Sustainable biomass power for rural India: Case study of biomass gasifier for village electrification

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The performance and impact of a decentralized biomass gasifier-based power generation system in an unelectrified village are presented. In Hosahalli village, Karnataka, India, lighting, drinking water, irrigation water and flour-milling services are provided using power derived from the biomass gasifier-based power generation system. The system consists of a 20 kW gasifier-engine generator system with all the accessories for fuel processing and electricity distribution. The biomass power system has functioned for over 14 years (1988–2004) in Hosahalli village (population of 218 during 2003), meeting all the electricity needs of the village. Lighting and piped drinking water supply using biomass electricity, was provided for over 85% of the days during the past six years. The fuel, operation and maintenance cost ranged from Rs 5.85/kWh at a load of 5 kW to Rs 3.34/kWh at a load of 20 kW. Technical, social, economic and management-related lessons learnt are presented here.

ACCESS to quality, reliable and affordable energy is critical for promoting economic and social development in rural areas. The energy situation in rural India is characterized by low quality of fuel, low efficiency of use, low reliability of supply and limited access leading to lower productivity of land, water and human effort, ultimately leading to low quality of life and environmental degradation. First, dependence on biomass (fuelwood, crop residue and cattle dung) and traditional cook stoves with low efficiency which emit smoke into kitchen, leads to low quality of life for most rural women[1]. Secondly, dependence on kerosene and wick lamps for lighting with uncertain supply of the fuel leads to low quality and intermittent lighting. Thirdly, dependence on centralized grid electricity supply to low-load rural situations is characterized by fluctuating voltage, unreliable supply and shortage of power in most parts of rural India. Dependence on coal-based electric power plants (accounting for 70% of power generation) is leading to environmental degradation; local (land degradation), regional (air, water and soil pollution) and global (greenhouse gas build-up leading to climate change).

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There is a realization on the need to search for decentralized and renewable energy-based options to meet the rural energy needs in a sustainable way[1–3]. Among all the renewable energy sources, biomass is the largest, most diverse and readily exploitable resource[4]. In India, among the renewable energy options, bioenergy technologies have been promoted for meeting rural electricity needs. Further, amongst the bioenergy technologies, the biomass gasifier option for meeting the rural electricity needs of domestic, agricultural pumping and rural industrial (such as milling) activities is shown to have a large potential[1].

Biomass gasification involves partial combustion of biomass under controlled air supply, leading to generation of producer gas constituting the combustible gases H_2 (20%), CO (20%) and CH_4 (1–2%). The energy value of producer gas is about 5.0 MJ/m^3. The producer gas can be used as fuel for internal combustion engine for mechanical and electrical applications. The Centre for Sustainable Technologies (CST; formerly ASTRA), Indian Institute of Science (IISc), Bangalore is a leading R&D Centre on combustion and gasification technologies. Several designs based on different biomass fuels and of different capacities have been developed and disseminated[5]. Biomass gasifier systems based on woody biomass, raised on wastelands, have been shown to have the largest potential to meet rural electricity needs in most parts of India[1]. The use of biomass gasifier system, for provision of village-scale energy needs, based on sustained biomass supply from captive energy forest and agro-residue is explored here.

This article presents the performance, impacts and lessons learnt from planning, implementing and monitoring of biomass gasifier-based village electrification systems in operation in Tumkur district. The two biomass gasifier-based power systems in Tumkur district are unique as there are hardly any examples of renewable energy systems that have functioned at the village level for 5–10 years and that have been continuously monitored, anywhere in the developing world.

Features of Hosahalli and Hanumanthanagara project

The biomass gasifier-based decentralized power generation systems were implemented in Hosahalli and Hanumanthanagara villages of Kunigal taluk, Tumkur district. Hosahalli was a non-electrified village and Hanumanthanagara was electrified (grid-connected); however, only 30% of the houses were electrified, at the time of project initiation. The number of households in Hosahalli is 35 and Hanumanthanagara 58 (Table 1). Hosahalli did not have any pumps or a flourmill. Kerosene-based traditional wick lamps were used for lighting[6]. Women carried water from a polluted open water tank nearly 1 km away from the village. Farmers depended on rainfed agriculture which is subjected to vagaries of monsoon, with low crop yields and occasionally hired diesel engines to pump water for irrigation or partial supply from irrigation tank.

The bioenergy project was planned and implemented by CST and the following steps were adopted:

Step 1: Discussion meetings were held with the Hosahalli and Hanumanthanagara village communities explaining the technology, roles, responsibilities, benefits and the need for their participation before initiating the project.
Step 2: The village community agreed to participate and help in raising and protecting an energy forest. Energy forests were established in both the villages; Hosahalli during 1988 and Hanumanthanagara during 1996.
Step 3: The gasifier-based power generation system was installed in Hosahalli during 1988 and in Hanumanthanagara during 1996 and the end-use systems were installed in phases.
Step 4: Local youth were trained to operate and undertake minor maintenance of the systems.
Step 5: CST obtained funds for the implementation of gasifier power system in both the villages.
Step 6: Village committees managed the systems, taking decisions on operation, supervision of the operator, protection of the forest and ensuring payment for the services provided.

Features of biomass power systems

Installed capacity and load

The installed capacity and load for different services are given in Table 1. The capacity of biomass gasifier system installed is 20 kW in both the villages. Even though the installed end-use capacity is higher (30 and 37 kW), the load is distributed such that the irrigation load is scheduled for day hours and other load activities are planned for evening hours (6 to 11 p.m.). In addition, all irrigation pumps are not switched on simultaneously.

Table 1. Features of biomass gasifier systems

Description	Hosahalli	Hanumanthanagara
Year of establishment	1988*	1996
Size of village (number of households)	35	58
Population	218	319
Energy plantation (ha) raised	4	8
Installed capacity (kWe)	20	20
Installed end-use capacity (load)		
Lighting	4.0	4.0
Drinking water	2.6	2.6
Flour mill	5.6	5.6
Irrigation pump	18.5	25.5
Total installed end-use capacity	30.7	37.7

*The installed capacity in 1988 was 3.7 kW and was expanded to 20 kW in 1997.

Energy forest and biomass supply

The area planted was determined by availability of community lands. The biomass feedstock in the initial years came from social forestry plantations in the nearby villages. The area under energy forest was 2.5 ha in Hosahalli planted during 1988 and an additional 1.5 ha in 1991–92, and 8 ha in Hanumanthanagara planted during 1996. A mixed species forestry concept was adopted. For example, in Hosahalli the species planted include *Acacia auriculiformis* (13%), *Eucalyptus* (58%), *Dalbergia sisso* (7%) and *Casia siamea* (22%). Fast-growing coppicing species were preferred. A productivity of 6 t/ha/yr was reported during the initial years, when detailed measurements of productivity were made[7].

Investment

The investment for creating the entire infrastructure, including installing power generation (gasifier, diesel engine, generator and building), distribution and end-use (lighting, irrigation water pump, flour mill, etc.) systems and raising energy forest was provided by several funding sources under different projects.

Performance of biomass gasifier power system

In Hosahalli, initially a 3.7 kW power generation system was commissioned in 1988. The 20 kW biomass gasifier system was commissioned in 1997 at Hosahalli and 1996 at Hanumanthanagara. The detailed performance data are available for Hosahalli, originally a non-electrified village. Thus, most of the performance and impact analysis is restricted to Hosahalli only. Performance data are presented for six years (1998–2003). Preliminary findings of monitoring for initial years were presented[7,8].

Performance with respect to functioning of the system

Table 2 and Figure 1 provide details regarding the performance of the system and services provided to the village over the last six years. It is important to note that the power generation system was operational in Hosahalli for over 90% of the days during 1998–2003 as shown in Figure 1, except in year 2000, where it was below 300 days.

The power generation system functioned for over 70% (Figure 1) of the days on dual fuel mode, indicating the operation of the gasifier system for power generation using biomass. The system was operated in diesel-only mode for power generation in about 25% of days, due to non-availability of processed wood fuel or problems with the gasifier system and sub-elements or non-availability of trained operators (addressed later in the article). The total electricity generated varied from 12 to 22 MWh per year, as shown in Table 3.

Provision of services

Provision of reliable services such as home and street lighting, piped water supply and flour milling is critical for determining the quality of life of the people. In India, even in cities and towns, these services are not available on all days; for example, piped water supply in most towns and cities in Karnataka varies from 1 to 3 days per week. The general philosophy adopted in this project implementation was to provide these basic services in a reliable manner. Though towards achieving this objective, occasionally services are provided using diesel system, if gasifiers cannot be operated.

In Hosahalli, lighting and piped drinking water services were provided for over 85% of the days during most years. The flour mill was operated twice or thrice a week depending on the demand for milling of grains. The irrigation system was operated depending on the crops grown, area irrigated, cropping season and demand from farmers. Thus the percentage of days when irrigation water was provided is relatively low. The basic services critical for determining the quality of life, such as home and street lighting and piped water supply were provided on most days, again a unique achievement for a village in India (Table 2).

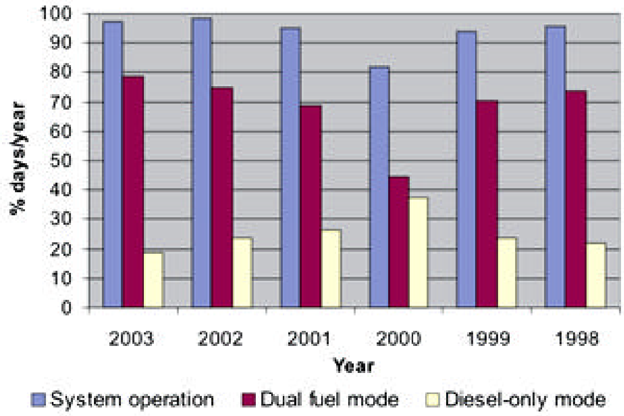

Figure 1. Operational performance of the system: Percentage of days that the system operated in dual fuel and diesel mode (% of days/yr).

Technical performance

In this section, system performance with respect to the consumption of biomass and fossil fuel for dual fuel operation and the overall efficiency are presented. The dual fuel system operation requires the use of diesel for start-up operation and during system shutdown to run the engine to support auxiliaries of the system. Table 3 provides data on electricity generation and biomass and diesel consumption per kWh during 1998–2003 at Hosahalli.

From the data provided in Table 2, it is clear that the system operates with lighting and drinking water load for majority of the days in a year. Table 4 provides details with respect to the various combinations of load pattern and fuel consumption observed in Hosahalli village.

Table 2. Hosahalli: System operation and provision of utility services

System operation and services provided	2003	2002	2001	2000	1999	1998
Days operated during the year	355	358	347	298	343	349
Days on dual fuel mode	287	272	250	162	257	269
Days on diesel mode	68	86	97	136	86	80
Days services provided for lighting during the year	355	349	347	287	310	300
Days services provided for drinking water	353	344	339	293	338	295
Days services provided for flour milling	162	97	155	92	180	125
Days services provided for irrigation water	79	88	39	–	–	–

Table 3. Hosahalli: Total annual electricity generation and fuel consumption

Description	2003	2002	2001	2000	1999	1998
Electricity generated kWh/yr in dual fuel mode	18651	17185	12775	7238	9617	9300
Electricity generated kWh/yr in diesel-only mode	3326	3992	3476	5251	3267	2723
Total electricity generated kWh/yr	21977	21557	16251	12489	12884	12023
Average wood consumption rate kg/kWh in dual fuel mode	1.8	1.64	2.07	1.28	1.27	1.32
Diesel use in duel fuel mode l/kWh	0.063	0.077	0.086	0.109	0.173	0.182
Diesel use in diesel-only mode l/kWh	0.567	0.76	0.779	0.564	0.379	0.432
Diesel substitution in per cent under dual fuel mode	85.55	87.02	80.69	80.67	54.35	58.33

Figure 2 provides details about the overall conversion efficiency from fuel to electricity in diesel and dual fuel mode. The overall conversion efficiency is defined as the ratio of electrical energy output to energy input; only diesel or diesel plus biomass depending upon the mode of operation. The diesel mode efficiency is derived from laboratory tests, where a maximum efficiency of about 30% has been achieved at nominal rating of the engine. At about 40% of the rated capacity, the efficiency is about 20%. In dual fuel mode, the efficiency is calculated using the data from Table 4, where the diesel and biomass consumption is presented for various load conditions. There is a fall in efficiency by about 12 to 15% when the efficiency is estimated using wood as the input and the difference reduces when the factor for gasification efficiency, i.e. the energy in the biomass converted to gas is incorporated. The gasification efficiency is set at 75%. At low loads of operation, the gasification efficiency of around 70% is expected, implying the overall conversion efficiency of about 8% lower than that of diesel mode of operation, which is consistent with the results from various studies[9,10].

The specific wood consumption is relatively high, between 1.27 and 1.6 kg/kWh (Table 3), due to the consistently high diesel replacement. Under these conditions,

Table 4. Fuel consumption under various load conditions

Service	Load (kW)	Diesel (l/h)	Air dry wood (kg/h)	Diesel (ml/kWh)	Wood (kg/kWh)
L	9	0.9	14	100	1.55
W	6.5	0.7	12	108	1.84
FM	9	0.8	14	88	1.55
L + FM	16	1.1	24	69	1.5
L + W	14	0.95	20	68	1.43
L + W + FM	24	1.8	34	75	1.42
IP 7.5 (1)	7	0.65	12	93	1.71
IP 7.5 (2)	7	0.65	12	93	1.71
IP 10,	9.5	0.75	15	79	1.58

L, Lighting; W, Drinking water pumping; FM, Flour milling; IP, Irrigation pumping.

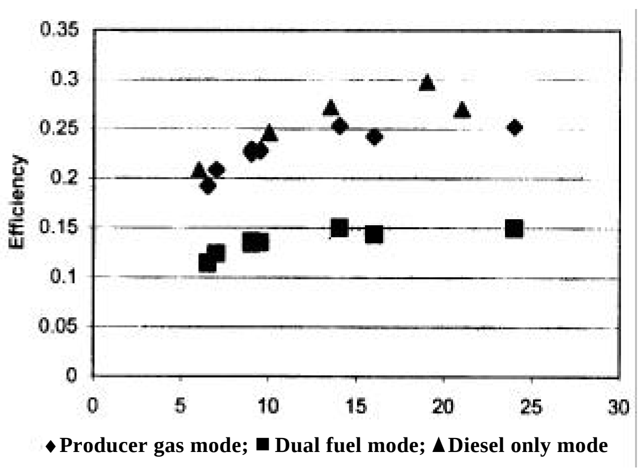

Figure 2. Overall efficiency in diesel-only and dual fuel mode with load.

the losses through the exhaust in the form of sensible heat and chemical energy are high. Under the conditions of high diesel substitution, the energy contribution from diesel is small and the major portion of the energy is from the producer gas, which is one of the major objectives of this implementation programme.

Diesel substitution or conservation, which is one of the main aims of the project, has been demonstrated with diesel substitution of up to 85%, indicating the high performance of the technology and design and the high efficiency of operational performance. Diesel substitution was lower in earlier years due to lack of discipline in operation such as use of moist fuel, use of diesel engine over longer time and lower hours of operation.

Irrigation pumping

Maximizing the load or capacity utilization is critical for the financial viability of the decentralized power generation system. Thus, there is a need to generate demand for power from various activities. One of the most important activities that has the potential to generate load as well as income to farmers is irrigation water pumping. An earlier experiment conducted at Pallerayanahalli has also shown that farmers need water and are willing to pay the operation and maintenance (O&M) costs of irrigation water pumping based on decentralized power generation using biomass gasifier system[11]. Even though the goal of the project was to provide irrigation for at least one acre for three crops per farmer, due to financial limitations, irrigation could be provided to only less than 50% of the farmers and only for one crop. Data for a recent year (2002) on the number of farmers and area irrigated along with gross income and cost of irrigation as percentage of gross income are given in Table 5.

Irrigation water pumped using gasifier-based power was supplied to 17 farmers irrigating an area of 20 acres (8 ha) during 2002. Whereas in the year 2003, 28 farmers raised six crops (inclusive of providing life-saving irrigation to crops such as paddy and banana) in 15.75 acres (6.3 ha). The total number of hours of biomass power system operation for irrigation activity during 2002 and 2003 was 443 and 316 respectively. This accounts for only a 5% load on the system. The cost of irrigation (power + water) accounted for 10 to 20% of gross income for majority of the farmers. The rate charged per irrigation of Rs 40/h is based on the current rate charged for diesel-based pumping, which is affordable. The baseline situation would be rainfed or dry land crop production with only one crop during the rainy season, resulting in low and uncertain income.

Economic analysis

Economic analysis includes most often adopting the discounted cash-flow techniques based on the life-cycle cost analysis approach. In this study, cost analysis is carried out using only the variable or recurring costs, namely the mean monthly fuel, O&M costs.

Cost of electricity: The cost of electricity is estimated using only the variable costs, since the system is not operating to its rated capacity. The fuel, O&M costs at different loads are given in Table 6. The cost per kWh of electricity is calculated by taking the fuel and O&M costs actually expended at different loads on the power generation system in Hosahalli. Plant load factor is one of the key factors contributing to the cost of electricity, as the cost per hour of operation is same for the system irrespective of the load, particularly the operator cost and start-up diesel use.

Engine maintenance accounts for the cost of all the consumables, such as lubricating oil, oil filters and gaskets used during the maintenance of the engine-genset and the electrical distribution. Similarly, gasifier maintenance includes all the costs involved in operating the gasifier system, such as the gaskets and filter changes. The labour cost includes the operator's monthly salary. Biomass cost includes transportation from the forest to the power plant and fuel preparation. The biomass feedstock preparation is carried out by the village households manually.

It can be observed from Table 5, that the O&M cost per unit declines from Rs 5.85/kWh at a load of 5 kW to Rs 3.34/kWh at a full load of nearly 20 kW on selected days (2003 cost data).

In Hosahalli, there are two types of activities, namely base or fixed load activities such as lighting, pumping water for domestic use and flour mill operation, and seasonal or variable load of pumping water for irrigation. Lighting and pumping drinking water load, which is constant throughout the year, is about 6 kW and load due to operating a flour mill, about 2 to 3 days in a week, is an additional 5.6 kW. Load on the system ranges between 6 kW on 4 days a week and 12 kW on 3 days in a week. Thus, the load, excluding irrigation water pumping, ranges between 6 and 12 kW, largely in the evenings for 3 to 5 h a day for providing domestic services. Load due to irrigation activity is still limited due to lack of funds to extend the area irrigated. But the potential exists for increasing the load to full capacity if a new water source is found and additional funds are available for supplying irrigation water to crop fields.

Opportunity for reducing costs: To make the decentralized power generation systems financially more attractive to investors, the cost of power should be reduced and if possible made cheaper than the grid power. There are opportunities to reduce the cost of decentralized biomass gasifier-based power systems for large-scale application.

Optimizing the capacity of decentralized power generation system: The capacity of the power generation system, which could be a stand-alone system servicing one or a cluster of villages or an industry, needs to be optimized

Table 5. Crops grown, area irrigated, number of farmers using irrigation and cost of irrigation as percentage of total cost during 2002

Crops grown	Number of farmers	Area (acre)	Number of irrigations given	Total hours of system operation	Average gross income/acre (Rs)	Average cost of water and electricity (Rs/acre)	Proportion of cost of irrigation to gross income (%)
Watermelon	6	5.75	84	120.25	7033	836	12
Maize	8	4.5	9	42.0	4065	373	9
Banana	4	1.0	5	11.0	6000	440	7
Sugarcane	6	4.5	19	122.75	16920	1091	6
Ragi (Finger millet)	2	1.0	3	15.0	3000	600	20
Tour dal (Gram)	1	0.5	1	2.75	Own use	–	–
Chilli	2	1.0	4	3.75	Own use	–	–
Cucumber	1	0.2	5	4.25	Own use	–	–
Mulberry	2	1.75	28	121.25	11200	2771	25
Total	17	20.2	158	443			

Table 6. Fuel consumption, units of electricity generated and O&M costs at different loads

Load (kW)	Diesel cost (Rs/h)	Biomass cost (Rs/h)	Maintenance: Engine (Rs/h)	Maintenance: Gasifier (Rs/h)	Labour cost (Rs/h)	Total cost (Rs/h)	Cost/kWh (Rs/kWh)
6.0	16.4	9	5.42	0.98	6.25	38.05	5.85
7.0	21.1	10.5	5.42	0.98	6.25	44.25	4.92
8.5	18.74	10.5	5.42	0.98	6.25	41.81	4.65
11.5	22.26	15	5.42	0.98	6.25	49.91	3.56
15	25.77	18	5.42	0.98	6.25	56.42	3.52
20	42.17	25.5	5.42	0.98	6.25	80.32	3.34

Cost: Wood = Rs 0.75/kg; Diesel + transport = Rs 23.45/l; Engine maintenance = Rs 5.42/h; Gasifier maintenance = Rs 0.98/h; Operator wage = Rs 6.25/h.

to match the load. Another option is to feed the surplus power generated into the power grid, which has to be addressed particularly at higher capacities. The investment cost can be reduced by optimizing the installed capacity for a given area and the load.

Increasing plant load factor: The unit cost of electricity could be reduced by increasing the load, which is low in Hosahalli, as shown in Table 5.

Shift to gas engines: The present operations at the Hosahalli system are carried out using a diesel engine as a dual fuel system, where 62 to 86 ml of diesel is consumed per kWh costing, at current rate of Rs 1.3 to 1.8/kWh. Recent developments at IISc[12] in the area of producer gas-based engine systems eliminate the use of diesel in the engine. The ignition is by a spark. Thus, the cost of diesel, which accounts for a large share of O&M costs is replaced by additional (20%) excess biomass per kWh. This switch from dual fuel to gas-alone mode could lead to a reduction of unit cost of electricity by about 25%.

Using mechanical system for wood fuel preparation: At higher capacities, the biomass transportation and preparation can be mechanized, reducing the cost of biomass preparation leading to a net reduction in the unit cost of electricity. Use of mechanical system for wood chip preparation using a fraction of surplus electricity during off-peak period could reduce the cost/kg of feedstock.

Repair, maintenance and servicing costs: If multiple systems are installed in a given area along with adoption of a cluster approach towards maintenance of the system, it would result in a cost-effective maintenance system, thus further reducing the cost/kWh.

Tariff charged and recovery

A 'fee-for-service' concept was adopted in consultation with the village community by providing all the information on inputs and costs, and explaining the need to move towards financial stability. The tariff was determined jointly by the scientists and village community. An 'end-use' or 'service'-based tariff structure was adopted rather than the usual approach of charging for kWh of electricity used. Fee for lighting was Rs 5/bulb-point/month, Rs 10/household/month for piped water supply; the rates if converted to cost/kWh are lower than the prevailing grid supply rates. One of the important factors in deciding the rates was the affordability of the households and to ensure 100% of households benefit from lighting and piped water supply and all farmers from irrigation service equitably. The rationale was that economic rates would be charged once the incomes of households increase. The initial approach was to promote quality of life and equity.

The collection of fee for each service was the responsibility of the local operator, with the help of the village management committee. The recovery data for recent years is given in Table 7. The payment for domestic services, lighting and piped water supply during 2001–2003 is nearly complete (94 to 99%), which is rare in India for any service provided by various utilities to rural communities. Similarly, recovery for the irrigation water supply during 2001 and 2002 is in the range of 76 to 82%. First, the approach of fixing tariff based on 'service-oriented' concept seems to have been accepted by the village community, where the payment is for the service such as piped water supply for 2 h/day or irrigation water supply per irrigation per acre. Secondly, involving local community in the recovery process and providing information to them on all the costs and potential benefits have helped near full recovery (Table 7).

Problems encountered

A decentralized power generation system based on an emerging technology, implemented by an educational institution in a village situation could face a number of technical, social, political and financial problems over the 15-year period of its life. Here, some of the problems encountered particularly focused on the performance of the technology are presented for the period 1998 to 2003. The frequency of occurrence of the problems is given in Table 8.

Technical problems

With respect to the technology package, the two critical components are the gasifier and diesel engine. Gasifier-related problems were encountered on 152 days during

Table 7. Tariff collection in Hosahalli for services provided

Year	Domestic + flour mill bill amount	Amount collected	Percentage recovery	Irrigation bill amount	Amount collected	Percentage recovery
1998	9465	6051	64	–	–	–
1999	9570	5564	58	–	–	–
2000	9790	3622	37	–	–	–
2001	11655	10965	94	10560	8640	82
2002	10475	10388	99	17720	13480	76
Total	59270	40440		40940	32240	
	Average recovery		68			79

the six-year period, amounting to about 7% of the total days. These include the failure of material in the top shell (twice), filter replacement and grate repairs. The gasifier maintenance-related problems occurred 98 times during the period, which related to the operational problems, use of moist fuel, wrong size fuel, etc. affecting the quality of gas. Engine-related problems occurred 33 times, which are related partly to gasifier operation and also to the failure of the radiator. Electrical system of the alternator failed twice. These gives an indication about the reliability of different components of the system.

Some of the gasifier-related problems have been addressed by the R&D group. The problem related to the reactor material has now been resolved using high temperature ceramics and also the filter failure using fabric filters.

Input supply

Non-availability of wood chips in cut and dried form was one of the dominant problems encountered on 297 days over the six-year period. The utility does not have adequate storage facility. Thus during rainy seasons the cutting and drying of wood is a problem. The labour availability for harvesting wood in the energy forest and then chopping to the size needed is limited, particularly during the peak crop season. The power generation system was operated on diesel mode during such days, when cut and dried wood chips were not available. The nearest diesel source is about 30 km away and often diesel is not available or accessible to the operator. The system could be operated on days when diesel was not available.

The mitigation measures for sustained biomass feedstock supply include: creation of storage capacity, mechanical system for cutting wood to the desired size and drying of wood using the exhaust gas of the engine. The ultimate solution to the diesel problem is the adoption of a 'gas engine', which is at an advanced field testing stage.

Non availability of operator

Due to financial constraints, only one fully trained operator was employed. The operator was not available for running the system for only 59 days over the entire period, largely due to family or personal reasons. The mitigation measure would be to train a number of operators in the village.

Social problems

The social problems obstructed the functioning of the system only on 28 occasions or days during the six-years period. These included some disagreement among the members of the management committee or political rivalry. Social problems-related disruption was infrequent, this is a tribute to the village community of Hosahalli. The other social problems not included is Table 8 are: unauthorized removal of trees from the forest occasionally, grazing of livestock in the forest, attempted encroachment of the forest land and opposition to the operator from one section of the village community. It is no surprise that the village communities in India are divided over political affiliations, castes, land ownership, etc. Hosahalli cannot be an exception. But what is surprising is that despite the social and political problems and lack of their understanding by the project team, the decentralized system has functioned almost uninterrupted for six-years. The rationale could be that the village community, particularly women obtain crucial services such as piped water supply, lighting and access to flour mill.

Table 8. Problems encountered in operation and maintenance of gasifier power system

Problems	1998	1999	2000	2001	2002	2003	Total	Percentage of days with problems
Gasifier-related								
Repair/replacement of components	25	16	0	27	29	55	152	22
Maintenance	20	22	16	20	19	1	98	14
Engine-related								
Maintenance/repair	0	4	6	15	5	3	33	5
Inputs								
Non-availability of processed biomass	35	30	137	45	37	13	297	42
Non-availability of diesel	4	9	6	5	1	1	26	4
Operator availability	5	10	34	3	2	5	59	9
Others								
Social, etc.	7	17	4	0	0	0	28	4
Total no. of days system operated on diesel mode	80	86	136	97	86	68	553	80
Total no. of days system did not operated	16	22	67	18	7	10	140	20
Total	96	108	203	115	93	78	693	
Total days	365	365	365	365	365	365	2190	100

Impact of decentralized biomass power system

The biomass-based decentralized power generation system implemented in Hosahalli village has provided multiple social, economic and environmental benefits; some measurable and others not. The potential benefits of large-scale spread of decentralized biomass power systems in India are as follows.

Social benefits

Provision of reliable and safe water supply for households on most days near the door-step, from a deep borewell. This reduces the drudgery involved in lifting and carrying water from an open water pond nearly a kilometre away. Women in this region spend about 2.6 h/day in collecting water. Further, the quantity of water consumed, an indicator of quality of life, which was low earlier (26 l/capita/day) has gone up based on field observations, due to nearly 2 h of water supply near the door-step of the houses. Women reported improvement in their own health as well as that of their children due to safe water supply and increased use of water and better hygiene.

Electricity for lighting in all houses has helped school-going children in their studies and women in their household chores. Earlier, women used to walk miles to the neighbouring village for milling grains at least once a week. Now a flourmill has been installed in Hosahalli itself.

The unique feature of the project in Hosahalli is equitable sharing of benefits by all the households and reliable provision of services on most days in a year, contributing to improved quality of life for all.

Economic benefits

These include employment and income generation and increased crop production. Establishment of energy forest, harvesting, transportation, wood-fuel chips, preparation and operation of the decentralized power generation system has created employment for two persons on most days and many more during different seasons. In Hosahalli 17 farmers irrigated 20 acres, growing labour-intensive cash crops such as vegetables and mulberry, thus creating employment and generating income.

Environmental impacts

Raising multi-species energy forest has led to soil and water conservation in the lands subjected to degradation. If mixed species forestry, as done in Hosahalli, is adopted, it will contribute to biodiversity conservation in degraded or wastelands. Biomass is low in ash compared to coal, leading to no or insignificant ash production. Finally, biomass combustion leads to insignificant sulphur emission.

Fossil fuel conservation and carbon mitigation

In the absence of biomass gasifier-based power supply, Hosahalli village would have used kerosene for lighting and diesel engine for pumping water for irrigation or would have been connected to the centralized grid, where nearly 70% of electricity is generated from coal power plants. Diesel, kerosene or coal combustion leads to emission of CO_2 and other greenhouse gases. The population of Hosahalli is 218 and in India 70% of its 587,000 villages has a population of less than 500. Thus, decentralized sustainable biomass-based power systems could substitute kerosene and diesel as well as coal-based power used in a large percentage of villages and contribute to reduction in the emission of greenhouse gases.

In Hosahalli, if all the services (Table 2) were to be provided by diesel-based decentralized generation system, the total diesel consumption for generating 18,900 kWh of electricity annually (average of 2001 and 2002) would be 12,995 l. The CO_2 emission from diesel use avoided would be 35 t CO_2/yr. The Hosahalli case study shows the potential of sustainable biomass-based decentralized power generation system for mitigation of greenhouse gases in small villages (< 500 population), which dominate rural India.

Forestry in degraded lands is a well-known climate mitigation option to sequester carbon in soil and standing trees. Biomass power based on sustainable biomass supply is a climate mitigation option for substituting fossil fuels (coal used in power stations, kerosene and diesel), leading to reduction in the emission of greenhouse gases.

Why biomass gasifier technology for rural electrification?

The biomass-based decentralized power generation system in Hosahalli has shown the technical and operational feasibility and acceptability by the rural community. Among the renewable energy technologies, biomass gasifier-based decentralized power generation holds great promise for meeting rural energy needs due to the following:

Technology maturity

Technology is mature with several designs and manufacturers who undertake planning and commissioning of small-scale biomass power systems and who also provide performance guarantee.

Availability in different capacity scales

Biomass gasifiers are available in different capacities for decentralized applications from 5, 20, 100 to 500 kW in India.

Feasibility of operating for different hours and periods

Biomass gasifier-based system can be operated from 1 to 24 h a day, depending on the load. The system can be operated 365 days in a year, if needed. Such a flexibility does not exist for other renewables such as wind, solar and micro-hydro system. Woody biomass feedstock can be transported over shorter distances and stored.

Feasibility of installation in any location or village

Biomass gasifiers can be installed and operated in any village where biomass is available or can be grown, except probably in desert areas. Such flexibility does not exist for other renewables such as solar, wind, micro-hydro and biogas systems.

Indigenous availability of technology and backup systems

Biomass gasifier technology is indigenously developed and transferred to manufacturers. Maintenance, spare-part supply and servicing facility, and infrastructure are available or can be organized, if demand arises in Karnataka and other states in India.

Economic viability

The economic viability is yet to be proven for renewables in India based on monitoring of field-based systems. Preliminary assessments available show that biomass gasifiers are economically feasible and have lower cost per kilowatt hour compared to other energy technologies[13].

Socio-economic benefits

Biomass gasifier-based power generation systems create jobs and skills in rural areas in biomass feedstock production, transportation and processing, and in operation and maintenance of the gasifier–engine–genset systems as well as end-use systems.

Land reclamation

India has vast degraded or wastelands (over 60 million ha), which urgently require revegetation to prevent further degradation. Biomass production, as feedstock for power generation, provides economic incentive to re-vegetate wastelands with energy forests.

Biodiversity conservation

Appropriate guidelines to discourage monoculture plantations and incentives to promote mixed species forestry, with appropriate density will promote biodiversity in degraded lands[14]. Use of forestlands to supply biomass or conversion of natural forest to energy plantations is not desirable and banned in India.

Climate change mitigation

In India, coal-based power plants account for 70% of electricity generated. Thus, every kilowatt hour of electricity generated based on sustainable biomass supply, leads to reduction in CO_2 emission by 1.0 kg. Biomass power is recognized as a prime option with high potential for reduction in carbon emission and climate change mitigation[15].

Despite the above advantages the rate of spread of biomass-based power generation technology in India is low, due to a number of policy, institutional and financial barriers[16]. There is need to address such barriers to promote biomass power in India.

Sustainable biomass power

In India demand for electricity is growing at 7% annually, particularly in rural areas. The power generation and supply situation is grim, with shortages in installed capacity and peak power supply. Electricity supply to low-load rural areas is characterized by high transmission and distribution costs and losses, low reliability of supply, shortages and subsidized pricing. Coal-based thermal power will continue to account for 70% of the installed capacity. Coal-based power generation is characterized by local and regional environmental degradation as well as greenhouse gas emissions, leading to climate change. Thus, the search is on for an environmentally sound alternative for meeting the power needs, particularly of rural areas in developing countries.

The Hosahalli (and Hanumanthanagara, though not described here) case study has demonstrated the technical and operational feasibility of a decentralized biomass gasifier-based power generation system to meet all the rural electricity needs in an environmentally sustainable manner. The technology is on the verge of commercialization. There is need for large-scale demonstration in different parts of India along with policy, institutional and financial support for large-scale spread of environmentally sustainable biomass power systems in India and other developing countries.

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