Biomass Gasification for Rural Electrification: Prospects and Challenges

Sangeeta Kohli and M.R. Ravi

Department of Mechanical Engineering
Indian Institute of Technology, Hauz Khas, New Delhi 110 016

Abstract

In the development of rural India, employment generation is the most fundamental issue to be addressed, which, in today's context, is very closely connected to the power supply to villages. Decentralised power supply is being increasingly recognised as having much greater potential for supplying quality power to the remote areas as compared to the conventional centralised supply. Biomass gasification has emerged as a very promising technology for decentralised power generation and hence must be utilised for rural electrification to its full potential. In this paper, an effort has been made to draw attention to the suitability of this technology for power supply to villages and also to the challenges which must be addressed for effective use of the technology for this purpose. Many issues which need careful consideration, like resource and demand assessment, various aspects of plant management, economics and the government policies have been discussed. Many of these are pertaining to field situations and hence pose considerable challenge for effective handling. The paper is directed towards a wide class of readership – from those responsible for rural electrification including policy makers and implementers, who may need to know even the basics of the technology to those familiar with technology but with little or no experience in field implementation. It is hoped that such a paper will provide the concerned people with adequate exposure to the complexities associated with rural electrification using biomass gasification and hence help in its more effective implementation.

Keywords

Biomass Gasification, Rural Electrification, Decentralised Power, Renewable Energy Technologies

Introduction

One just needs to drive about 50 km away from Lucknow on the highway towards Shahjahanabad. Pockets of the highway are glittering with well-lit hoardings showing no shortage of power. If one turns away from the highway a few kilometres into one of the interior villages of Hardoi district, the darkness all around creates a glaring contrast. There is not even an electricity pole there. Only days around the full moon have the advantage of some brightness in the otherwise dark nights. This is one of the more than 95,000 villages, which are not electrified even on paper [1]. On one hand, the Mission-2012 of the Rural Electrification Corporation Ltd. of the Ministry of Power envisages "electricity to every household of the nation" by year 2012 [2], and on the other hand, the supply situation struggles to cope with increasing demand. According to Census of India carried out in 2001, only 43.5% of the rural households have electricity connections [3]. While the per capita commercial energy consumption of India was around 5.6 GJ per year in 1997, far behind the figure of about 94.6 GJ per year for USA and a world

average of around 19 GJ per year [4], the corresponding figure for Indian villages would be far lower than even the national average.

While this scenario is indicative of the growing inequity in the society, the large discrepancy in the power availability to the urban and the rural sector is also, in turn, adding to this widening gap. Any attempt at employment generation to develop the rural sector needs a sincere parallel attempt to increase the power supply to this sector. The decentralized mode of power generation is yet to get the attention it deserves. If the realization of the Gandhian vision of self-sufficient village republics had been planned for, the need for grid connection to the remote areas would not have arisen. The problems of centralization in every sector are being recognized even by the United Nations Organization [5], and power sector is not free from them either. The need for empowerment of the rural masses is closely connected to the satisfaction of their basic needs of employment, which in turn has direct dependence on power availability in today's context. A decentralized model of development [6] simultaneously needs development of decentralized power generation systems catering to the rural needs.

Status of Rural Electrification in India

The installed electricity generation capacity of the country has increased from 1362 MWe at the time of independence to over 100000 MWe. From only 21,700 electrified villages in 1961, the number of villages electrified increased to 5,07,451 in 2001. Out of the total number of 587258 villages as per the 1991 census of India, the number of electrified villages was reported to be about 4.97 lakhs in 1991, 5.08 lakhs in 2002 and about 4.95 lakhs in 2003 [1]. The fluctuation in this number is attributed to the change in the definition of an "electrified village" according to the Ministry of Power [7]. Prior to 1997, *a village will be deemed to be electrified if electricity is used within the revenue boundary of the village for any purpose whatsoever.* This definition was revised in October 1997 to: *a village will be deemed to be electrified if electricity is used in the inhabited locality within the revenue boundary of the village for any purpose whatsoever.* However, states have taken their time in revising the data as per the new definition, and even today, many states are yet to do so. As and when a state revised its data, the total number of electrified villages decreased, showing the fluctuating trend mentioned above. While the Gokak Report on Distributed Generation [7] puts the number of un-electrified villages at 78240 as in 2001, it adds that there are a number of villages which have hamlets at a distance of about 1-3 km from the main village, with populations of 50-200, which are not officially listed as villages, and are not electrified. According to the India-2004 report [1], this number has gone above 95000 in 2003, and it is highly likely that the actual number of villages yet to be electrified is over one lakh.

Out of these, 18000 villages have been declared remote and inaccessible, with reference to connection to the grid. The electrification of these villages has been taken up by the Ministry of Non-Conventional Energy Sources (MNES) [8]. MNES has revised the definition of an electrified village as follows: *A remote village or remote hamlet will be deemed to be electrified if at least 10% of the households are provided with lighting facility. In addition, energy may also be provided for community facilities, pumping for*

drinking water supply or irrigation, as well as for economic and income generating activities in the village. [9]. The Rural Electrification Corporation Ltd. (REC) has been entrusted with the task of electrifying all the remaining villages by 2007, by providing financial assistance to State Electricity Boards (SEBs), State Power Corporations, Electricity Departments of the State Governments and Rural Electric Cooperatives. In fact, the rural electrification programme has been at a low key in the recent past with the number of additional villages electrified dropping from about 100000 in the 7th plan period to 18500 in the 8th plan period and less than 10000 in the 9th plan period. This was primarily due to the financial difficulties of the state electricity boards, which were increasingly reluctant to move to rural areas because of high costs and low returns [7]. With the renewed impetus given to rural electrification by the *Pradhan Mantri Gram Vidyut Yojana*, which allocated Rs. 10000 crores of Centrally Supported Schemes (CSS) over the 10th and 11th plan periods, to be routed through REC, it is expected that this trend could be reversed.

Extending grid connection to villages is not without problems as highlighted by the Gokak Committee Report [7]. The high costs of transmission lines and high percentage of transmission losses increase the capital and operational costs; high connected load results in voltage fluctuations of the grid and frequent power failures; ground water resources undergo fast depletion owing to the pricing subsidies given to farmers by SEBs; and increase in diesel pumpsets as backup units cost the nation dearly in terms of foreign exchange spent on oil imports. In view of all these problems, the Electricity Act of 2003 [10] states that the Central Government shall evolve a national policy in consultation with the State Governments to permit decentralized generation of power including using renewable resources, and its decentralized distribution. A national policy to this effect, though, is yet to be formulated. Even from the point of view of capital cost, decentrlised power generation can compare favourably with the grid power. According to an estimate by NETPRO Renewable Energy (India) Ltd., the cost of decentralized power through biomass gasification at about Rs 44 million per MW can be considerably lower than the cost of centralised grid supply at Rs 57 million per MW [11].

Thus, the decentralized energy technologies, which may appear to contribute very little to the national energy scenario, have to play the lead role for the large rural population of our country. Biomass has already been recognized as an ideal energy resource for the decentralized energy systems, due to its availability in the remotest of the locales. 86.1% of India's rural population is still dependent on biomass for its primary energy needs [3]. The estimated annual availability of agricultural residues is 515.1 million tonnes, while its usage at present is roughly 377.7 million tonnes [12]. In large parts of the country, the agricultural residues are burnt away in the field itself for the purpose of disposal as well as providing the mineral content for the fields.

The traditional technologies using biomass are grossly inefficient. There is, therefore, ample scope to utilize biomass more productively. The technologies of gasification through thermochemical route, biomethanation and destructive distillation are some of the alternative routes which are being increasingly accepted as the viable alternatives to the conventional energy technologies for the decentralized sector. While cellulosic

material with high moisture content is more suitable for biomethanation, biomass with higher lignin content and low moisture is more suited for thermochemical gasification. The two technologies are, therefore, largely complimentary.

Both biogas from biomethanation and producer gas from gasification could be used in internal combustion engines for motive power or electric power generation. Although biogas has a higher calorific value as compared to the producer gas, gasification has a distinct advantage for power generation: the rate of biomethanation is much slower than gasification and hence continuous power generation becomes difficult with the requirement of very large storage of biogas. On the other hand, there is no need for storage of producer gas: by proper system design, the capacity of the gasifier can be matched with the capacity of the engine. The on-line generation of gas, as per the requirements of the engine, makes the system more convenient and compact to use.

Biomass Gasification for Decentralized Power

Gasification Technology

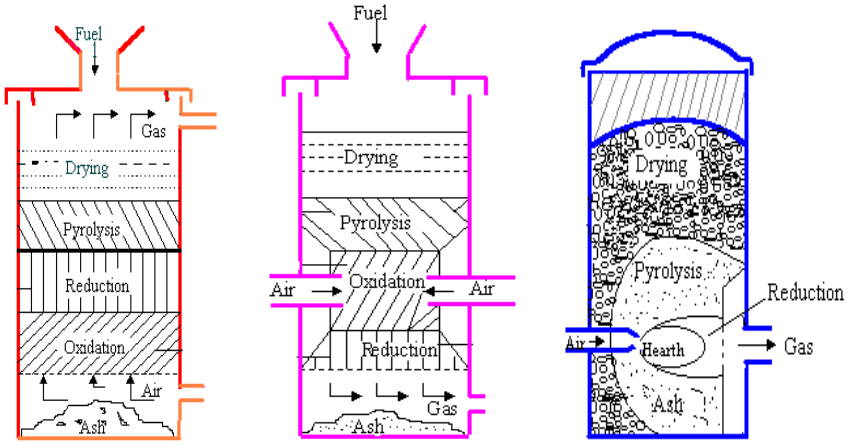
Biomass gasification involves the thermochemical conversion of the cellulose and lignin in biomass into a combustible gaseous mixture. In a reactor commonly referred to as the biomass gasifier, biomass undergoes drying, pyrolysis, oxidation and reduction reactions in a limited supply of air, to ultimately yield a mixture of combustible gases such as carbon monoxide, hydrogen and methane, and diluents such as carbon dioxide and nitrogen.

Drying takes place in those regions in the gasifier where the feedstock gets heated to temperatures of 100-160°C. The moisture so removed from the feedstock mixes with the air that is present in the drying zone of the gasifier. When the dried feedstock gets heated to temperatures in the range of 200-500°C, pyrolysis of the feedstock takes place, and the volatile combustible matter in the feedstock is released, leaving behind a residue, commonly called char. The volatiles contain non-condensible gases as well as condensible oils. At lower temperatures, the condensible matter becomes tar, a sticky material that adheres to solid surfaces. The volatile matter and part of the char burn in the oxidation zone, in the presence of oxygen in the reactor. In this process, since a limited air supply is provided to the reactor, all the oxygen gets consumed, and a reducing environment is created. In this reduction zone, the carbon dioxide and water vapour formed by the oxidation of volatiles and char get reduced by the remaining carbon in the char to carbon monoxide, hydrogen and some methane.

Types of gasifiers

On the basis of the flow direction of air/gas *vis-à-vis* biomass in a gasification reactor, the gasifiers are classified as updraught, downdraught and cross-draught gasifiers. In all these gasifiers, biomass flows downwards by gravity. If the flow of air and gas is upwards, resulting in a counter-flow configuration, it is an updraught gasifier. If the air/gas flow is also downwards, resulting in a co-current configuration, it is downdrught gasifier. In a cross-draught gasifier, the air/gas flow is horizontal, perpendicular to the flow direction of biomass. Figure 1 illustrates the above three types of gasifiers. Besides

these fixed bed gasification reactors, there are also fluidized bed gasifiers, which are more commonly used in larger output power ranges: while the fixed bed reactors are used from small 5kW units upwards to a few MW, the fluidized bed design is used in units of a few hundred kilowatts upwards. In this article, since we are concerned with village electrification applications, we shall confine our attention to fixed bed designs only.



Updraught Gasifier | Downdraught Gasifier | Cross-draught Gasifier

Figure 1. Types of Fixed-bed Gasifiers

Several designs have been developed for the gasification of woody biomass. On the other hand, the designs for using biomass such as sawdust, rice husk, dried leaves, and other such agricultural wastes in loose or powdery form are very few. More often than not, the designs using powdery biomass in fixed bed configuration run into difficulties owing to low bulk density, clogging and lack of free movement of the feedstock in the gasifier. Quite often, briquetting of this type of biomass has been recommended for use in gasifiers for woody biomass.

Gas composition and tar content

The composition of producer gas obtained from a gasifier depends on several widely varying factors: the chemical composition of the feedstock, its moisture and ash content, its size and density, the gasifier flow configuration, air inflow, temperature of the reaction zone, the turn-down of power level, etc. However, the standard composition of producer gas is usually quoted in terms of the range of the volumetric fractions of the constituent gases. Typically, producer gas contains 15-30% CO, 10-20% H_2, 2-4% CH_4, 5-15% CO_2, 6-8% H_2O and the remainder N_2. Besides these major constituents, the gas also contains tar, which is the result of incomplete oxidation of volatiles, and ash, picked up from the reaction zone by the flowing gas. The gas composition for a certain gasifier also varies from startup time until the temperature of the reaction zones in the gasifier stabilize to thier steady state values, after which time, the composition reaches a steady state. In fact, even during operation, variations in the airflow rates caused by clogging at grate or change in connected load can result in variation of gas composition.

Effect of gasifier configuration

Out of the different fixed bed gasifier configurations discussed above, the downdraught gasifiers have the potential for the best gas composition owing to their flow configuration: the co-current flow design demands that the biomass has the drying zone at the top, and passes through the pyrolysis, oxidation and reduction zones, in that order, and the gas also flows through the zones in the same order: this ensures that all the volatiles pass through the oxidation zone, thereby ensuring that a larger fraction of volatiles get oxidized. Even the unoxidized portion of the volatiles get cracked into lower hydrocarbon compounds at the high temperatures encountered in the oxidation and reduction zones. This results in low tar content of the producer gas generated in downdraught gasifiers. In addition, since all the products of oxidation pass over the reduction zone, there is a better contact between the char bed and the products of oxidation, ensuring that a larger fraction of CO_2 and H_2O get reduced to CO, H_2 and CH_4, thus improving the calorific value of the gas. But the gas that comes out of this type of gasifiers is at the temperature of the reduction zone, typically around 500^oC, which could be a disadvantage if it is to be used to run an engine, since high temperature results in poor volumetric efficiency and hence lower power output.

In contrast, the biomass in an updraught gasifier has the oxidation zone at the bottom, and reduction zone falls between this zone and oxidation zone. Thus, the gases pass through oxidation, reduction, pyrolysis and drying zones, in that order. We can readily see that the gas would pick up a lot of volatile matter from the pyrolysis zone, and flow through the colder drying zone out of the gasifier. This results in excessive tar content, since the volatiles do not get cracked or oxidized in their flow path. The gas is cooled in the process to much lower temperatures as compared to a downdraught gasifier.

In a cross-draught gasifier, the biomass flows across the reaction zone. The gas flows through drying, pyrolysis, oxidation and reduction zones in that order, thus ensuring tar cracking and oxidation. However, since the geometry is such that some volatile matter can bypass the hot oxidation-reduction zones and still find their way to the gas outlet, tar content of gas from cross-draught gasifiers is still higher than that from downdraught gasifiers. This design is commonly used where a large gas flow rate is desired with smaller gasifier size. This design is more common in coal gasification than in biomass gasification.

Effect of operating parameters

Out of all operating parameters, the maximum temperature of reaction zone is of prime importance in determining gas composition and tar content. The higher this temperature, the lower is the tar content owing to better cracking. Also, reaction rates of oxidation and reduction reactions are higher at higher temperatures, and hence better is the gasification. Therefore, it has always been attempted to maintain the oxidation and reduction zones at as high temperatures as possible: typically, 1100-1200K in oxidation zone and 900-1000K in reduction zone is found to result in producer gas of high calorific value and low tar content.

Any design or operating parameter that results in the decrease of maximum reaction zone temperature has an adverse effect on gas composition. Fuel moisture absorbs its latent heat of vaporization, and thus, excessive moisture in the fuel can reduce reaction zone temperatures, degrading gas quality. Larger particle size of feedstock retards the penetration of heat into the feedstock, thus reducing reaction rates and hence the temperature of the reaction zone. During startup period, reaction zone temperatures could be lower than the maximum owing to the reactor walls being cold. Clogging of grate results in poor air supply, thus reducing the reaction rates and hence temperatures. This explains the variation in gas composition over such a wide range.

Gas cooling and cleaning

The gas generated in the reactor of a gasifier is at a high temperature, and carries along with it some ash, besides its tar content, which are undesirable features, particularly when one needs to use the gas for applications such as running an internal combustion engine or a gas turbine. While tar can adhere to surfaces and cause jamming of moving parts and blockage of small passages, ash and other particulate matter would aggravate the problem. High temperature of the gas reduces the volumetric efficiency of an IC engine, since at these temperatures, since the density of the gas is low, the mass of gas-air mixture the cylinder can aspirate decreases, resulting in decrease in power output of the engine. This necessitates the cooling and cleaning of producer gas prior to its use. Cooling and cleaning is not as important in thermal applications as in the case of power generation applications.

Conventionally, dust removal from gases is effected by the use of cyclones, scrubbers or filters. Cyclones are effective when the gas flows at high velocity, and when particle sizes are larger than 15-20 microns. Scrubbers can serve a dual purpose of tar removal as well as particle removal. Filters can also serve this purpose, and it is necessary to replace the filter material periodically so as to prevent its clogging with tar. Commonly, all these three are used with gasifiers. Usually, more than one of these systems are used in series in most practical gasifiers in order to meet the cooling and cleaning requirements of the end use system.

Gasifier-Engine Systems

Gasifier-Engine systems are those in which the producer gas is used as fuel to drive a prime mover such as an IC engine or a gas turbine, and the shaft work so generated is either directly used, for example, for water pumping or grain grinding or such applications, or connected to an electric generator to produce electrical energy. IC engines have been proved to be the most efficient prime movers for power generation in the range of a few kW to a few MW, and are also the least expensive for this power range. Gas turbines, on the other hand, have proved economical and cost effective in power ranges of 20 MW and above, and research work to make this technology cost-effective and efficient in lower power range is in progress worldwide.

Dual-fuel mode of operation

Producer gas obtained from gasifiers has been successfully employed as IC engine fuel, both in dual-fuel mode, using diesel as pilot fuel, and in single-fuel mode. In dual fuel

operation, commercially available diesel engines are directly used, with the inlet manifold connected to the gasifier outlet through a T-joint so as to aspirate a gas-air mixture in place of pure air. The gas-air ratio is regulated often manually by controlling the valves on the gas and air lines connecting to the manifold. Diesel is sprayed into the cylinder to initiate combustion of the lean mixture of producer gas and air. This mode of operation results replacement of diesel upto a maximum of 80%, *i.e.*, pilot diesel quantity required can be reduced to 20% of what an engine running on diesel alone would consume. This technology is easy to adopt, and needs minimal modifications to the engine system. But it still needs a fossil fuel to run the engine. The main advantage of this technology is that when the gasifier is down for some reason, the engine can continue to operate using diesel fuel alone, since the engine system has not been modified.

Single-fuel mode of operation

In single-fuel mode, on the other hand, the engine needs to be spark-ignited. This necessitates custom development of engine system for use with producer gas, or drastic modifications on existing engine systems to adapt them for use with producer gas. It has been often said that the compression ratio for pure producer gas operation should be less than those commonly used in diesel engines. While diesel engines operate at compression ratios ranging between 17 and 23, most producer gas engines have been run at compression ratios of 10-12. Recently, it has been shown on a 20 kW engine that the compression ratio need not be reduced from 17, and in fact, the engine was shown to be performing better at higher compression ratios. Thus, if we intend to convert a commercially available diesel engine for operating on producer gas, it is necessary to replace the diesel injection system with a spark ignition system, with its timings tuned to suit producer gas operation. If, on the other hand, we intend to convert a commercially available gasoline engine for operating on producer gas, modifications to increase its compression ratio and spark timing would be necessary. Either way, the engine system needs drastic modifications, and cannot readily be reverted to diesel or gasoline operation. The main attraction of this type of system is that it replaces fossil fuels completely, and hence is suitable for remote localities where availability of fossil fuels is scarce.

A collection of references and reports related to biomass gasification can be found in the SARGOB (State of the Art Report on Gasification Of Biomass) website [13]. Other websites maintained by Biomass Energy Foundation [14] and Biomass Technology Group (BTG) [15,16] provide information on the technology, its manufacturers and installations around the world. There are websites specially meant for biomass energy, both through pyrolysis and gasification routes [17-19] maintained by BTG. A comprehensive report on the design methodology and engineering of gasification systems is dealt with in detail in [12].

Commercialization of Gasification Technology

While the gasifier-engines were first used in the World War II, in the wake of the more compact and convenient liquid fuel engines, the technology did not have many takers. However, in the past few decades, the technology has got considerable attention and consequently has matured a lot. The research on gasification has been supported by

MNES for many years, earlier under the banner of Action Research Centres (ARC) and more recently under the title of Gasifier Action Research Projects (GARP) [8]. GARP activities have been supported at Indian Institute of Technology (IIT), Delhi; IIT, Mumbai; Indian Institute of Science (IISc), Bangalore; Madurai Kamaraj University, Madurai; and Sardar Patel Renewable Energy Research Institute (SPRERI), Vallabh Vidyanagar. Many other institutes/organisations have been involved in field projects supported by MNES, which include Anna University, Chennai; CBRI, Roorkee; Ankur Scientific Energy Technologies Pvt Ltd., Vadodara and Tata Energy Research Institute (TERI), New Delhi [8]. IISc, Bangalore, Ankur Scientific Company, Vadodara, Associated Engineering Works (AEW), Tanuku, Cosmo Powertech, Raipur and TERI, New Delhi have commercialized their designs of gasifiers [20-24]. Ankur Scientific Co., AEW and Cosmo Powertech manufacture and market their gasifiers by themselves, while IISc and TERI have tied up with entrepreneurs who manufacture and market their gasifiers at a commercial scale as licensees of the respective designs. NETPRO Renewable Energy (India) Ltd. is one of the prominent licensees of IISc gasifier systems for power generation, who provide field services as well as training of the personnel. DESI Power is a sister company of NETPRO which has emerged as the first commercial Independent Rural Power Producer (IRPP) in India with the main objective of building and operating biomass gasification based power plants in association with NGOs, panchayats or co-operative bodies. About 30 gasifiers designed by IISc have been installed in the country for power generation[25]. While many of these are captive generation units for industry, some are rural electrification plants, as listed in Table 1. Some of these have been directly installed by IISc while some others have been installed by their licensees. Ankur also more than 15 power generation installations to its credit. Three of these are village electrification projects as listed in Table 1. All the installations by AEW are only for captive power generation [22]. Cosmo Powertech has been involved in one rural electrification project with grid connection [24]. TERI has been hitherto concentrating on thermal applications. However, they are in the process of installing power generation systems using gasifiers for captive power generation as well as rural electrification [23]. The authors are also aware of private entrepreneurs who have developed gasifier-engine systems and have been using them in the field for water pumping, grain grinding and electricity generation applications, as well as gasifiers for thermal applications using a variety of biomass including powdery biomass [26]. If biomass energy for rural electrification is to be promoted on a wide scale, such entrepreneurship also needs adequate encouragement and support from the concerned agencies.

Majority of these installations use wood from energy plantations, weeds like *Ipomea* or *Lantana* or agro-residues like coconut shells, cotton stalks etc. as the feedstock [12]. One of the systems installed by AEW uses rice husk, a powdery biomass. All the systems already in operation work in dual-fuel mode with diesel as the other fuel. Field installations of pure producer gas systems are being undertaken currently. The installed capacity in these systems varies with smallest being 20 kWe for some village electrification projects and largest going upto 1 MW with 4 units of 250 kWe. Most available designers and manufacturers focus on high capacity systems of 50 kWe or higher, while experience shows that there is widespread need for systems of smaller

capacity: typically 20 kWe for village electrification and even lower for water-pumping, running of small machinery such as flour mills, etc. It is essential that MNES should support the development and commercialization of low-cost, low-power gasifier-engine systems of this power range with the same enthusiasm and thrust as given to the larger systems.

Table 1. Selected list of gasifier-based village electrification installations

S. No.	Capacity	Location	End-use	Gasifier installed by	Year of installation
1	20 kWe	Hosahalli, Karnataka	Lighting, drinking water supply, flour milling	IISc-NETPRO	1995
2	20 kWe	Hanmanthnagara, Karnataka	--do--	IISc-NETPRO	1996
3	20+16 kWe	Dewana Estates, Kolar, Karnataka	Village Electrification	IISc-NETPRO	2000
4	24+50 kWe	Baharbari, Bihar	Village Electrification	IISc-Desi Power	2001
5	5X100 kWe	Gosaba, Sunderbans, WB	Island electrification	Ankur	1997
6	4X125 kWe	Chhotomollahkhali, WB	--do--	Ankur	2001
7	2X50 kWe	Kumari Kanan, WB	Village Electrification	Ankur	n.a.

Village Electrification

Some of these systems are being managed by the gram panchayat to provide drinking water, illumination, flour mill and irrigation water to the village and are being run by the local boys as is the case in Hosahalli [12]. The installation at Baharbari is being owned and operated by DESI Power, Baharbari which is a partnership between DESI Power and a panchayat level co-operative *Baharbari Odyogic Vikas Swavalamvi Sahakari Samiti.* This co-operative runs a small scale industrial complex linked to the power station with electric pumpsets to sell water, battery charging, rice mill, flour mill and a briquetting press. A similar system at Varlakonda at Karnataka is being operated by DESI Power, Varlakonda with *Women for Sustainable Development* as the local partner [25]. These are examples of linking the rural electrification with micro-enterprises, the route which has much greater potential for success than the programmes which aim at mainly providing lighting to the village households.

From the perspective of rural electrification, this is a very important aspect of commercialisation of the technology. Not only are there entrepreneurs to fabricate, install and maintain systems of their own design or as licensees of the original developers, the domain of the ownership and the operation of the plant is being commercialised which can bring much greater seriousness from the users end in the entire exercise and provide much greater benefit to the user in terms of employment generation. Even though, many of the installations have been initially possible due to MNES grants and subsidies, the above trends at commercialisation indicate the maturing of the technology with a promise of greater acceptance from the users.

At this point, it is pertinent to mention that all the information available at present on the different gasifier systems designed by the various groups are from the sources of the respective designers / manufacturers themselves. No independent assessment is available for any of these systems. Thus, there is a clear need for a comprehensive evaluation of the whole variety of these power generation systems from various angles –their technical performance, their economics and the social impact. Such an evaluation should provide valuable inputs to all parties concerned: to MNES, which must know how well the finances provided by them have had an impact and to plan future programmes accordingly; to the developers, entrepreneurs and promoters who can get a clearer picture of the relative standing of their systems and can take concrete measures to increase the acceptability of their systems; and also to the potential entrepreneurs who can be attracted into the business so as to provide a wider reach of the technology.

Issues in Rural Electrification using Gasification

The above account of gasifier based power generation installations in India, by any means, gives a very encouraging picture. Moreover, the list of groups seriously involved in the further development of technology is only increasing. Improvements in technology at the laboratory level and subsequently in the field are bound to happen with such efforts. However, for the technology to cater to the need of power generation in general and rural electrification in particular effectively, there are large number of other factors which need to be given due consideration.

Foremost point to be considered is the objective of *Rural Electrification*. If the objective is only to energise pumpsets, as was the case initially or to provide lighting to the households or at the community centres, as is the thrust by the government at present, the methodology that needs to be adopted for the purpose shall be of one kind. However, if the purpose of Rural Electrification is much wider and essentially aims at the overall development of the villages addressing the key problem of employment and making the villages self-sufficient in their primary needs, the whole strategy needs to be different with an integrated view of these needs that the supply of electricity is meant to cater to. It is in this light that we would like to discuss the wide variety of issues related to gasification based rural electrification projects. These issues must be taken into account at the time of the feasibility study or the preparation of the Detailed Project Report (DPR). Many of these issues have arisen directly from the field experience and thus it will be very useful for the future projects to learn from these and avoid the possible pitfalls at the planning stage itself.

Detailed Project Reports

In fact, the importance given to the feasibility study or the DPR is an important issue in itself. Any good project has its foundation in a good DPR. It is important for us to realise that providing electricity to a village, particularly using renewable energy systems, is not a simple task. Ensuring a sustainable operation and effective use of the technology needs taking into account details of every operation involved at the planning stage itself. Any project must provide for sufficient time and money so as to allow field level surveys or access to authentic information as inputs to the DPR. The DPR must account for details

starting from biomass availability and its management, the mode of plant operation, load management and technical support for the maintenance of the plant.

Biomass Availability and Management

Biomass management is a very important part of a gasifier based power plant. This includes two main aspects – one of quantitative estimates of availability of biomass on a sustainable basis, considering the current extent of consumption and the second, the system of biomass supply in the form required by the gasifier.

In certain situations, there can be a tendency of the implementing agency to identify the capacity of the power plant based on the current demand, assuming that biomass shall be available. This can be nothing less than disastrous. A detailed quantitative assessment of all the varieties of biomass available in the area and their present use is a must in any feasibility study. It is also preferable to avoid diversion of the biomass from its current use for it can seriously disturb the village systems. Diversion of biomass using economic incentives can be easy but if the objective of the overall welfare of the village has to be kept in mind, this strategy must be avoided. It is the surplus biomass which should be considered while planning for the gasifier system. Otherwise, more efficient technologies for the current usage can be promoted so as to create greater surplus for use in gasification.

If the biomass is being obtained from an energy plantation, the sustainable yearly yield can be obtained easily from the data available on the growth rate of different species. This takes into account the availability of prunings or the regeneration rate of the plants if the complete plant is harvested for use as fuel.

However, in situations where the feedstock is a wild species like *Lantana* or *Ipomea*, the feasibility study must include field estimations of the area covered by the plant, yield per unit area, realistic estimates of the regeneration rate to the right maturity and the current usage of the same. In case of agricultural residues, the availability can be more accurately estimated from the area under cultivation for the concerned crop.

In some urban installations, the wood for the gasifiers is purchased from the market. The ultimate source of biomass, in such cases, is not of very serious consideration. In the authors' view, this is not a very healthy situation. Market forces can completely overrule the environmental consideration. It is therefore extremely important that specifcally in a village situation, only the local biomass should be used in a sustainable manner.

The arrangement of biomass supply is very important for smooth functioning of the plant. The experiences of DESI Power, Orchha [25] provide valuable inputs on this account. Biomass supply can be a very important source of employment generation for the locals as was experienced in Orchha. The mode of supply can be a serious issue – whether the supply should be contractual or involving locals on daily wages. The contractual supply may be of the prepared biomass (harvested, cut and dried) or in semi-prepared form. The cutting to size may be manual or mechanised - considering the drudgery involved, the cost and the need for employment. The seasonality of biomass availability and the difficulties associated with its harvesting needs special consideration in the planning of

the same. Particularly in rainy season, the problems related to biomass shoot up. Despite abundant growth of certain biomass during that period, harvesting may become a major difficulty as was found to happen in case of *Ipomea* being used in Orchha. Drying can also be a major bottleneck in the biomass supply in rainy as well as winter seasons.

Interestingly, the biomass management can have a very strong bearing on the overall economics of a gasifier plant. On one hand, for the biomass supply to become a good economic activity for villagers, they must get good returns from it. This, on the other hand, can cause the cost of biomass to be high resulting in a high unit cost of the electricity generated [25]. There is, thus, a need for maintaining a balance between the two, which is not an easy task. It is, therefore, desirable that in a village situation, the villagers are directly involved in decision making related to such issues.

The experiences in commercialisation of the gasification technology and the operation of power plants has shown the high potential for employment generation for villagers in various forms – not only through the end-use of electricity for commercial purposes but in the very process of electricity generation starting from biomass harvesting, through its processing to the day-to-day operation and maintenance of the plant.

Mode of Power Generation and Supply

For a very long time, the government policies in India did not allow power generation or distribution by any party other than the government agencies. However, for the rural sector, the small scale power generation by interested parties holds the main hope and with the thrust on rural electrification by MNES as well as REC and the new Electricity Act, the generation and supply by private parties is becoming a reality. Even the projects supported by the government, more often than not, need involvement of local agencies – NGOs or panchayat level committees, for the success of the project. There are, therefore, different modes in which the power generation using renewables can be actualised –

Feeding to the grid – this needs synchronisation with the grid and needs special equipment for the same. A 500 kWe plant at Jabalpur installed by Cosmo Powertech was operated in this mode [24]. This is of course, possible only if the grid extends to the location of the plant. The linking to the grid is

Captive power generation - this mode is very widely used by the industry. In the context of villages, this will be possible only when the user sets up the plant and owns it. The electricity generated is used in-house without any external distribution or sale.

Generation and sale by a private party –According to the new electricity act [11], the generation and sale of electricity by a private party is allowed. However the government is to frame a clear policy for implementation.

Generation and distribution by a society – This model is being tried out at a few sites for rural electrification by TERI [23]. Here the supply would be to the members of the society only.

The first mode of operation, viz., feeding to the grid, becomes feasible generally when the plant capacity is high. The capital cost of the grid synchronising equipment is one factor which can act as a deterrant for small entrepreneurs but even more important than that is the buy back price paid by most electricity authorities. In certain states, the price

paid by the government per unit of electricity fed into the grid is so low that it does not even help the entrepreneur to break even after meeting the cost of operation and maintenance. The buy back price of Rs 2.25 and at most Rs 3.00 per unit can be feasible under present situations only with tax incentives and subsidies, even with pure producer gas operation.

The second mode of operation, i.e., captive generation has been the most widely used and does not have much difficulty in practice, but is not of much relevance in projects on rural electrification.

The third mode of operation holds a lot of promise if the government policies support the same. Currently only a few states like Chattisgarh, Gujarat, Karnataka, Maharashtra, Rajasthan and UP have allowed third party sale of power. The feasibility of this mode of operation is also very closely linked with the economics of the plant, which in turn depends heavily on the plant load factor. Thus, this mode can be attractive essentially when the supply of electricity is closely linked with the income generation activities ensuring high plant load factor and also higher capacity of the user to pay for a price of electricity which can make the whole operation by the private party a reasonably profitable one. Various installations of DESI Power come under this category [25].

The fourth mode of operation can have difficulties similar to the third mode and also certain additional ones. The operation of the plant, even on a no profit basis must be sustainable and without loss. As is the experience of IISc [12], collection of revenue by the society can be a major problem. Even when terms and conditions of supply of power to members of the society are clear, their implementation may not be very easy. Again, with a low plant load factor (PLF), the cost of power shall be high and the users may be reluctant to pay for the same. It can be a vicious circle. Users may be unwilling to pay for the electricity initially, due to high cost and that can keep the PLF low, raising the cost further and keeping more potential users away. It is therefore important that a minimum number of users must agree to paying for power before such a plant can be put up.

Load Assessment and Management

As is clear from the above, the load on the power plant is very crucial for the plant management. In addition, the load profile also affects the technical performance of the plant very strongly. The problems of load management can be viewed under two categories : that of domestic load and of the industrial load.

If a plant is used essentially for providing lighting to the village, the plant is likely to run for only 5-6 hours a day and the fluctuations in load are likely to be low. However, this will result in a very low plant load factor. On the other hand, an industrial load can be highly fluctuating depending on the kind of machinery connected. There can even be a large variation in the number of machines running at a given time due to various factors. Thus, there is a strong likelihood of not only a large variation in the load on day-to-day basis but also large fluctuations in the instantaneous load [12]. This has two negative implications. First of all, the average connected load is much lower than the capacity of the plant resulting in operation of the plant at part load most of the time, which is not a very healthy situation for the engine. Secondly, the instantaneously fluctuating load is

also not favourable for the efficiency of the engine as well as its long term life. If the system used is a dual-fuel one, this gets reflected directly in very high speicifc fuel consumption on one hand and low diesel replacement on the other. Both of these lead to considerable enhancement in overall diesel consumption per unit of generation and hence high cost of power. In single fuel operation, the impact may be less visible, since it will essentially lead to higher gas consumption and hence higher biomass usage. If the cost of biomass is a large fraction of the total operating cost, this can have significant impact on the overall economics. This is in contrast to the grid supply which can very easily absorb such fluctuations.

It is therefore important that the load must be managed carefully. This essentially involves, careful planning at the implementation stage itself. The decision of the number of engines to be used for the total desired capacity depends on the expected load profiles. It is generally desirable to have more than one engines so as to have reasonable load on the engine in use. The distribution of the load on the multiple engines can also be decided in such a way as to avoid very small loads on any engine. The expected load patterns must be studied carefully at the time of deciding the plant capacity itself and attempts made to even out the load during the time of operation to the extent possible.

Water and Waste Management

The environmental factors are very important in the operation of any plant and this holds true for a gasification based plant as well. The basic raw material may be biomass, but the cooling-cleaning operation does result in generation of an effluent which needs careful treatment before disposal. In many plants, this may not be considered as something very important. However, this aspect must not be neglected. Moreover, the need for cooling water in these plants can be quite large. The availability of water must therefore be considered at the planning stage. Recycling of water for cleaning after suitable treatment is a desirable feature which all plants must incorporate. At times, the effluent water from some other application can be good enough for use as cooling and cleaning water for gasifier, as is the case in Orchha where the effluent from paper unit is used in the gasifier unit after preliminary treatment.

The char from the gasifier and the ash also need suitable handling. The char can be used as a fuel as is being done in Orchha by briquetting it after mixing with other ingredients. If the ash content of biomass is substantial, it can be used in the building material.

Training, Operation and Maintenance

The operation of the plant needs skilled workers. It is most desirable that the local people be trained to do this work as has been the practice in many cases [12]. The routine maintenance can also be carried out by the trained operators.

For breakdown maintenance of the plant, faster access to professionals can be a major difficulty , particularly in remote areas. This is one aspect that must be adequately addressed by the suppliers of the systems as well as implementing and funding agencies. In today's context, advancements in IT can be effectively used for the purpose where the problems can be communicated to the professionals, many of which can possibly be resolved by the operators through proper guidance. Good documentation of the plant

operation, maintenance and trouble shooting, in local language, is a pre-requisite for this to be possible. The suppliers and developers must, therefore, give considerable attention to developing these manuals. As the number of field units of each design are increasing gradually, the field experience must be used in making the trouble shooting documents to be more and more exhaustive. If this aspect is not given due attention, even small breakdowns, not attended to properly can cause a drastic decline in the acceptability of the technology by the potential users.

Safety

It is not clear how many of the installations in the field have sufficient safety measures to prevent mishaps due to malfunctioning of any of the components. Good safety measures can be expensive. If the costs of such measures are prohibitive, simple systems can be evolved which can act as good safety guards. Providing multiple safety guards should, indeed, become an essential aspect before the technology is considered for field iinstallations. The possibility of explosions can be checked by providing pressure relief arrangement as is the case in IISc gasifiers with water seal at the bottom. The provision of flame arresters, even in the form of water bubblers can act as an effective safety device. However, such devices, even though inexpensive, need careful designing and care at the time of operation.

The gasifier system involves use of carbon-monoxide, which is a poisonous gas. As long as the gas is not stored, it does not cause much difficulty. However, in the instance of any leakage in a closed environment, it can be dangerous for the plant personnel and hence it is very essential that any gasifier plant must have adequate ventilation and enough open space around. Storage of biomass can also be hazardous particularly in summer. Adequate measures must be taken to prevent any instance of fire. More importantly, the villagers must be aware of the possible mishaps that can occur and how to deal with them. This should not be neglected for the fear of rejection of the technology by the users. This is a professional commitment that all parties involved must adhere to.

Economics and User Acceptability

The above discussion has adequately highlighted how the economics of the plant is closely connected to various factors such as the mode of engine operation (dual-fuel or pure producer gas); the plant load factor; the load profile; and the biomass management system. While, NETPRO's analysis gives the capital cost of the plant to be lower than that of a conventional power plant of same capacity, the reality is that the unit cost of electricity from a gasifier plant can vary a lot depending on the above factors. According to an analysis by DESI Power [25], the cost of electricity from a plant operating on pure producer gas can vary from about Rs 3/- per unit to Rs 5/- per unit depending upon the PLF and the cost of biomass. In dual fuel mode, this variation can be from Rs 5/- per unit to Rs 8/- per unit. This compares favourably with the cost of more than Rs 8/- per unit in pure diesel mode. Thus, the biomass power can become quite attractive when there is no access to grid power at all or is so erratic that there is heavy dependence on diesel fuel. According to the same analysis, the pay back period for a gasifier based plant can be as low as 1.5 years. However, the crucial aspect comes when the cost of the electricity from the gasification unit is compared with that from the grid or any other source. If the plant is put up by the industry concerned for captive generation, this does not cause much

difficulty, for the industry looks at the overall economics of their operations and not at the economics of the power generation plant in isolation. The cost of captive plant generation, even if higher than the unit cost of grid power, thus, gets offset by the increased productivity of the industry, during hours of non-availability of the grid supply.

On the other hand, if the gasifier –based power plant is to be installed by a private party for sale of electricity in the region, where grid power is already existing but is erratic, the situation becomes much more complex. With the government subsidies, the cost of gasifier-based power is likely to be higher than the grid electricity. The non-industrial users are, thus, likely to shy away from having connection from such a plant. The industrial users, at times, face another difficulty. Their payment for the grid connection entails a minimum charge and hence they prefer to use grid electricity whenever it is available to cover up that charge. Their use of biomass based power is then limited to the hours of non-availability of grid power. This leads to a very low PLF for the gasifier plant and hence a very high cost of the electricity from it. This further acts as a deterrent for the user to use this power and they prefer to use grid power even after their minimum units are consumed. The biomass power use can, therefore, be reduced to the minimum.

Similarly if a society puts up such a plant in the region with some grid connection, the cost comparison between the two can go strongly against the use of biomass power. Such problems become evident even at the stage of feasibility study. When a site which has very erratic grid supply is considered for such an installation and if an industrial party is approached for the purpose, the economics as well as reliability of the system get linked closely. An industrial user for whom the PLF is likely to be high, would also be very particular about the reliability of the system so as to cause minimum loss in productivity due to any breakdown. Such a user normally prefers to have a diesel engine as a back-up. Experience shows that many a times, it becomes difficult to convince the prospective user to try out the technology. On the other hand, users who are not very particular about the reliability of the technology, will not use the plant with a high PLF and hence the cost of biomass electricity can act as a deterrent. When the commercialization of the technology is in its nascent stage, the teething problems in the field are bound to be there. The laboratory level testing can bring the technology to one level of reliability. However, the field trials over long term bring out some of the problems which no lab test can identify. Therefore, for the improvement in reliability, it is important to have good number of plants in the field. This, as experience showed, was like a catch 22 situation at least a few years back and hence has been responsible for slow diffusion of the technology. The gradual removal of the field problems and improvements in the design by the manufacturers has considerably improved the acceptability and hence the prospects for a faster increase in the technology diffusion seem much better.

Economics of such plants for rural electrification also depends a great deal on the duration of operation. If the power is to be supplied for the whole day, the cost of operation is very high due to the salary of the operator. If the power is being used only for domestic purposes, the plant load factor will generally be very low and hence the cost of power will shoot up sharply. If the power is supplied only for the evening hours, cost of operation is lower, but the villagers may not feel as satisfied due to the lack of

flexibility in the use of various appliances. The level of villagers' satisfaction depends essentially on the culture of the place. If the power plant can be linked with an income generating activity during the day, the plant load factor can be high and the cost of operation can be partly met from the earnings of the activity.

The economics of the plant also depends strongly on the kind of engine being used in the plant – dual fuel or single fuel. The single-fuel technology has matured for commercial implementation only recently. There too, the engines available are mainly for higher power. Most of the systems installed in the field in the past few years are primarily dual-fuel engines. With these engines, if the plant runs under part load condition, the diesel substitution goes down drastically causing very high cost of operation due to the high diesel consumption. The choice of the engine size, thus, is a very important factor in the system design. If the system is likely to run at part load for large part of the operation time, it is better to install two small engines rather than a single large one. This can help in achieving better diesel substitution even at part load conditions. This also helps in keeping the plant running even during maintenance period of one of the engines.

Government Policies

All the above notwithstanding, the rural electrification programmes can truly get a fillip only if the government policies are conducive to the above considerations. The provision of private party generation and distribution in the new Electricity Act is indeed very welcome. It is now upto the various state governments to initiate the formulation of the detailed policies for implementation so that the private parties can come forward to play the required role in this regard.

The buy back rates for grid connection also must be revised to meet the actual costs of the electricity generation. If the buy back price can provide feasibility to private producers only with subsidy and tax benefits, the whole policy needs a re-look. Policy makers also need to watch out against entrepreneurs and users installing a system purely for subsidies alone, thereby contributing to the failure of a biomass energy venture.

As already mentioned, the government must take a more integrated view of the process of rural electrification. Special incentives should be given for linking the employment generation activities at the village level with electricity generation. The efforts should be essentially to provide the initial impetus in this direction and encourage the ventures to become self-sufficient in due course. If the focus is only on providing lighting and irrigation water, the sustainability of the system has to be carefully looked into. Specifically the collection of revenues for power supply can be a serious problem. Thus it may be difficult to pay for even the routine operation and maintenance costs which include the salary of the operator, cost of biomass etc. [12]

Concluding Remarks

The above discussion has attempted to show that biomass gasification is indeed a very promising technology for decentralised power generation in rural areas both on account of difficulties in providing good quality grid power, and due to the wide availability of biomass even in remote villages. The biomass gasification provides a simple to operate

and efficient technology for using this biomass for power generation. There is adequate field experience of various developers and entrepreneurs to show that the technology has matured to a level suitable for wide dissemination for the purpose. The need for decentralised power is also being recognised by the government and that brings further impetus to the technology for rural electrification. There is a need to link the concept of rural electrification with generation of micro-enterprises so as to allow the power availability to truly help in the development of the villages. This route can be a very attractive one if planned and implemented carefully.

While the prospects for the technology are very good, the challenges in the implementation are also very high. Although several designs of gasifiers have successfully been demonstrated on field level, a comprehensive, relative evaluation of these systems with respect to technical performance, economics and social impact is not available, and must be carried out. The need for careful conceptualisation of the projects through detailed feasibility studies cannot be overemphasised. Various aspects associated with a gasifier power plant including biomass management, load management, mode of operation and power supply, waste management, safety issues and the economics of the plant along with the acceptability of the users can pose difficulties which need careful consideration by the entrepreneurs, funding agencies and the promoters alike for long term impact of the rural electrification programmes on the village scenario. As of present, the technology seems to be a viable alternative for rural electrification only as a part of an integrated development programme, rather than as a commercial competitor to subsidised grid power. In this context, artificially making the renewable energy technology viable using subsidies should be avoided, for the betterment of the technology application in its own merit. Instead, adequate encouragement and support with simplified procedures must be made available to the entrepreneurs investing in this technology. The government policies on commercialization of electricity generation and distribution also need to be formulated clearly with regards to decentralized systems so as to be commensurate with its objectives of rural upliftment and power to villages.

Acknowledgements

The authors are thankful to Dr Hari Sharan (DESI Power), Mr. B.V. Ravi Kumar (Cosmo Powertech), Dr Sunil Dhingra (TERI) and Mr. R.K.Verma (CEA) for their valuable inputs. Assistance provided by Mr.A.V.V.V.G.Satheesh, M.Tech. student at IITD in collecting information is also gratefully acknowledged.

References

1. *India 2004, A Reference Annual*, Publications Division, Ministry of Information and Broadcasting, Government of India, 2004, p 227.
2. http://recindia.nic.in/mop.htm Rural Electrification Corporation website.
3. TERI Energy Data Directory and Yearbook (TEDDY) 2002/03, The Energy and Resources Institute, New Delhi, 2003.
4. www.osc.edu/research/pcrm/emissions/background.shtml

5.*Human Development Report 2003*, UNDP Programme, Oxford Univ. Press 2003, pp 134-140.
6.*India of My Dreams*, M.K. Gandhi, Navjivan Prakashan Mandir, Ahmedabad, 1949.
7.http://powermin.nic.in/gokak_report.pdf, *Gokak Committee Report on Distributed Generation*, also in Indian Economy Documents Yearbook – Reports Policy Documents and Discussion Reports, Academic Foundation, New Delhi, 2003.
8.Annual Report 2002-2003, Ministry of Non-conventional Energy Sources, Government of India, 2003.
9.Office Order No.61/1/2003-RVE, Government of India, Ministry of Non-Conventional Energy Sources, Remote Village Electrification Division, December 2003.
10.*Biomass Gasification-based Power Stations,* internal report, NETPRO Renewable Energy (India) Ltd., Bangalore, January 2004.
11.http://powermin.nic.in/The%20Electricity%20Act_2003.pdf, The Electricity Act, Ministry of Power, Government of India, 2003.
12.Biomass to Energy – The Science and Technology of IISc Bio-Energy Systems, ABETS, Indian Institute of Science, Bangalore, 2003.
13.http://www.iitb.ac.in/~mech : State-of the Art Report on Gasification of Biomass (SARGOB) website, IIT, Mumbai.
14.http://www.woodgas.com, Biomass Energy Foundation Website
15.www.btgworld.com/technologies/gasification.html
16.www.gasifiers.org
17.www.gasnet.uk.net
18.www.pyne.co.uk
19.www.thermonet.co.uk
20.http://cgpl.iisc.ernet.in CGPL website, IISc, Bangalore
21.http://www.ankurscientific.com/AppElectrical.htm Ankur Scientific Co., Vadodara
22.http://aewgasifiers.netfirms.com/installations.htm Associated Engineering Works, Tanuku, A.P.
23.Dhingra, S. Biomass Energy Technology Applications, The Energy and Resources Institute, New Delhi (Personal Communication).
24.Ravi Kumar B.V. Cosmo Powertech Pvt. Ltd., Raipur (Personal Communication).
25.http://www.desipower.com
26.Malik, S.D. Navreet Energy Research and Information, Rohtak, Haryana (Personal Communication).