Low cost, high efficiency biofuel-to-electricity, past and future

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Abstract

Biofuel-to-electricity through gasification technology has reached a stage where the performance of a 1 MWe and a number of lower capacity plants is comparable to conventional steam power generation systems, with much higher efficiency. Stage is set for Independent power producers to develop projects through understanding of the issues involved. Every body concerned has something to gain. The investors gain return on investments. Project developers have a new hunting ground that is green. Waste land development authorities as well as authorities responsible for greening the country by leasing out land to developers to develop multi-purpose plantations that provide fuel for electricity and other societal needs for the less privileged part of the society in a net-return on investment mode. Reciprocating engine manufacturers in selling new type of engines that can burn producer gas with the promise of lowest cost power generation under the control of an individual or a group. Electrical utility companies have ways of shedding “unprofitable” loads by *partnering* with these developments that can deal with agricultural pumping with local arrangements for managing fuel, electricity generation and utilization with grid treated as a back up. Politicians by realizing the promises of new routes of reliable electricity for the farming community with more jobs created per MWh generated. The local and central governments positioning themselves as favoring GHG neutral technologies in international fora apart from substantial economic benefits due to the availability of electricity on demand for the needy and greater rural job creation that may help reduced urbanization.

Introduction

The needed IT/BT to ET/IT/BT transformation

In the recent past, much enthusiasm and euphoria have been created with regard to information technology and biotechnology. They are considered harbingers of new age economic transformation and as providers of enhanced national self-esteem. It is conceived that they should reach the rural millions and benefits obtained from the availability of instant information on markets, weather and all that would make agricultural operations to graduate to agricultural industry. It is quietly forgotten by nearly all concerned that unless electricity is made available in a reliable manner, the benefits of the new technologies cannot be reaped. This statement may be considered motivated and biased. But hardly has any conference on IT /BT or the statement by their worshipped leaders brings out the picture in this light. From this has arisen the paradigm that societal progress will need "ET/IT/BT" frame work with ET representing Energy Technologies and these in a way are as recent in development as IT and BT. Sooner the society realizes this situation, better would it be to ensure that development will occur with much less pain.

The New technology vs. Old technology or Gasification vs. Combustion

Gasification route is somewhat more recent and less known. Combustion route is much better known for a long time technically and commercially. Essentially, the gasification converts solid fuel into a gaseous fuel through a process of high temperature *oxidation-reduction* reactions, but the combustion process converts solid fuel into gaseous products of combustion through high temperature *oxidation* reactions. One can think of gasification as packaging the heat into chemical bonds by converting the energy into those in gaseous fuels. Combustion releases the energy into high temperature product gas.

The product of gasification is a fuel. It can be further used for combustion purposes (or others like fuel cell, methanol production etc). Compared to direct combustion process, gasification route to combustion can be interpreted as a two stage combustion process. The gasification process also termed thermo-chemical conversion process leads to a gas called producer gas with typical composition of 20 % CO, 20 % H_2, 2 % CH_4, 12% CO_2, and rest nitrogen. This gas is brought to ambient temperature and can be transported over economically meaningful distances of 50 to 100 m for being used in one location or several locations. In contrast, when combustion process is performed, the hot gases consisting of CO_2 and H_2O along with some fraction of emissions that need to be controlled or treated will need to be used locally.

It is possible that even producer gas needs to be treated for difficult fuels like used wood, for instance. The throughput of the gas to be treated is less than half the throughput of a combustion process for treatment purposes. This will make it a more economical proposition for treatment purposes. Gaseous fuel combustion process can be managed for high environmental compatibility through minimizing undesired emissions. For achieving these, two stage combustion processes are adopted (even for gaseous fuels). If a two-stage combustion process is adopted for biomass based gaseous fuel, it implies that we have a three-stage biomass–to–heat/electricity conversion process. Such conversion processes promise the ability to fulfill even extreme demands of environmental compatibility using renewable biofuels at reasonable costs.

It is conventionally understood that combustion – steam power generation process is economical for large power levels, typically in excess of 3 MWe. The cost per MWe installed is about 0.7 to 0.9 million USD. The actual performance shows a fuel-to-electricity efficiency of ~ 30 %. But then even a **200 MWe** steam power generation systems deliver fuel-electricity efficiency of 35 % (using coal with higher calorific value). The primary reason for this feature is that while the flame temperatures from combustion of fuels is about 1400 to 1600 °C, it is transferred to a working fluid, namely steam, with operating temperatures of 600 to 800 °C and hence the thermodynamic conversion efficiencies will be limited.

If, on the other hand, one uses the high temperatures of combustion directly as will happen in reciprocating internal combustion engines or continuous internal combustion based gas turbine engines, one can derive higher efficiencies in open cycle mode. For instance, reciprocating engines of 1 MWe capacity using biogas (75 % CH_4 and rest CO_2) give conversion efficiencies of 36 to 40 % on an open cycle basis. There is still heat at 350 – 400 C to be captured by using waste heat boilers.

Realized performance in rigorous tests have shown that through the gasification route with the gas used in a gas engine, a gas engine has given an efficiency of 24 % at an output of 58 kWe (from wood chips-to-electricity). In a field dual-fuel installation (using light diesel oil and biomass) of 1 MWe capacity, overall conversion efficiencies of 30 % have been clocked at delivered loads of 750 kWe. The efficiency will reach 35 % when the system is run at full load. Use of internal combustion engines, thus promise achieving of efficiencies of the order of 40 % (from biomass – to- electricity) even on open cycle at power levels of 1 to 3 MWe.

One can add at large gasification based power generation systems ~ 5 MWe, a downstream steam power generation segment that can generate additional 2 MWe of steam power taking the overall conversion efficiencies of 43 to 45 %, making the system an IGCC (integrated gasification combined cycle) with investment costs of the order of 1.2 to 1.4 million dollars per MWe. The crucial benefit of the above package is that it can be achieved today with no risk – just employing modules of the existing 1 MWe class systems or a combination of a few gasifiers providing gas to a single larger size dual-fuel or gas engines of 2.5 or 3.5 MWe ; it is the perceived risk that needs to be managed by putting up a demonstration system. In doing all these, the emissions – (a) gaseous – NOx, CO, HC, and SOx can be shown to meet international norms, (b) liquid effluents

– can be treated by water treatment processes that are standard and the disposal of the sludge meeting international norms and (c) solid residues – like ash and char used for landfill after further treatment that would be not be necessary in most cases.

In summary, classical combustion technology with steam power generation is a subset of the multi-stage process with moderate biomass-to-electricity conversion efficiency and either limited interventional capabilities at reasonable cost or expensive interventional capabilities for emissions. Gasification technology is multistage combustion process with high conversion efficiency (from biomass – to – electricity) and moderate costs from very low power levels ~ tens of kilowatts to several megawatts in which one derives the benefit of eliminating the undesirables at several stages between the staring point and the end point using the currently available technologies for a variety of intermediate interventions. In short it is the equivalent of Clean Coal Technology – it is **Clean Biomass Technology.**

The Technology Basis

The biofuel gasification technology has had long history; almost all of it has been concerned with clean wood wastes, from forest operations or residues. The technology using closed top throat based idea was developed in response to the shortage of fossil fuels during the World War II. Shortly after the war, Germany had a large number of fabricators who developed various versions of gasifiers and marketed them with no guarantees on performance and negligible maintenance support generating a bad name for the technology. Coupled with this and the free availability of fossil fuels, interest in the biofuel based power generation system in Europe and other countries has waned and the subject is considered for research support without much expectation of societally meaningful results. Occasional developments from enthusiasts have hit headlines of newspapers but no substantive foundation of scientific development seems to have been created.

India has had the benefit with the Ministry of Non-conventional Energy Sources (MNES) taking interest in providing financial support for well conceived efforts on research, development, demonstration and dissemination. Much of what is seen today is directly attributable to the governmental support. Consequent upon the two decade program attendant with minor hiccups and human drama, other countries can look upon India as a leader in this field. While one technological route of closed top gasification system is used by several manufacturers of gasification systems, and is considered adequate for woody biomass used in a certain size range, it is very fuel specific. However, a new route of open top downdraft reburn gasification system developed at the Indian

Institute of Science promises to be tolerant to a whole range of biomass with high ash content. This implies that many agricultural residues that are currently poorly used or wasted can be utilized in a single gasification system. Appendix I provides a comparative statement of the closed top and the IISc class technology. Much of the scientific details can be found in the work published from the laboratory and they can be accessed at its web address: http://cgpl.iisc.ernet.in.

What will be outlined presently are the steps taken to put the whole technology on a proper foundation. Though the technological rudiments had been put together in 1985-86, it was only in 1994 that opportunity got provided to demonstrate the capability of the new design. An international team of experts at IISc and in Switzerland along with Dr. Sharan of DASAG, Switzerland were involved in a rigorous joint testing of the system at IISc. After ten tests of 8 to 10 hour duration were found successful, a system was required to be installed in Switzerland and similar tests were gone through. These cover a wide range of fuels – Causarina wood chips, European Pine, Eucalyptus wood chips, and briquettes of Restholz (Furniture industry waste, Rice husk briquettes, Briquettes of Sawdust and Grass). After a joint review of the results, they have been published and examined by a large number of experts in India and overseas. This testing of the system has taken place at 100 and 500 kWe levels. At power levels of 500 kWe, no gasifier in the world has been tested, certainly not with the rigor applied in these tests and this is unique to IISc system. Results of these tests have shown extraordinary performance of the gasifier with gas calorific value at 5.2 MJ/m^3, and the reasons for this performance have been related to the open top downdraft re-burn concept. It is the application of a scientific approach of documentation of well researched output that has caused the skeptics of gasification technology of the earlier generation to accept the new technology.

Field Performance of systems.

Field systems have been built from 1987 onwards. About four hundred gasifier based dual-fuel operating mechanical power generation systems for water pumping applications and electrical systems at 20 kWe (6), 50 kWe (2), 80 kWe, (8) 500 kWe (1) and 1000 kWe (1) totally to eighteen. Three of the 20 kWe systems have been installed in Chile and Brazil. Thermal systems at 200 kg/hr (1), 300 kg/hr (2) , 500 kg/hr (1) have been functional from the last 3 to 4 years. Research systems include a 1 kg/hr system as well. Most systems have functioned on demand, some times at 90 % availability and other times 70 % availability. There were several operational problems and some design issues as well that were uncovered during this period and incorporated into the design of the systems. In some cases, some of the developments that occurred later were incorporated into earlier systems. When the development made a qualitative difference to the performance and added perceivably to the cost, it was offered separately at cost.

The systems have been developing continuously and with feed back from field operations. The major inputs into the technology in the first few years were that the point performance of the gasification systems was excellent. Even not-too-well trained farmers were able to extract 75 % diesel replacement and that the performance was consistent. This brought considerable confidence in the conceptual framework that was very different from the existing design. Biomass processing to small size chips demanded by the designers was considered difficult to comply with and this needed thinking of biomass processing strategies. The life of stainless steel reactors was no more than 1200 hours. This led to the development of hybrid reactor system with bottom section made of ceramic inner segment with a mild steel shell cover and a top twin stain- less steel shell. Larger systems did not need the hybrid construction. The entire shell was made of mild steel outer shell inside which is set ceramic system to take care of high temperature and oxidizing-reducing environments. The ceramic shell arrangement itself has undergone metamorphosis over a period of time. Low Alumina bricks/tiles were found to react with the low ash fusing material leading to lumps. This demanded the choice of high alumina bricks. The water pumping systems operated no more than 700 hours a season (and year). The village electrification systems did not need to work beyond 2000 hours an year and only four to six hours a day. The marigold flower drying systems need to work round the clock for about 4000 to 5000 hours an year. The electricity generation systems for an industry that works one or one-and a half shift needed to run only for 3000 hours an year. The thermal system for heat treatment application and grid linked power generation systems could be expected to demand 7000 to 8000 operating hours an year.

Thermal systems have performed 900 hours continuously with stoppage demanded by the process and not the gasification process. They have clocked 6700 hours an year. Electrical systems have performed 100 hours continuously, the limits arising from grid failure or need to pay attention to the process other than electricity generation. Hence continuous running with coconut shells, woody biomass or good briquettes can be considered established. It is the periodic start and stop on a daily basis that is clearly more difficult to handle. There are good reasons for this. The biomass, even if dry has still bound moisture and more often free moisture of 8 to 12 %, if sundry biomass is used. When the system is stopped for twelve to fourteen hours a day, some of the moisture would move to the top, some of the volatiles would deposit on the cooler parts of the reactor holding the biomass near the wall nearly rigidly to the wall. The next day's operations will have material movement problems because of the binding of the biomass to the walls. One would need to do poking, something that may have subsidiary undesirable effects of additional packing of the char towards the bottom of the reactor and consequent increased pressure drops, etc. If one is accustomed to seeing small power generation systems in operation, one would permanently have discouraging impressions of the technology. It is in this context that it is important to build professional MWe class systems to showcase the true potentialities of the technology; smaller systems may be built and used profitably. But it should be understood that the economic benefit will also imply additional issues of biomass feed management in the case of non-continuously operating power generation systems.

Techno-economic features

In terms of technical performance, field data over thousands of hours suggest that (a) in the case of thermal systems, every litre of diesel is replaced by 3.4 ± 0.1 kg of coconut shells/woody biomass, (b) in the case of dual fuel operating systems at 100 kWe level, 1 litre of diesel generates 2.8 to 3 kWe in diesel mode and 14 to 18 kWh in dual-fuel mode with the consumption of 1 kg/kWh of biomass, and (c) in the case of dual fuel operating high power engines, one generates 4 kWh per litre diesel in diesel/LDO mode and 14 to 16 kWh per litre in dual-fuel mode with the consumption of 0.65 to 0.75 kg/kWh of biomass. This would amount to a fuel-to-electricity conversion efficiency of 28 to 29 %, and (d) in the case of gas engines, one generates 1 kWh per kg biomass at 100 kWe level and can expect to generate 1.1 to 1.3 kWh per kg biomass at 250 kWe level. These amount to fuel costs of electricity generated at (i) Rs. 2.2 to 2.5 per kWh for dual fuel operation of which 50 % of the cost is from the small amount of diesel/LDO and (ii) Rs. 1.00 to 1.50 in the case of gas engines. If one adds Rs. 0.50 to 0.75 per kWh as the operation and maintenance cost and 0.60 to 0.80 as the cost of finance, one gets the cost of power generation at Rs. 3.30 to 3.80 per kWh for dual fuel mode engines and Rs. 2.30 to 2.80 per kWh for gas engines operations.

Operational issues

The crucial point on which problems have been faced in operating gasifiers is the quality of biomass – moisture content, ash content and size. If the biomass transported by an uncovered truck passed through a heavy rain arrives at the gasifier based power station and the operator loads this material because dry material was exhausted the day earlier, the results would be worse than not operating the system for day or two. Tar would surely be the significant product of gasification and it would deposit in unwanted places, cleaning which would take time. If one would allow mud and grit to get into the reactor without the elementary procedures to separate them from the biomass, surely, there would be lumps of ash, fragile and not-so-fragile trying to form even larger lumps choking the reactor and reducing the performance significantly. Subsequent operations to get rid of the unwanted material could be so clumsy that one would need to have discipline not to introduce mud and grit into the reactor. If fine chips of biomass instead of coarse chips were used, again one would wish that the gasifier was not operated. The simple rule of thumb is that if one keeps in mind that even gasifiers need to be given "clean fuels" like other automotive engines for them to function, one will have no problems in operating gasifiers.

Limits to growth

a. Technical

The learning gained from laboratory studies, tests, field installations amounting to eight thousand hours equivalent of experience with a single installation clocking more than 12000 hours, the body of knowledge acquired now is adequate to install 1 MWe class power stations or 1000 kg/hr thermal gasifiers. One area that needs to be addressed is biomass processing. While briquetting machines are generally available for fine biomass, large scale chippers at throughputs of a few tonnes per hour for producing larger size chips rather than flakes are not known in the market. Also, briquetting machines may be inadequate in terms of life of the die and the economics of operation, but they are available in the market; however, the adaptation of chippers to produce larger size chips has not been addressed at all. This could prove to be a limiting condition in large projects.

b. Biomass availability

This is an area where all concerned believe they have clear understanding. In reality most are highly opinionated. Some who think that there is no excess biomass in the society with industries using them extensively; others who see mounds of waste biomass in a few places are gung-ho that so much biomass is available for power generation. Neither of the extremes is right. There are two sources for biomass – agricultural and plantation residues. Estimates made of agricultural residues by several means including detailed (production – utilization) has led to values of 16000 ± 2000 MWe from agricultural residues excluding sugarcane based residues. District-wise details are available for all the states in India. Two major agricultural residues are sugarcane and rice based – bagasse, cane tops/leaves/trash and rice husk. Bagasse is a captive fuel and used at 50 % moisture content with boilers of relatively low pressure (~ 40 ata) with inevitable performance limitations. One limitation – of low pressure boiler – is being overcome by encouraging the use of high pressure boilers (~ 62/85/105 ata) through the MNES program of sugar cogeneration with moderate success till date. The other limitation of the use of wet bagasse can be overcome through the development of suitable driers using the exhaust heat going through the chimney. Interestingly, this issue is not new and many brave efforts without adequate thinking have gone on in the country with a negative state of mind at present. More serious demonstration is required before it is considered applicable. Limited efforts are currently underway at CGPL, IISc.

Rice husk is another well know fuel considered abundantly available and also used extensively, till recently at low end use efficiencies and in recent times at reasonable efficiencies in high pressure boilers at power levels of 3 to 6 MWe. Acquisition of the rice husk at huge quantities (at 10000 -12000 tonnes per MWe per year) involving traders with advance payments or payments against delivery with short term contracts or long term ones is beset with hazards along any of the options. In the midst of all this, there are small producers of rice husk who have no difficulty in selling rice husk at 1000 to 1800 Rs. per tonne also talking about putting up small power plants ~ 100 to 200 kWe using rice husk as a fuel. Most gasifiers other than of IISc design have two classes – one for wood chips and another for rice husk alone – the Chinese design – of open top design (without a second air-entry or in other words, no reburn concept). If the investor sets up a small power generation system with rice husk gasifier assuming a cost of fuel at 500 to 800 Rs. per tonne as may be prevalent at one point of time, a few months or an year later, the rice husk demanded by an investor of a 3 - 6 MWe power station nearby who will naturally turn out to be more demanding and powerful might upset the price by more than 50 % of the prevalent value and under these circumstances, the original investor may find it profitable to sell the rice husk at 1200 to 1500 per tonne rather than run a 200 kWe power station using the costly fuel. Further, since the gasifier is specific to rice husk, it cannot be used for any other biofuel that may be available cheaper than rice husk. Under these circumstances, the investment on the small power station will not bring in any returns and the unit may need to be closed. This scenario is not an imaginary one and indeed has happened in the case of rice husk gasifiers in several states in the country. There are two answers to these problems. Firstly, no investor should think of only one fuel for the purpose of power generation. Gasifiers that can operate on multi-fuels should be chosen for power generation. And one should avoid rice husk as a fuel of choice since alternate technologies or uses will draw away the fuel. In the case of other agricultural residues, somewhat of a similar strategy in the choice of the technology is vital – a gasification system that can accept a variety of fuels (and the IISc design has qualified itself for a range of fuels including urban solid waste with ash content less than 30 %).

Plantation residues have not been paid attention they deserve. It is to be recognized that the waste land in the country amounts to 60 to 100 million Hectares as estimated in several studies. One Hectare of land when developed well can generate 15 to 20 tonnes (dry) of solid biomass, and handled poorly will generate 4 to 6 tonnes (dry) of biomass. This amounts to 300 to 1500 million tonnes of solid biomass availability. Simple energy calculations at 8000 tonnes per MWe operating for 8000 hours a year, yield an energy potential of 40000 to 180,000 MWe capacity. These are surely mind boggling and even if we achieve 10 % of these values, they amount to very significant values of 4000 to 18000 MWe. Hence, there is urgent need to realize this potential and set up national strategies to use the waste land to grow biomass for electricity generation. There is a further question of what biomass to grow. Biomass grown in plantations fetches market prices of Rs. 800 to 1200 per tonne and hence every hectare will yield revenues of no more than Rs. 5000 to 24000 depending on the output. Getting higher levels of output will mean greater expenditure on the plantation care and nutrients. Hence the net output may range between Rs. 4000 to 15000 per hectare. One can enhance the monetary output of the plantation by choosing what should be grown. By a suitable mix of horticulture, non-edible oil bearing trees and other solid bearing stock, it is possible to extract multiple outputs from the land – oil, fruit and wastes (for instance, coconut tree yields 100 nuts and an equivalent of 10 tonnes per hectare per year of wastes in the form of fronds, coconut shells, and fibre bearing outer skin). By using these strategies, it is possible to enthuse industrialists to green the land over a period of time and allow them to reap the benefits for a lease period of 30 to 50 years or an appropriate meaningful period.

c. Partnership with State Electricity boards?

No development of value to society can take place unless and until all relevant segments take partnership role. State electricity boards over the last two decades have taken a defensive position or more appropriately, have been forced to take defensive position. They have become the tools to achieve the political ambitions of the state governments. They have not been given the freedom to position themselves as fair-profit centers. The state governments want to provide "free" electricity to farmers even though what is required to be provided is adequate electricity at what is clear to all as a reasonable tariff. Because of continuous political patronage to an admittedly wrong thinking (as nothing is "free" and somebody has to pay for it) by all the political parties, and *not taking on the burden of the decision on its own*, but passing it on to the electricity boards, the governance has ruined the ethical foundation of the functioning of the electricity utilities as fair-profit centers. Knowing that the foundations are being wrecked by the governance itself, many in-house practices have crept into the system to an extent that normal functioning is a far cry from reality. To cite an example, one state electricity board pumped into the grid in one year 69 billion kWh, but billed about 23 billion kWh. How could the revenue from this meet the cost of generation and other expenditure at all? Unfortunately, the recovery path is very painful for all concerned.

The fact that "free" electricity has always implied in reality "bad" electricity in terms of quality – voltage and frequency – that too, provided at the will of the board, when not really required, has led to serious backlash in the whole electricity supply system. This pathetic societal situation can be converted into a benefit if the boards accept distributed power generation as a part of their thinking as well and promote it for the benefit of the supply of good quality electricity locally, with local fuel, operation, maintenance and management. It can help by allowing grid power to flow in as a back-up system. This is possible since the cost of electricity from biofuels locally available using gas engines works out to Rs. 2.30 to 2.80 as discussed already. Investment at Rs. 3.5 crores per MWe even at small scales can be supported by the state electricity board /government/financial institutions like NABARD as loans at subsidized interest rates.

d. Awareness

It must be stated the awareness of administrators, financial institutions, industrialists and others who matter is abysmally low for the new technology intervention that can make a new life structure possible. In many instances, the problem is one of A vs. B rather than A with B. As time is progressing with spiraling rates of fossil fuel, the companies involved in fossil fuel generation and distribution must not treat these fuels as competitors as they are likely to think under the normal mode of thinking in trading. They must partner the development in a 20 year scale by which time they should be able to use at least 50 % from renewables as the pressures for economic industrial operations mount even more seriously than what they are today.

The Win-win-win-win (Win^4) situation?

The farmer in a village has wished that Government take care of all his/her needs particularly in terms of promised "free" electricity. When this fails him at a crucial time when prayed-for rains have failed, respectability at repaying loans and inability to do this because of crop failure, have resulted in suicides in several states. Even the free electricity is not free. Because on occasions, the voltage has been very low, the burn-up of the motor winding has resulted in repair costs which when added up would reveal that it was better to rely on paid electricity with a degree of commitment to service the need rather than free electricity. Instead of shying away from this situation, it should be possible to construct a meaningful partnership when the state will provide through any of the routes finances – small in magnitude to set up a local biomass based power package that could be used in shared mode between a group of farmers – since each man does not need more than a few hours of pumping. Because water will be available on demand, the farmer can choose the crop of his choice that may need water, grow the crop and make money. The state electricity board may bless this venture by assuring stand-by electricity. Since the land output goes up by a factor of 2.5 to 3.5 with the assured supply of water, the net revenue will enhance the buying capacity of the farmer and in just a few years, the farmer may improve his economic situation to an extent that his self-esteem will be no less that the neighboring "rich" farmer. Because, the electricity board has saved on the supply of electricity to this segment, it can use it to supply to the better paying industrial client. Since the pressures from one community will decrease by this arrangement, the Electricity board and the Government must feel better in having met their professed objectives better. This is the case of not just win-win situation. All the partners – Farmers, Industrialists, Electricity boards and the state governments get included in the Win^4 situation.

Closure

This paper has brought out several aspects – technical and economic – on a new route to realizing power from biofuels. It has asserted that the technology is ready for being capitalized and methods of achieving would require awareness on the part of all the partners, construction of several low risk societally meaningful projects for the large group of investors to take the necessary initiatives.

Appendix includes a few pictures of systems that have worked in industrially meaningful manner over the last two years.

Appendix I

The Comparison of IISc Open Top Gasification System with Others

1. All gasification systems in the world at power levels of 1 MWe and below are fixed bed systems. Several R & D efforts in India and abroad on Fluid bed systems at these or lower power levels have shown severe tar problems. Fluidised bed systems generally produce so much of tar (typically, the tar in a fixed bed downdraft reactor is between 100 to 1000 ppm. In a fluid bed system it is 5000 to 20000 ppm. The ratio is 50 to 200 compared to fixed bed systems) that at these power levels, the tar cleanup becomes a major issue for application involving electricity generation. This is why fluid bed systems, bubbling or circulating variety are applied at large power levels – 5 MWe upwards with separate Dolomite or other tar cracking systems. In a recent assessment the builders (TPS) of the ARBRE in UK using atmospheric pressure circulating fluid bed systems voiced a concern that the power level they were working with was at the lower fringe of economic investment. Hence, there is no economic and

technically sound alternative to fixed bed gasification systems at power levels of a MWe or lower.

2. Most developers/manufacturers of Fixed bed gasifiers have adopted closed top designs using MS as outer wall and the reactor also acting as a storage bin. They are all based on World War II class designs.
3. The IISc design is the only open top twin air entry system in the world for solid biofuels. It is also called open top downdraft reburn gasifier. The system design allows for the use of a wide range of fuels – agro-residues with wide range of ash content, solid urban waste, all of them briquetted so that they are physically like woody biomass. The reactors for rice husk from China and adopted by other manufacturers noted above are also open top designs. But they are not twin air entry. The Chinese designs use rice husk in as-received condition leading to poor solid conversion and larger tar and hence extensive cleaning system. The twin air entry system is crucial to good solid conversion and good quality gas (CO ~ 24 %, H_2~18%, CH_4~1.5 %, rest CO_2 and N_2).
4. The advantages of open top twin air entry system are (a) low tar fraction in the gas at a wide variety of loads demanded of the gasification system, (b) gas quality which permits diesel replacement in diesel engines up to 85 % in non-turbo-supercharged engines, whereas even according to the best claims of closed top WW II class designs in our country the maximum diesel replacement is 70 %.
5. The IISc design has a ceramic shell in the most critical zone and thus promises much higher life compared to other systems. Even in other chemically or thermally affected zones specific coatings are provided to prevent corrosion.

Appendix II

Photographs of a few working gasification systems

The 1 MWe grid linked gasification based power package at M/S Arashi Hitech Biopower limited, Coimbatore.

A 500 kg/hr thermal gasification system for drying of Marigold flowers at Harihar. It has worked 24 hours a day, 600 hours per month, eight months in an year

A 75 kWe gasification system at an National Institute of Engineering, Mysore; It is used for cheaper power generation for the college, education, training and experimental research

A 20 kWe gasifier for rural electrification at Hanumanthanagar. It is a companion system for the system at Hosahalli. They are used for house illumination, drinking water supply and supply of irrigation water, and operating the hulling machine