Biomass and Coal
Indian perspectives@2016

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H S Mukunda

IISc and Jain University, Bangalore, India

What is discussed now

- Countries to distinguish in terms of economy and resources – Developing countries - India, South east Asia, China, parts of Latin America and Africa ; Some OECD countries - Europe, US and Canada
- Biomass and coal in India
- Biomass and Coal: Large vs. Small
- Examples of issues with large systems, biomass & coal
- Some new technologies on combustion via gasification
- What does it mean to developing economies
- …Discussions…

Distinguishing features

1. Most people in developing countries wish to have energy devices as good as in developed nations – electricity or gas for cooking, electricity for other household requirements. Some countries encourage liquid fuels.
2. Approximately 600 million households (of which about 100 million in India) still depend on biomass for large cooking. These are traditional devices – mud stove or an "improved" one
3. A small fraction of the households that has LPG connections uses it to position itself in terms of self-esteem in the society (is prestige is right word?) and very limited actual use.
4. A single LPG cylinder of 14 kg LPG lasts for nearly 180 days whereas it will last for a 30 to 45 days if used alone. In many cases, the location of the households is such that getting a refill is too difficult or expensive (because of distances involved from the LPG distribution center and their residence).

Distinguishing features

- We must remember that small biomass is a distributed source and LPG is a concentrated resource to be dealt with using complex distribution network. Partial and significant failure of the network implies failure of cooking energy supply.
- Experiencing failure of central services due to local and global factors most cooking solutions are arranged by having multiple sources – LPG. Kerosene and biomass being in this matrix.
- Yet, Stanford university professors and google think that the energy for the new World can be constructed out of solar photovoltaic and wind power with water/geothermal alternatives as well ignoring biomass resource completely for small and large power.

  Ref: A path to sustainable energy by Jacobson and Deluchhi

  [https://web.stanford.edu/group/efmh/jacobson/Articles/I/sad1109Jaco5p.indd.pdf]

  Google plan: [https://googleblog.blogspot.com/2008/10/clean-energy-2030.html]
- Contrast this approach with International energy agency study + WHO report….

What “IEA” and “WHO” state:

Key facts – February 2016

- Around 3 billion people cook and heat their homes using open fires and simple stoves burning biomass (wood, animal dung and crop waste) and coal.
- Over 4 million people die prematurely from illness attributable to the household air pollution from cooking with solid fuels.
- More than 50% of premature deaths due to pneumonia among children under 5 are caused by the particulate matter (soot) inhaled from household air pollution.
- 3.8 million premature deaths annually from non-communicable diseases including stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer are attributed to exposure to household air pollution.
- In poorly ventilated dwellings, indoor smoke can be 100 times higher than acceptable levels for fine particles. Exposure is particularly high among women and young children, who spend the most time near the domestic hearth.

Table 15.2: **People Relying on Traditional Biomass** (million)

	2004	2015	2030
Sub-Saharan Africa	575	627	720
North Africa	4	5	5
India	740	777	782
China	480	453	394
Indonesia	156	171	180
Rest of Asia	489	521	561
Brazil	23	26	27
Rest of Latin America	60	60	58
Total	**2 528**	**2 640**	**2 727**

From: https://www.**iea**.org/publications/freepublications/publication/**cooking**.pdf

Fuel usage over rural and urban households (HH) and their efficiency

(mmt = million metric tonnes) in India

Fuel	Rural HH million	Urban HH million	Fuel used mmt/year	Tonnes /yr/HH
Fire wood	87	15	250	2.5
Agro-residue	20	2	120	5.5
Cow-dung cake	20	2	35	1.6
Coal	2	2	6	1.5
Kerosene	2	8	5	0.5
LPG	9	25	8	0.24
Others	1	2	-	-
Total	141	57		

Note: While all bio-fuels are used inefficiently compared to LPG/Kerosene; *Agro-residue use is most inefficient!*
Efficiency comparison through water boiling tests: LPG stove eff ~ 70 %, kerosene stove ~ 65 %, biomass stoves ~ 5 to 30 %
The total biomass use is 400+ mmt. This is comparable to coal use for power generation. We must raise the end use efficiency of solid bio-fuels…These results are consistent to within 25 % from independent studies.

It is therefore very surprising that influential Stanford professors and Google think differently….Is it that one must be very watchful of such opinion makers in a complex world such as ours?

Cooking fuels used in India and their characteristics (H =calorific value at 10 % moisture)

Fuel	Density, kg/m^3	Shape	Size, mm	Ash, %	H, MJ/kg
Fire wood	300 - 700	Regular	10-100	~ 1	15
Agro-residue	50 - 100	Fine, odd	1 - 10	1 - 20	15 - 13
Cow-dung cake	~ 150	Regular	100	~ 10	~ 12
Coal	~1000	Pieces	5 to 50	30 - 45	18 - 16
Kerosene	780	-	-	-	42
LPG	500	-	-	-	48

Designing a combustion system for solid fuels with widely varying sizes and calorific value is tough. There is a tendency for people to use even wet fuels to get energy out….smoke and tears…

Biomass and Coal in India

- Biomass is largely a fuel of/in the unorganized and uncontrolled sector.
- At more inaccessible places, it is more than "plenty" and left without use because the community does not see value in it except for whatever and whenever it wishes to utilize.
- Though 3.5 to 4 kg of almost any dry biomass has the same calorific value as 1 kg of kerosene, kerosene receives high value and biomass almost nothing!
- Its availability is known to be large, but when explored "becomes unavailable" or available at "unaffordable cost" – largely because the trading practices are highly "local".
- Coal is a highly organized fuel, mined, prepared, transported and traded.
- While coal is largely a power plant fuel, biomass is largely a cooking fuel though there are large exceptions.

Biomass and coal: Large vs. Small

- Large biomass ~ 10 tonnes/hr ~ 4.5 MWth ~ 1 to 1.5 MWe – Performance affected by moisture in the biomass and sourcing these large amounts – 70,000 tonnes a year at sundry conditions or 120,000 at 35 % moisture - requires large command area – 100,000 to 150,000 hectares – 1000 sq. km to 150 sq. km – a command radius of 30 to 60 km.
- Large coal ~ 1000 t/h ~ 4000 MWth ~ 1500 MWe – Excellent operability and reasonable performance in coal mining areas and areas close to it (~ 500 km) and influenced by transportation problems at distances far from coal pitheads (~ 1500 to 2000 km)
- Small biomass ~ 200 to 1000 kg/h ~ 800 to 4000 kWth ~ 200 to 1000 kWe – gasification – reciprocating engines route is the most economical
- Very small biomass ~ 1 to 50 kg/h – thermal applications – (domestic and community cooking applications + hospitality industry) ~ very vital for existence.
- Small coal ~ 1 to 10 kg/h – thermal applications – valid near coal pit head areas – issues of smoke because of lighting issues

An example of large biomass power industry

Biomass based steam power - 1

- There are a large number of biomass based steam power plants in the country at power levels of 4 to 12 MWe (some may be of even larger capacity).
- Those based on captive fuel – largely like rice husk have been working well largely due to fuel homogeneity and continuous – or near continuous availability.
- Those that depend on procuring a large range of agro residues and bio-industrial wastes have serious problems.
- These arise from (a) availability that reduces or procurement cost keeps rising with time, (b) moisture related issues and (c) sodium/potassium related deposits in the super heater sections of high pressure boilers (60 ata).
- A visit to one of these typical plants in Tamilnadu has revealed lack of understanding of some basic issues – this permeates the boiler consultant group as well

10 MWe, 14 t/h sun-dry biomass, largely, 65 ata boiler and Triveni steam turbine

On an annual basis, they roughly use

1. Coconut frond (20,000 t at 65 % moisture)
2. Topioca (10,000 t at 20 % moisture)
3. Mango stones (10,000 tonnes at 40 % moisture)
4. Plywood waste, cashew wood (40,000 t at 50 % m)
5. Bagasse (10,000 t at 45 % moisture)
6. Juliflora prosopis (10,000 t at 30 % moisture)
7. Other biomass ~ 11,000 t at 30 % moisture)
8. Usage~100,000 t/y of 60 % moisture over 3 years
9. 70000 t (> 500 kg/m^3) and 12000 t (< 400 kg/m^3)
9. Procurement radius ~ 10 to 250 km,
10. Cost ~ 1000 – 2500 Rs/t (14 to 35 Euros)

All solid waste use drum chipper and wood chippers using 10 % generated power (~ 1 MWe)

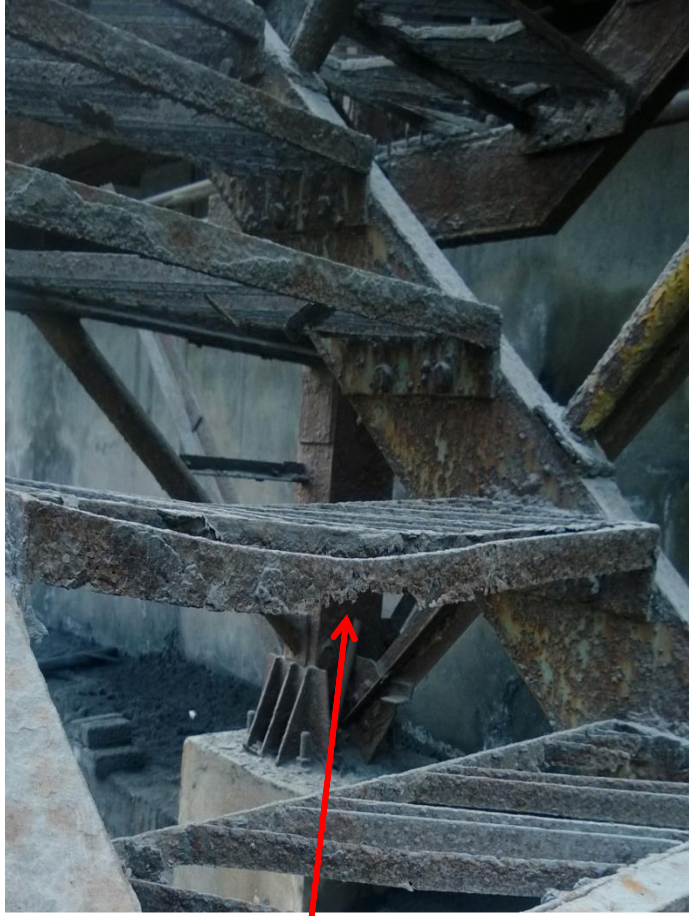
PLANT PERFORMANCE DATA

Description	2010-11	2011-12	2012-13
Power generation in MU	41.48	44.58	59.50
Plant Load Factor	47.35	50.89	67.93
Steam generation in Tons	185547	204956	273372
Fuel Consumption in Tons	77230	97161	119781
Average fuel GCV Kcal/kg	2300	2170	2317
Enthalpy of steam in K.Cal - h1	810	810	810
Enthalpy of feed water in K Cal - h2	155	155	155
Boiler Efficiency in %	62.42	63.67	69.11
Sp. Steam Consumption - Kgs / Kwh	4.47	4.60	4.59
Specific fuel consumption Kgs/Kwh	2.15	2.18	2.01
Steam generation/Ton of fuel	2.09	2.11	2.40
Auxiliary Consumption %	12.45	11.72	10.77
Turbine heat rate Kcal/Kwh	2930	3011	3009
Station heat rate Kcal/Kwh	4282	4729	4060

Best specific biomass consumption - 1.4 kg/kWh; Now – 2 kg/kWh at 50 % mean moisture and chipper power consumption of 1 MWe; Generated power ~ 6 - 7 MWe instead of 10 MWe.

There is no dryer. It is unclear to the management if drying outside is better than drying inside the boiler.

It is assumed that chipping is the most appropriate way to homogenize the biomass shape and size.



Significant chemical corrosion due to Na, K and Cl. Use of coconut fronds that collects a fair amount of NaCl that Is usually administered as a nutrient is considered responsible

What is the solution?

- Change the philosophy from reducing the fuels to small size to retaining the larger size of fuels as it were and increasing the size of fine fuels through baling/briquetting. This is because most fuels obtained (80 %) belong to large size category.
- This implies that the net energy used in the conversion process is smaller. Reduction of internal use of energy implies adding more to the grid.
- With regard to coconut fronds and others with Na & K problems, the chipped material is to be soaked in water so that leaching of the potassium and sodium salts occurs and then squeezed and dried. That coconut fronds occupy only 20 % mix on the average implies energy use in this can be lived with.
- Drying the fuels outside the combustion system is to be understood as more efficient. Heat for drying is to be derived from exhaust gases.
- This material mix should used in a conceptually new combustion system to enable conversion with little emissions.

Drying outside vs. Drying inside

Hot gases at 1500 K

Biomass with 10 % moisture

0.9 kg dry biomass + 0.1 kg moisture

Heat from 0.9 kg biomass (16.2 MJ) releases 0.1 kg water into steam (0.22 MJ) and then raises it to flame temperature that requires a heat of 0.2 MJ of heat. The net heat derived is about 15.7 MJ - 1.1 MJ required anyway leading to 14.6 MJ

Hot gases at 1000 K

Biomass with 50 % moisture

0.5 kg dry biomass +0.5 kg moisture

Heat from 0.5 kg biomass (9 MJ) releases 0.5 kg water into steam (1.1 MJ) and then raises it to flame temperature that requires a heat of 1.1 MJ of heat. The net heat derived is about 6.8 MJ

Benefits are very obvious!

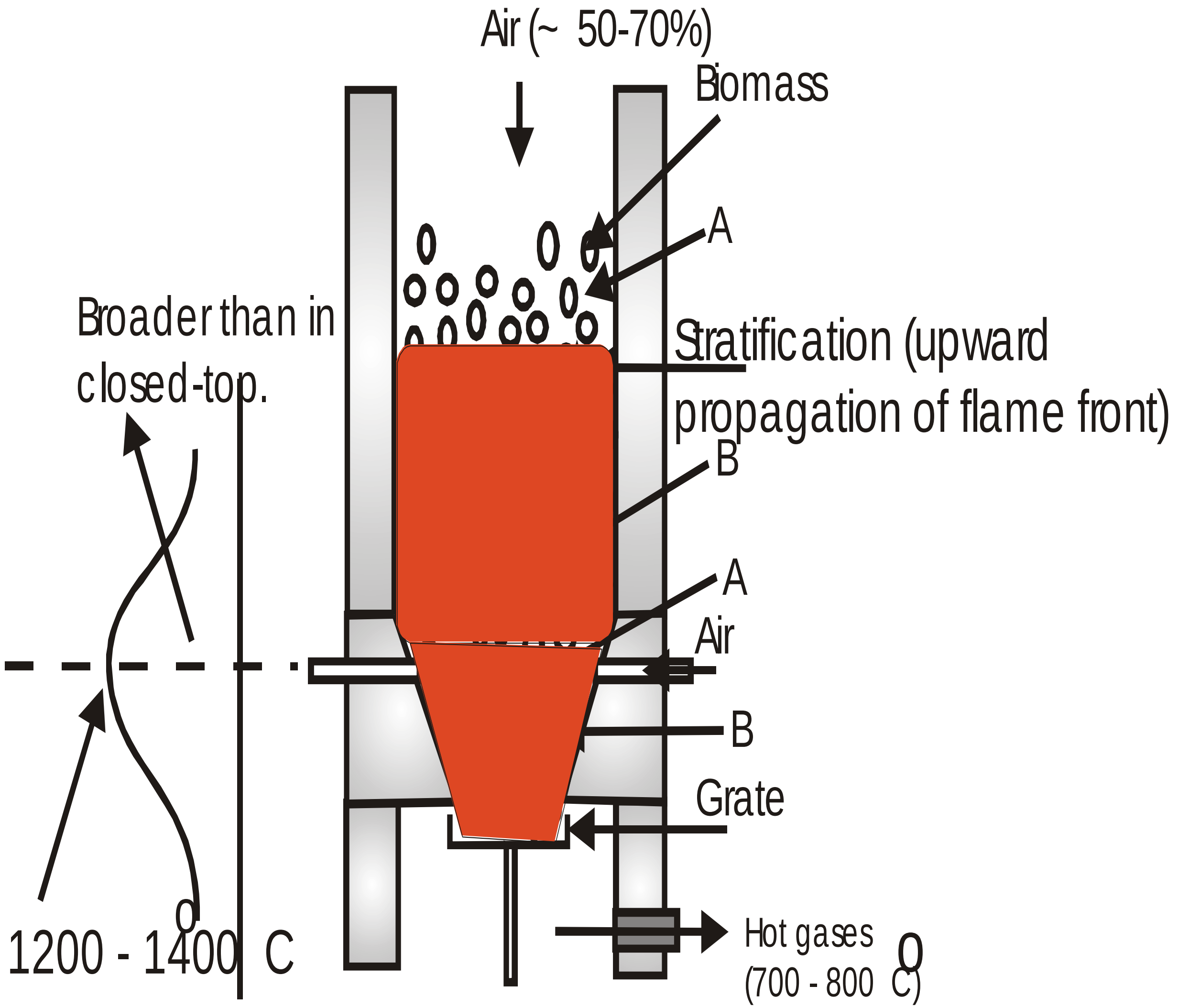
Large Coal

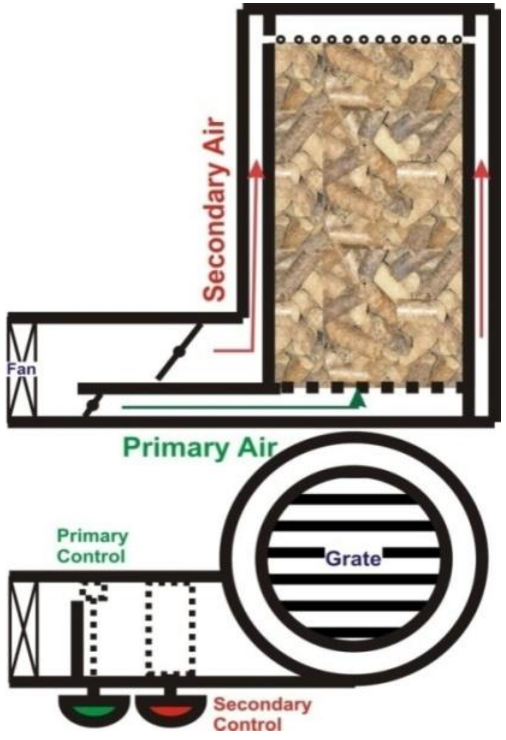
- India has a total of 200,000 MWe (62 % of total power) of coal based power using about 500 million tonnes of coal.
- In comparison, hydel is 42,000 MWe, nuclear 6000 MWe, Other renewables ~ 43000 MWe.
- Other segments are natural gas ~ 24000 MWe and Diesel ~ 1000 MWe.
- Traditional sources (operating 24 x 7 basis) generate about 1000,000 GigaWh (1 PetaWatt = 10^{15} W) and intermittent sources generate about 190,000 GWh (150 TWe).
- Over 1.2 billion people, this amounts to the availability of 1000 kWh (per capita).
- Thus coal generating about 1.3 kWh/kg cannot be displaced for a reasonably long time (unlike the thoughts in Germany for instance).
- This has given rise to ideas of "clean coal technology" currently under intense discussion.
- One idea on clean coal technology that implies gasification, ideas of atmospheric weakly fluidized heated coal-heated air- steam based are suggested here.
- Such a combustible gas, cleaned and cooled is expected to be used in gas engines for power.

Domestic heat

not-so-old a technology,
based on reverse downdraft ideas

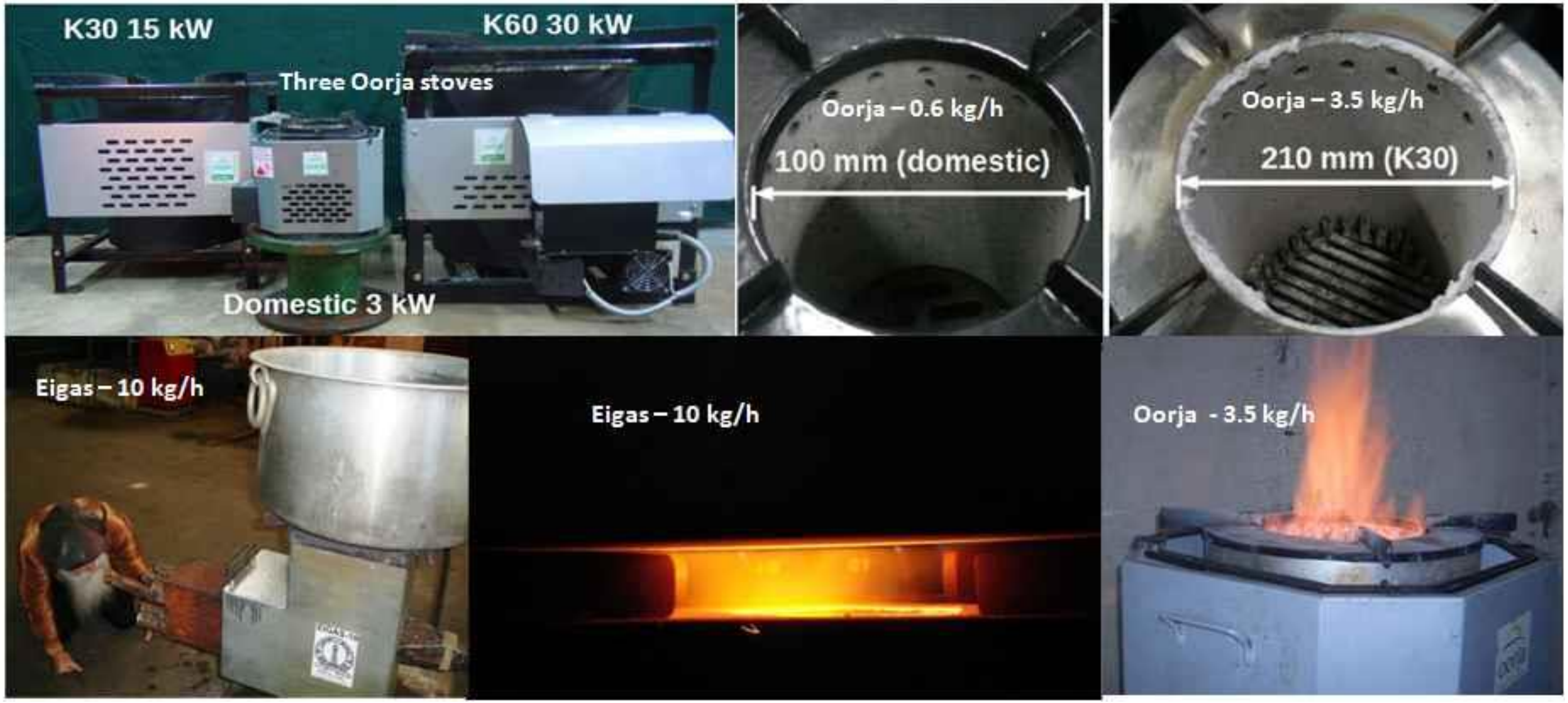
Domestic heat? – Reverse the downdraft gasifier





Close the side air nozzles; invert the gasifier

REDS – Gasifier Stove Tec transferred to BP, India and FEPL, Pune



Various industrialized modern fan based HELE biomass stove designs realized by industries and used in practice

Achieved: 2 x 0.6 kg = 1.2 kg pellet fuel using agro-residues or fuel wood for cooking

Efficiency = 55 % (water boiling efficiency) = 80 % more than three-stone fire stove

Emissions – see next…


9

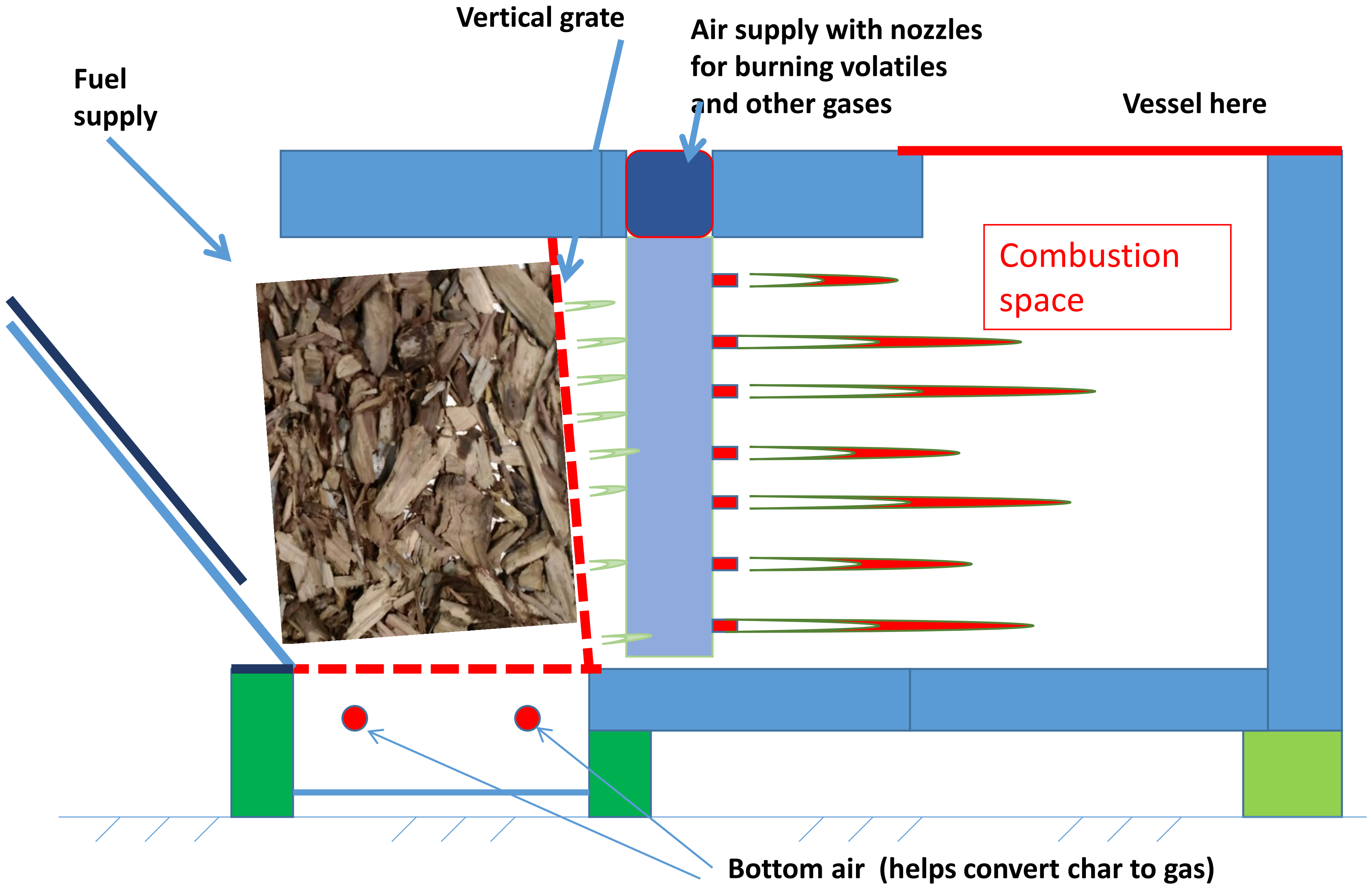
Horizontal continuous clean combustion device – a new technology

?......

The new device performs continuous combustion in a horizontal mode for all dry fuels chipped or simply hand broken - very wide range of local fuels – should also be supplied via outlets. Density should be larger than a minimum – 250 kg/m^3, ash less than 15 %.

Blower based new technology promises clean combustion

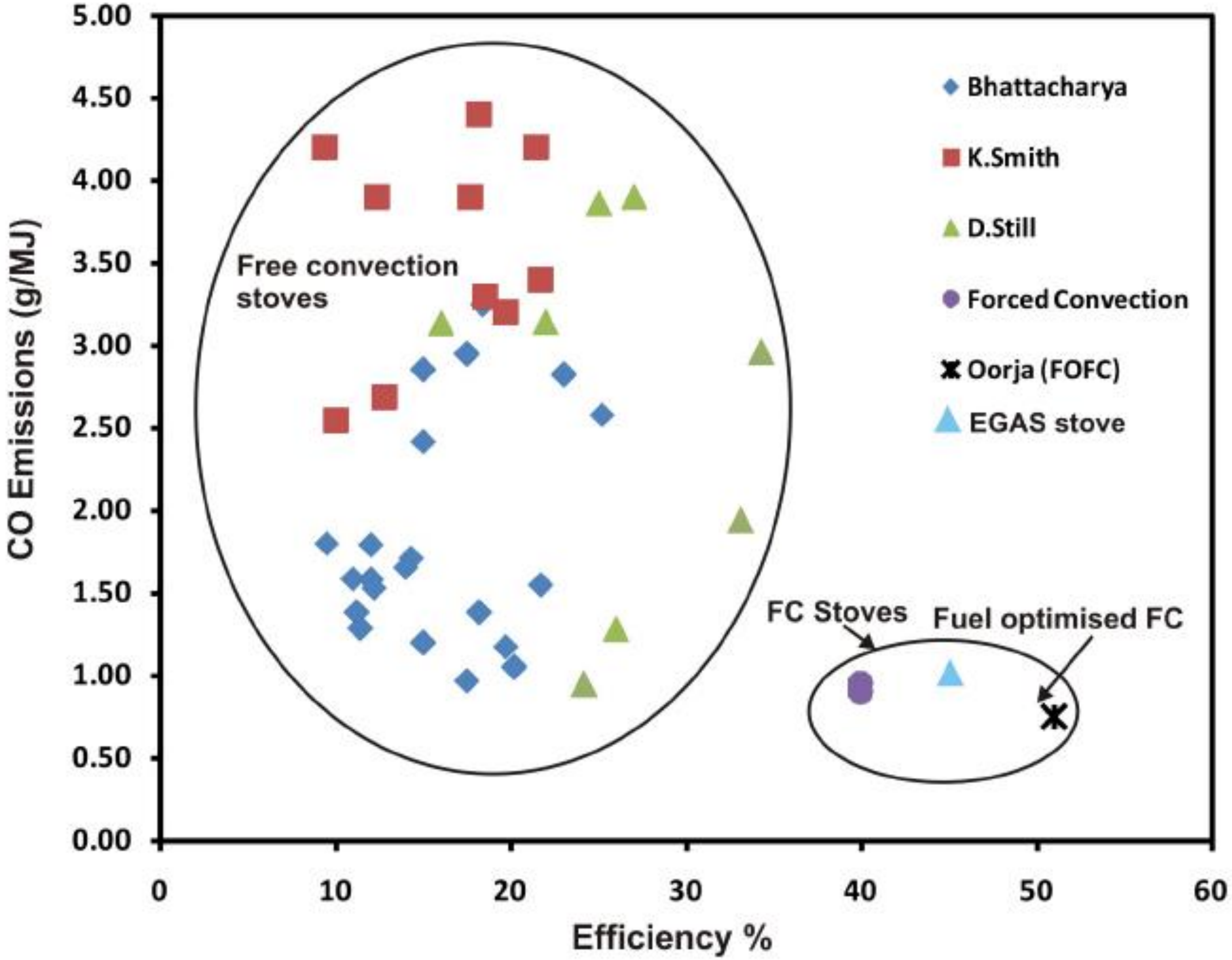
Principles of a new combustion process – HC^{3}D



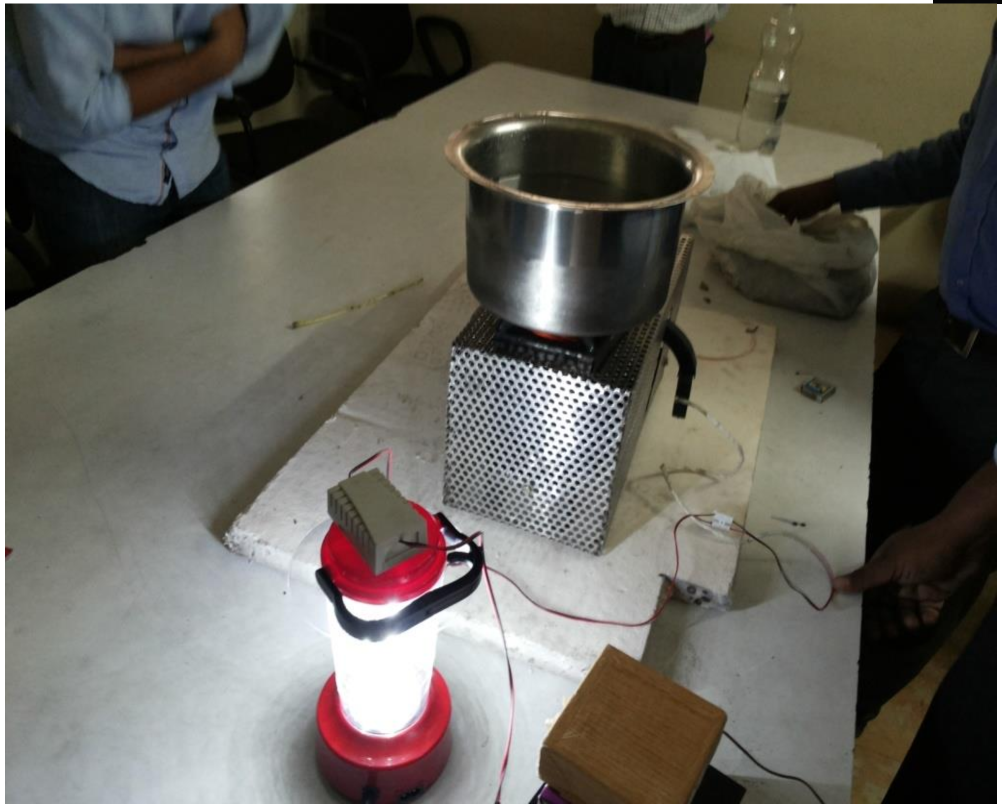
AGNI – SAKHI on a emission-efficiency test

Efficiency and emissions

Bhattacharya et al (2002) have tested efficiencies and emissions from 24 different wood and charcoal stoves of east Asian origin – all of them free convection based. Other data have been compared with new technology stoves based on controlled forced convecton.



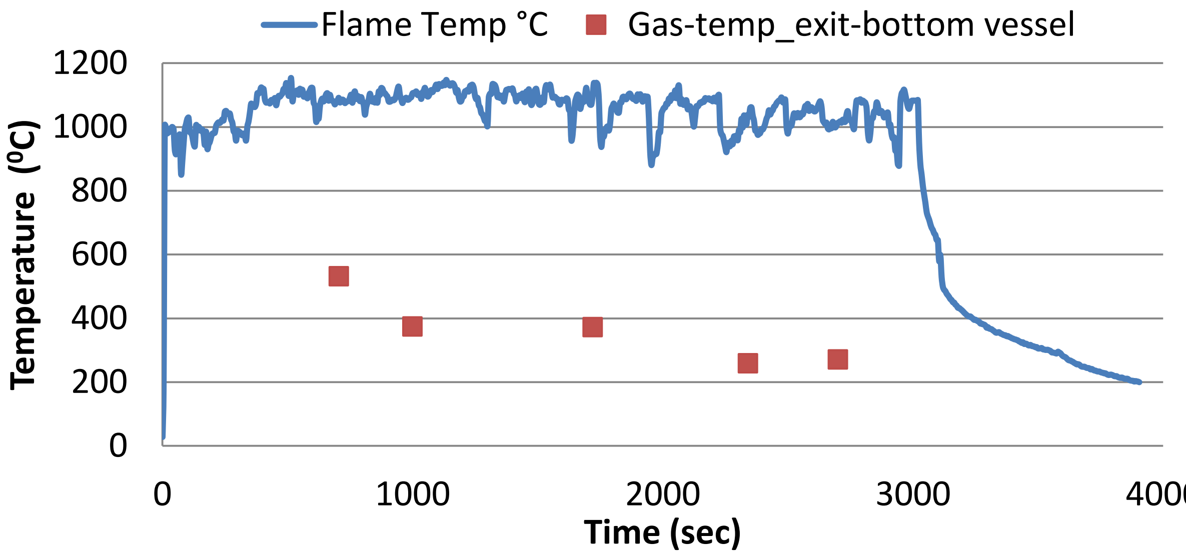
Cooker on a 1 kg/hr single pan stove (with a 12 V fan) running on chipped dry fuel

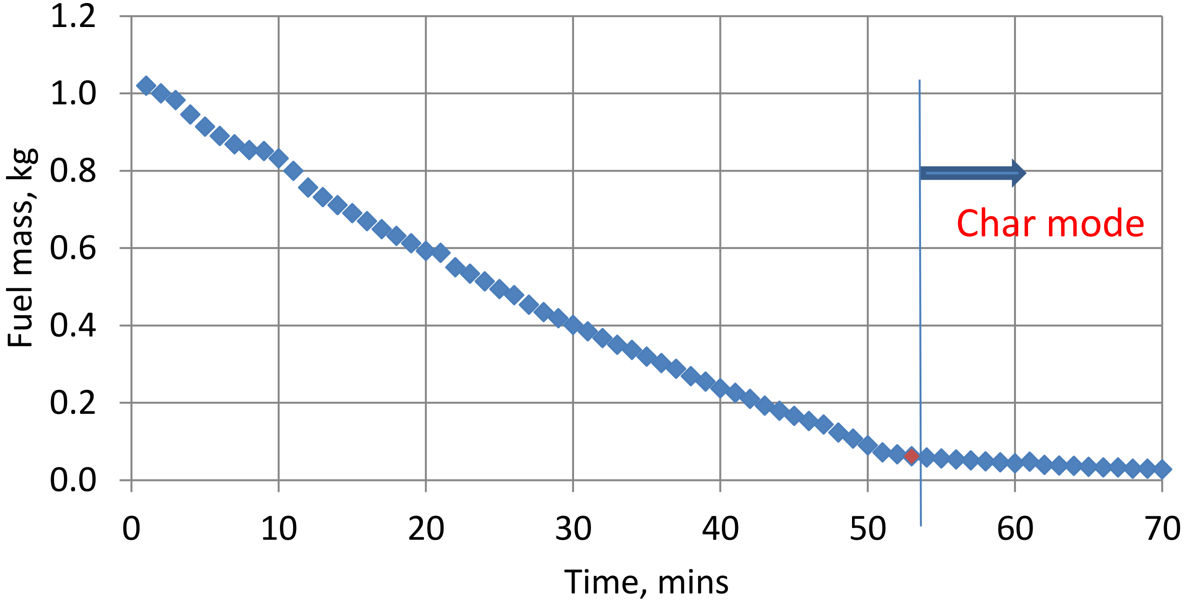


The stove with a stainless steel vessel operated on a power supply that also has a LED lighting system

Bath water heating system

Performance





3 kg/h system (AGNI-MITRA)

System in laboratory test

System at Mother Theresa's care home for distressed

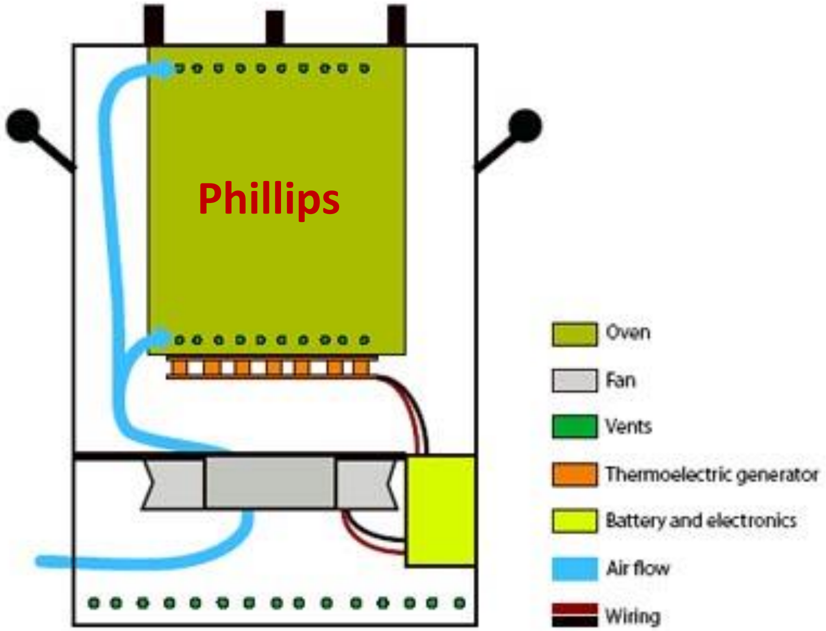
Comparison of stoves for bringing to boil 5 liters of water

Stove	Fuel g	CO g	PM g	CO g/MJ	PM g/MJ
Three stone Fire	**1118**	56	2363	3.13	42.27
Ghana Wood	**996**	50	4287	3.14	68.32
20L Can Rocket	**733**	15	1289	1.28	15.12
Wood Flame Fan	**626**	**9**	48	0.90	0.48
Wood Gas Fan	**459**	**7**	**27**	**0.95**	**0.20**
Mali Charcoal	**674**	113	260	10.48	2.80
Gyapa Charcoal	**694**	135	587	12.16	6.52
Indian VITA Test 1	**1135**	38	1490	2.09	27.06
T-LUD	**933**	25	694	1.67	10.36
Institutional 310 Rocket	**483**	6	414	0.78	3.20
Lutfiyah's Improved Stove	**823**	16	1231	1.22	16.21
T-LUD	**1296**	18	437	0.87	9.06
BP Stove (IISc)	380	4.5	6	0.75	0.06
EIGAS - 1 (IISc)	400	7.2	9.6	1.12	0.1

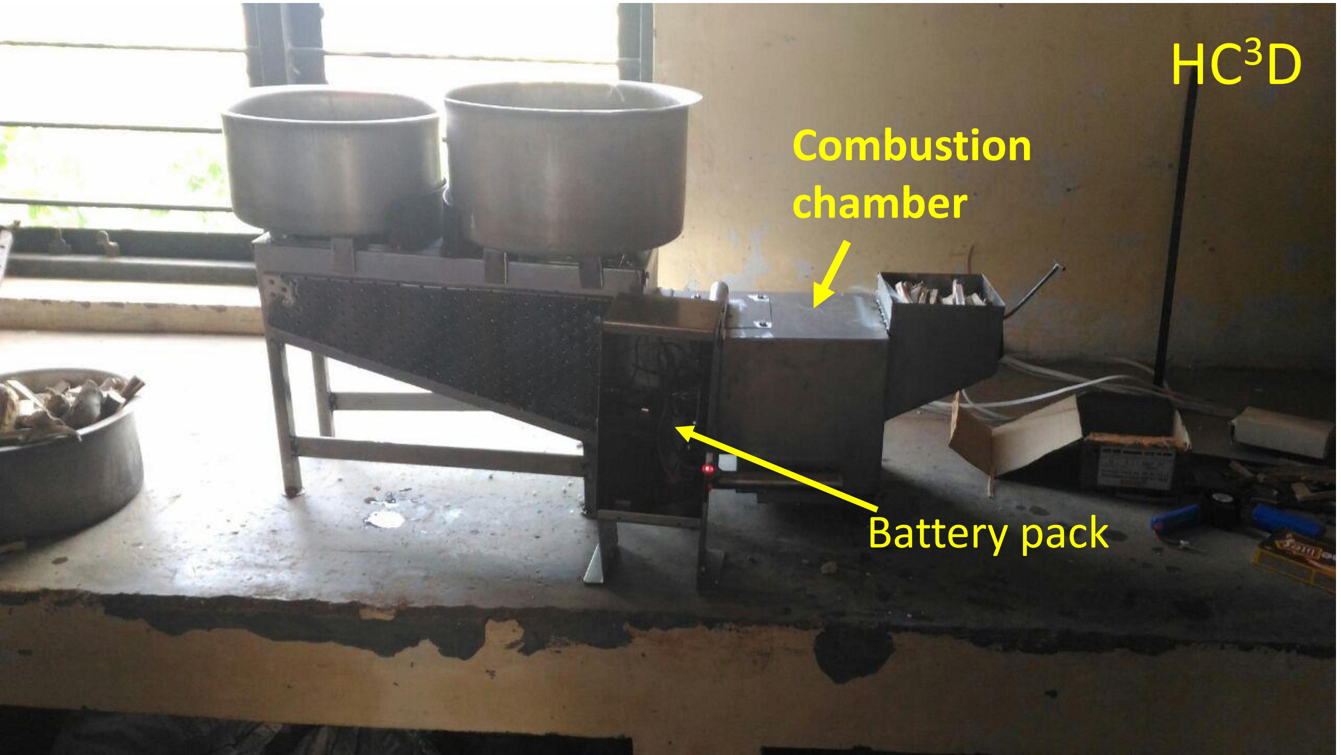
A single window testing comparison of some stoves

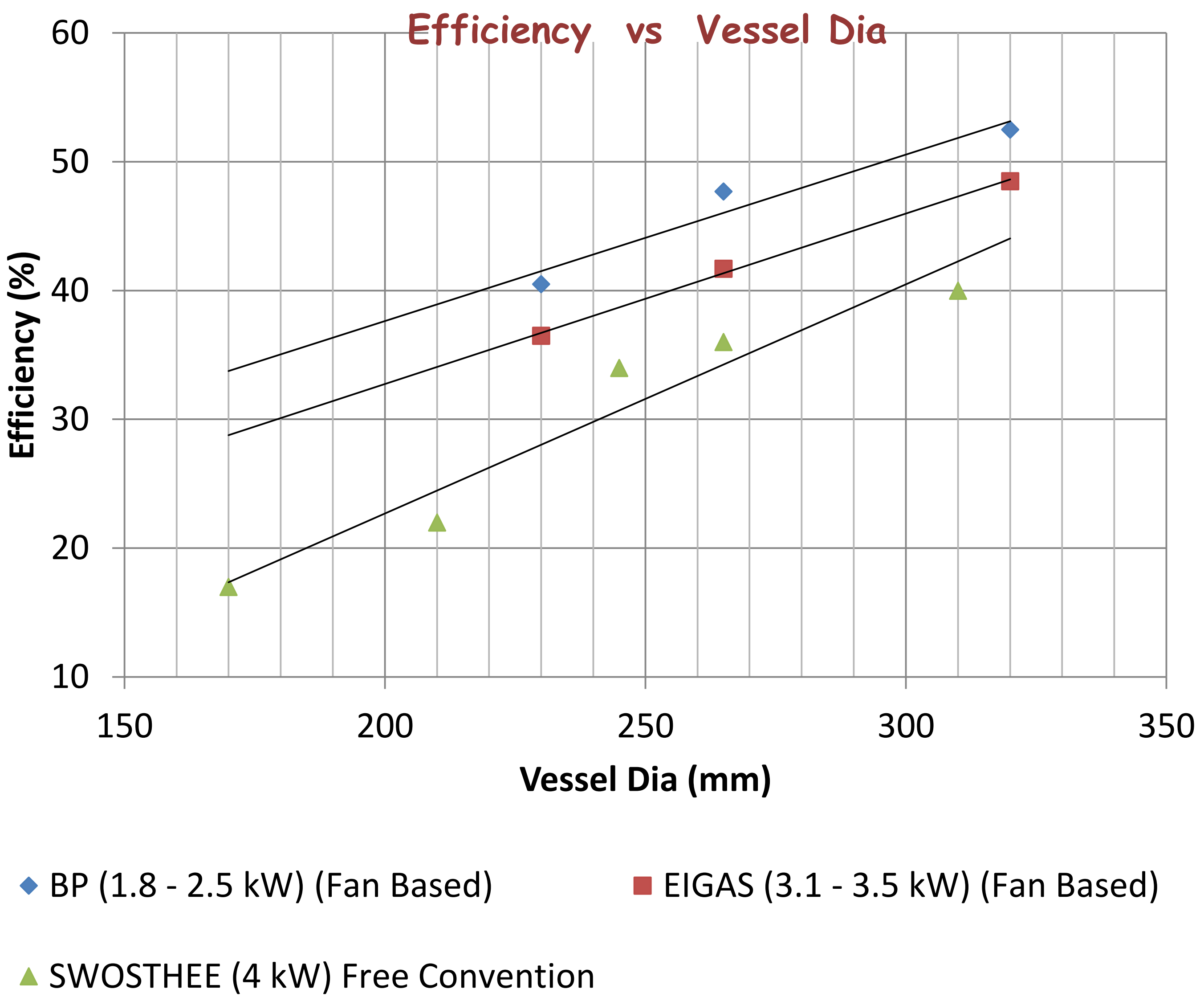
Subject	Envirofit	Phillip	Oorja	HC^{3}D
Consumption, kg/h	0.6 to 2, Operator dependent larger levels	~ 0.6	0.6	1 kg/h single pan; 1.5 kg/h 2 pan (Unique new design)
Power level , kWth	3 to 10	~ 3,	~3	4 kWth (1-pan); 6 kWth (2 pan)
Fuel	Firewood, suggestions on the usage of dry fuel	Tiny firewood pieces	Supply of prepared dry agro-residue pellets	Sized dry fuel - wide variety, density does not matter
Natural convection or fan based	Natural convection	Thermo-electric based power supply to fan	Rechargeable battery based power supply to a specifically designed fan	Rechargeable battery based power supply to a specifically designed fan
In-situ combustion?	Yes	Yes	Gasification + combustion	Gasification + combustion
Continuous?	Yes	Yes	No, fixed fuel, 60 - 70 mins	Continuous
Efficiency (10 lit water + Al vessel)	20 to 35 % depends on the operation	~ 40 %	48 to 52 %	36 to 40 %
Emissions	Largely sooty since users tend to drive high power levels	Depends on loading periodicity, slight smoke or soot	Independent of the user. Operator only controls the power of the stove	Simple operational procedure limits the emissions.
CO emission, g/MJ	2 to 3	~ 1	1	0.08 to 0.1 (fuel lean operation)
$\Sigma CO/\Sigma CO_2$	0.02 to 0.04	0.02 to 0.04	0.015 to 0.02	0.008 to 0.01
Soot	Generally heavy	Little	None	None
Particulate matter	3 to 10 mg/MJ, due to operator intervention	7 mg/MJ, Operator intervention	0.75 mg/MJ (due to low velocities in critical zones)	0.8 to 1 mg/MJ


Envirofit


Phillips
Oven
Fan
Vents
Thermoelectric generator
Battery and electronics
Air flow
Wiring


oorja


HC^{3}D
Combustion chamber
Battery pack

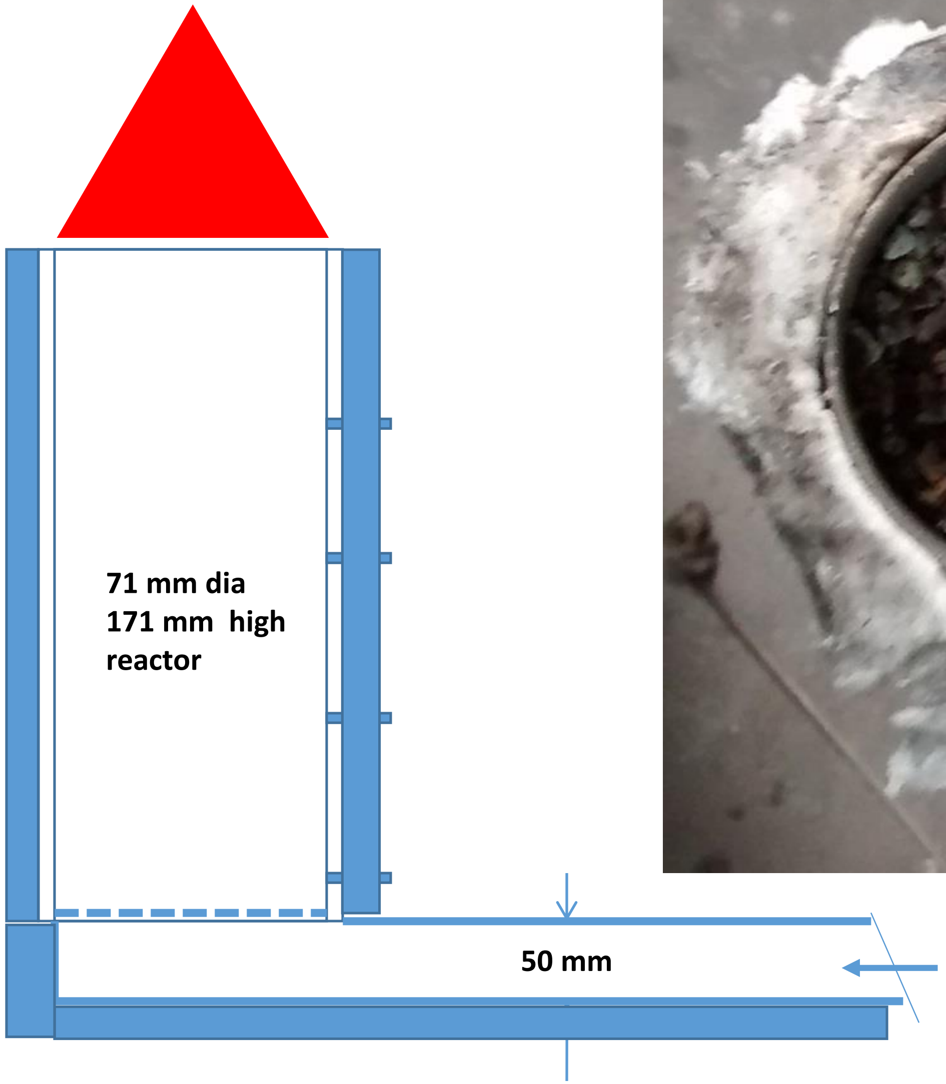


Water boiling efficiencies in flat Al vessels with 230, 265 and 320 mm diameter carrying 2.5, 6 and 10 liters of water.

Small coal – combustion via gasification and gasification – e-power @ 250 kWe or less - why and how?

Some considerations.

- Coal considered is <28 % ash available from the market. Studies made on 21 to 28 % coal.
- Coal sizing is expected to be limited to 3 to 8 mm (mean around 5 mm) to reduce the burden on grinding
- Questions asked are: What is to be done to avoid ash fusion and clinkering? What are the conditions required to get the coal to undergo gasification.
- Results at ambient pressure showed that beyond a *temperature of fuel and air beyond 100 C is helpful for combustion as well as gasification (a new approach).*
- Limiting the temperature to less than 800 C and a particle residence time less than a few minutes is adequate for eliminate ash fusion.
- Using a specific air-to-steam ratio in a weakly fluidized bed provides excellent conditions for gasification.
- Subsequent ash separation with a cyclone and cooling techniques follow the earlier experience in biomass gasification.
- The cooled (and clean) gas is ready for use in reciprocating gas engines.

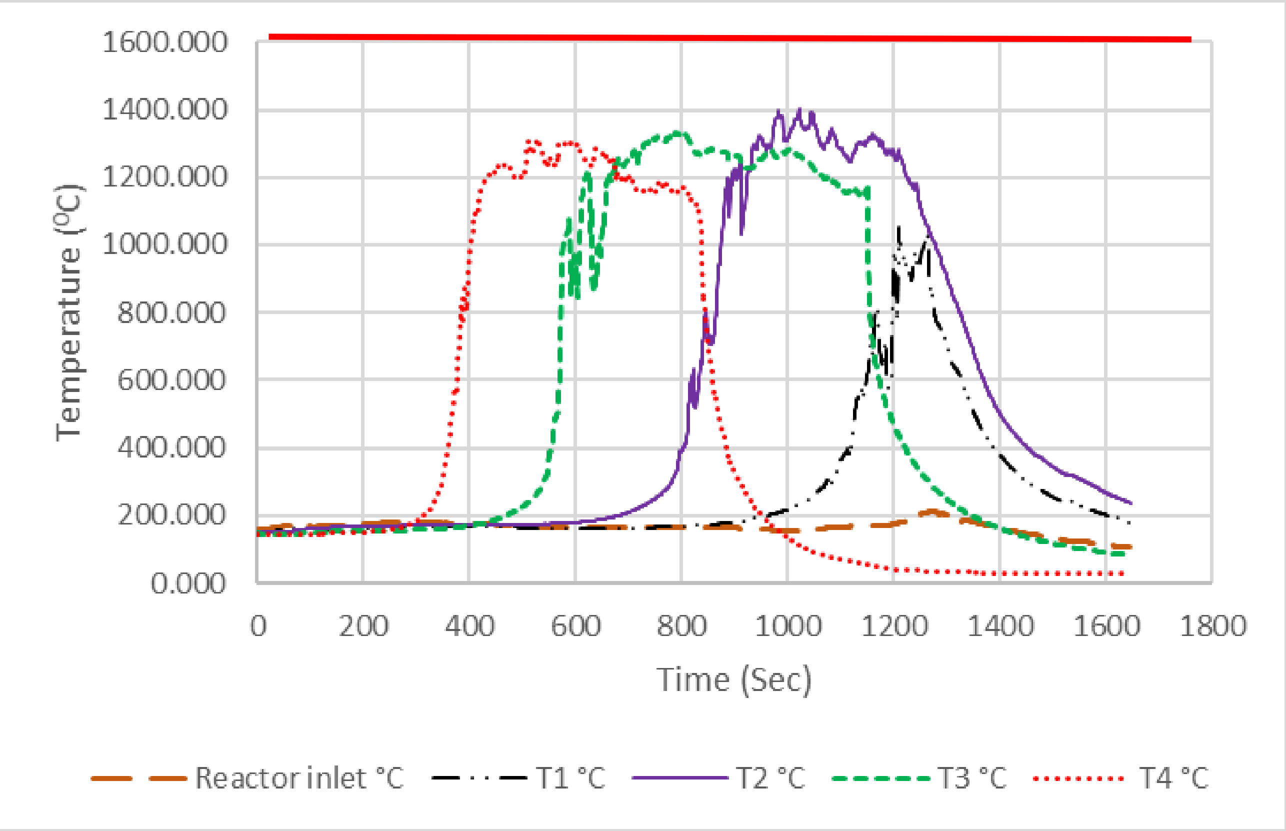


Sup vel = 28.3 cm/s, Steam flow rate= 22.3 gms/min;
Initial coal packing density = 711.68 kg/m^3


Storm Power

Results on coal combustion/gasification.

Item	Indian Coal with Air			Indian Coal Air + steam	
$\rho_{biomass}$, kg/m^3	1250			1250	
Size, mm	3 - 8			3 - 8	
Ash content, %	21			21	
Volatiles, %	27			27	
Sup. Vel, cm/s	5.7	19	28	43.89	68.03
Air temp (^oC)	145	150	155	170	170
Fuel flux, kg/m^{2}h	126	728	960	799	604
ρ_{char}, kg/m^3	800	736	729	777	711
X_{H2O}	-	-	-	0.29	0.31
Coal size, mm	2 - 7	3-8	3-8	3-8	3-8



In these experiments conversion was complete. The process is diffusion limited; ash remained unfused Whenever the temperature was kept below 800 C. When the temperature crossed 800 C. larger residence time beyond about 5 mins would result in ash fusion.

An alternate route on coal for power

- Based on the studies that involved steam-air mixture in model reactors, diffusion limited approach to design with *heated* air and steam allows simplified designs of reactors *not contemplated earlier*

- With modest R & D funds, it is possible to demonstrate a electric power generation system using a gas engine based power pack at 25 kWe to instill confidence.

- Scaling up to about 250 kWe is also possible in a laboratory environment with suitable funding after the small system is shown to be successful.

- Once this demonstration is complete, scale up to several MWe is feasible. The economics of these systems (1 to 2.5 MWe +) looks reasonable and these can be undertaken with industrial participation


75 LPM WITH STEAM – 22.36g/min
50 LPM WITH STEAM – 13.5g/min
50 LPM WITHOUT STEAM

Takeaways from what I spoke

1. We should not forget that biomass is a renewable source from solar energy – stored by plant life that was there even before the homo sapiens came into existence and we should nurture it and utilize it in a renewable manner
2. Its use for clean heat is needed in kitchens for cooking as a first, second, or third alternative depending on the circumstances – economic level and/or urban or rural surrounding.
3. Technological solutions have become available and they need to be integrated into the system – mainstreaming availability of prepared biomass at affordable cost by standard elements – procurement, upgrading, storage and distribution; in addition, technology availability needs to be ramped up as well.
4. Biomass as a energy resource continued to be poorly understood and needs attention through education and awareness creation by multiple agencies.

Discussions……Thanks