Perspectives on Clean Energy – 2007

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What you will hear about?

- Clean Energy?
- Energy needs of the society
  - Nature and size of issues
- Clean energy conversion for
  - Domestic cooking/heating needs
  - Electricity – Centralized generation
    – Distributed generation

Clean Energy?

- Energy generated and supplied with little or no undesirable emissions or effluent discharges
- Undesirable emissions – CO_2 (principal product of combustion), CO, UHC (PAH), NO_x Other heavy metals, toxic chemicals, etc
- Every production system has always some impact on the environment. Minimizing this constitutes "clean energy initiative"
- Let us look at the issues of lack of cleanliness in various systems

Clean Energy?

- Large dams for hydro-electric power generation cause ecological impacts – displacement of population, destruction of flora and fauna and these form an environmental load.
- Mini-hydel and micro-hydel power stations have nearly no environmental load
- Wind energy based power stations have little environmental load

Clean Energy?

- In solar photovoltaic power supply system, the wafer production process involves complex chemicals (98 % of semi-conductor grade poly -silicon is produced by tri-chloro-silane distillation and reduction process).
- The process is also very energy intensive and the toxic substances need care in recycling and disposal
- Some less polluting new processes are being developed
- Making the wafer-to-system production process environmentally benign is simpler

Clean Energy?

- Biomass in the from of firewood as well as coal where available are used as cooking fuels in poorer communities world over.
- China has established the beehive briquettes with coal dust and clay as a cooking fuel for more than ten years.
- Biomass use in stoves, both traditional and improved ones suffer large emissions of CO, UHC (PAH), NO_x and low efficiency
- Smith has argued rightly that from the point of view of GHG emissions, having a high combustion efficiency fossil fuel device (up to 99 %) is better than a lower efficiency biomass/coal based combustion system (< 85 %)

Table 2.1: **World Primary Energy Demand in the Reference Scenario**
(Mtoe)

	1980	**2004**	**2010**	**2015**	**2030**	**2004 - 2030***
Coal	1 785	2 773	3 354	3 666	4 441	1.8%
Oil	3 107	3 940	4 366	4 750	5 575	1.3%
Gas	1 237	2 302	2 686	3 017	3 869	2.0%
Nuclear	186	714	775	810	861	0.7%
Hydro	148	242	280	317	408	2.0%
Biomass and waste	765	1 176	1 283	1 375	1 645	1.3%
Other renewables	33	57	99	136	296	6.6%
Total	**7 261**	**11 204**	**12 842**	**14 071**	**17 095**	**1.6%**

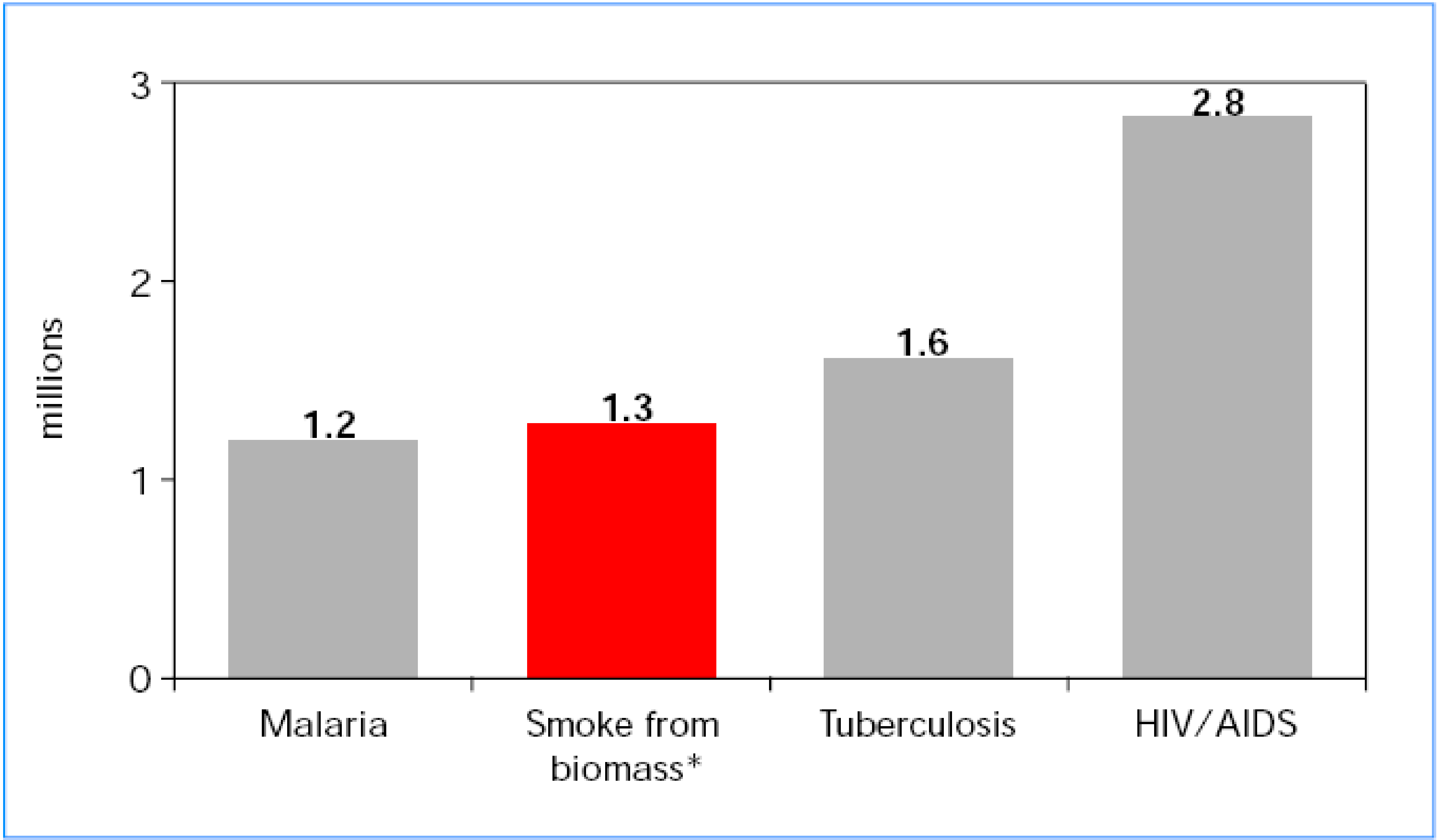
* Average annual growth rate.

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**

In India, coal use is about 350 million tonnes/year, (power plants). The biomass use is 250 to 280 million tonnes/year (cooking and industrial applications)

Figure 15.3: **Annual Deaths Worldwide by Cause**



* IEA estimate based on WHO figure for all solid fuels.

Source: WHO Statistical Information System, available at www.who.int/whosis.


Kunming,
China - 2004

Improved Stove from Cambodia

Metal covered baked clay produced by potters & stove artisans

0.55 m dia, 0.6 m high

Price: 12 to 15 USD

Main Users: Large capacity cooking – mostly restaurants

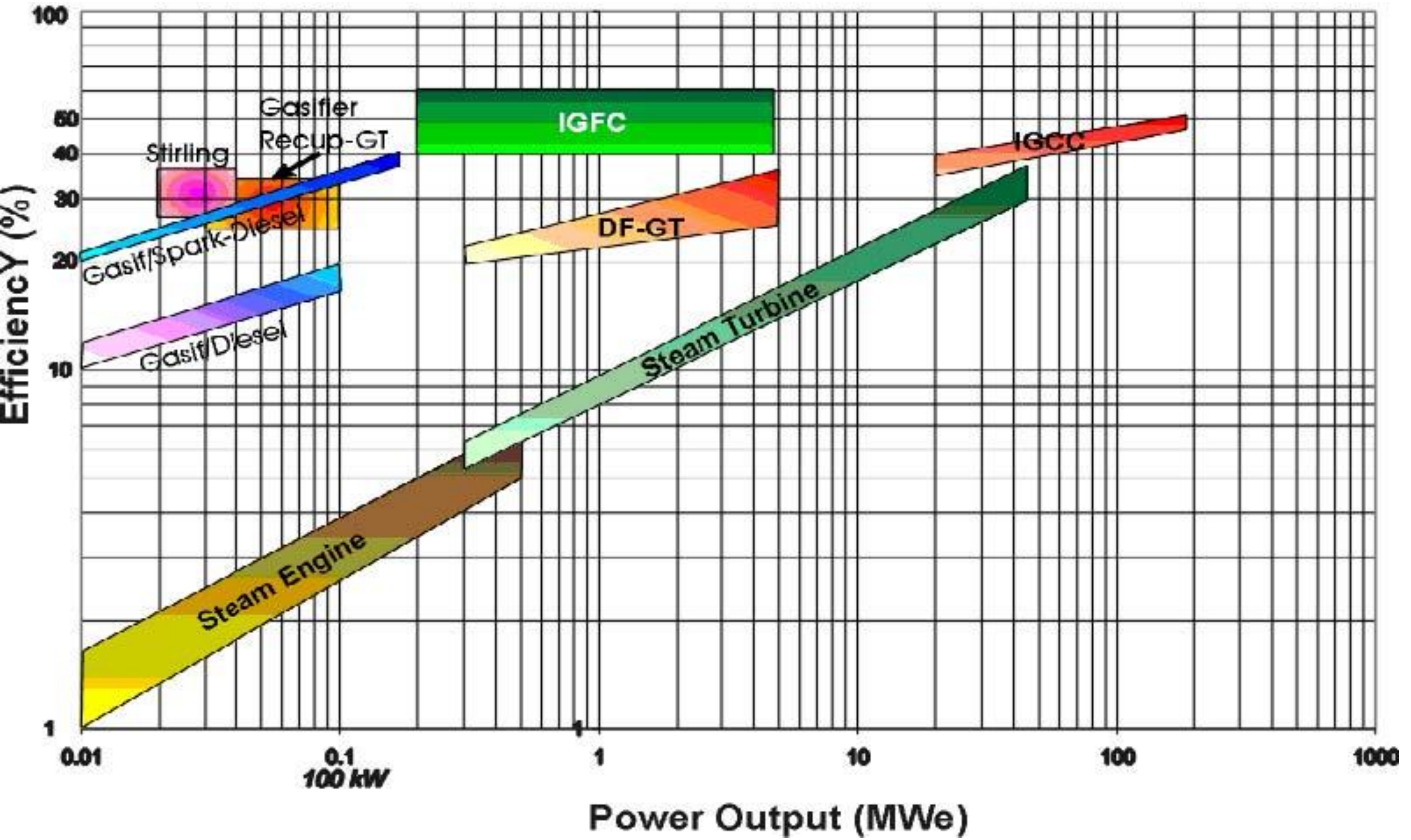
Fuel: Split Fuelwood & Charcoal;

Water Boiling Efficiency: 25 to 35 %

Major Power Stations

- Thermal power stations use pulverized coal.
- Most power stations operate under rigorous pollution control board norms
- The CO_2 emissions can be reduced by increasing the fuel-to-electricity efficiency
- This has reached a maximum of 36.5 %
- Any improvements need technology change
- The size of the power generation is about 84,000 MWe from coal (70 % of the total)

Efficiency vs. Power for a variety of power generation systems



Needs of a Developing Society

Domestic needs

- Heat for cooking – low emission, high efficiency biomass stoves with control on power with suitable "standard" fuel supply at affordable cost – *about **0.6 tonne**/yr/family (currently 1.5 tonnes/yr/family)*
- Electricity – illumination, fans, television, and refrigerator *on demand (250 W/family)*

For 150 million rural house-holds this would mean 90 million tonnes dry biomass for cooking and 300 million tonnes dry biomass for generating electricity

These lead to "Clean energy" approach

Needs of a developing society

- Large scale power generation – grid linked hydro-power stations and thermal power stations
- Enhancement in conversion efficiencies by about 5 to 8 % through the use of new technologies, these resulting in reduced emissions
- Use of distributed power generation to help meet off-grid power demand for habitats located distantly from grid line

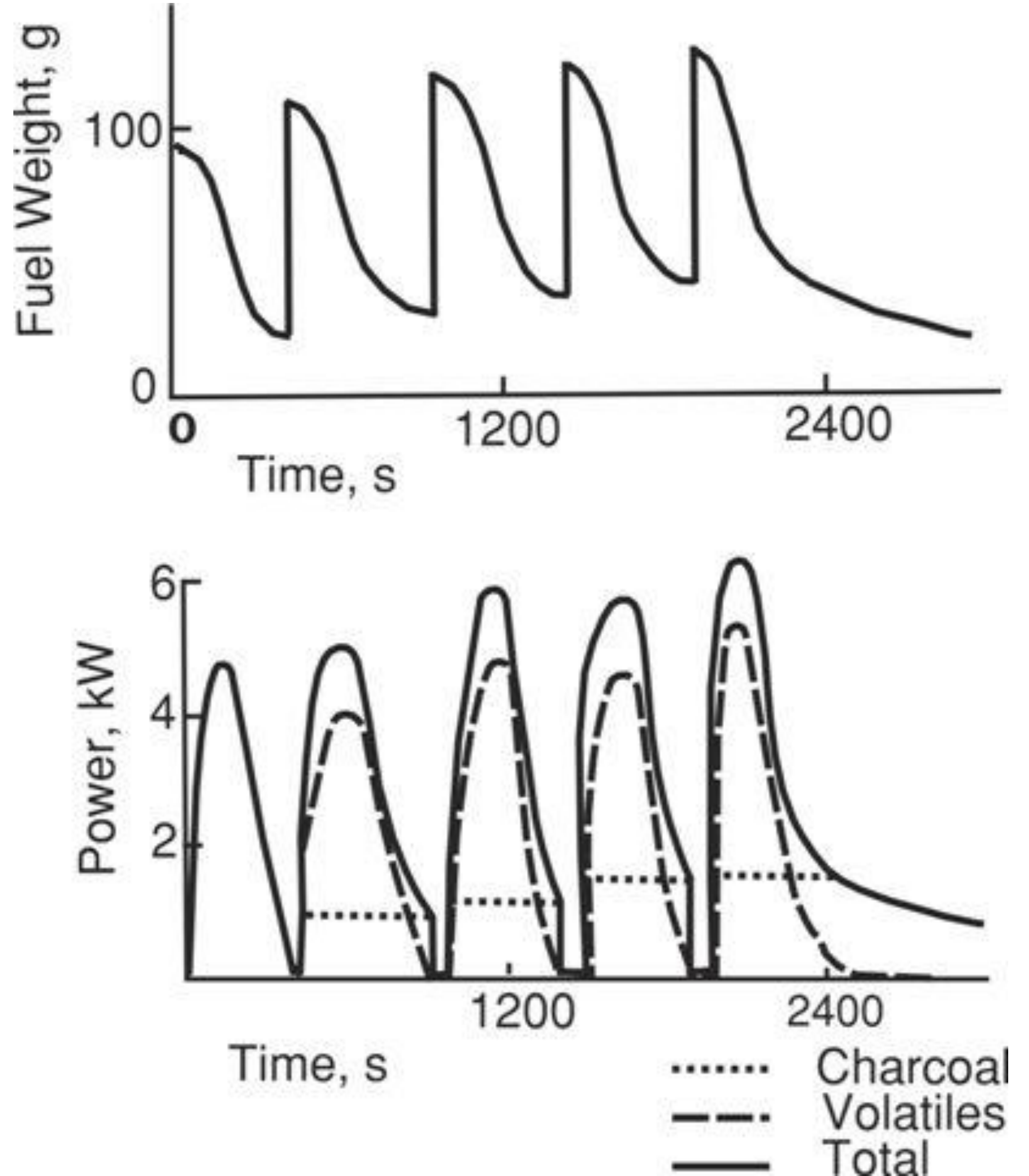
New methods for
– Domestic cooking/heating needs

Principles - first technique – fire and forget/control

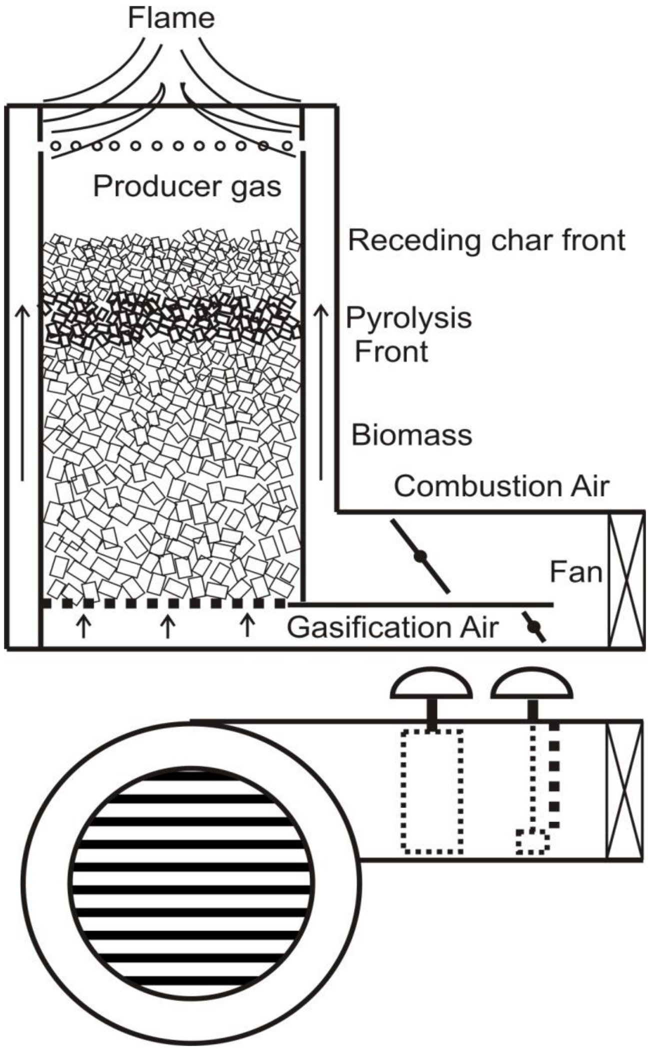
1. Burn from top to bottom of a pile instead of bottom to top (practiced for several thousand years)
2. Recognize that this is a two stage combustion process in which sub-stoichiometric combustion occurs first and then combustion of the gases is completed at near-stoichiometric conditions. The first phase is also termed gasification. Such devices are called “Gasifier Stoves”
3. The power output is proportional to the air flow rate. Hence, controlling it helps vary the power.

Fuel and Power vs. time in an "old" biomass stove

When biomass is loaded, power Increases a little afterwards, since it takes a few seconds to a few minutes depending on the size for the wood to heat up and begin to give off volatiles. When all the volatiles are consumed, biomass becomes char whose weight is about 20 to 25 % of the biomass. After this char oxidation occurs.

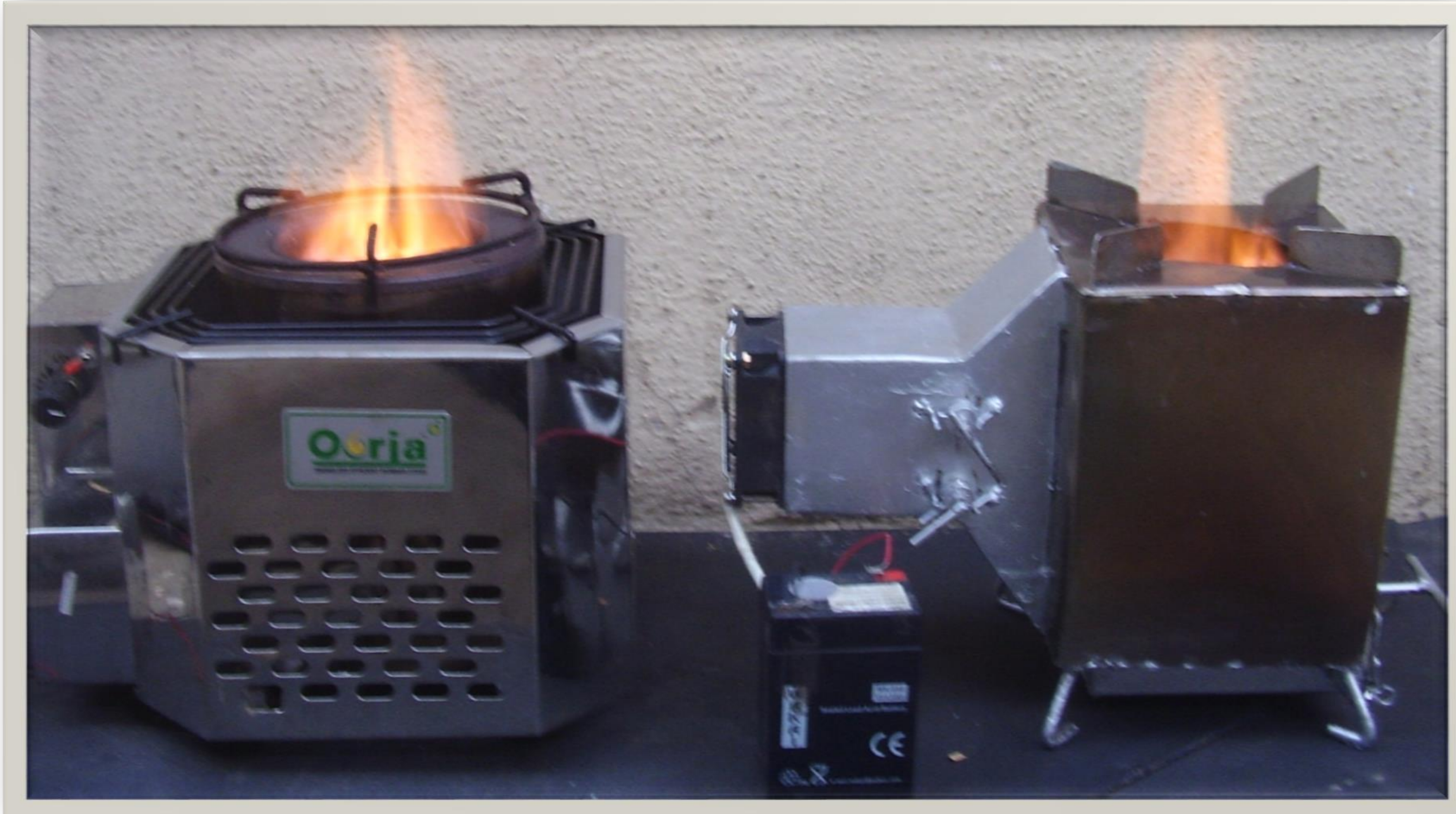


The gasification stove.



Air from the bottom – primary air – produces combustible gas over the solid fuel bed

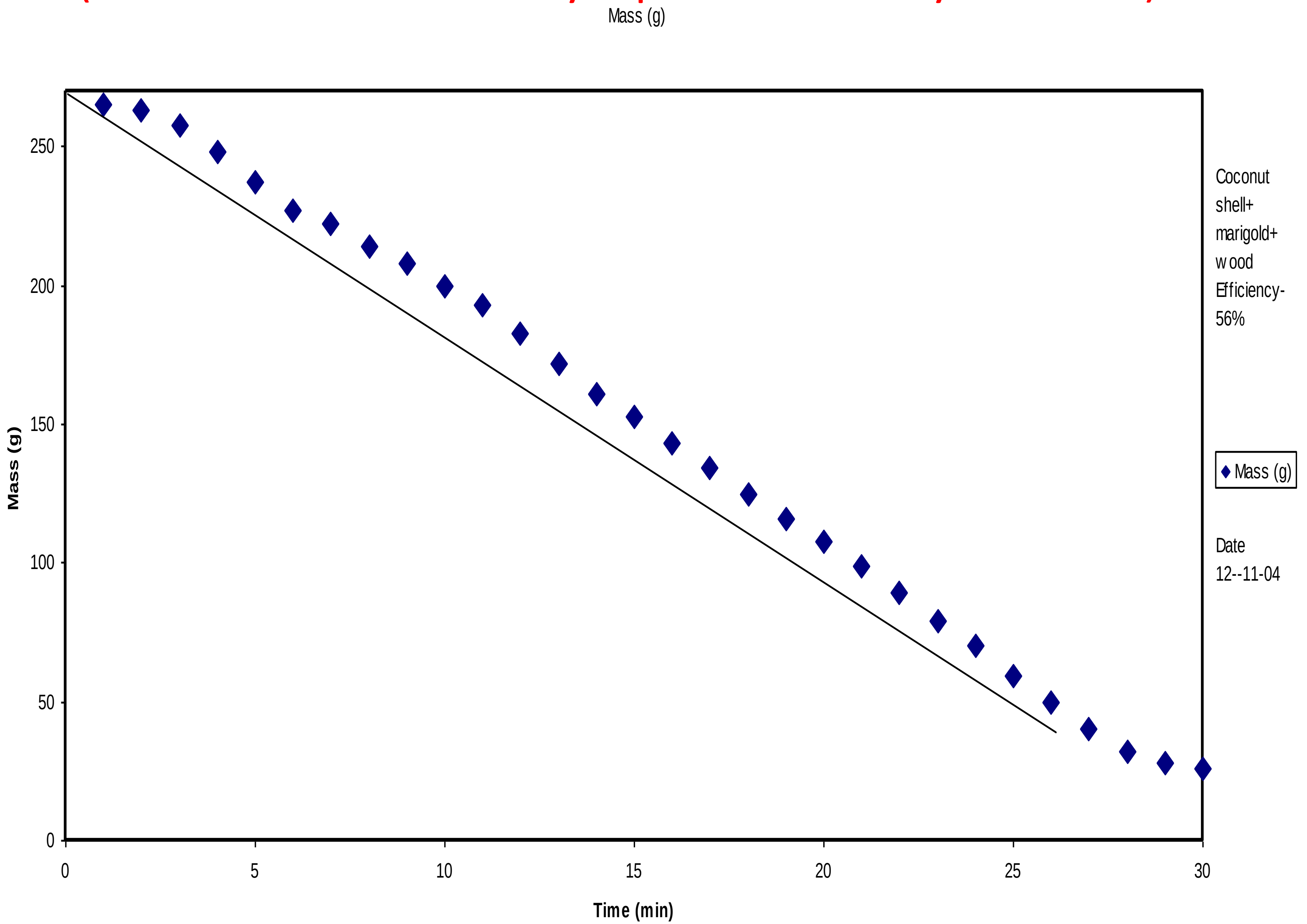
Air at the top region – secondary air – burns up the gas at near stoichiometric proportions



Biomass Stoves; built by BP: Design 1 (Valveless)
Modified Design 2: two valve type with ash removal tray at the bottom

Power variation in a gasifier stove.

(mass loss varies linearly – power is nearly constant)



Why is the power nearly constant in gasifier mode?

- In the gasification process, excess carbon is always present in the form of charcoal.
- Only that amount of carbon that is required to cause the reduction reactions is consumed.
- The propagation of the thermal profile against the flow of air occurs at a rate to reach equilibrium composition or conversion.
- With the use of sizes of biomass not widely different, the amount of biomass covered by the thermal profile is also nearly same.
- This keeps the consumption rate constant.

Why is the power nearly constant in gasifier mode?

Suppose you take two well arranged sets of wood sticks in the form of a crib. You light one of them at the top and another at the bottom, We now examine what happens

- When lit from the bottom, the heat propagates to the top by free convection and the availability of oxidant (air) from outside will let it burn up. Hence all the biomass will burn up together till it becomes char. The power level will come down, then. Thus the power variation has a peak and steep fall.
- When lit at the top, the stratification process – flame propagation process regulates the weight loss rate. Then the passage of the gases through the char bed controls the conversion to combustible gases again and this gas burns at the top. Power level is nearly constant till the end.
- Both the above processes are controlled by the size distribution of biomass and their moisture content.

Results on water boiling efficiency

100 mm dia stove, 6 liter vessel

Biomass	Amount, g	Ash %	Power kW	Time min	ΔT_w °C	Efficiency %
Wo	130	0.8	2.1	21	36	47.7
Wo + M	30 + 225	10.4	2.5	24	62	47.3
Wo + CS	30 + 242	1.0	1.6	48	71	47.1
Wo + CHB	25 + 360	4.0	2.2	51	67 + 57	51.2

100 mm dia stove,10 liter vessel

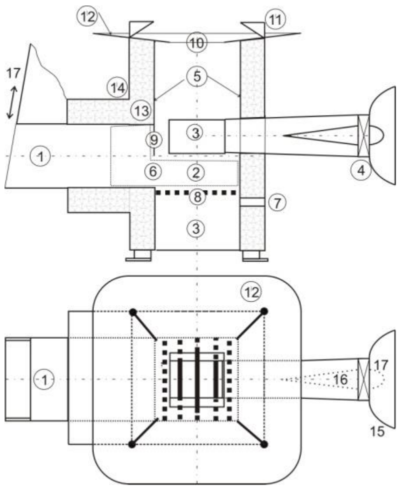
Biomass	Amount, g	Ash %	Power kW	Time min	ΔT_w °C	Efficiency %
Wo	130	1.1	2.5	16	23	52.5
Wo + M	85 + 120	7.8	2.0	26	38	58.2
Wo + CS	30 + 230	0.6	2.1	40	46	53.5
Wo + CHB	25 + 360	4.0	2.0	60	67	54.2

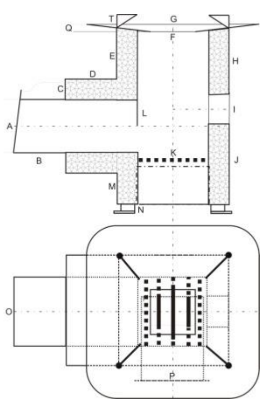
New methods for
– Domestic cooking/heating needs

- Principles – a second approach – Ejector induced gasification based stoves – continuous fuel feed

1. An ejector induces an air current below it. This is made use of to draw air through a fuel bed horizontally located
2. The use of partial blockage helps the gasification process.
3. The char bed on the grate allows gasification process to be completed.
4. Controlled air flow through the grate from the bottom section helps char conversion and maintain a high temperature in the fuel preparation zone

Ejector induced gasifier stove (EIGAS) - Continuous





- An ejector induces an air current below it. This is made use of to draw air through a fuel bed horizontally located
- The use of partial blockage helps the gasification process.
- The char bed on the grate allows gasification process to be completed.
- Controlled air flow through the grate from the bottom section helps char conversion and maintain a high temperature in the fuel preparation zone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EIGAS-10
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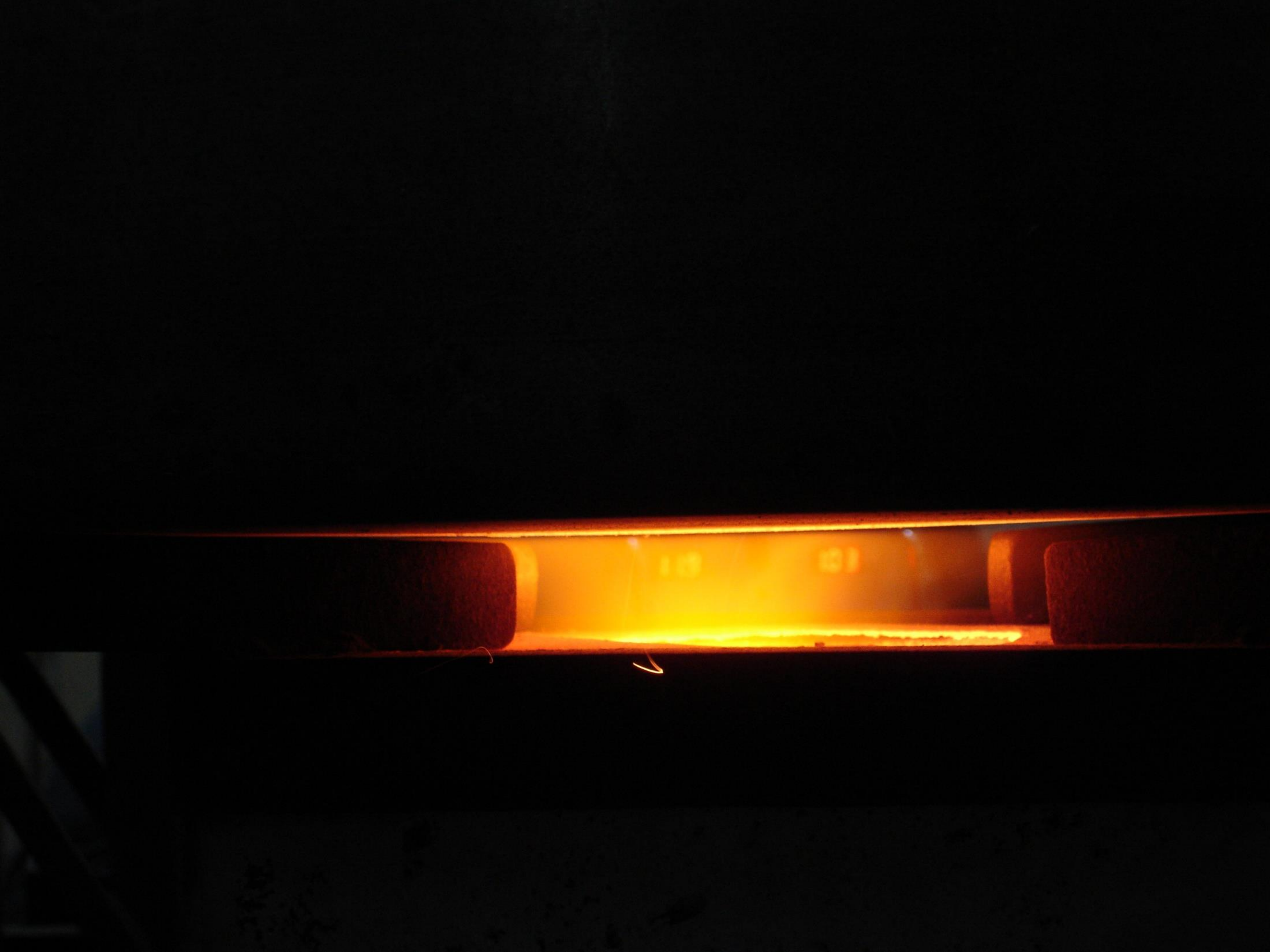

Comparison of stoves for bringing to boil 5 liters of water

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**

Distributed Electricity generation

a. Stand-alone systems –

village electrification and industrial systems (10 to 500 kWe)

b. Grid linked systems (< 2 MWe)

Distributed Power Generation

- These require gasification based power generation systems; steam power systems are far more expensive in this power range of less than 3 MWe
- The biomass consumption in combustion based steam power systems is typically 1.4 to1.6 kg/kWh compared to 0.9 to 1.1 kg/kWh for gasification systems.
- Also, the demand for water for operations is much lower for gasification systems.

Open Top downdraft re-burn Gasifier (IISc design) for electricity on 24 x 7 basis

Cold clean gas
CO ~ 20 %, H_2 ~ 18 %, CH_4 ~ 1.5 %, CO_2 ~ 12 %, Rest N_2

Ceramic reactor to withstand high temp oxidizing and reducing environment; bottom screw system meant for ash extraction (hi ash biomass)

Generation of activated carbon with surface area of 450 to 550 m2/g in the bottom section (600 to 800 C)

Cooling and cleaning train to get dry gas at (P + T) < 5 ppm

The crucial difference between the classical closed top and Open top re-burn system (IISc design)

All the air enters only through one set of radial holes in the closed top design. At high throughput, peak temperatures may cause ash fusion or at low throughputs tar may leak through some azimuthal sectors

In IISc design, air entry occurs in stages and the flow from the top makes the access to oxidizer more uniform over the cross section.

It is possible to control the peak temperature to ensure "No ash fusion" + "Low tar" over a range of throughputs enabling the same technology for use in urban solid waste

Biomass that have been used in gasification systems

Coconut Shells

Coffee Husk

Dry Grass

Marigold Pellets

Biomass that have been used in IISc gasification systems

Paper Trash

Pine Needles

Rice Husk

Sawdust

The building housing the 100 kWe system

The gasification system and the power delivery panel

Snapshots of grid-linked1 MWe biomass based power plant (Coimbatore, 2004)

The Power Plant

Gas Cleaning Unit

Cummins engines Ltd has accepted IISc gasifiers for operations on their engines with guarantees and warranties

Fuels used: Coconut shell for 1 year → then Prosopis Juliflora for an year → and then again Coconut shell

PG Engine

Performance of systems as independently operated plants

SYSTEM	ESTBLD	CAPACITY	FUEL	HRS PER YEAR (OPERATD)	PLANT AVAI-LABILE?
ARASHI HI-TECH BIOPOWER	2002 (D-F) 2004 (GAS)	1 MWe	Julifora Prosopis, Coconut shell	6500	>85 %
HINDUSTAN PENCILS	2003 (D-F) 2005 (GAS)	200 kWe	Sawdust briquette	5500	> 95%
TANFAC	2003	1100 kg/hr	Juliflora Prosopis, Forest waste	7500	>95%
TAHAFET	2001	300 kg/hr	Juliflora Prosopis	7000	>95%
CRUMB RUBBER (1)	2002	80 kg/hr	Wood, Coconut shell	7000	>97%

Liquid, solid and gaseous emissions

Liquid effluents

- Cooling and cleaning systems carry water that has particulates, dissolved chemicals, largely phenols and some tar compounds.
- The magnitude of particulates in water is about 0.8 g/kg biomass; the amount of dissolved chemicals is 0.3 g/kg biomass.

• A 1 MWe plant has to deal with 800 gm/hr of particulates and 300 gm/hr of dissolved chemicals.

These are handled by using a continuous effluent treatment plant that deals with particulates by a process of flocculation and settling and activated carbon bed to absorb the dissolved chemicals.

Liquid, solid and gaseous emissions

Solids

- The ash extraction system takes away the ash and some unconverted char.
- The char extracted from solid wood stock or coconut shell at 5 % extraction (10 % wet) is activated to the extent of having an Iodine number of 450 to 550 (~ m^2/g surface area).
- This is separated and can be marketed at 20 to 25 Rs a kg (~ Rs 1.0 to 1.23 recovery on biomass cost)

The remaining ash is dry and can be recycled into soil as part nutrient supply.

Gaseous emissions from engines

Parameter/Country	USA	EU	Japan	India
CO	3.06	1.4 - 1.8	1.67	**1.25 (3.9)**
NOx	2.56	2.56	2.6 - 3.06	**2.22 (5.0)**
HC	0.36	0.36	0.4 - 0.56	**0.3 (0.98)**
PM	0.15	0.15 - 0.24	-	**0.1–0.2 (<3.5 Bosch)**
Cummins Engine results at normal operating conditions				
CO			**0.4 – 1.8**	
NOx			**0.2 – 0.7**	
PM			**<< 0.0005**	

Large Coal Power stations

- Most power stations have to follow CPCB norms. If they do not, there are regulatory approaches for ensuring compliance.
- Enhancing the performance needs new technology – IGCC (Integrated Gasification Combined Cycle).
- Circulating fluid bed gasifiers (CFBG) with hot gas filters for limiting particulate matter form the core of gasifiers
- These technologies are in practice in Europe and the USA. They are expensive – 2000 USD/kWe at 200 to 500 MWe and have been used with low ash coals.
- Attempts to test them out with high ash Indian coals have not proved very successful till recently.

Large Coal Power stations

- A less expensive alternate strategy for Indian coals seems possible.
- Open core re-burn fixed bed downdraft technology meant for biomass have been tested in a preliminary way for operations with Indian coals.
- These show steady operability. Of course, the hydrogen sulfide clean up is to be added into the circuit.
- The suggestion is that one can build 20 to 30 MWe class IGCC systems with reciprocating engines. The exhaust from reciprocating engines along with additional heat can be used to operate heat recovery steam turbines.
- One can hope to get 42 to 45 % overall efficiency with this approach at costs of 1200 USD per kWe

Large Coal power stations

This is clean energy as the CO_2 emissions will be brought down significantly. Perhaps one can claim CDM benefits as well.

New horizon technologies – Liquid biofuels, Fuel Cells and H_2

- Liquid biofuels are obtained by catalytic conversion of producer gas at high pressures ~ up to 50 atm and high temperatures ~ 300 °C. These are called second generation technologies to be made economically meaningful in coming times.
- Fuel cells are being researched currently very intensely world over. Solid Oxide fuel cells are being explored by Dr. R. N. Basu at CGCRI
- The fuel for fuel cells can be producer gas, having CO, H_2 as the primary fuel components. No reforming of fuel is required (as required for natural gas based fuel cells).
- Experiments in Europe suggest that this should be a straight-forward action.
- Perhaps the Indian developed fuel cells with producer gas will happen soon.

New horizon technologies – Liquid biofuels, Fuel Cells and Hydrogen

- Economic production of hydrogen from biomass is possible through O_2 – H_2O mix instead of air as the gaseous reactant.
- The hydrogen fraction can go up to 45 – 50 %.
- Hydrogen separation can be done in several ways – pressure swing adsorption that is available commercially. Other ways include membrane technologies
- The first part of research will get done at IISc in coming times

Summary

1. The subject of clean energy needs to be explored as domestic cooking issue as well as electricity production both in distributed mode as well as centralized mode.

2. The needs and technological tools required to meet them are described.

3. The assimilation of these into developing societies needs significant effort of many partners – Research institutions, MNC’s, NGO’s, and Govts.

Thank you
for your attention