Heat and electricity from solid bio-fuels – Progress@ 2008

1. What solid bio-fuels and why?
2. Cooking heat
3. Industrial heat
4. Quality-of-life electricity
5. Stand-alone and grid electricity
6. What more from solid biofuels?

H S Mukunda,

ABETS, CGPL, IISc, Bangalore, March 2008

What solid biofuels?

Agro-residues, Plantation residues, Residues of oil extraction from seeds, Urban solid wastes

Why?

- 500 million households across the world depend on agro-residues and plantation residues for cooking
- IEA statistics – 2006 indicates "according to best available figures, household energy in developing countries totalled 1090 Mtoe in 2004, almost 10 % of the world energy demand"
- This amounts to 4500 to 5000 million tonnes of biomass/year and therefore, 9 to 10 tonnes/family/year (perhaps, 5 – 6 dry tonnes / family / yr)

......Why?

- In India, some 140 million households (average family size = 5.3) depend on firewood, crop residues and dried cow-dung for cooking estimated at nearly 370 million tonnes of firewood (equivalent) per year – equivalent of 0.5 tonnes per person per year or 2.6 tonnes per family per year (difference between these values and international figures needs serious reconciliation)

- Cooking in several countries (Indo-Chinese culture and in Africa) depends on wood-charcoal produced at 16 to 20 % of wood. The amount of charcoal used by a family for cooking is about the same as wood by other families (this amounts to the use of six times the biomass for cooking by charcoal)
- Urban solid wastes are truly wasted mostly.
- It is possible to generate electricity from solid fuels through gasification process allowing local generation within local control

It is good to remember that handling solid fuels offers greater challenge because it is technically far more difficult to handle due to size, shape, moisture effects

The Size and nature of the cooking problem

- The cooking is done with “such” devices in “such” kitchens that there are an estimated million deaths due to poor indoor air pollution issues

- Can we not make cooking from solid bio-fuels as close to that with LPG? – because LPG occupies the highest position in the development ladder (in the minds of all), even if aspects, namely, instant ignition and fast control cannot be achieved

Biomass Cooking devices

- Biomass stoves are widely explored. There is even a website on this subject. Informative and interesting.

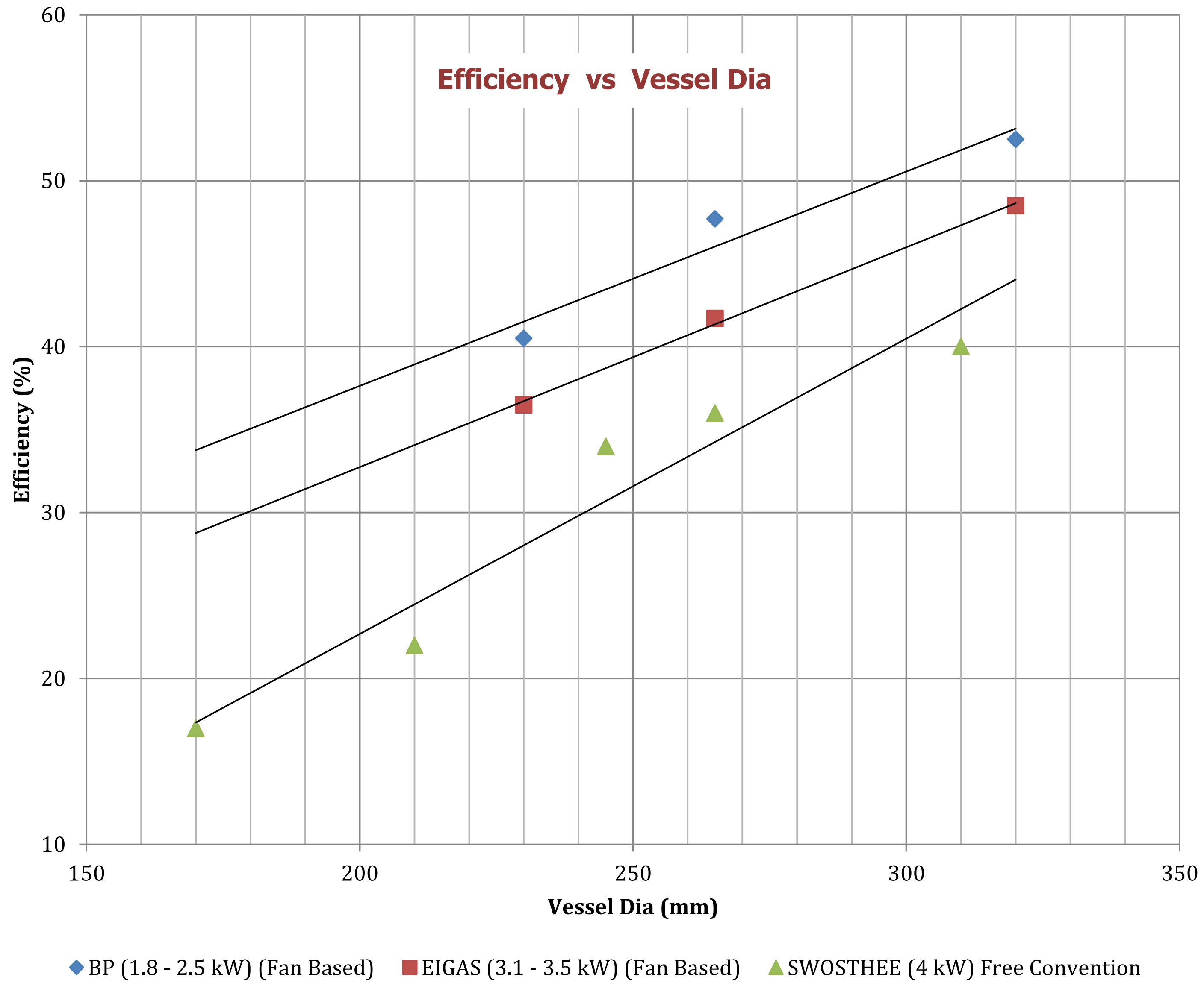
- Stove designs are enthusiasts' field area.
  Very little relevant science is used in designs.
  Simple specifications like power level, and burn time are not presented always. Vessel size and shape are outside the scope of consideration.

- Even the scientists involved seem to get immersed in the variety with little attention to science of the designs

- What is that scientific understanding and current technology can do……..

Science of stoves with an eye on high performance

- In 1985 – 87, research was conducted at Indian Institute of Science on stoves
- Kerosene and LPG stoves recorded utilization efficiencies of 65 % and 70 % and wood stoves from elsewhere showed efficiencies of less than 30 % (water boiling tests).
- Question was asked: What is it that limits the utilization efficiency in wood stoves
- Experimental, modeling and computational studies showed that better efficiency could be obtained with:
- Higher peak temperature in the flame and larger vessel with a flat bottom



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

Science of stoves with an eye on high performance

- Solid bio-fuels for stoves are non-standard. This is often extolled as a virtue – they are considered affordable as they are picked by the poor by travelling distances – the general principle being "finders – keepers"
- All other fuels are processed to specs, sold commercially and they perform to specs.
- Would it be scientifically appropriate to expect a wood stove to accept wood fuel what ever size, shape and moisture fraction and perform with high eff. and low emissions?
- The answer is a clear NO. Unfortunately, All the stove programs of the world (other than the one addressed at IISc recently) disregard the issues.
- Hence – No stove commercialization effort will work unless the fuel is standardized and supplied commercially (perhaps with a subsidy to the "poor")

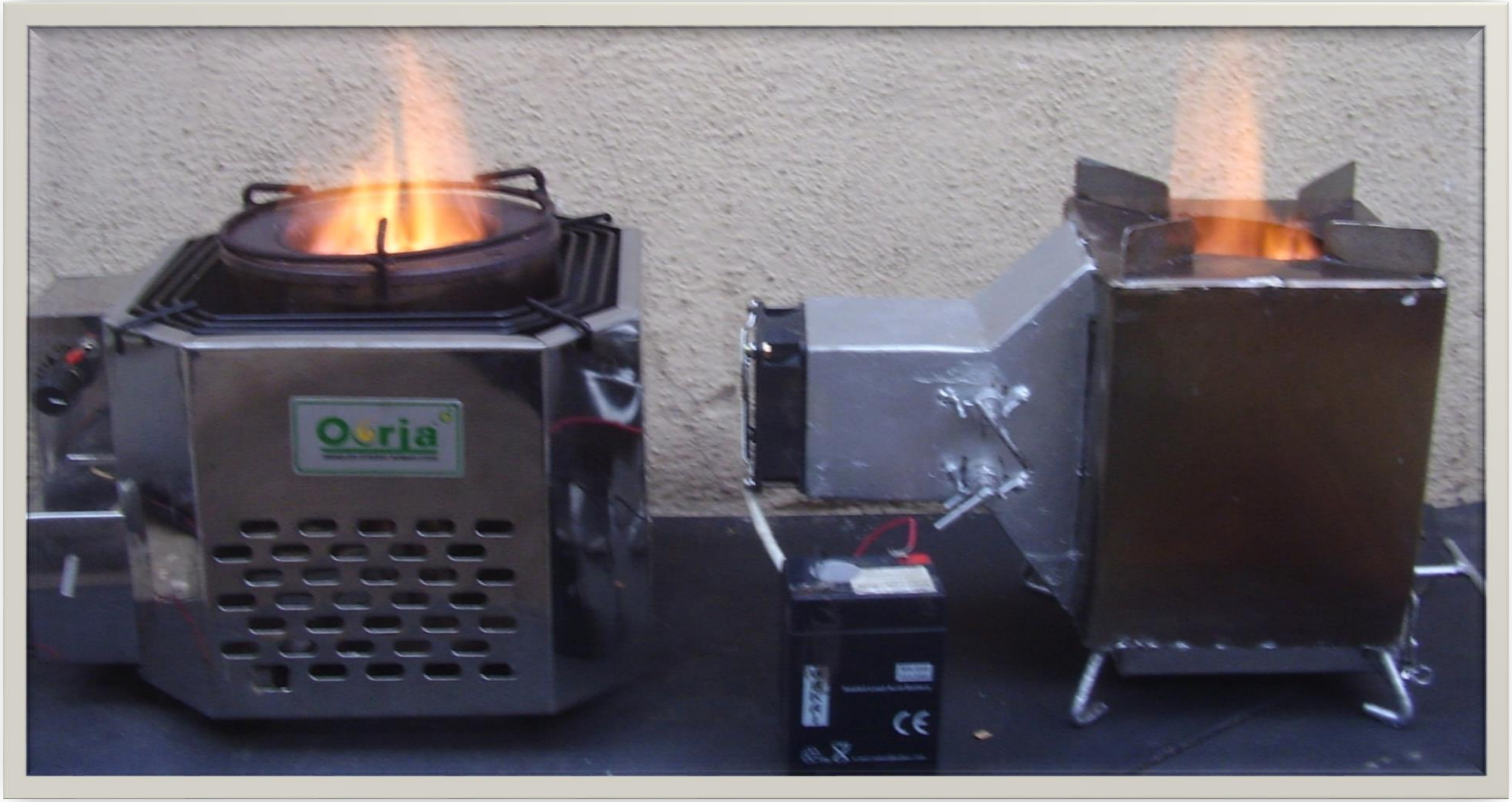
Science of stoves with an eye on high performance

- Stoves were built and tested with prepared pellets from agro-residues all to a size of 10-11 mm dia, 15 mm long, ash content ~ 6 – 10 % and moisture content of 5 to 7 %. The average density of these pellets is 900 to 1100 kg/m^3 .
- The higher density allows packing the required amount of fuel in a smaller space.
- These stoves use a ceramic walled combustion chamber and use fans obtained largely for computer industry (so, inexpensive)
- Water boiling efficiencies of 40 to 55 % for vessels of practical range (200 – 320 mm). Cooking for a family gets completed with 600 g in 60 to 70 mins – 1.2 kg/day.

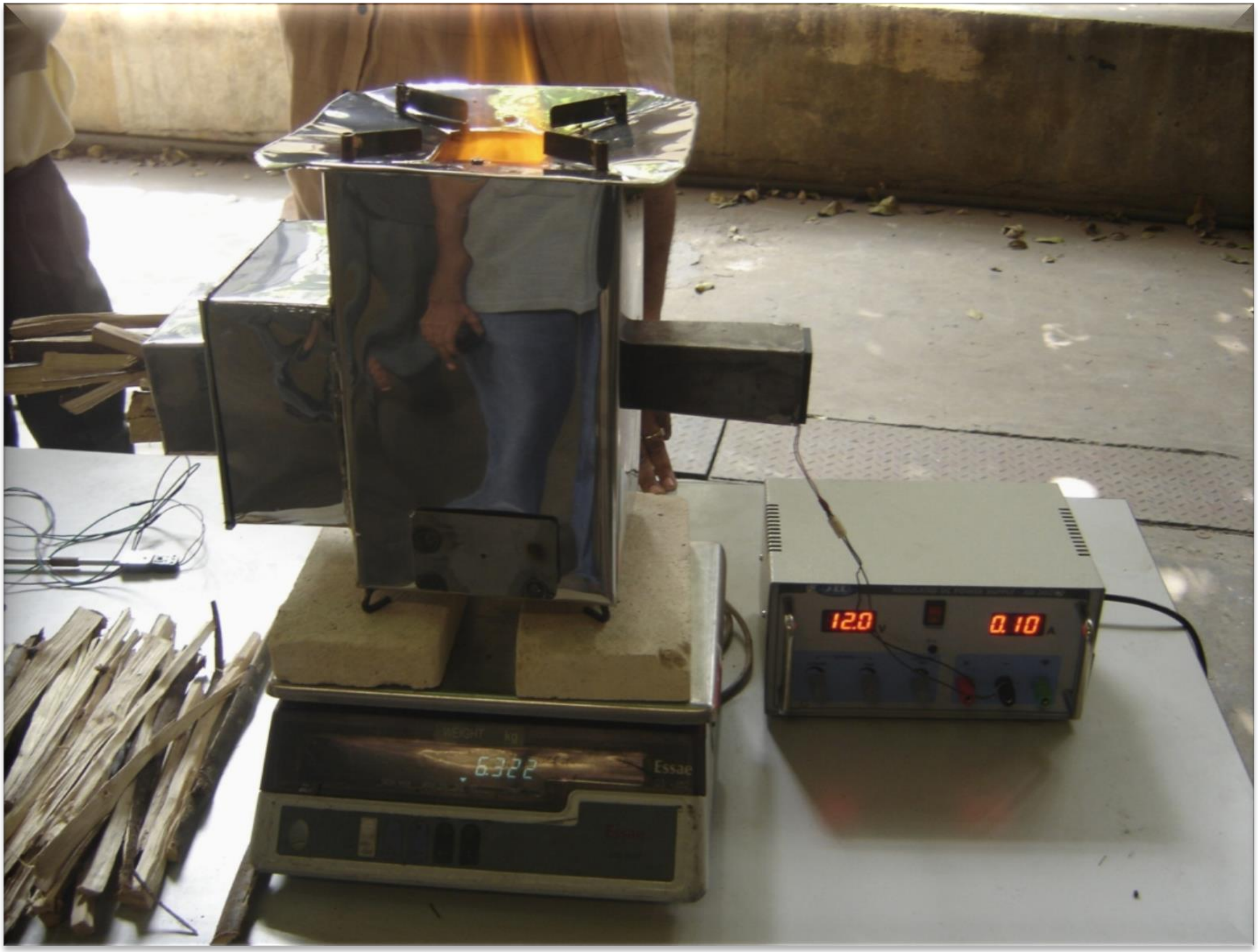
This stove works by gasification principle – air from the bottom controls the amount of hot combustible gases generated and hence power and air provided at the top burns up the hot gaseous fuel. Clean combustion at right A/F helps attainment of high peak temperature and reduction of incomplete products of combustion.

Science of stoves with an eye on high performance

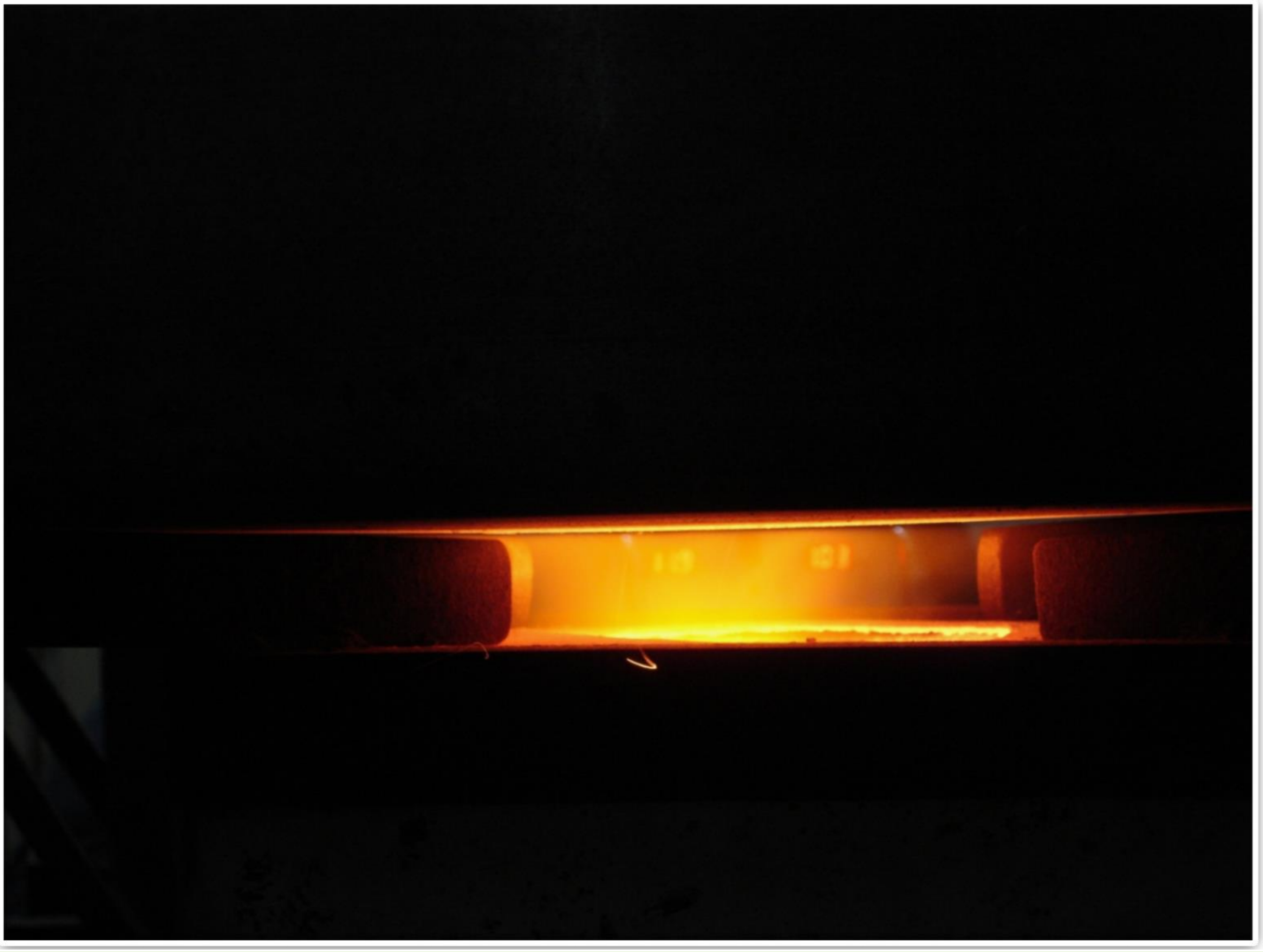
- Tech transferred to **BP (India)** who have commercialized it.
- Over 200,000 stoves have been sold to rural households in over 2500 villages in 4 states of India (1000 stoves every day, now).
- The expectation is that a million will be sold before 2009 – a clear landmark when it happens, as I see.
- Over 450 tonnes of prepared pellets of the above specs are supplied every week.
- These pellets are made from a mix of residues – bagasse, peanut shells, tamarind shells, deoiled rice bran, etc
- There are still certain basic aspects of fuel pellet preparation in terms of throughput that need to be resolved. These are being currently addressed.



Design 1 (Valveless); Modified Design 2: Two valve type with ash removal tray at the bottom



Design of a low emission fire wood continuous stove with new ideas – Ejector induced air flow and horizontal gasifier (EIGAS stove).
The power drawn is 1.2 W for 4.5 kW thermal output. Eff. ~ 40 to 50 %



Ejector induced gasifier stove (10 kg/hr, 45 kWth) with a vessel at the top – uses 12 W power with an advanced high speed fan with levitating bearings . Notice the near transparent flame;
used now for making Pattu in Kerala

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**

What does all this mean?

- The use of advanced stoves that are equivalent of gas stoves reduce the consumption to 1.2 to 1.5 kg/family/day (0.4 to 0.6 tonnes/person/year). Except for barbequing, one can replace the charcoal by processed biomass to obtain mind-boggling savings – From the current 5000 million tonnes per year (say, 3000 million tonnes dry) to a 1500 million tonnes per year with good indoor air quality.
- These are possible only with the vision and drive of a large organization. The Emerging Consumer Markets group of BP is committed to driving scale for this in India as well as entering other markets such as Vietnam and China.
- The key aspect, namely supplying solid fuel at affordable prices needs additional research, investment into technology and field level operations that are new areas (nobody else has even thought about the issues and hence, much needs to be done)

Industrial heat

- Heat through not-so-clean producer gas is known world over and there are a number of suppliers of equipment with different technologies.

- Heat in some applications has to be very clean, as clean as for engine applications
  - when the gas to be taken over a distance before use
  - when the gas to pass through control system elements with fine passages

Systems have been built even with these demands and the uptime has been very high – more than 90 % in most cases; the continuous non-stop operating time of the system >2000 hours and total operational time > 20000 hours at large throughput (1100 kg/hr single reactor)

The important aspect about these systems is that the investment costs are returned in a short time (less than an year) when compared to operations with fossil fuels – fuel oil including.

Q-of-L Electricity
Stand-alone and grid electricity

The difference between these is in the scale and load management strategies.

Capacities vary between 10 to 2000 kWe (1500 kWe IPP's have been built in India)

There are several technologies developed/being developed over the world.

It is important to appreciate what is so critical about the technology.

Necessary condition:

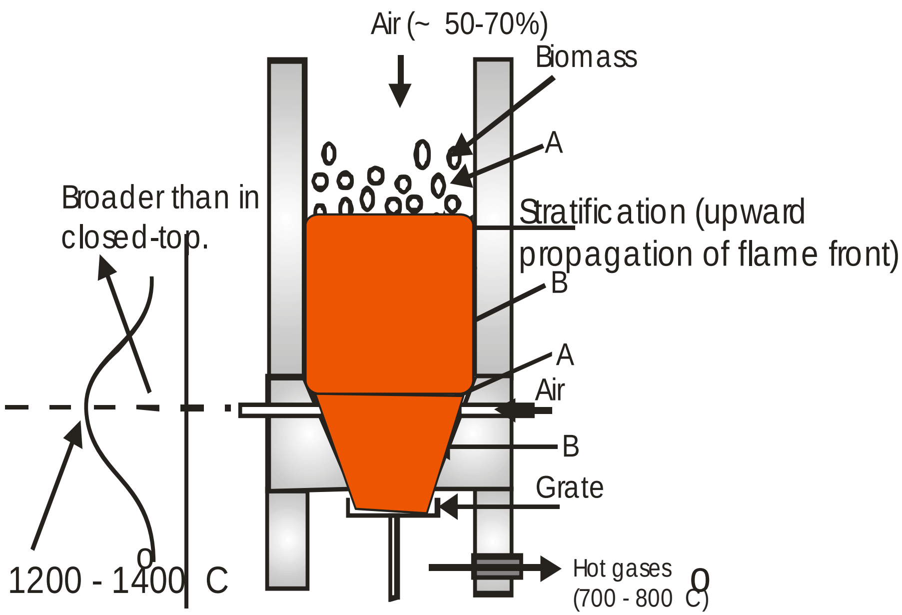
- **Achieving high gasification efficiency with minimum load on tar removal beyond the reactor;**
- **Design must be robust – help good operability even without automation**

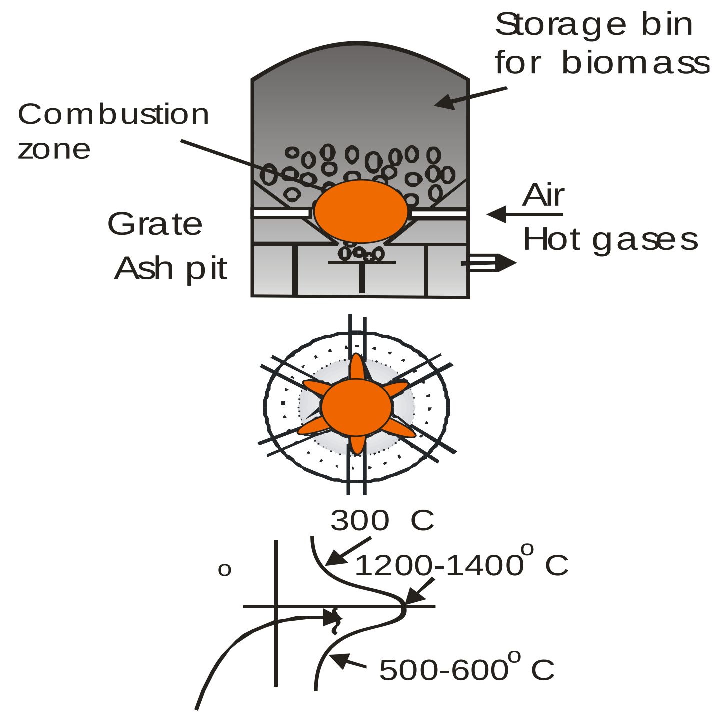
Desirable condition:

- **Fuel-flex capability for the reactor – particularly important for developing countries where a range of agro-residues are available seasonally;**
  - **if fuel-flex includes urban solid waste, it is even better**

.....Electricity, contd

One of the key elements is the reactor. The IISc design is unique (compared to every other design in the world). The other classical design is based on WW II concept. There are also other recent designs – some what fancy ones, at that.





The air entry is both from the top and sides. In larger systems this could be in stages, 2 or 3. This helps control the gas flow flux to maintain enough peak temperature to reduce tar at several loads and yet not allow ash fusion that might occur with the inorganic matter in the ash; can handle urban solid waste briquettes as well

The single air entry zone implies either too hot zones leading to ash fusion or too low a temperature with higher leakage of tar; can handle woody biomass at nominal conditions well. Some others impossible

…..Electricity, contd

The IISc reactor can be operated variously

- With both all air entry points open, one can get 5 % dry char that is activated (Iodine number ~ 500 = 500 m^2/g surface area) suitable for several industrial applications
- With bottom air nozzles closed, the char conversion will not take place and the flame front keeps moving up. One can extract char at 24 – 26 % of the raw biomass. This is activated to a surface area of about 400 m^2/g
- Coconut shell is an excellent fuel for activated charcoal (because of intrinsic density). Interestingly, coconut shell cannot be used in *closed top designs* because the inherent surface area of the feed stock generates so much tar that the reactor cannot deal with. Inevitably, this ends up in the engine.

One power station of closed top design of 1 MWe shutdown for 3 weeks with serious engine problems after the use of coconut shell that was available cheaper

- By operating the reactor with appropriate air flow sizes, rice husk briquettes (rice husk has 20 % ash) and urban solid waste briquettes can also be used with smooth operations ensured.

….. Electricity contd

Even though much effort has gone into technology and there seem to be no bugs, progress in the field seems below expectation

– there are impediments and distractions.

a. It is far more difficult to achieve commercially satisfactory operation in small systems – plant load factor, peak-to-low load ratio.

b. Over-enthusiasm on the part of the Government leads to creation of a portfolio of projects that can be argued even initially as not proper. Yet, they go ahead, manufacturers participate for there is money to make.

In this state – Tamilnadu, >130, 3 to 5 kWe systems based on closed top gasification were deployed. I understand they are all non-functional now.

This brings bad name to the technology that does not distinguish between designs or manufacturers!

c. Electricity is not an easy commodity to sell; State intervenes and creates difficulties – depending on the government.

d. IISc design producing activated carbon has made electricity as a by-product leading to lower electricity output, but more char due to better revenue.

e. This situation is spatially confined and presumably temporal in nature.

Some insight into other technologies for biomass-to-electricity

There are many “small scale” technologies under development in the UK, DK, Austria, Finland, Germany, Belgium, etc..

Of these, Biomass Engineering Co from the UK seems very robust.

- Uses WW II closed top downdraft ideas, suitably tuned. Recognizes that biomass size should be larger than “flakes” very different from others in Europe; also recognizes that biomass must be dried.
- Uses hot gas filtration with ceramic filters – some 150 of them for a 250 kWe class system with backwashing by clean gas – I believe it is too complex for the job.

Those that use updraft gasification systems have serious problems of lubrication oil contamination even if cleaning system problems are brutally dealt with.

One design is biomass specific – straw, etc; two and three stage gasification systems pursued by a few others are good for long time research without having to promise a working product.

Time alone will decide which one of these will survive!

What more from solid fuels?

1. Waste-to-Energy at small throughputs (~ 50 to 100 tonnes per day) important for at least 300 class I cities in India
2. IGCC using R/C engines to ramp the conversion eff. From 30 to 38+ %
3. Producer gas – high temp fuel cell strategy – Some work will be done in India – R N Basu (CGCRI) – IISc – BHEL grouping is at it.
4. Hydrogen from biomass – Oxygen + steam gasification of biomass – extension of the current work at IISc + hydrogen separation using PSA (Pressure swing adsorption) or membrane technologies in the market
5. Second generation liquid biofuels - Process @ 4 + FT process.

Items 1 – 5 are targeted by the IISc team for R & D in the next five years with the support of MNRE

………….Thank you for your attention