Science for affordable and sustainable energy for Asia-pacific region

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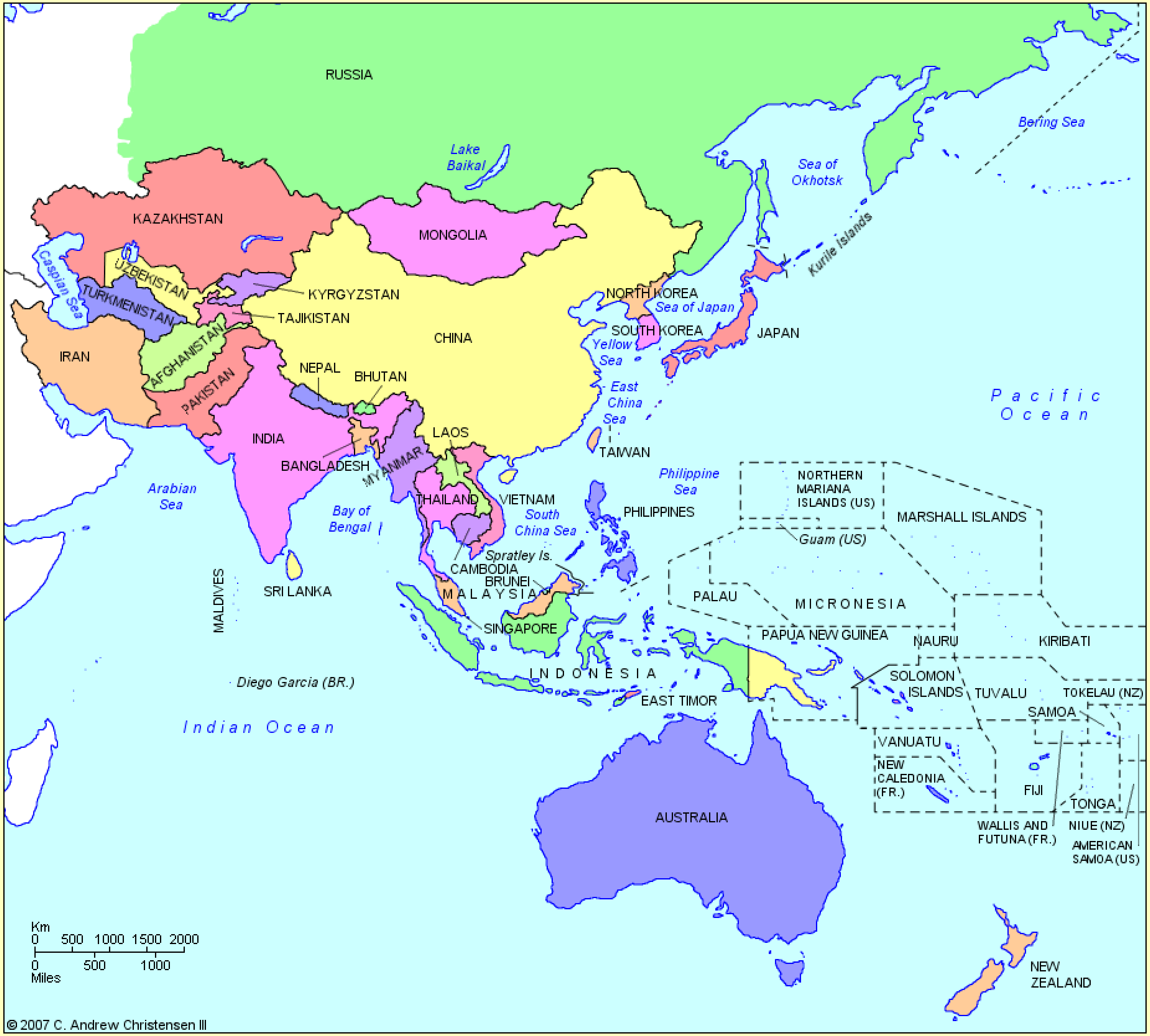
The plan

1. Characteristics of the region
2. Biomass resources
3. Interventions for cooking
4. Interventions for Q-of-L electricity and power for industry
5. Multiple possibilities
6. On-the-horizon technologies

The Asia Pacific region



Sl. No.	Country	Country Area 1000 ha	People millions	GDP PPP USD	Oil Prod. mmt/yr	Oil used mmt/yr	Oil used -Prud. mmt/yr	Fire wood mmt
1	Tuvalu	2.6	1.2	1,600	0	0.02	0.02	0.5
2	N. Korea	12054	23	1,700	0.5	1	0.5	10
3	Solomon Islands	285	0.6	1900	0	0.05	0.05	
4	Cambodia	18104	14.5	2000	0	0.5	0.5	2
5	Laos	23680	6.8	2100	0	0.15	0.15	1
6	Fd. Sta. Micronesia	70	0.1	2200	0			
7	Papua New Guinea	46	6.1	2200	15	10	1.1	
8	Timor-Leste	1500	1.1	2400	28			
9	Marshall Islands	181	0.06	2500				
10	Vietnam	32931	86	2800	20	12	-8	5
11	Kiribati	81	1.1	3200	0	0.02	0.02	0.5
12	Bangladesh	14400	150	2300	0.4	4.4	4	7
13	Philippines	30000	97	3200	1	17	16	2
14	Fiji	1827	1	3900	0	0.5	0.5	1
Ref	India	328726	1166	2800	32	122	83	180
Ref	China	959809	1322	6080	180	324	144	200

Total population of the Asia-Pacific islands considered ~ 390 million

Low GDP, Import of oil resources, little industrial activity, and subsistence living seem interrelated in at least fourteen countries

Sl. No.	Country	Country Area 1000 ha	People millions	GDP PPP USD	Oil Prod. mmt/yr	Oil used mmt/yr	Oil used -Prud. mmt/yr	Fire wood mmt/yr
1	Indonesia	191957	240	3900	25	58	33	19
2	Tonga	74	0.1	4600	0	0.02	0.02	0.5
3	Vanuata	1220	0.2	4600	0	0.04	0.04	0.8
4	Sri Lanka	6561	21	4700	0	4.5	4.5	4
5	Samoa	290	0.2	4900	0	0.05	0.05	1
6	China	959809	1322	6080	180	324	144	200
7	Thailand	51312	65	9200	11	45	33	15
8	Malaysia	32974	25	12800	38	26	-13	
9	S. Korea	9926	49	24500	1	107	106	
10	New Zealand	26771	4	26200	1	7	6	1
11	Taiwan	35,98	23	29600	-	48	48	1
12	Singapore	70	5	31400	-	60	60	
13	Japan	37791	127	33100	6	277	271	
Ref	India	328726	1166	2800	32	122	83	180

Higher GDP - PPP, significant industrial activity, import of oil, highly disparate economic levels and quality of living in several other countries.

Those with GDP – PPP > 10000 seem to manage import of oil without sacrifice of high quality of living through advanced S & T based industrial activities.

These imply..

1. On the scale of a country, vision, culture, affordability will be different between low GDP-PP and high GDP-PPP countries.
2. Even in higher level of GDP-PPP countries the disparity of reasonably large classes of “poor” and “rich” exists (India is certainly one example)

In both these cases, the energy solutions must proceed in steps; large jumps will be difficult to achieve.

One must look for solutions that use locally available resources first and introduce more sophisticated ones later. It is important to look for commercially meaningful approaches before interventions are thought introduced.

These imply… (contd)

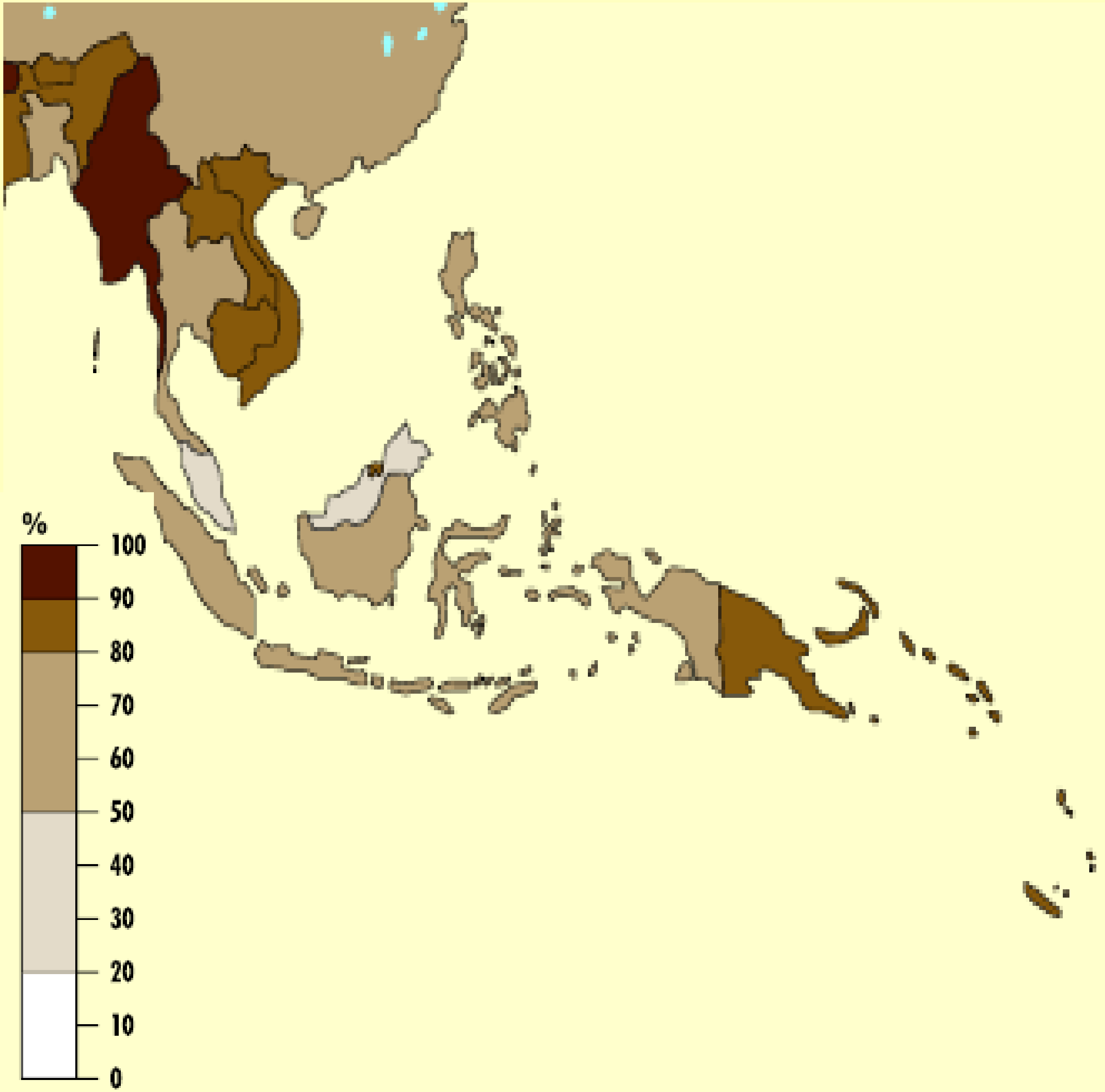
- Most of the islands enjoy a tropical climate.
- Biomass can be expected to be available in substantial amounts.
- It is perhaps not well known that biomass is wasted or used with very low end use efficiency with much smoke and other emissions even in countries with better know-how and understanding like China and India.
- Thus, there is a huge opportunity for introducing modern science based devices for cooking and electricity generation in these islands.
- These oil importing countries stand to benefit from better health and economics from these developments.

People relying on biomass resources as their primary fuel for cooking

	Total population		Rural		Urban	
	%	million	%	million	%	million
Sub-Saharan Africa	76	575	93	413	58	162
North Africa	3	4	6	4	0.2	0.2
India	69	740	87	663	25	77
China	37	480	55	428	10	52
Indonesia	72	156	95	110	45	46
Rest of Asia	65	489	93	455	35	92
Brazil	13	23	53	16	5	8
Rest of Latin America	23	60	62	59	9	25
Total	**52**	**2 528**	**83**	**2 147**	**23**	**461**

Sources: IEA analysis based on the latest available national census and survey data, including the 2001 Population and Household Census of Botswana; the 2003 Demographic and Health Survey of Nigeria; the National Bureau of Statistics of Tanzania, 2000/01; the 2001 Census of India; Energy Statistics for Indonesia, 2006; the Bangladesh Bureau of Statistics, 2005; the National Statistical Office Thailand, 2000; ORC Macro (2006); WHO (2006).

Share of traditional biomass in domestic consumption



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

Fuel	Density t/m^3	Shape	Size mm	Ash %	H MJ/kg
Fire wood	0.3 – 0.7	Regular	10-100	~ 1	15
Agro-residue	0.05 - 0.1	Fine, odd	1 - 10	1 - 20	15 - 13
Cow-dung cake	~ 0.15	Regular	100	~ 10	~ 12
Coal	~ 1.2	Pieces	5 - 50	30 - 45	18 - 16
Kerosene	0.78	-	-	-	42
LPG	0.5	-	-	-	48

Further….

- 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!*).
- To exemplify, wood used for cooking in Cambodia is about 2 kg per meal (for a family of 5). The amount of charcoal used is also about 2 kg. But to produce 2 kg charcoal one would have used 12 kg biomass!
- There is a concern that the forests are being felled to produce charcoal for cooking to such an extent that in not too distant a time, forests may just not be there at all.

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

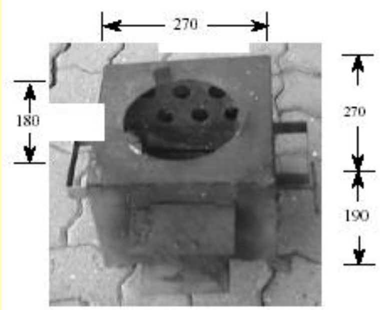
Wood burning stoves - efficiency and emissions

24 wood and charcoal stoves of east Asian origin from Bhattacharya et al (2002)

Thailand, η =14%,
CO 26.4 g/kg fuel

Traditional Rungsit stove

Thailand, 12%
25.2 g/kg fuel

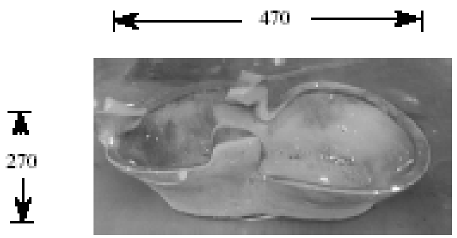


Indian "Harsha" Cookstove

India, 25.2 %
41.2 g/kg fuel

Malaysian traditional

Malaysia, 9.5%
28.7 g/kg fuel



Nepalese one-pot ceramic

Note: All dimensions are in mm

Fig. 12. Nepalese one-pot clay stove.

Nepal, 10.5 %
CO 136 g/kg fuel

Lao traditional stove

Lao, 14.3%
27.3 g/kg fuel

Phil. traditional

Philippines, 12%
28.6 g/kg fuel

Vietnamese traditional

Vietnam, 15%
38.6 g/kg fuel

We will see what happens in a conventional stove where you feed fuel periodically

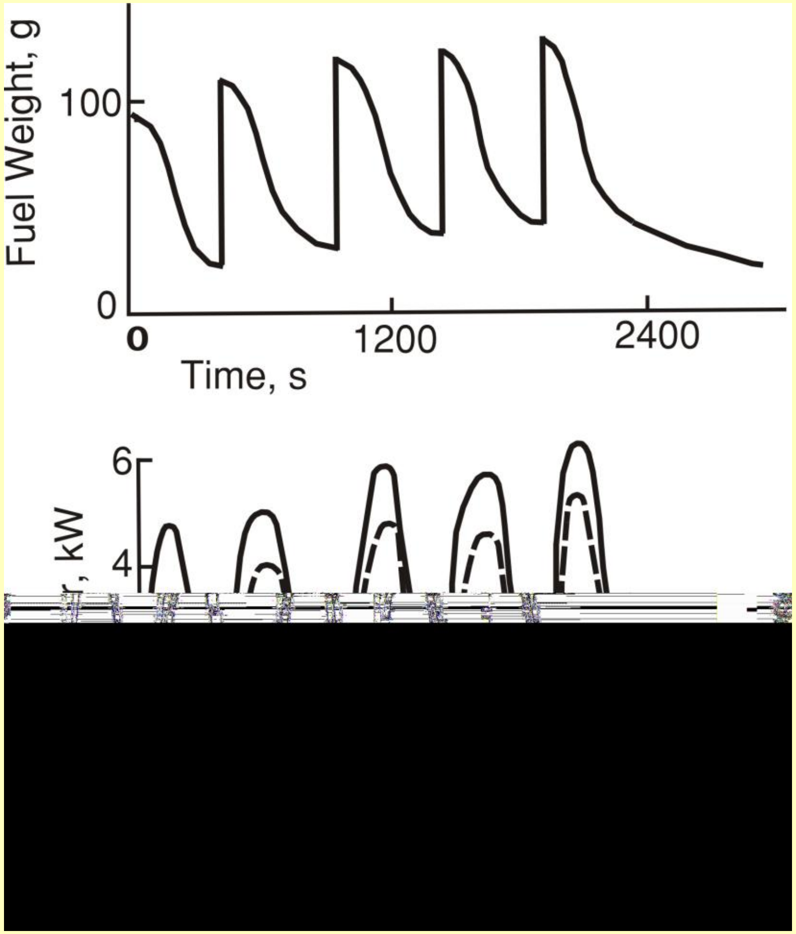
and

see what scientific understanding and current technology can do……..

Behavior of conventional stove

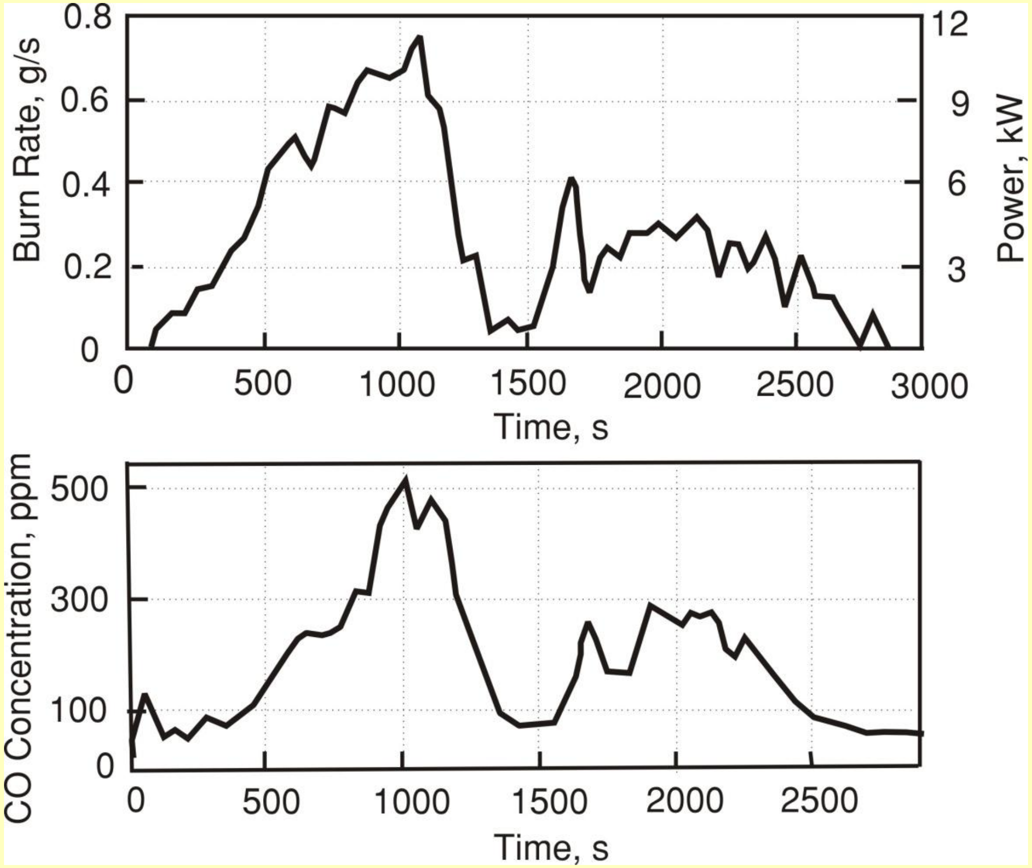
Conventional wood stoves requiring periodic supply of fuel are characterized by volatile generation with large peaks: leading to large fluctuations in a/f - sooting & smoking.

CO & other products of incomplete combustion (PIC) also get emitted.



Emission patterns

There is a clear link between higher CO emissions with intermittent fuel feeding



Operation of a typical one pot metal stove with periodic fuel supply

Science of stoves with an eye on high performance

- In 1985 – 87, research was conducted at Indian Institute of Science on stoves
- In view of higher efficiencies of LPG and Kerosene stoves (70 and 65 %), a fundamental question was posed.
- 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*

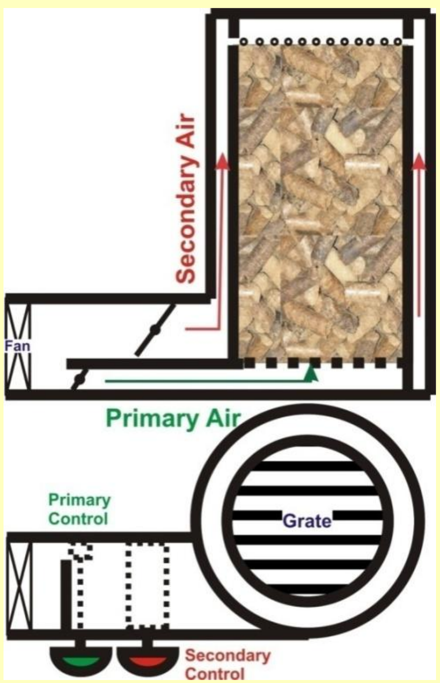
  ⟶*Operation of the stove near stoichiometric conditions; one can do even better by producing a gas from the solids using gasification principles and then burn the gas with the correct amount of air. Let us see…..*

Gasifier stove….

Reverse the classical downdraft gasifier. Push air from the bottom and you get the reverse downdraft gasifier.

Fan provides the air. This fan is about the same as a computer fan
Air from the bottom is called the primary air and
it controls the power (how? The air for gasification is about 1.8 times the mass consumption rate, the number 1.8 related to the biomass composition. The hot char on the top participates in the conversion process).

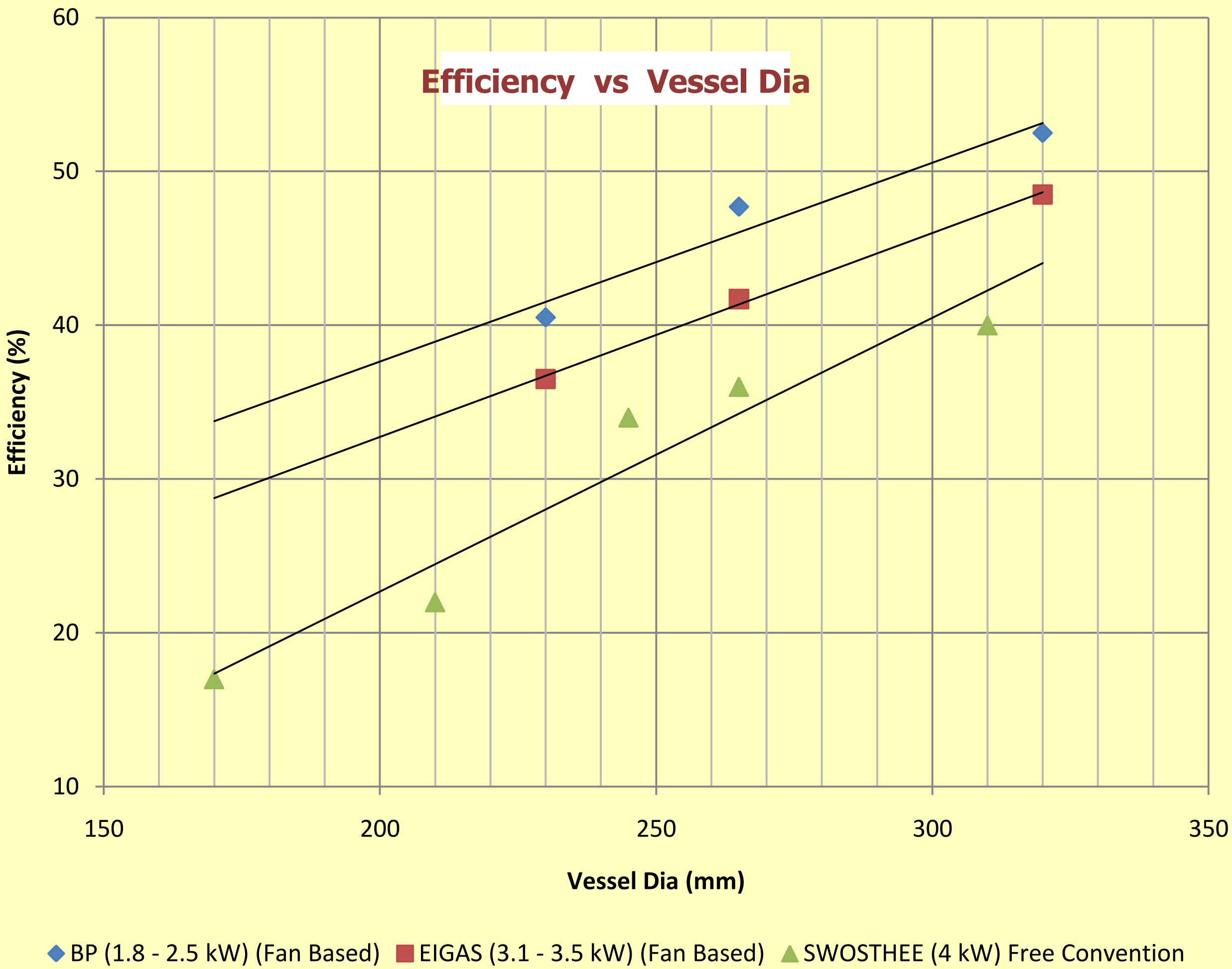
The air at the top is proportioned such that it burns up all the fuel gas. This ensures the air-to-fuel ratio for combustion to be such as the peak temperature close to a maximum.



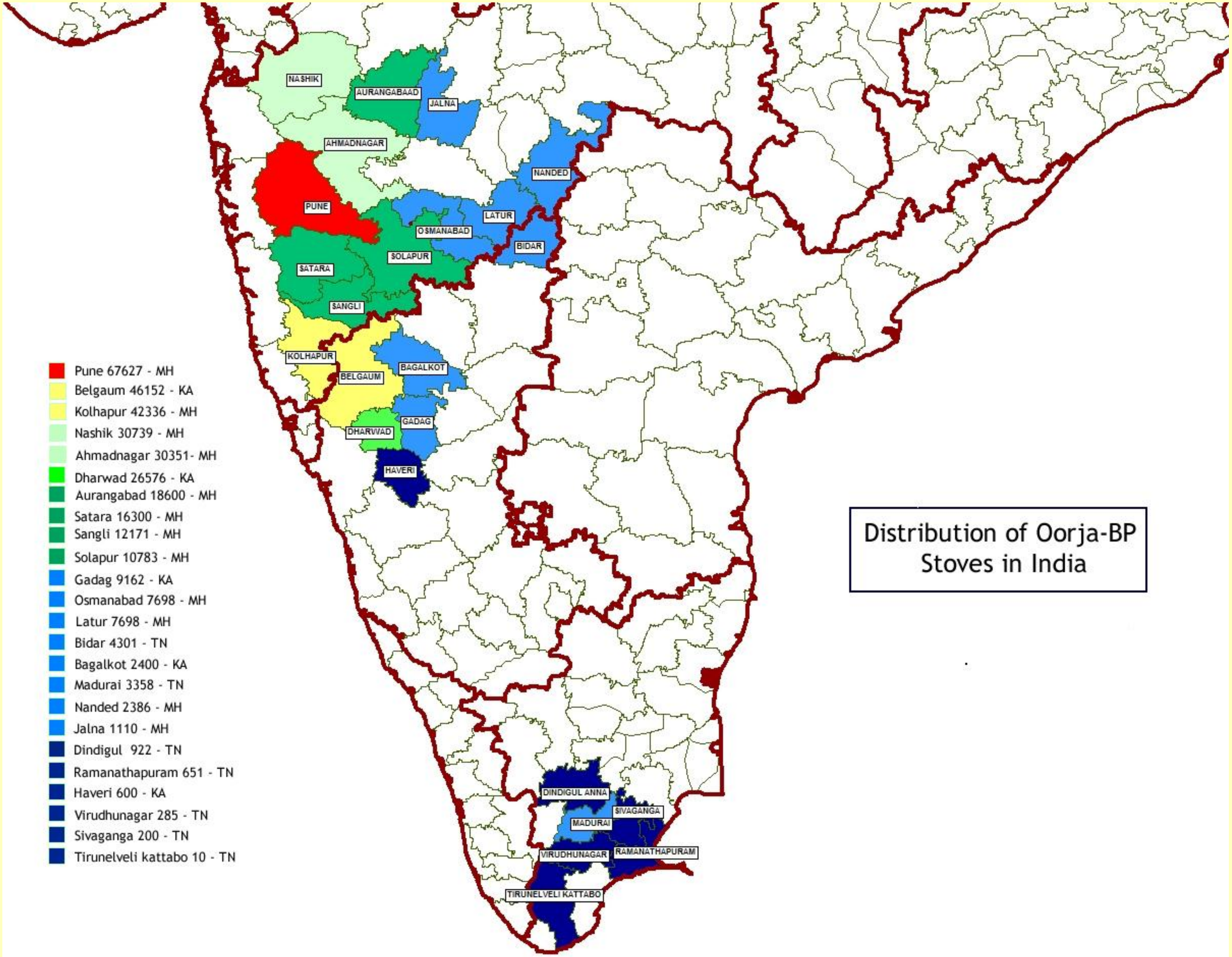
Science of stoves with an eye on high performance

- Tech transferred to **BP (India)** who have commercialized it.
- Over 390,000 stoves have been sold to rural households in 2500 villages in 4 states of India (1500 stoves every day, now).
- These pellets are made from a mix of residues – bagasse, peanut shells, tamarind shells, deoiled rice bran, etc such that the ash content is 8 to 10 %, moisture less than 5 % and density 750 to 900 kg/m^3.
- Over 500 tonnes of prepared pellets of the above specs are supplied every week.

REDS – Gasifier Stove sold by BP, India under the name “Oorja”

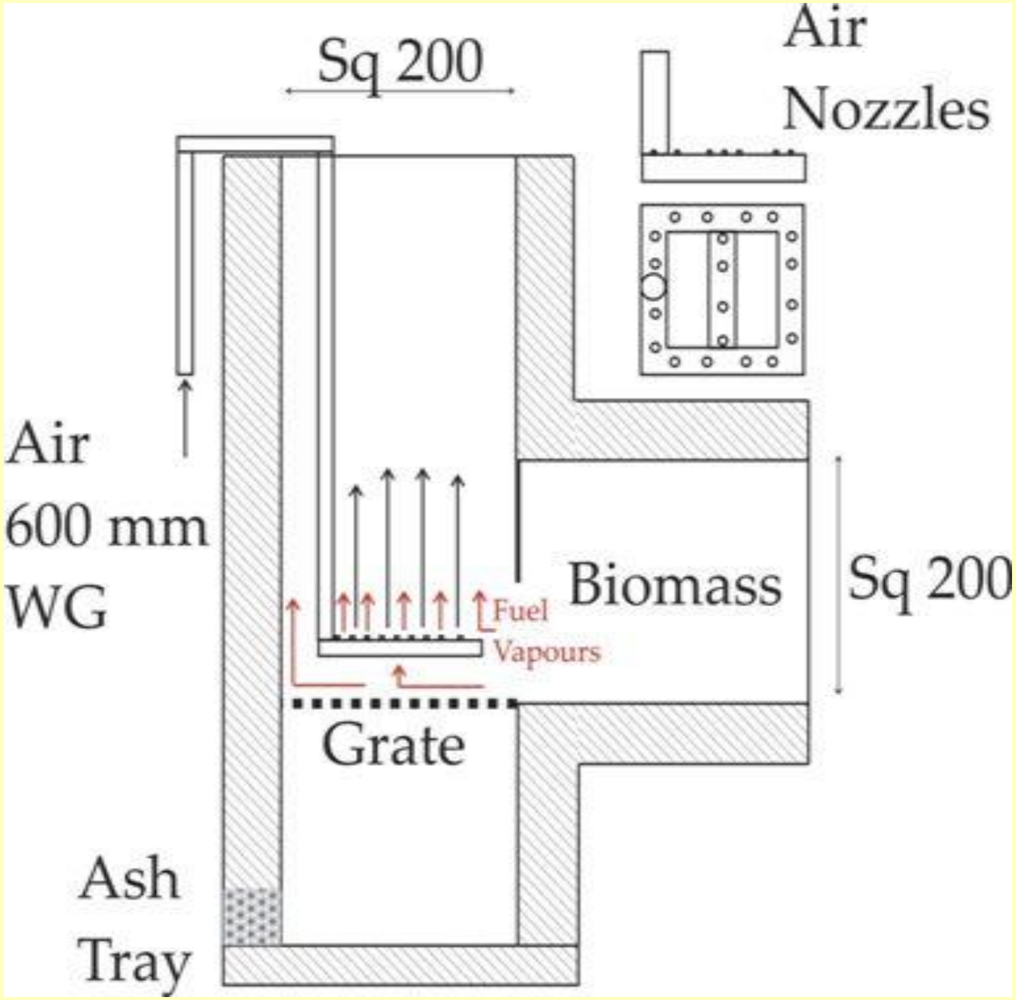


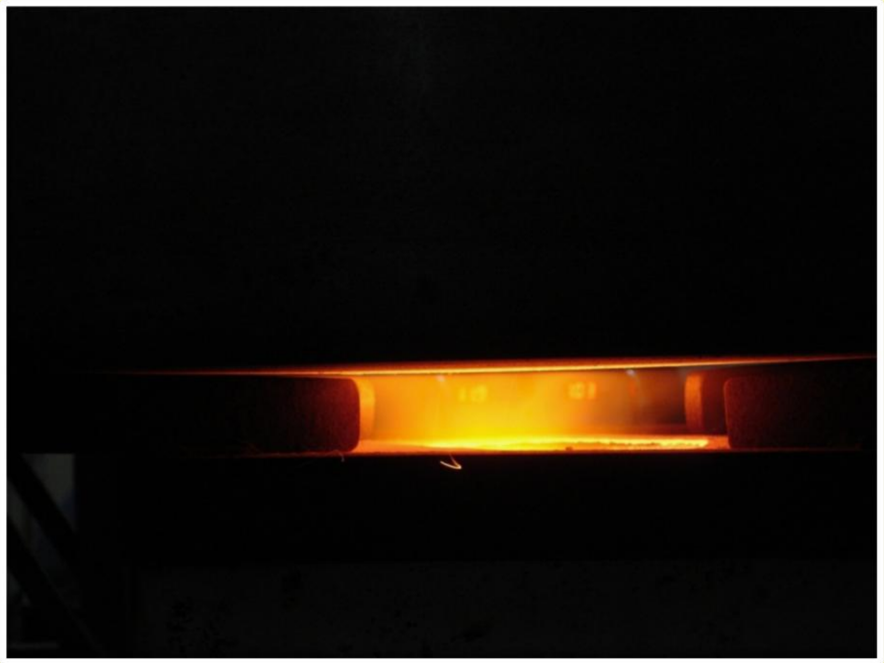
Water boiling efficiencies in flat Al vessels with 230 , 265 , and 320 mm diameter carrying 2.5, 6 and 10 liters of water.



BP, India has commercialized and marketed 400,000 stoves

Another design - Ejector Stove with a horizontal gasifier.





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

Functionality? Affordability?

- The stove uses rechargeable batteries. Each charge can allow three days cooking (twice a day)
- Electricity for charging the batteries some time during the day is adequate for this purpose.
- The stove costs about 25 USD.
- The up-gradation cost of the fuel is about 3 US cents per kg. Depending on the cost of raw biomass (1 – 2 US cents per kg) and finance costs of 1 to 2 cents per kg, the pellets would cost 5 to 7 US cents per kg.
- Those who cannot afford to buy the fuel can be provided using state subsidies or cross subsidizing the cost.
- Microfinance and other strategies also can be used.

Thus, new technology solutions based on scientific principles are currently available for commercial implementation.

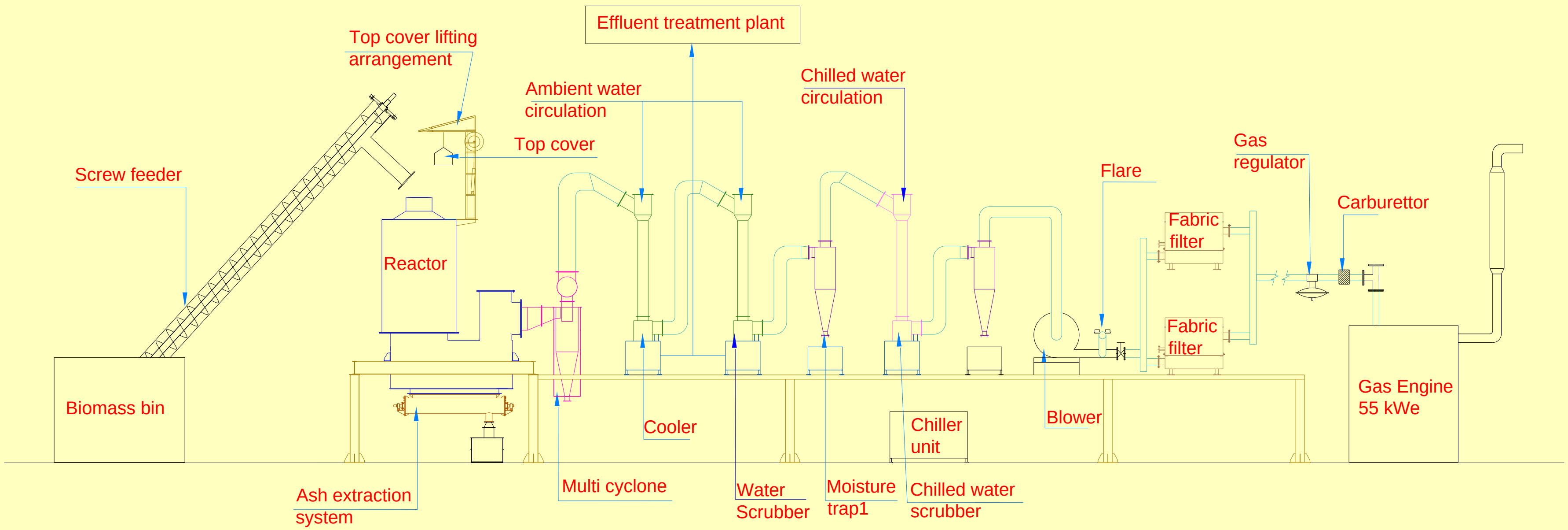
We now move to electricity generation at small power levels ~ 10 to 1000 kWe

The gasification technologies

There are several gasification technologies at small power. Very few of these have been tested in a commercial mode.

The two technologies that have had intense commercial testing in India are the closed top design and the open top re-burn design (of IISc). This unique design has undergone severe third party evaluation in Europe with one plant completing more than 5000 operating hours in one year

Open Top downdraft re-burn Gasifier (IISc design) for electricity



In the final design that you see, nearly all the WW II design concepts (closed top design) were tried and most of it abandoned in favor of new ones (staged air supply, screw ash extraction, chiller for final dust removal and drying the gas and a very high quality filter).

Open Top downdraft re-burn Gasifier (IISc design) for electricity

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

Generation of activated carbon with surface area of 450 to 550 m^2/g in the bottom section (450 – 550 °C)

Cooling and cleaning train to get dry gas at (P + T) < 1 ppm

Gas composition: 20 % each of CO and H_2, ~ 1 % CH_4, 10 % CO_2 and rest N_2

(Note that CO burns slowly, H_2 burns very fast)

…Its characteristics…

- System can run on 24 x 7 basis for > 7000 hours/year.
- It takes ~ 1 kg/kWh of sundry biomass of < 2 % ash (for instance coconut shell and wood have < 1 % ash, rice husk 20 % ash). This means one needs ~7000 t dry biomass at 1 MWe level
- Package costs ~2000 USD/kWe at ~ 1 MWe and costs 2500 USD/kWe at 100 kWe
- The O & M costs are Rs. 2 US cents at 1 MWe and 3 US cents at 100 kWe if the plant is operated for > 6000 hours
- These are data from plants installed and run ~ 50 electrical systems from 20 kWe to 1500 kWe

The Biomass gasification technology variants

Technology	Output	Capacity	No. systems
Biomass gasification Input: Solid biomass and air Output: producer gas and charcoal	Producer gas for heat, charcoal (~5%)	10 to 1000 kg/h	~ 100, 1 to 1500 kg/h + 25 kW to 5 MWe
	producer gas for electricity	10 to 1000 kWe	
	charcoal (~33%) and heat	~ 700 kg/h	1
H_2S removal from biogas (digester gas)	Sweetened gas and Sulfur and electricity	10 to 5000 m^3/h	4
Precipitated silica from rice husk ash	Precipitated Silica of various grades	1 to 10 t/day	Pilot plant
Gasification based combustion devices	Industrial heat	5 to 10 kg/h	15
	Domestic heat	1 kg/h	400,000


1KgPH DINJAM PLANT

Investment ~ 1.3 million USD/MWe

Fuel cost : 3 to 4 cents/kWh,
O & M ~2 cents/kWh

Cost of energy ~ 5 to 6 US cents/kWh without factoring finance costs

System cost~ 3000 USD/kWe


BMC GASIFIER PLANT(1700Kgph)