Indonesia Clean Biomass Cookstove Program

Creating a Culture of Context

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October 21st, 2014

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Building on success

The stove replacement program in Ulaanbaatar, Mongolia – WB, ADB, MCC, UB City

- ≈75% of small home stoves replaced in 3 years
- Fuel type and condition are the same
- Air quality has improved 22%/year for 2 years

UB-CAP described as a ‘spectacular success’

- Product selection: lab tests predict performance
- Lab tests mimic typical use and fuels
- Buzz is now about ‘clean stoves’ not ‘dirty fuels’

Predicting performance

Stove performance is affected most strongly by

- User behaviour
- Fuel type and condition
- The burn cycle from ignition to extinction
- The stove itself

Stove performance is not 'inherent'

- All stoves can be operated in ways that give higher or lower performance on any metric
- Lab testing should reflect typical patterns of use

Social Science Team – feedback

Indonesians answering a census question on fuel:

‘ Primary cooking fuel is Biomass’

40% of households **primarily** cook with biomass **however** LPG is in common use when available – about 70% of them also use LPG

‘Primary cooking fuel is LPG’ **Liquid Propane Gas**

40% of households **primarily** cook with LPG **however** biomass is in common use – about 70% of them also use biomass, mainly for heating water.

Product types to promote

- Domestic cooking stoves – applicable to the lower income groups
- Water heating devices – applicable to the majority of income groups
- A cooking stove can be used for heating water, but a specialized water heater can be much more fuel efficient.

Full range of burn cycles = National context

Indonesia

- 10,000 occupied Islands
- Large range of fuels available
- Many types of fuel presently wasted/burned
- Large variation in foods cooked
- Large variation in pot sizes
- Large variation in cooking cycles
- Results Based Finance <u>requires</u> a reasonably good prediction of performance in the community

Localized burn cycles = Local context

Cultural preferences dominate what a stove should do, therefore what it looks like.

This stove from Gorontalo Province has well-controlled excess air, a well-made clay combustion chamber and a tray for roasting *sate* (shishkabob) over charcoal produced by the fire.

Predicting performance: Individual context

User behaviour affects

- What fuels they select
- What burn cycles they use
- What pots are used – size and number
- What cooking sequence and style is preferred

Predicting stove performance means

- Assessing how the stove deals with those four variables
- How will the stove perform when operated 'in that way' or in a 'set of ways'?

Supporting the objectives of the Pilot

A common testing framework must address:

- **Market-based sector development**
- **Technology neutral:** Test methods must consider every known technology fairly
- **Incentives are based on results achieved:** Test methods must reasonably predict what happens in particular communities to justify the incentives
- **The requirement is:** a common testing framework into which candidate stoves, local fuels, pots and burn cycles can be accommodated.

What is the context for the baseline?

There are multiple baselines

- **Central Java** baseline stoves include the clay 'Keren', open fires, two-pot no chimney. Most homes have 3 or more stoves of different sizes.
- **Sumba Island** baseline is a large open 3-stone fire
- **Pots** are highly variable, even within a region

What are the performance target metrics?

	Overall Thermal Efficiency		Emissions		Safety, Environment and Durability	
	Stove	Water Boiler	CO (g/MJ_{NET})	PM2.5 (mg/MJ_{NET})	Safety Enviro	Durability
One Star **SNI draft**	≥25% 20-30%	≥45%	≤12	≤300	Expert Review	1 Yr.
Two Stars	≥30%	≥55%	≤10	≤200	Expert Review	1 Yr.
Three Stars	≥40%	≥65%	≤ 8	≤100	Expert Review	1 Yr.

Incentives are offered for three types of performance, after passing a basic safety and durability assessment: Fuel efficiency plus CO and $PM_{2.5}$ emissions.

A user-driven conceptual framework considers:

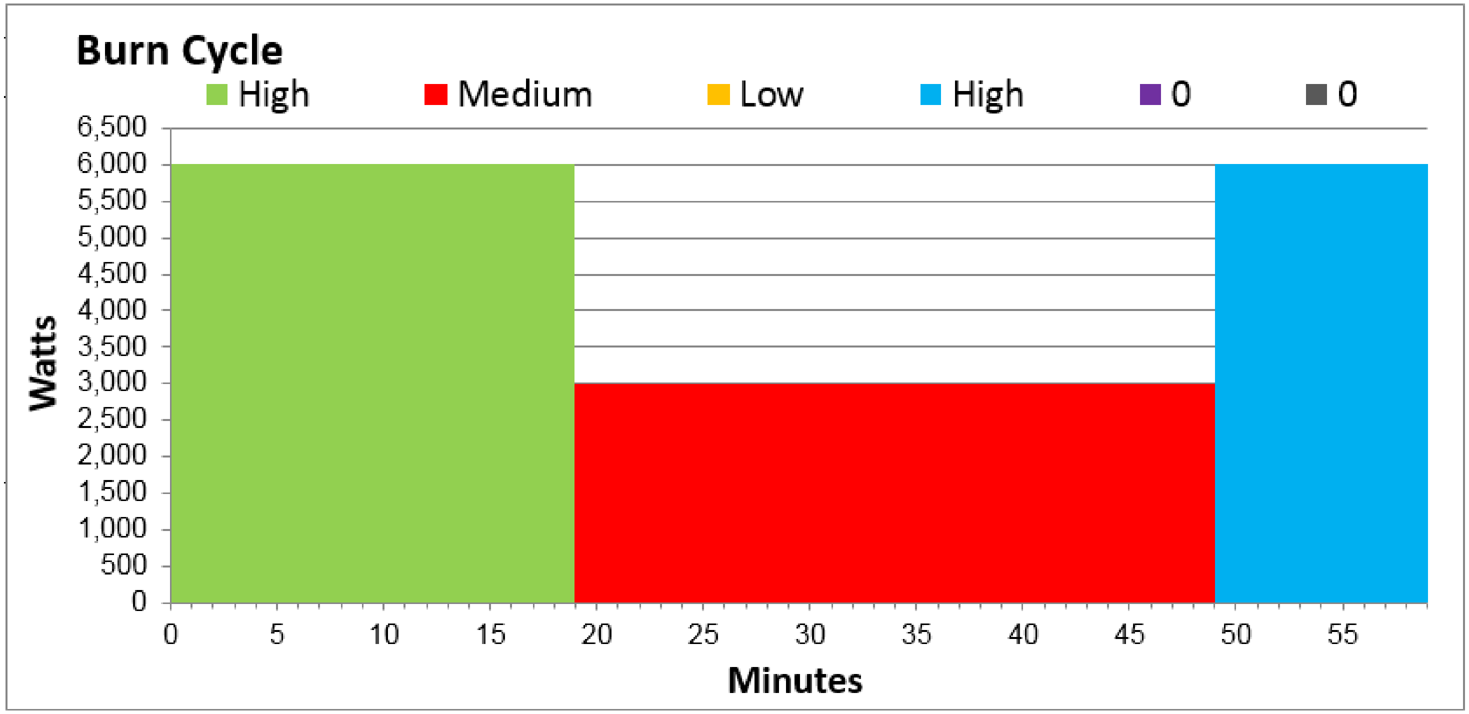
- Acceptable cooking power
- Turn-down ratio
- Controllability
- Fuel flexibility
- Fuel efficiency (consumption)
- Accepts pots in common use
- Durable (1 year guarantee)
- Stable including pot stability
- Reduces emissions and exposure to smoke

The Cooking Test

- Typical cooking practices are observed; burn cycles and cooking cycles are characterised.
- Two common, dissimilar burn cycles are selected.
- Cooks familiar with the cooking cycle and the baseline stoves perform a ‘Cooking Test’ in the laboratory. Focus groups may be involved.
- Performance is captured.

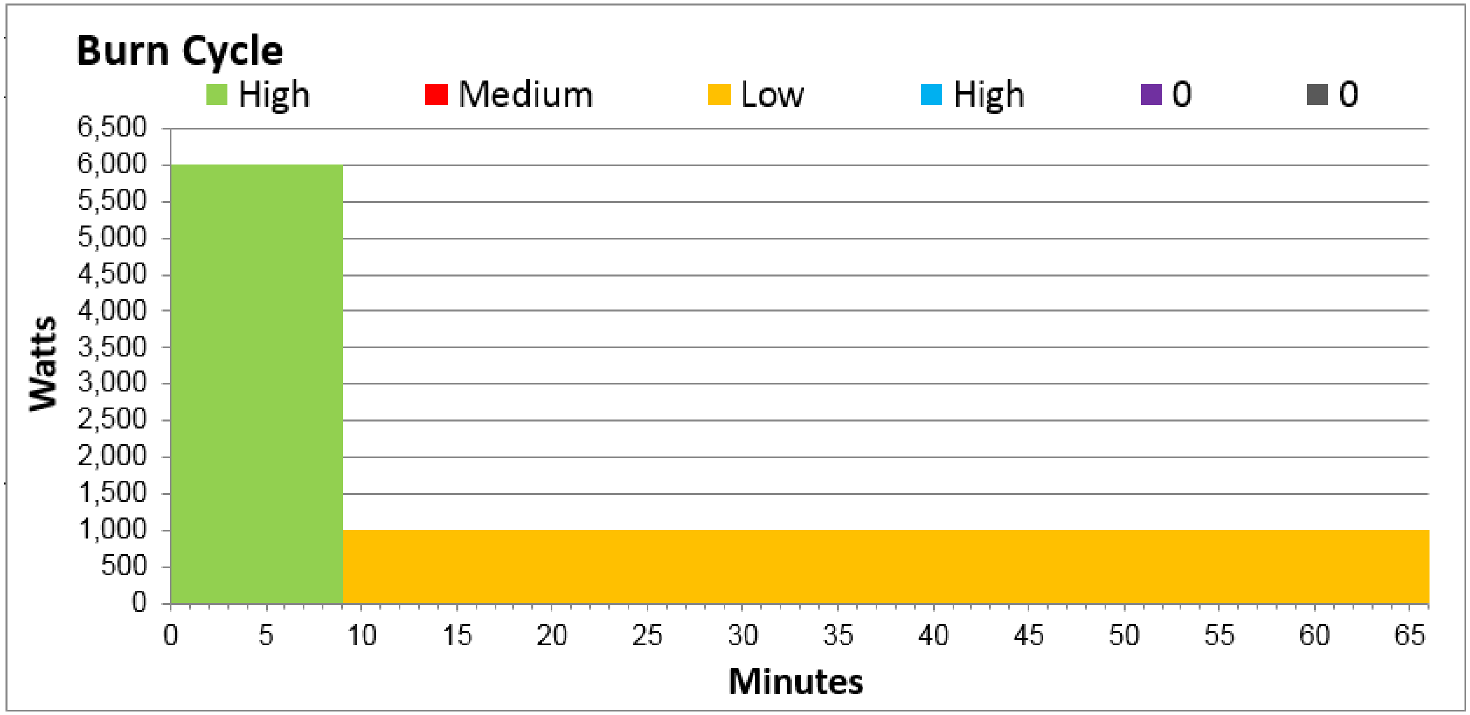
The Cooking Test 1

Cooking Power	High	Medium	Low	High			Total
Minutes	19	30	None	10	None	None	59



The Cooking Test 2

Cooking Power	High	Medium	Low	High			Total
Minutes	9	None	57	None	None	None	66



The Technical Test

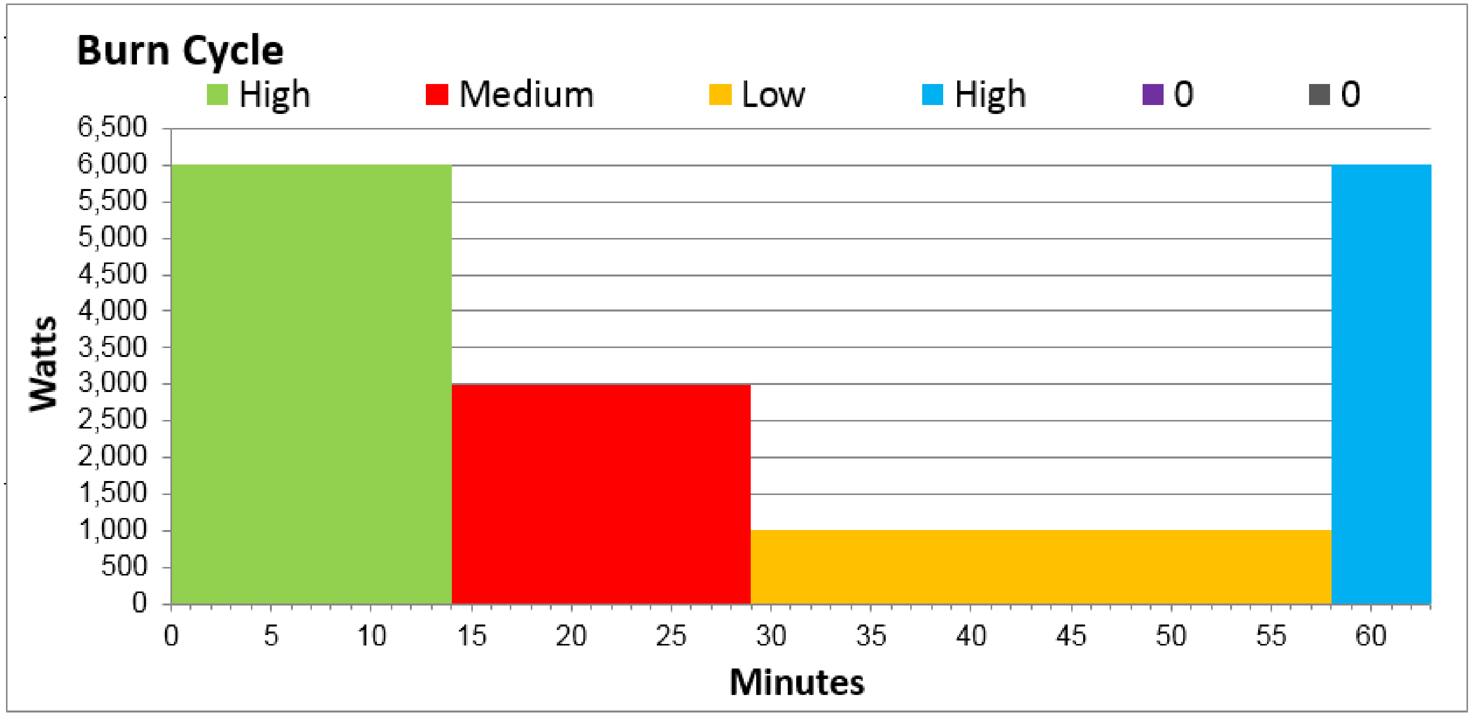
- A ‘Technical Test’ reasonably replicates the average power and duration of the Cooking Test burn cycles.
- Two cooking cycles are being used to create the Technical Test in Central Java.
- Additional cooking cycles can easily be included and the number of each can be weighted according to local practise.
- The weighting period could be weekly or monthly or seasonally.

Technical Test Design

- The burn cycles of the Cooking Tests are examined to establish the approximate fire power at various times, making use of Heat Flow Rate (HFR) tests as necessary.
- The power profiles are examined, selecting one that is mostly high power and one that is mostly low. The profiles should span the cooking power requirements.
- The resulting burn cycle is used during the Technical Test which represents average use in the community.

The Technical Test burn cycle

Cooking Power	High	Medium	Low	High			**Total**
Minutes	14	15	29	5	None	None	**63**



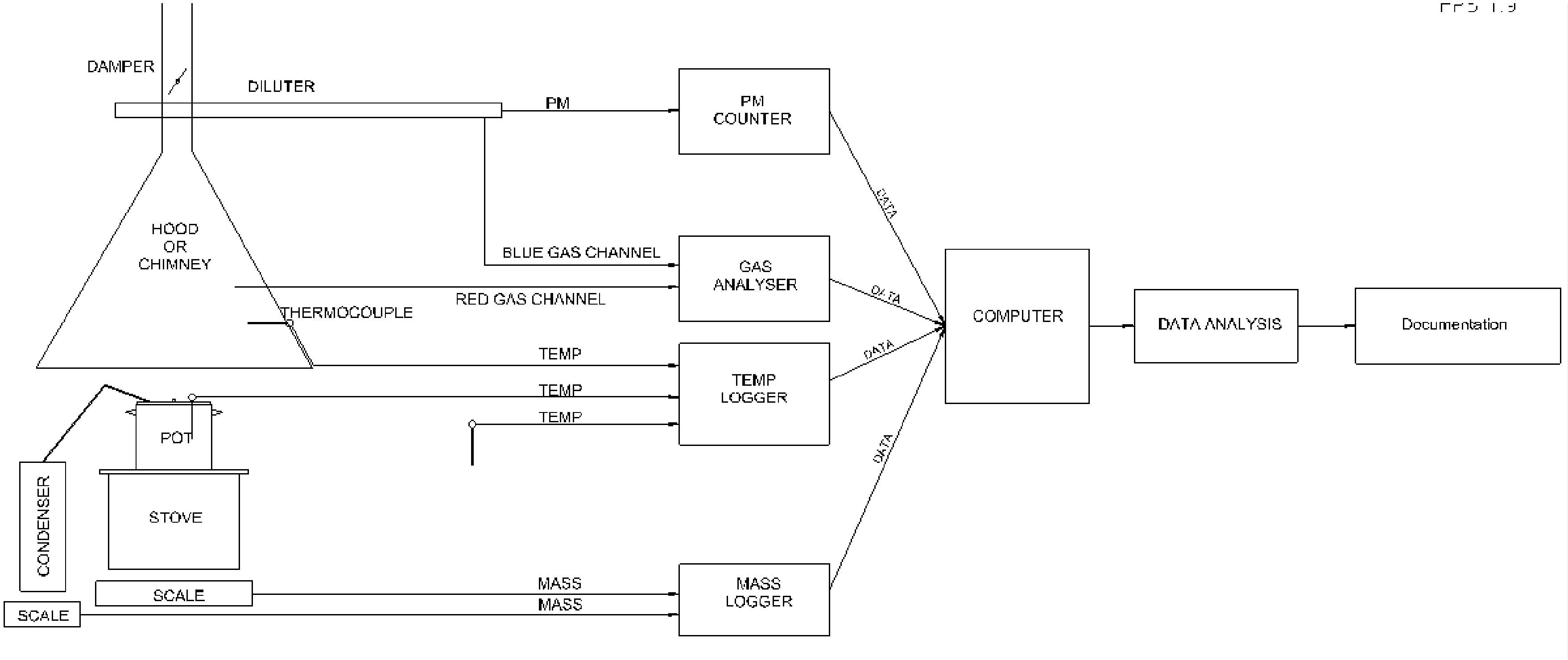
Cooking Test Metrics

Name	Method	Units	Variable
Total CO, whole test	Hood and volume	g	$\sum CO$
Total PM, whole test	Hood and volume	mg	$\sum PM$
Energy value of fuel used per burn cycle, reusable fuel considered	Fuel type, mass, moisture content, reusable and unusable fuel remaining is considered	MJ	$\sum MJ_n$

Technical Test Metrics

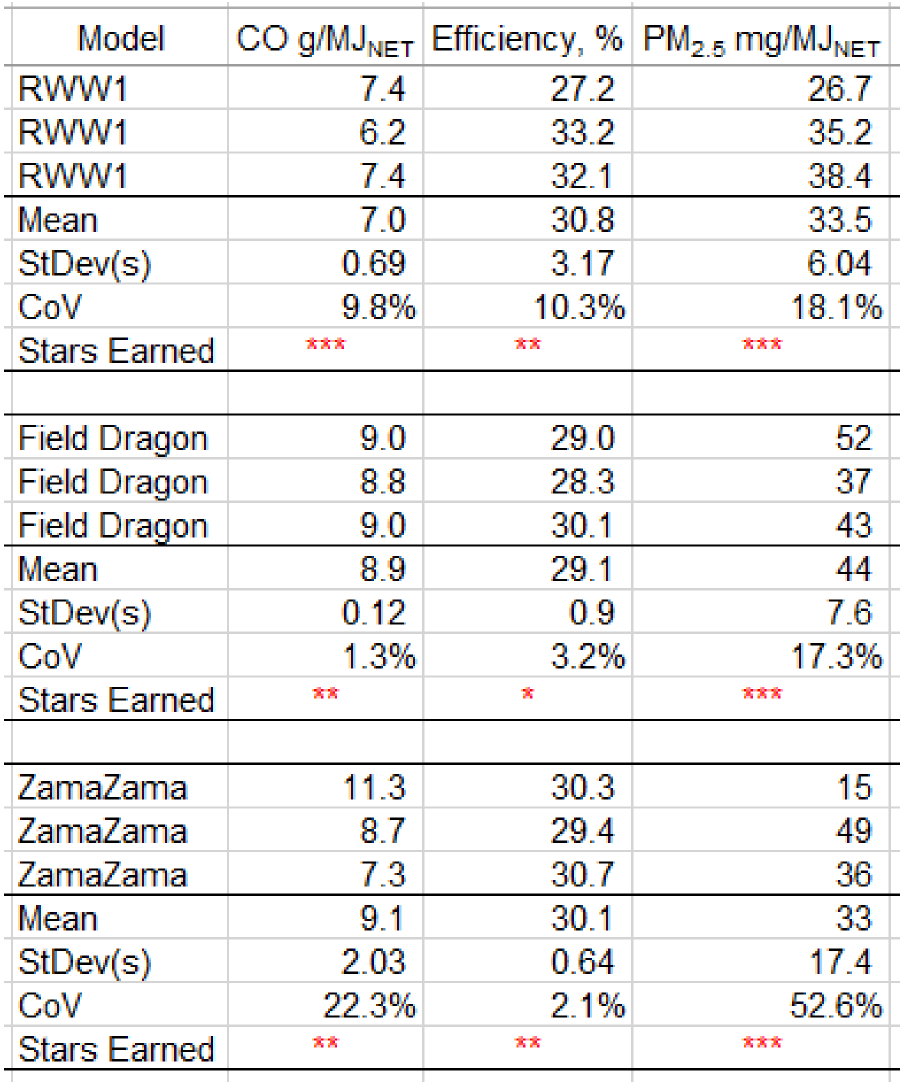
Name	Method	Units	Variable
System Efficiency, whole test	Energy gained by pots, potential net energy value of fuel consumed	%	η
CO/MJ_{NET}	Hood and volume, energy gained by pots	g/MJ_{NET}	CO'
$PM2.5/MJ_{NET}$	Hood and volume, energy gained by pots	mg/MJ_{NET}	PM'
Turn down ratio high/low Cooking stoves only	Average cooking power, high and low power phase	Ratio	TDR_L
Heat Flow Rate (HFR) into the pot	Average cooking power, heated pot surface	$Watts/cm^2$	Q''
Firepower on ‘high’ and ‘low’	Net energy value of fuel burned, CO mass, time	Watts	$\dot{W}_H$ $\dot{W}_L$

Test Laboratory *HTP* Method



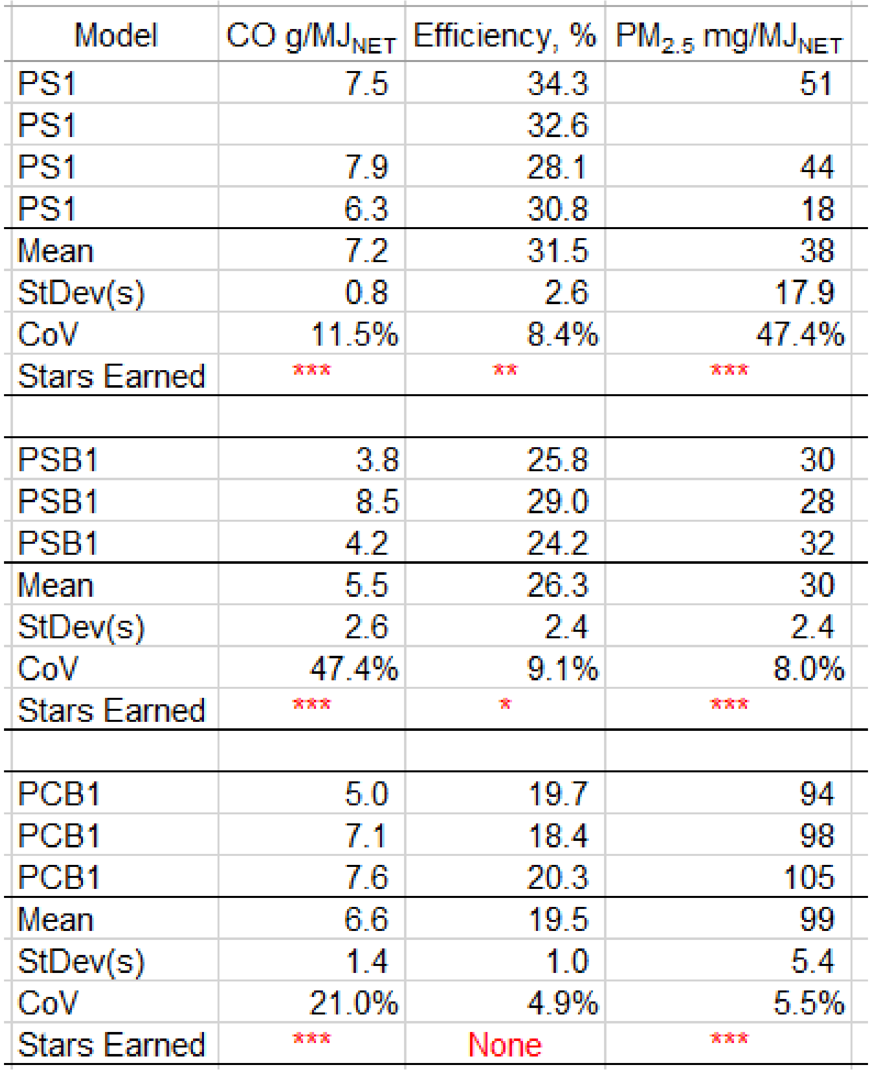
The *HTP* method uses a chemically balanced calculation of emissions and a determination of thermal performance based on heat crossing into the pot.

Test Laboratory *HTP* Results



Model	CO g/MJ_{NET}	Efficiency, %	$PM_{2.5}$ mg/MJ_{NET}
RWW1	7.4	27.2	26.7
RWW1	6.2	33.2	35.2
RWW1	7.4	32.1	38.4
Mean	7.0	30.8	33.5
StDev(s)	0.69	3.17	6.04
CoV	9.8%	10.3%	18.1%
Stars Earned	***	**	***
Field Dragon	9.0	29.0	52
Field Dragon	8.8	28.3	37
Field Dragon	9.0	30.1	43
Mean	8.9	29.1	44
StDev(s)	0.12	0.9	7.6
CoV	1.3%	3.2%	17.3%
Stars Earned	**	*	***
ZamaZama	11.3	30.3	15
ZamaZama	8.7	29.4	49
ZamaZama	7.3	30.7	36
Mean	9.1	30.1	33
StDev(s)	2.03	0.64	17.4
CoV	22.3%	2.1%	52.6%
Stars Earned	**	**	***

Test Laboratory *HTP* Results



Model	CO g/MJ_{NET}	Efficiency, %	$PM_{2.5}$ mg/MJ_{NET}
PS1	7.5	34.3	51
PS1		32.6	
PS1	7.9	28.1	44
PS1	6.3	30.8	18
Mean	7.2	31.5	38
StDev(s)	0.8	2.6	17.9
CoV	11.5%	8.4%	47.4%
Stars Earned	***	**	***
PSB1	3.8	25.8	30
PSB1	8.5	29.0	28
PSB1	4.2	24.2	32
Mean	5.5	26.3	30
StDev(s)	2.6	2.4	2.4
CoV	47.4%	9.1%	8.0%
Stars Earned	***	*	***
PCB1	5.0	19.7	94
PCB1	7.1	18.4	98
PCB1	7.6	20.3	105
Mean	6.6	19.5	99
StDev(s)	1.4	1.0	5.4
CoV	21.0%	4.9%	5.5%
Stars Earned	***	None	***

Thank you!

A lighting cone (left) is shown igniting damp wood on Sumba Island reducing smoke from ignition by 90%.

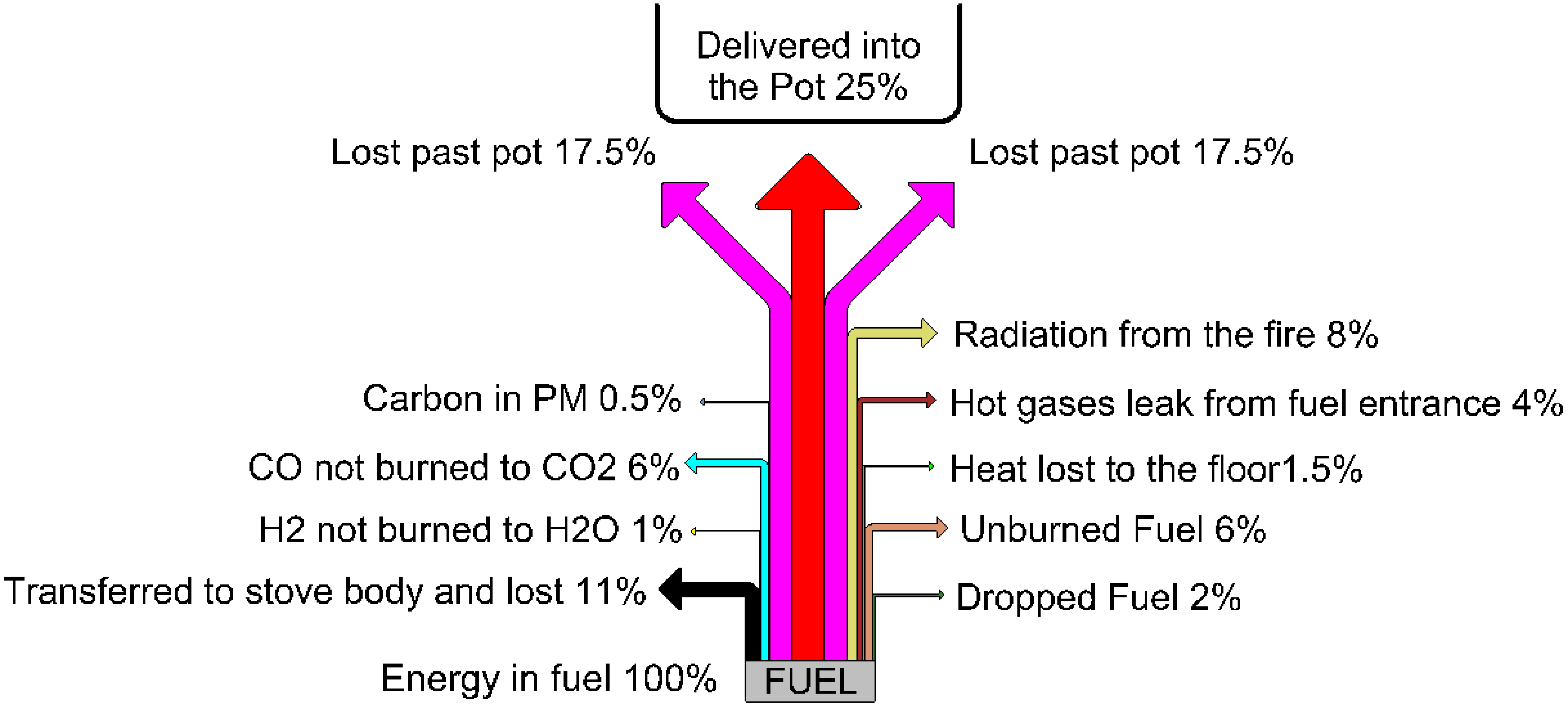
Average pot size is 25 litres.

Test methods should, as far as possible, not exclude unexpected innovations.

Test Theory – what is available to measure

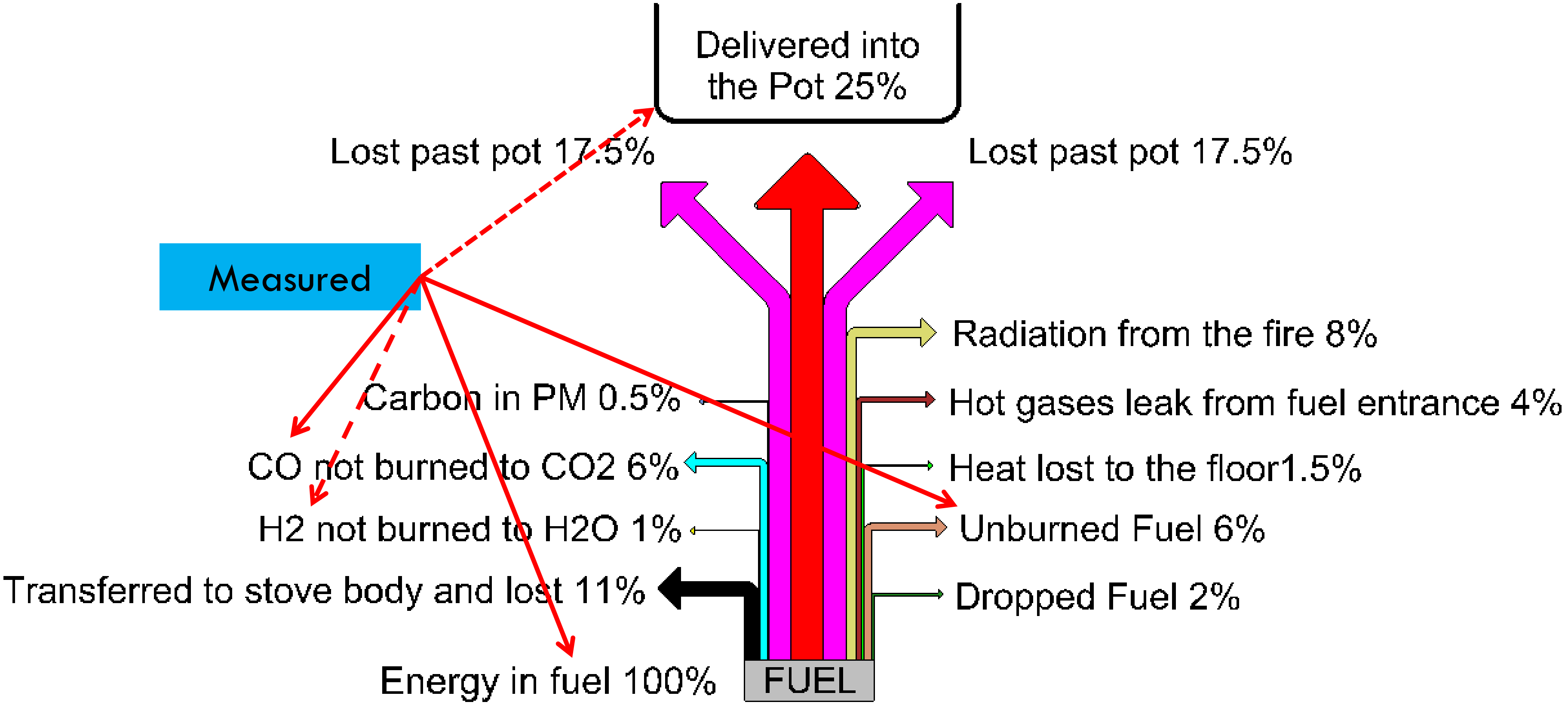
The following presentation explains where the heat goes during a cooking event, what is available to be measured, and why great care must be taken when selecting variables for analysis.

Heat Flow Diagram - Fire



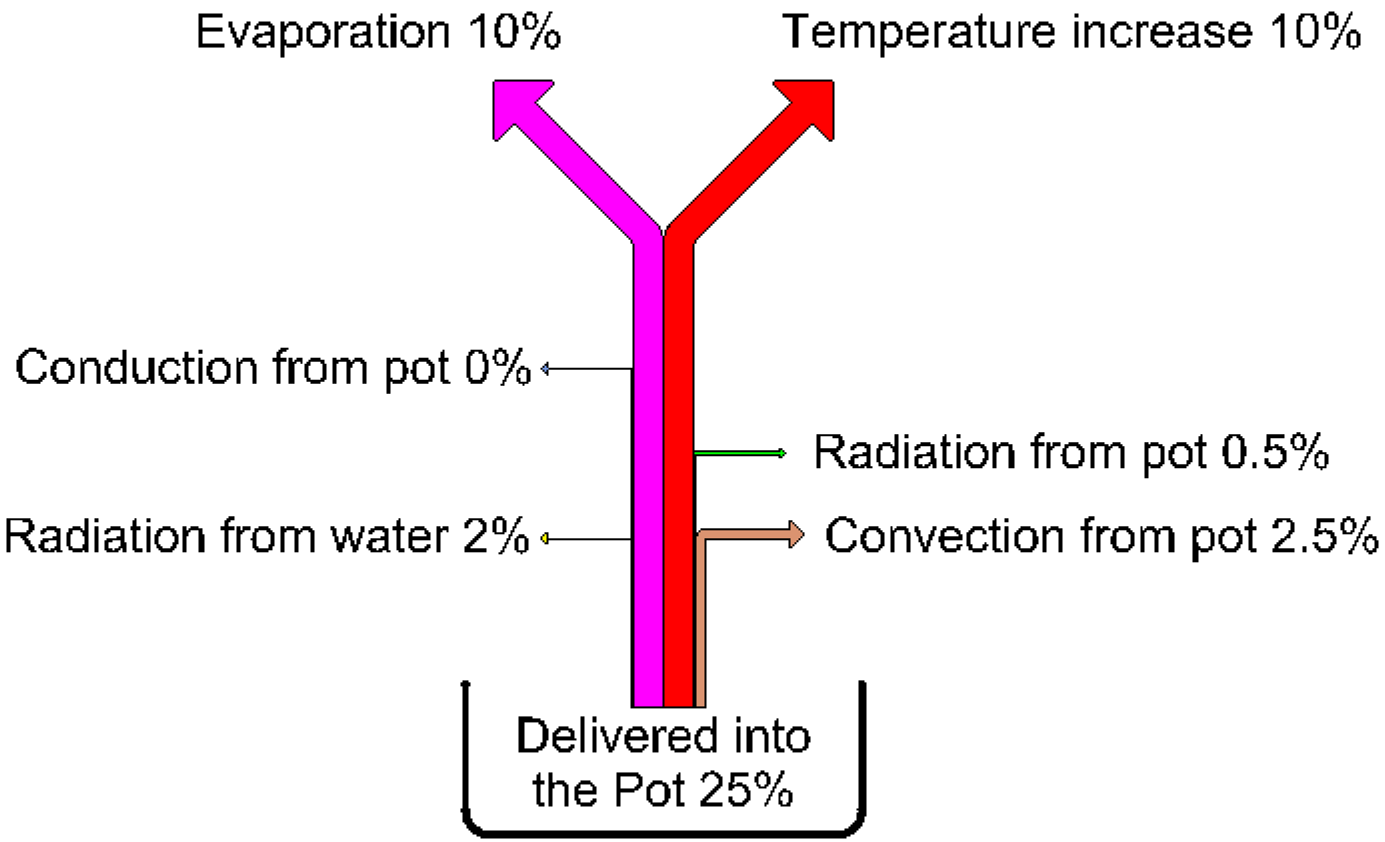
Some fuel energy paths can be measured easily. For example, heat is easier to trace than unburned fuel. Losses are chemical, mechanical or wasted heat in gases. “Efficiency” is 25%.

Heat Flow Diagram - Fire



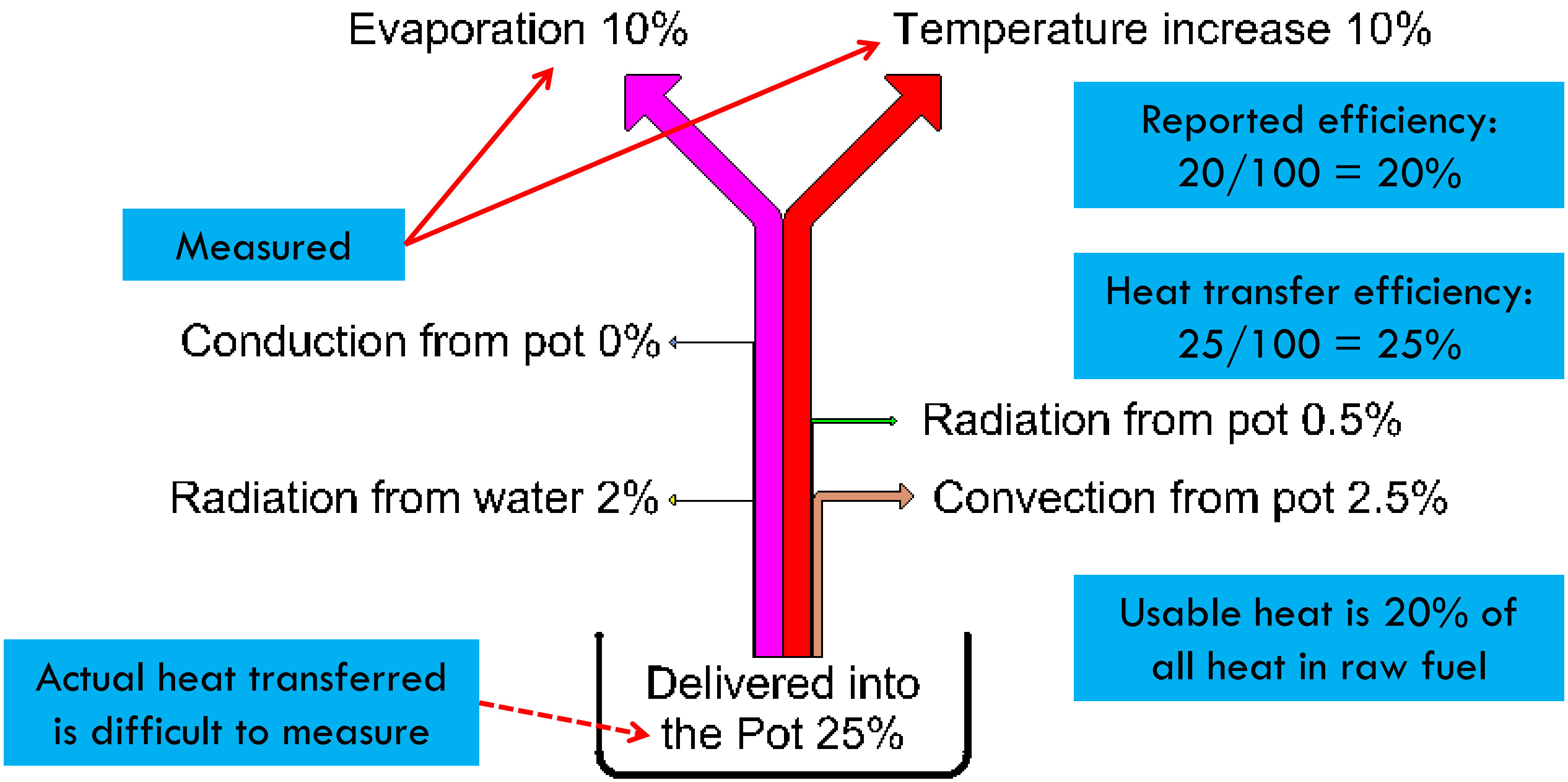
Some fuel energy flows can be measured easily. Heat flow is easier to evaluate than heat in unburned fuel. Losses are chemical, mechanical or wasted heat in gases. “Efficiency” is 25%.

Heat Flow Diagram: Cold Pot, High Power



Only some fuel energy paths can be measured easily. For example, heat is easier to trace than unburned fuel. Losses can be chemical, mechanical or wasted heat in gases.

Heat Flow Diagram – Cold Pot, High Power



Evaporation 10%

Temperature increase 10%

Reported efficiency:
20/100 = 20%

Measured

Conduction from pot 0%

Heat transfer efficiency:
25/100 = 25%

Radiation from pot 0.5%

Radiation from water 2%

Convection from pot 2.5%

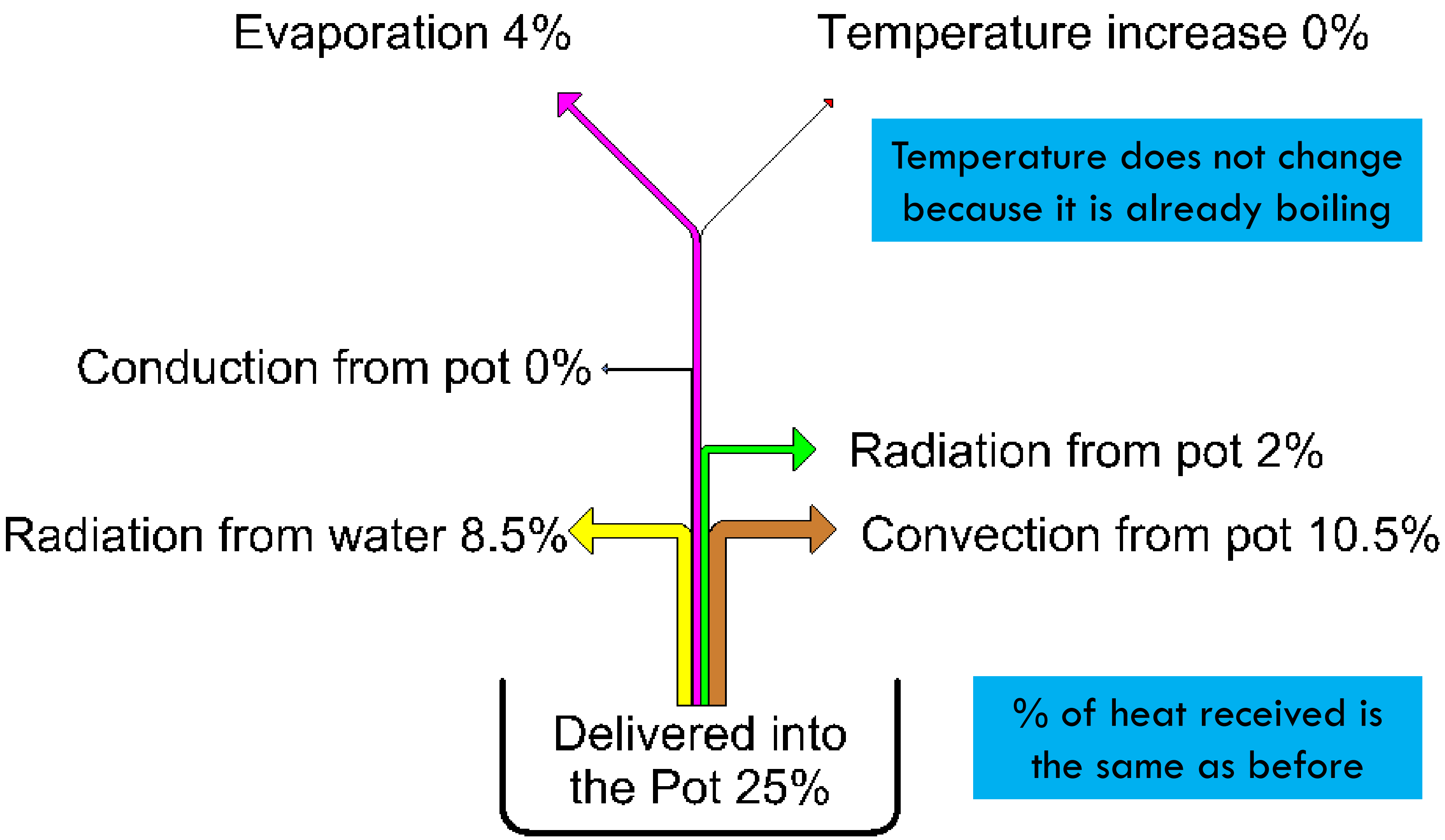
Usable heat is 20% of
all heat in raw fuel

Actual heat transferred
is difficult to measure

Delivered into
the Pot 25%

Only some fuel energy paths can be measured easily. For example, heat is easier to trace than unburned fuel. Losses can be chemical, mechanical or wasted heat in gases.

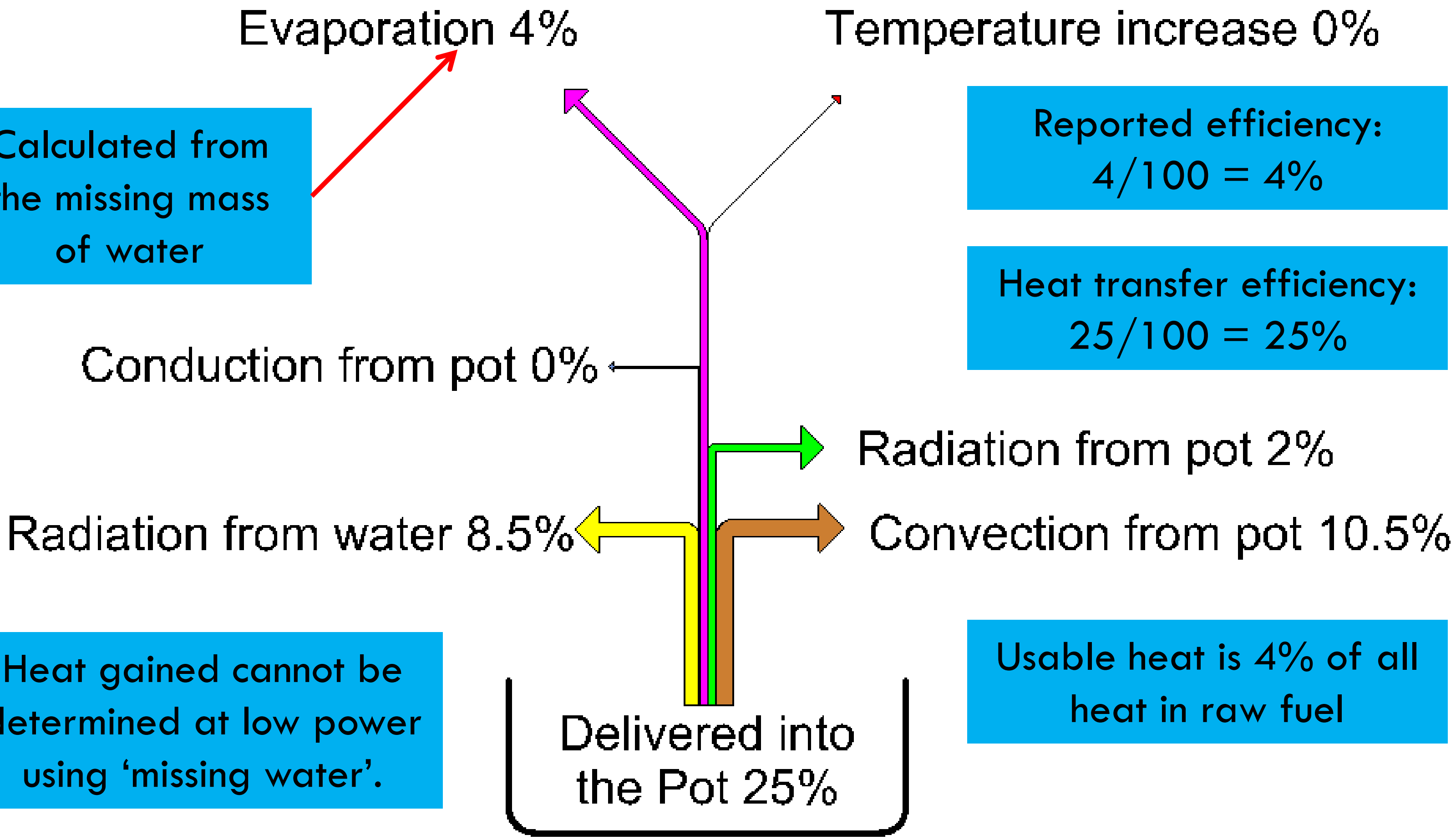
Heat Flow Diagram – Hot Pot, Low Power



Temperature does not change because it is already boiling

% of heat received is the same as before

Heat Flow Diagram – Hot Pot, Simmering



Evaporation 4%

Temperature increase 0%

Calculated from the missing mass of water

Reported efficiency:
4/100 = 4%

Heat transfer efficiency:
25/100 = 25%

Conduction from pot 0%

Radiation from pot 2%

Radiation from water 8.5%

Convection from pot 10.5%

Delivered into the Pot 25%

Heat gained cannot be determined at low power using ‘missing water’.

Usable heat is 4% of all heat in raw fuel

Thermal Efficiency – which one for cooking?

Efficiency is a ratio, but of what to what? Let us follow the heat and decide which ‘efficiency’ we want.

1. Heat available in the raw fuel if it was to be burned completely
2. Heat available in the dry portion of the raw fuel
3. Heat available from the fire considering incomplete combustion
4. Heat available to the pot, at the pot in the hot gas stream passing by

5. Heat transferred to the pot – all of it
6. Heat transferred to the pot and subsequently lost from the pot into the surrounding environment
7. Heat absorbed the pot material changing its temperature
8. Heat absorbed by the water – all of it
9. Heat absorbed by the water changing its temperature
10. Heat absorbed by the water and evaporating water (whether the water is hot or not)
11. Heat absorbed by the water and lost from the water (by radiation, not by evaporation)
12. Heat absorbed into the food and being absorbed chemically (transforming it into cooked food)

Which pair were you thinking of when asked to report the ‘efficiency’?
Heat transfer efficiency is …. ?
System efficiency is …. ?
[Overall thermal efficiency] is (7+9+10+12)/1 [When 12 is boiling water only,12=0]

Thermal Efficiency – what else can we know?

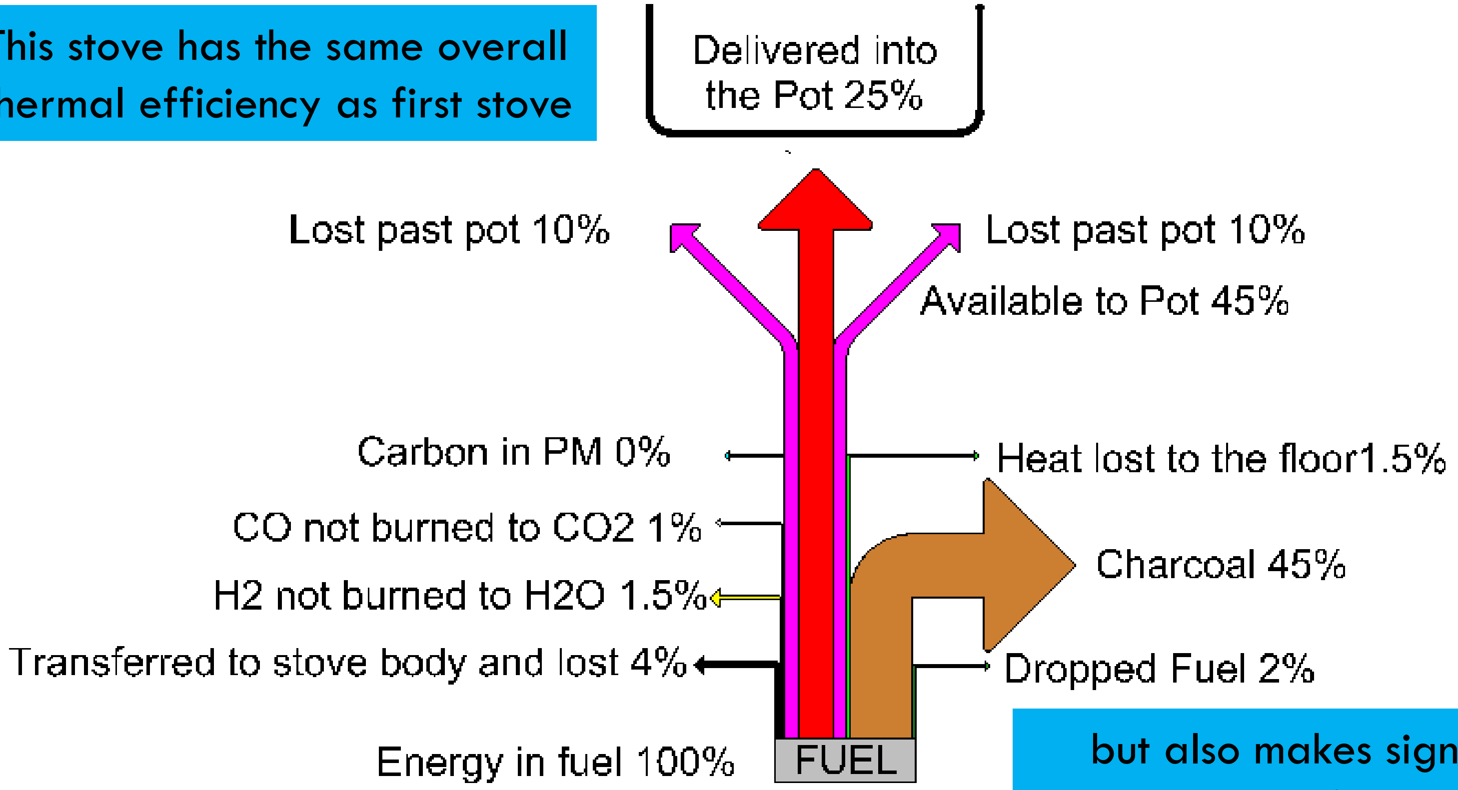
Energy reaching the pot (including the mass of the pot material)
Energy in the fuel remaining, divided in to two portions: usable fuel and unusable waste
Energy that escapes as heat that bypasses the pot and unburned H2, CO and H2S (etc) i.e. chemical losses.

The calculable outputs are:
Heat gained by the pot: quantity of heat Q [Joules], rate of heat gain Q' [Watts] and heat flow rate Q'' [Watts/cm^2]
Heat yielded by the fire considering chemical losses [J]
Energy consumption based on raw fuel consumed (potential total input energy)
Overall thermal efficiency (pot gain divided by Energy consumption)
Heat transfer efficiency (pot gain [J] divided by heat yielded [J])
Combustion efficiency (heat yielded [J] divided by heat theoretically yieldable [J])
Space heating efficiency (fire heat [J] minus chemical losses [J] and sensible heat losses [J], i.e. stack losses)
Average fuel consumption rate
Maximum power.

If the burn cycle is correctly chosen, a turn down ratio can be determined.

Heat Flow Diagram – Charcoal maker

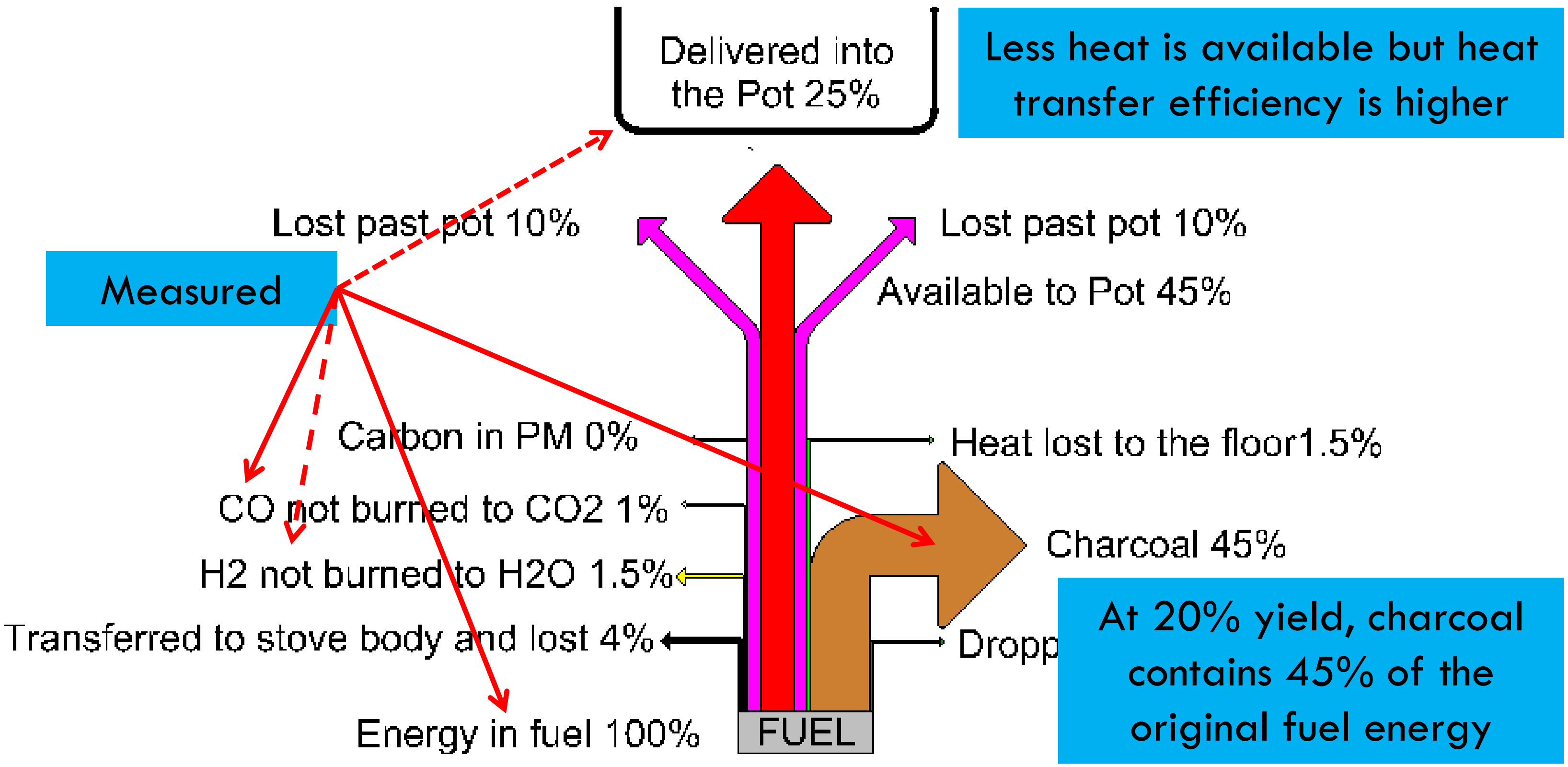
This stove has the same overall thermal efficiency as first stove



but also makes significant amounts of charcoal.

Charcoal Making pyrolyser

Heat Flow Diagram – 20% Charcoal maker



Delivered into the Pot 25%

Less heat is available but heat transfer efficiency is higher

Lost past pot 10%

Measured

Lost past pot 10%

Available to Pot 45%

Carbon in PM 0%

CO not burned to CO2 1%

H2 not burned to H2O 1.5%

Transferred to stove body and lost 4%

Energy in fuel 100%

FUEL

Heat lost to the floor1.5%

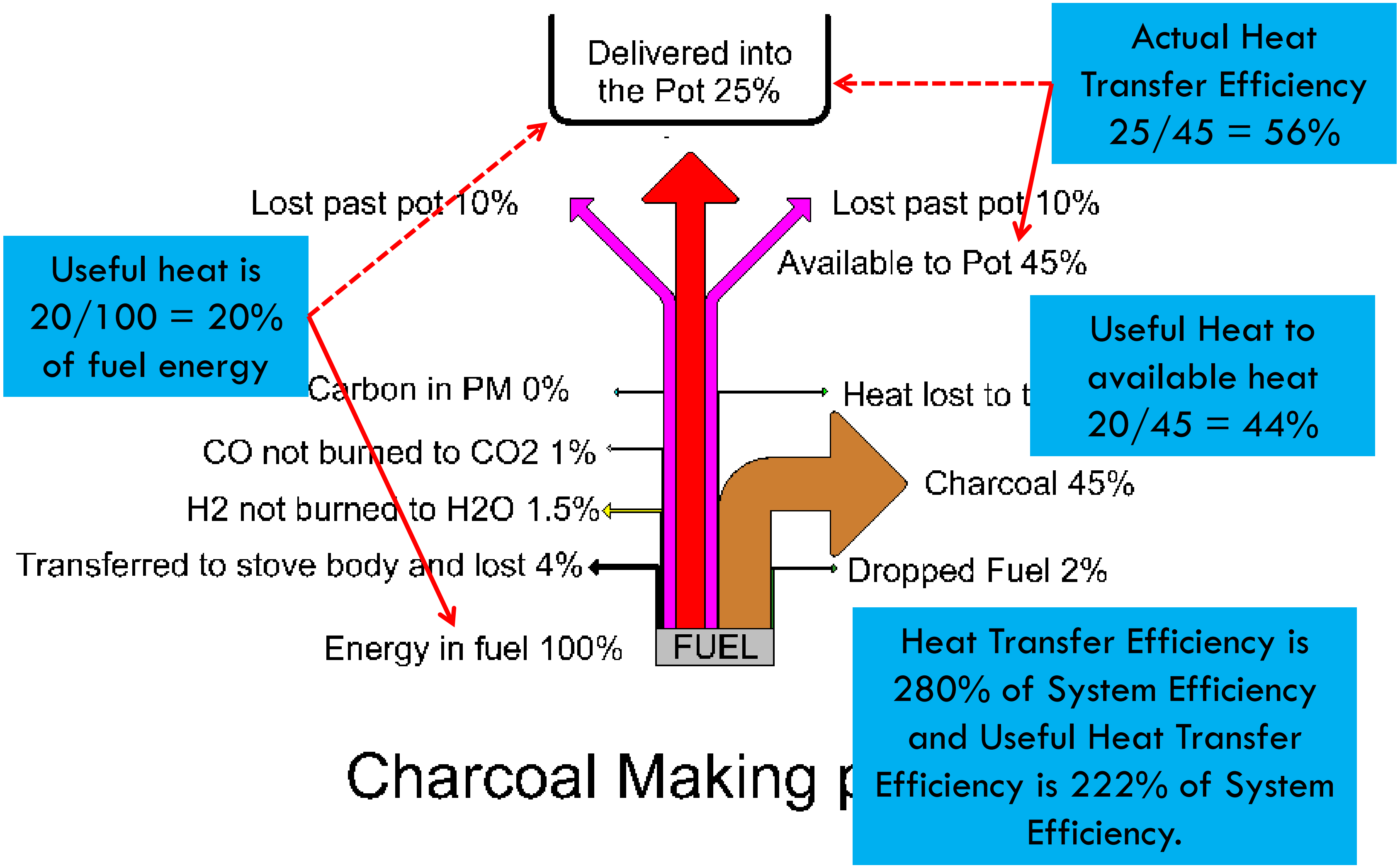
Charcoal 45%

Dropp

At 20% yield, charcoal contains 45% of the original fuel energy

Charcoal Making pyrolyser

Heat Flow Diagram – Thermal efficiency



Delivered into the Pot 25%

Actual Heat Transfer Efficiency 25/45 = 56%

Lost past pot 10%

Lost past pot 10%

Available to Pot 45%

Useful heat is 20/100 = 20% of fuel energy

Useful Heat to available heat 20/45 = 44%

Carbon in PM 0%

Heat lost to t

CO not burned to CO2 1%

H2 not burned to H2O 1.5%

Charcoal 45%

Transferred to stove body and lost 4%

Dropped Fuel 2%

Energy in fuel 100%

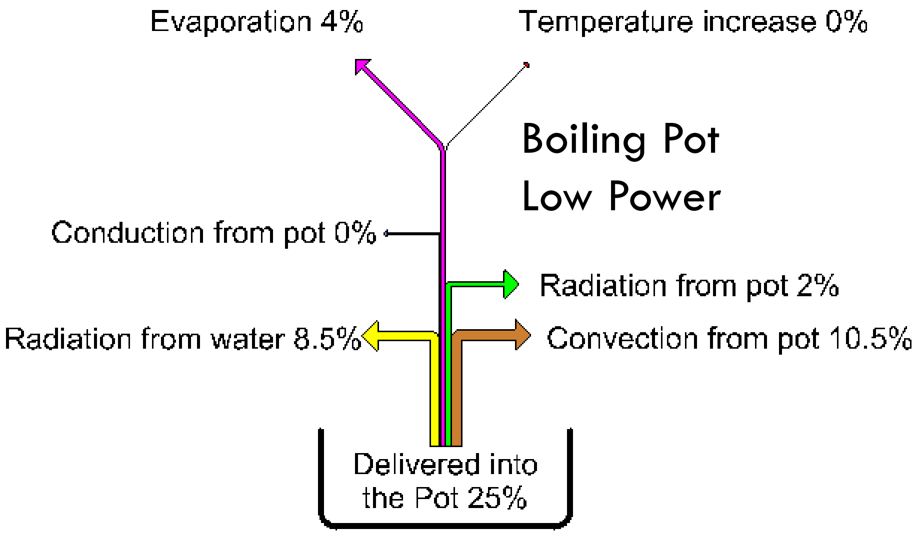
FUEL

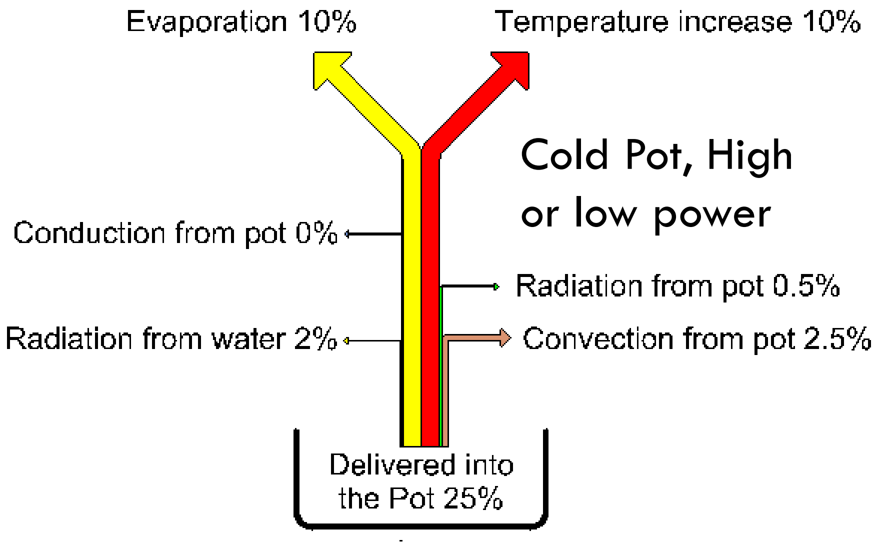
Heat Transfer Efficiency is 280% of System Efficiency and Useful Heat Transfer Efficiency is 222% of System Efficiency.

Charcoal Making p

Heat Flow Diagram – Thermal efficiency determined using a boiling or cold pot with high or low power produces very different results

Efficiency of heat transfer is the same as before in both cases: 25%





Low power *reported* efficiency = 4%

High power *reported* efficiency = 20%

While heat transfer efficiency *appears to be* 4/45 = 9%

While heat transfer efficiency *appears to be* 20/45 = 44%

Heat Flow Diagram – Conclusions

- Fuel consumption (the CSI program metric) is determined by the overall thermal performance based on the energy available in the fuel and the useful heat that is retained in the pot or evaporates water (only).
- It is difficult to accurately measure the quantity of heat entering a pot if it is already hot, even at high power.
- The heat transfer efficiency does not represent the fuel consumption in most cases but is often applied as if it does.
- The overall thermal efficiency, or system efficiency, represents energy consumed, expressed as ‘fuel’ consumed.
- Measuring thermal performance with cold water is (by far) the most accurate method.

Performance Evaluation using cold water

- Measurements are made with cold pots of water
- Pots are changed when water is ≤70°C (India uses 95°)
- Power of the fire is varied according to the documented burn cycle
- 'Fuel remaining' **fr** is weighed and reused on two conditions:
  - the stove can burn at least *some* of the remaining fuel
  - the *local practice* is to reuse fuel remaining
- The pot-swapping procedure can be used during all burn cycles
- The measurement precision of heat gained by a pot using **ΔT** is much more accurate than measuring evaporated water mass
- The procedure for the ignition and extinction of the fire is taken from local practise which varies greatly. Improved methods of ignition and extinction are accepted as part of the standard operating procedure of an improved stove.