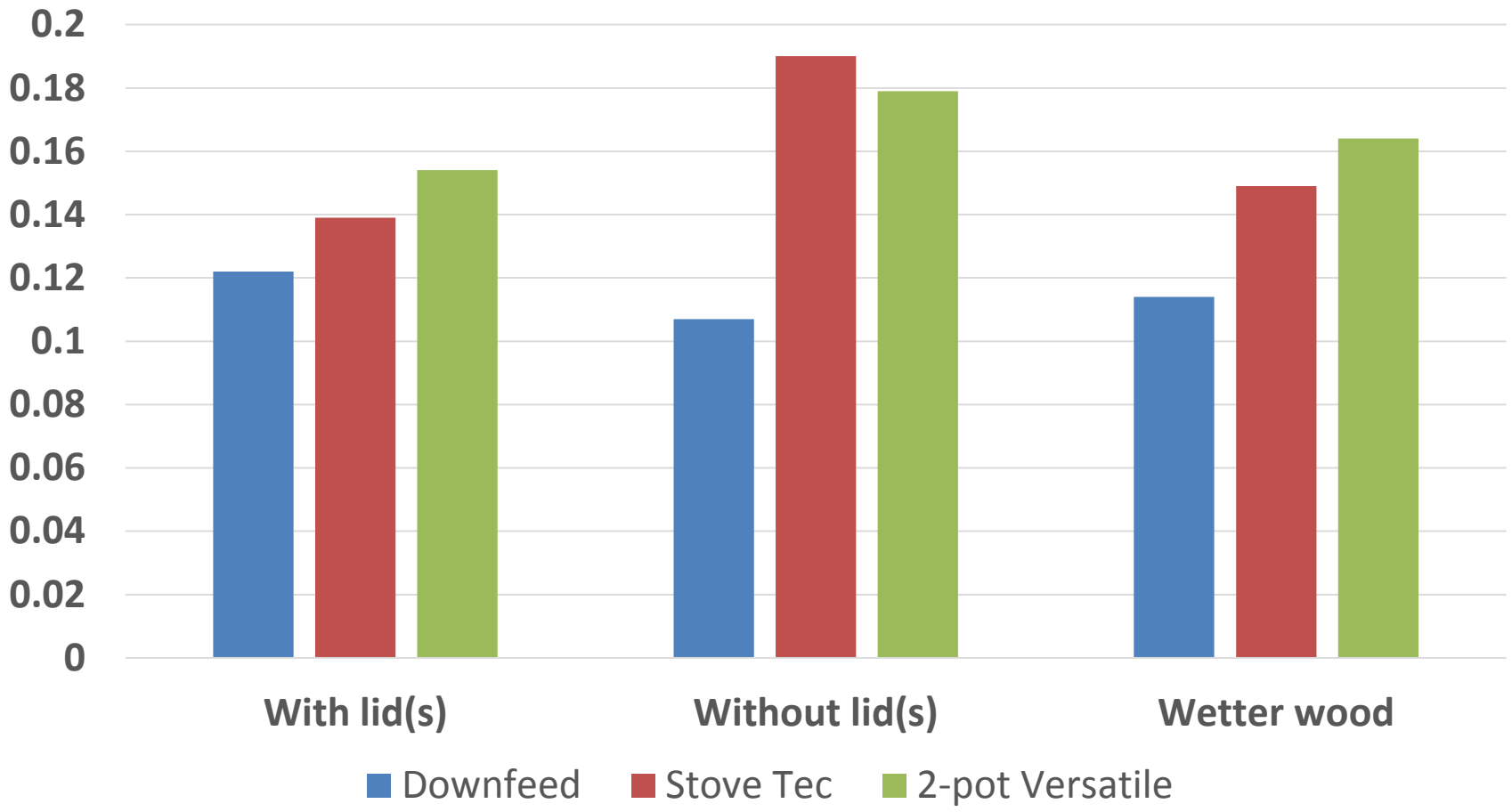
Notes from Comparison Tests

- Stove Tec was used without a skirt; reports from the field suggest that skirts are usually not used (because user can't see fire?) This hurts its performance considerably.
- For pollutant results, Versatile Stove was end feed with 2 pots. For other results, Versatile Stove was side feed with 2 pots.
- Time to boil for Versatile Stove is for the main pot.

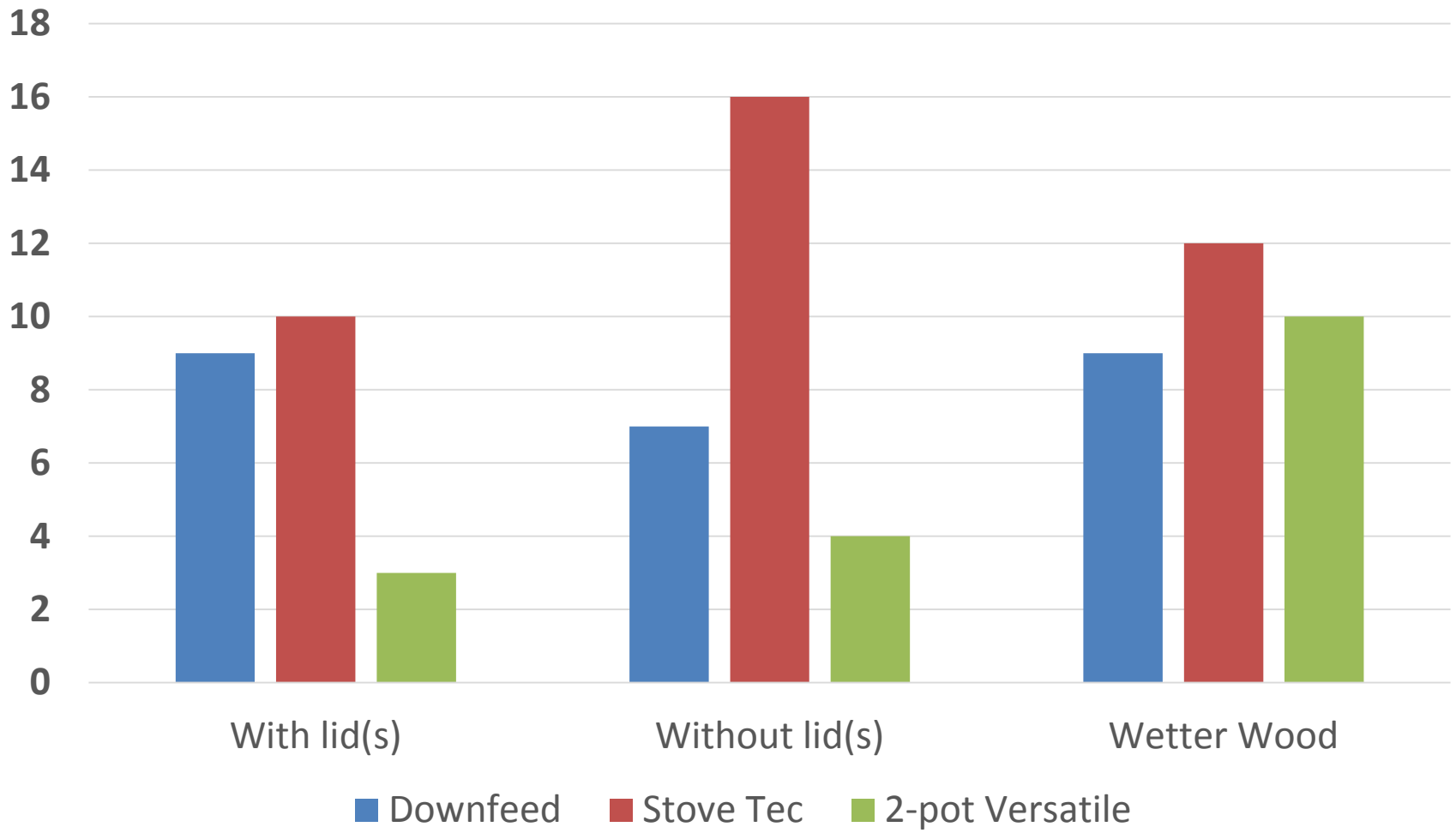
Time to Boil (Minutes)



Thermal Efficiency



Times Tending Fire



Key Points

- Stoves need to have practical benefits to be attractive to users.
- Two stove designs which offer practical features are:
- The downfeed rocket stove which is very good at burning wet wood, and allows the user to see the fire easily.
- The Versatile Stove with a large combustion chamber, which is powerful and can burn big branchy wood.

Backyard Pollutant Measurement

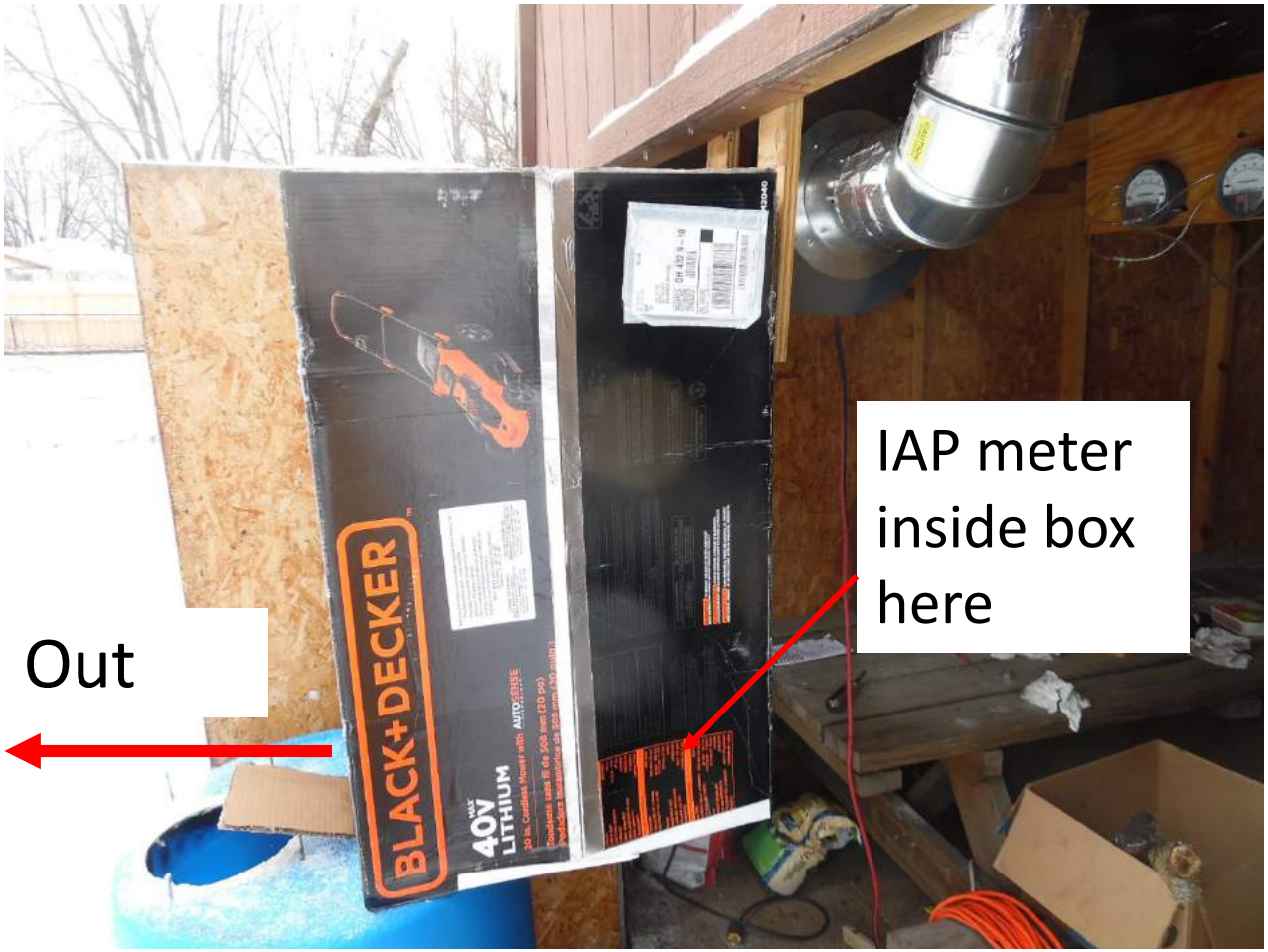
- With the Indoor Air Pollution meter from Aprovecho, I built a backyard pollutant hood in late 2017. Limited results to date.
- Particulate measurement are light-based, not gravimetric, so results are not terribly accurate.
- Stove comparisons can be made.
- Pollutants vs. time can be tracked.

Aprovecho Indoor Air Pollution Meter

Test shed

Burning Area

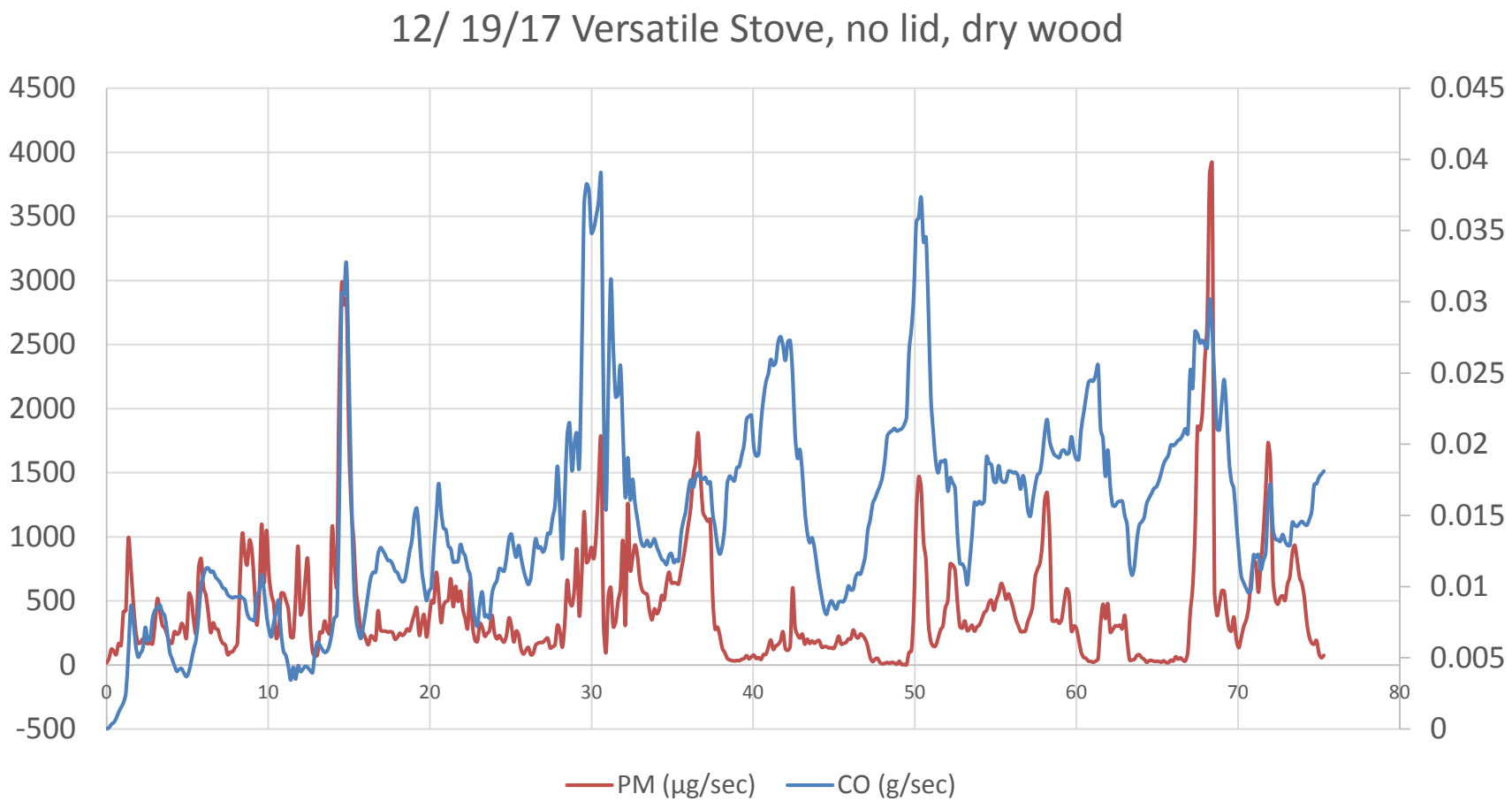
IAP meter goes inside box



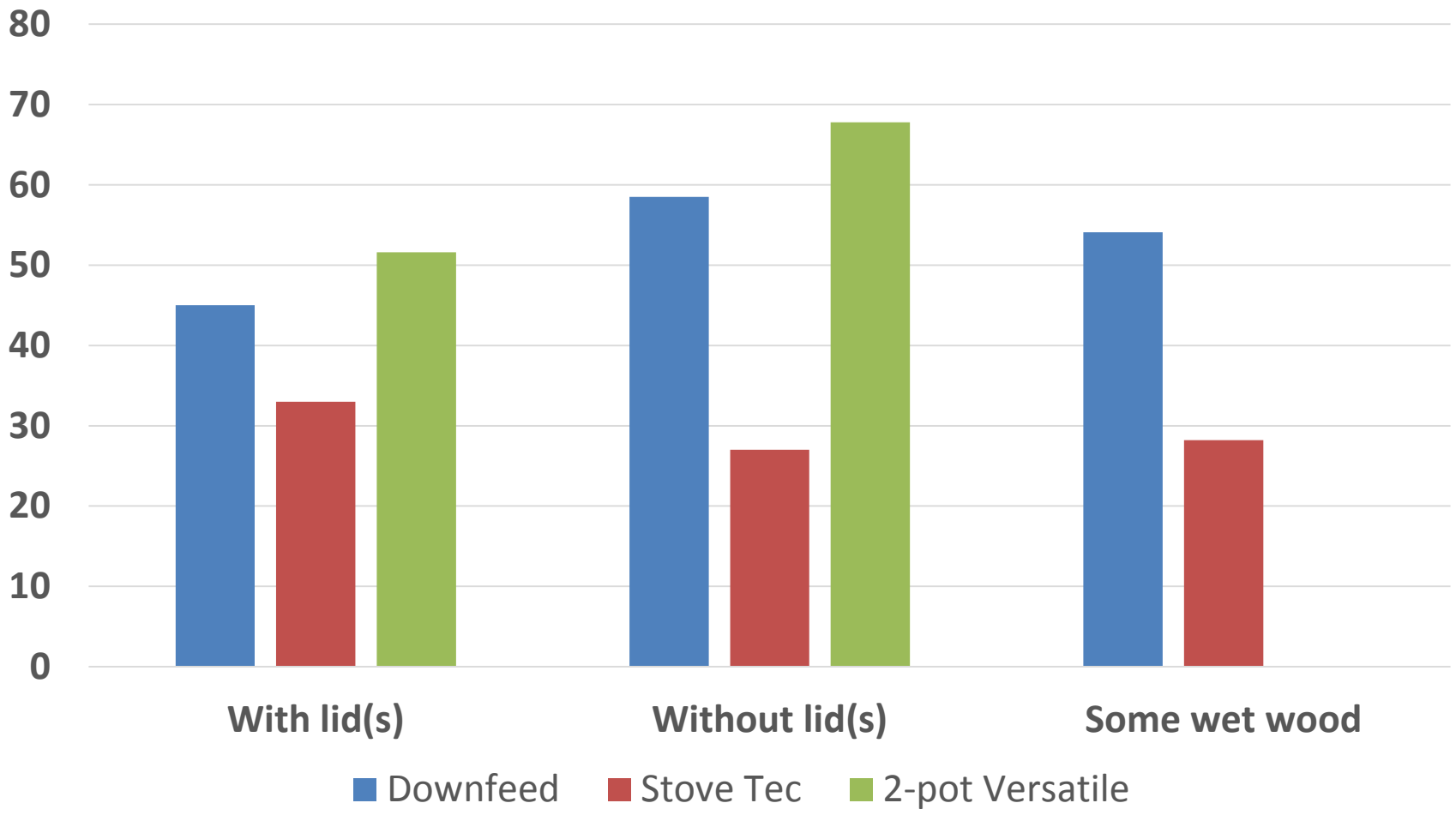
Flow Grid-type flow meter with pressure measurement

Typical pollutant graph

(Pollutant production rate vs. Time



Carbon Monoxide (grams)



Total Particulates (milligrams, all sizes)