Rural bioenergy centres based on biomass gasifiers for decentralized power generation: case study of two villages in southern India

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Case studies of rural bioenergy centres, for decentralized power generation, in Hosahalli and Hanumanthanagara villages in southern India are presented. In each village, electricity is generated from a 20 kW woody-biomass-based gasifier system connected to a diesel engine generation system. Electricity is provided for lighting, pumping water for domestic use and operating a flour mill. A water-pumping system for irrigation is being planned. The technical and operational feasibility of the decentralized power generation system and the willingness of the local community to pay for the services has been demonstrated. Capacity utilization and efficiency of operation of the power generation system are low, and potential exists for improving both. The bioenergy system has generated socio-economic and environmental benefits.

1. Introduction

Among all renewable energy sources, biomass (ligneous, herbaceous crops, agricultural and municipal wastes) is the largest, most diverse and most readily available resource [World Bank, 1996] for energy. Biomass, particularly woody biomass, can be converted to high-energy combustible gas for use in internal combustion engines for mechanical and electrical applications. The potential of bioenergy for meeting rural energy needs in developing countries, particularly in India, has been shown to be high. A national-level analysis in India has shown that small biomass gasifier-based decentralized power generation systems (of capacity 20 to 200 kW) can entirely meet rural electricity needs [Ravindranath and Hall, 1995]. The study has also explored the concept of a "rural bioenergy centre", based on bioenergy technologies, for meeting all rural energy needs. However, there are very few field demonstrations of the technical, operational and financial viability of rural bioenergy centres or bioenergy technologies for rural electrification [Ravindranath et al., 2000]. Two "rural bioenergy centres" in southern India are electrifying their villages using energy forests and small biomass gasifier systems. This study presents an overview of this system of rural electrification with reference to:

- the technical performance of the bioenergy system;
- the operational feasibility and acceptability to rural communities;
- the maintenance and management aspects; and
- socio-economic and environmental impact.

2. Profile of case-study villages

Over 85% of the villages in India and nearly 100% of the villages in the state of Karnataka in southern India are electrified. But the centralized grid electricity supply to rural areas is characterized by shortages, low and fluctuating voltage and low reliability. Moreover, even though nearly 100% of the villages are electrified, only 42% of the rural *households* are electrified in Karnataka [REC, 1999].

ASTRA (Centre for Application of Science and Technology for Rural Areas), Indian Institute of Science, has implemented bioenergy-based power generation systems in Hosahalli and Hanumanthanagara villages of Tumkur district in Karnataka. It is a semi-arid region with a mean annual rainfall of around 700 mm. The features of Hosahalli and Hanumanthanagara are displayed in Table 1. The first energy forest and biomass gasifier-based decentralized power generation system was commissioned in 1988 in Hosahalli [Ravindranath et al., 1990] and an identical capacity system was commissioned in Hanumanthanagara in 1997.

- *Hosahalli.* At the time of implementation of the project, this was a non-electrified village. There are 35 households with a population of 218. All households practise agriculture and all of them depend on kerosene for illumination. There is an irrigation tank (water storage system for irrigation), but there is no reliable water supply system for crop production, which is largely rain-fed.
- *Hanumanthanagara.* There are 58 households with a population of 319. Hanumanthanagara was electrified a decade ago, but only 43% of the households are electrified. There are 5 electric pumps for lifting water for irrigation. A minor irrigation system installed by the government, with a 35 h.p. electric pump for lifting water for irrigation, has not been in operation for many years due to uncertain power supply and lack of maintenance.

Table 1. Profile of Hosahalli and Hanumanthanagara villages

Particulars	Hosahalli	Hanumanthanagara
Number of households	35	58
Population	218	319
Number of houses with grid electricity	Unelectrified village	25
Number of irrigation pumps	0	5
Number of farmers	35	58
Irrigated land (ha) (currently)	13	17
Other land (ha)	35	21
End-use services using electricity from bioenergy system		
Number of street lights	8	0
Drinking water tank capacity (l)	5000	4000
Number of households provided with lighting (some families have 2 houses)	42	58
Number of households provided with water taps	32	50
Flour mills	1	1
Drinking water tubewells	1	1
Irrigation tubewells	3	5
Potential area for irrigation (ha)	10	12

Table 2. Energy forest: area, species distribution and biomass growth rate

	Hosahalli	Hanumanthanagara
Area (ha)	4	8
Year of planting	1988	1995
Density (number/ha)	1496	1488
Species distribution and density/ha		
Acacia auriculiformis	192	504
Acacia mangium	-	136
Casuarina equisetifolia	4	220
Cassia siamea	316	-
Dalbergia sissoo	104	-
Eucalyptus	872	628
Gmelina arborea	8	-
Biomass growth rate		
Basal area (m^2/ha)[1]	11.48	1.95
Total biomass (t/ha)[2]	126	
Mean annual increment of woody biomass (t/ha/yr)	10.5	

Notes

1. Basal area is the total cross-section area of all tree stems at 132 cm above ground in a hectare.
2. Biomass (t/ha) = 50.66 + 6.52 (BA), where BA is basal area in m^2/ha. Biomass growth rate is not estimated for Hanumanthanagara as basal area is low (at 1.95 m^2/ha).

3. Biomass feedstock production

Woody biomass is the feedstock for the biomass gasifier systems installed in both the villages. The wood required is around 1-1.25 kg/kWh of electricity, which works out to about 10 t/year, in each village, for generating power to meet the requirements of lighting, water lifting for domestic use and flour mill operation. Additional wood required for generating electricity for pumping water for irrigation could be in the range of 20 to 30 t/year, depending on the area to be irrigated, in each village. To conserve the existing forests and non-forest trees on village lands, the project aims to meet all the woody biomass needs from dedicated energy plantations in village common lands. Details of the energy forest raised in the two villages are presented in Table 2.

Energy forest area. A dedicated energy forest was raised on 4ha in Hosahalli (planted in 1987 and 1995) and 8ha in Hanumanthanagara (planted in 1996) for supplying woody biomass sustainably.

Density and tree species distribution. The energy forests in both the villages had mixed species, dominated by eucalyptus, *Cassia siamea, Acacia auriculiformis, Acacia mangium, Dalbergia sissoo, Casuarina equisetifolia* and *Gmelina arborea.* The density of trees is around 1500/ha. No fertilizer or water supplements were provided in either of the villages. Fast-growing and coppicing tree species were selected for the energy forest. Further, *Cassia siamea, Acacia auriculiformis, Acacia mangium, Dalbergia sissoo,* and *Casuarina equisetifolia* are nitrogen-fixing species. Growing woody biomass feedstock was the main objective of the energy forest. Thus, wood fuel was the main product harvested, apart from poles for construction.

Woody biomass productivity. Using estimates of basal area (based on measurement of tree diameter at 132 cm above ground) and biomass estimation equations, the standing biomass and mean annual increment were calculated (Table 2). The mean annual increment in Hosahalli is estimated to be 10.5 t/ha/year. Of the 140t of wood harvested in this village since 1990, about 100t has been used as feedstock for power generation since 1988, and the rest as fuelwood and timber. Woody biomass production is adequate to meet the biomass feedstock requirement to generate power for domestic activities. Any shortfall in biomass requirement for power generation for irrigation will be met from the woody residue of mulberry crop at around 10 t/ha/year, which in turn is grown using the irrigation water supplied by the bioenergy system. Coconut is another important crop grown in the villages in this region, whose woody residue could also be used as feedstock for gasifiers. If biogas plants or improved stoves are adopted significant savings in wood fuel are feasible and the wood fuel saved could be used as feedstock for gasifiers.

4. Power generation and end-use systems

The bioenergy system includes the power generation, distribution and end-use components. The gasification system consists of a reactor, cooling and cleaning system. The reactor is an open-top downdraft type with ceramic lining for the high temperature zone. There are a top and a bottom water seal. The raw hot gas is drawn through the coolers where water is sprayed to cool and clean the gas. The cooled gas is taken through coarse and fine sand-bed filters to remove any dust and condensables from the gas [Mukunda et al., 1994].

- *Power generation.* A 20 kW biomass gasifier developed at ASTRA, along with diesel-engine generation set, was installed in Hosahalli for generating power. An identical capacity biomass gasifier-based power generation system was installed in Hanumanthanagara. Descriptions of power generation capacity and end-use services of these systems are given in Table 3.

  The wood gasifier has a conversion efficiency of 21% from wood to electricity (including diesel used). It is a dual-fuel system with a diesel replacement of 85%. The typical gas composition is 18 ± 2% CO, 18 ± 2% H_2, 1-2% CH_4, 10 ± 1% CO_2, and the rest N_2; with an average calorific value of 4.5 MJ/kg. The cold gas efficiency is about 78%, while cold tar and particulates are 25 ± 5 mg/Nm^3 and 30 ± 5 mg/Nm^3.
- *Lighting.* A separate distribution line has provided to carry the electricity generated to all the end-use systems. All the households in Hosahalli and Hanumanthanagara are electrified and connected to the bioenergy system. Each house has been provided with power supply to energize either fluorescent or incandescent lamps. The load due to lighting is about 3.7 kW in Hosahalli and 4 kW in Hanumanthanagara.
- *Drinking water pumping.* A 3.5 hp submersible pump is connected to the power generation system for lifting water for domestic use from deep tubewells in each of the villages. All the households are provided with piped water supply through private taps.
- *Flour mill.* A 7.5 hp capacity flour mill was installed during 1994 in Hosahalli and 1997 in Hanumanthanagara for milling grain. The flour mill is being operated by a village entrepreneur on a contract basis. Residents of Hosahalli as well as neighboring villages get grain milled, leading to additional income for the entrepreneur.
- *Irrigation water pumps.* Deep tubewells for pumping ground water were drilled in both the villages for providing irrigation water to crop production. The connected load is 18.5 kW from 3 tubewells and pumps in Hosahalli and 25.5 kW from 5 tubewells and pumps in Hanumanthanagara.

Table 3. Installed capacity of power generation systems and end-use services

Particulars	Hosahalli kW	Hanumanthanagara kW
Power generation capacity	20	20
Drinking water pump	2.6	2.6
Flour mill	5.6	5.6
Irrigation water pumps	18.5	25.5
Lighting load (home + street)	4.0	4.0
Total installed capacity	30.7	37.7

5. Percentage of days operated and electricity generated

Even though the Hosahalli system has been in operation since 1988 and the Hanumanthanagara system since 1997, the percentage of days the system was operated and units of electricity generated is presented only for the latest years, namely, 1998 and 1999, in the following sections. The number of days the power generation system functioned and kWh of electricity generated are given in Table 4.

- *Hosahalli.* The system was operated for 96% and 94% of the days during 1998 and 1999 respectively. The system was operated for 4.0 to 4.5 hours per day. Electricity generated ranged from 34 to 38 kWh/day during 1998 and 1999, respectively. Thus, the power generation system was operated on most days and the reliability of decentralized power generation supply is very high.
- *Hanumanthanagara.* The system was operated for 86% and 90% of the days for 3.5 and 3.2 hours/day in 1998 and 1999, respectively. The electricity generated ranged from 16 to 17 kWh/day.

The main reasons for non-operation during 1999 in Hosahalli (for 23 days) and Hanumanthanagara (for 38 days) are given in Table 5. Non-availability of the operator and diesel were the main reasons for non-operation of the systems in Hosahalli and Hanumanthanagara. Social problems contributed marginally to non-operation in Hosahalli.

Though the system was operated for most of the days during 1998 and 1999, the load on the system was very low, leading to a capacity utilization of 7% ([12,023 kWh/year]/[8760 h/year and 20kW]) in Hosahalli and 3% in Hanumanthanagara.

The low capacity factor is due to the load being only from the domestic services. Irrigation water pumping is the dominant activity requiring electricity in rural areas in India [Ravindranath and Hall, 1995]. Irrigation and industrial activities have not yet been commissioned till the end of December 1999. The load on the power generation system and capacity use is likely to increase to over 40%, with the commissioning of the irrigation system during 2000, where irrigation water pumps will be operated for 12 hours/day for 200 to 250 days and all the domestic services will be operated for 4 to 5 hours/day for 365 days in a year.

6. Performance of the biomass gasifier-based power generation system

Performance data are presented for the latest years, 1998 and 1999. Performance data for Hosahalli for some of the earlier years are published elsewhere [Ravindranath et al., 1990; Srinivas et al., 1992].

6.1. Dual-fuel operation

Under the dual-fuel mode of operation, a diesel replacement

Table 4. Number of days power generation system operated and mean hours operated/day

Extent of system operation	Hosahalli		Hanumanthanagara	
	1998	1999	1998	1999
Total no. of hours system operated/year	1423.0	1550.0	1107.0	1048.0
Mean hours operated/day	4.0	4.5	3.5	3.2
Total electricity generated/year (kWh)	12023.0	12884.0	5462.0	5320.0
Electricity generated per day (kWh)	34.0	38.0	17.0	16.0
No. of days system operated/year	349.0	342.0	313.0	327.0

Table 5. Reasons for not operating the system and diesel mode of operation during 1999

Reasons	Reasons with number of days			
	Hosahalli		Hanumanthanagara	
	For not operating system	For diesel mode of operation	For not operating system	For diesel mode of operation
1. Engine related	4 (18%)	-	7 (18%)	-
2. Gasifier related	-	16 (19%)	-	35 (39%)
3. Operator non-availability	7 (30%)	-	15 (40%)	-
4. Diesel non-availability	9 (39%)	-	16 (42%)	-
5. Cut and dried fuelwood non-availability	-	70 (81%)	-	55 (61%)
6. Social problems	3 (13%)	-	-	-
7. Total number of days	23	86	38	90

Note

Values in the table are number of days assignable to the reason. Values in parenthesis are percentage (%) of total days.

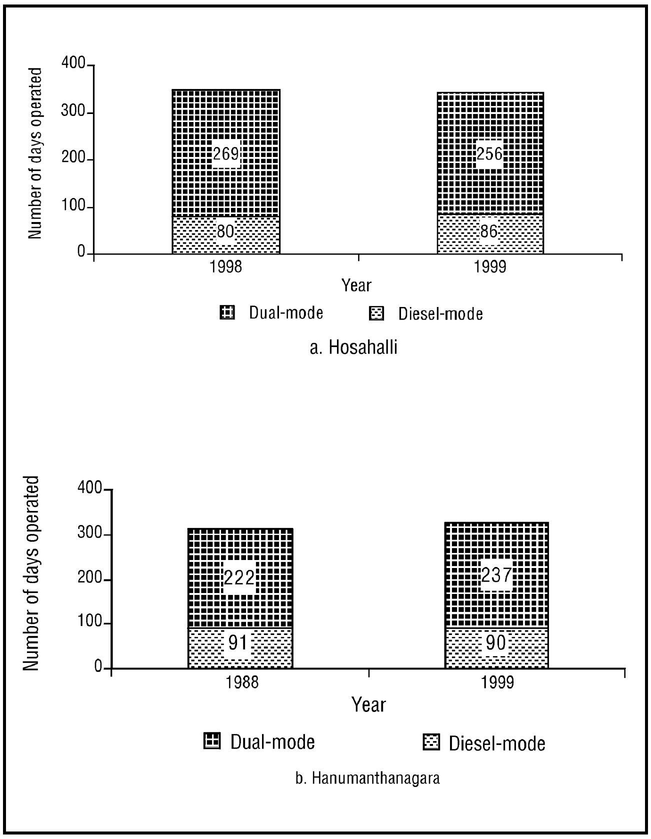

Figure 1. Number of days biomass gasifier system operated on diesel and dual-fuel mode in Hosahalli and Hanumanthanagara during 1998 and 1999.

of over 85% is feasible. The power generation system is expected to operate on dual-fuel mode on all the days in a year. However, the system operates on diesel-alone mode if there are any problems due to gasifier maintenance and non-availability of dried wood chips or the trained operator. The extent of operation of the power generation system on dual-fuel mode is given in Figure 1.

In Hosahalli, the gasifier-based power generation system was operated on dual-fuel mode for 77% and 75% of the days the system was in operation during 1998 and 1999 respectively. In Hanumanthanagara, the dual-fuel mode of operation was in the range of 71 to 73% of the days the system was in operation. The major reasons for operation on diesel-alone mode include shortage of dried, chopped and sized wood, due to non-availability of labour for cutting wood or due to rain preventing drying of wood. On the other hand it was encouraging to see that gasifier-related problems were only responsible for diesel-alone operation for a relatively small number of days.

6.2. Diesel replacement in power generation

Under the dual-fuel mode of operation and under ideal conditions of operation and maintenance, over 85% of diesel replacement is feasible. In both the villages diesel replacement of over 70% was achieved, though for a smaller percentage of days. Performance data from the field in the two villages for over two years shows that over 70% of diesel replacement is feasible even in rural conditions.

Table 6. Mean annual specific fuel and energy consumption for power generation

Village	Year	Diesel mode operation diesel use l/kWh	Dual-fuel mode		
			Diesel use l/kWh	Wood use kg/kWh	Specific energy consumption MJ/kWh
Hosahalli	1998	0.432 (15.42)	0.182 (6.49)	1.35 (20.25)	26.74
	1999	0.379 (13.53)	0.173 (6.17)	1.27 (19.05)	25.22
Hanumanthanagara	1998	0.502 (17.92)	0.258 (9.21)	1.30 (19.5)	28.71
	1999	0.499 (17.81)	0.248 (8.85)	1.15 (17.25)	26.10

Notes

Values in parenthesis are in MJ/kWh

1 kg of wood = 15 MJ; 1 kg diesel = 42 MJ.

Specific energy consumption = (for example, taking the first row) (0.182 l/kWh × 0.85 kg/l × 42 MJ/kg of diesel) + (1.35 kg/kWh × 15 MJ/kg of wood) = 26.74 MJ/kWh

6.3. Specific fuel and energy consumption

The specific fuel and energy consumption indicates the feedstock requirement per unit of electricity generation and the efficiency of the system (Table 6). The figures represent overall data for 1998 and 1999, where the diesel consumption in dual-fuel mode indicates the diesel used during start-up, shutdown and other periods during normal operation.

- *Diesel mode.* Specific diesel fuel consumption in diesel-alone mode ranged from 0.379 to 0.502 litre (l)/kWh. The observed range of diesel consumption is due to varying loads on the system. Under ideal operational conditions the diesel consumption would be 0.33 l/kWh above 60% of rated power.
- *Dual-fuel mode.* The diesel fuel consumption ranged from 0.173 to 0.258 l/kWh. The diesel fuel consumption under ideal operational conditions is 0.33 l/kWh. The specific fuelwood consumption ranged from 1.15 to 1.35 kg/kWh.
- *Specific energy consumption.* The specific energy (from diesel and fuelwood input) consumption ranged from 25 to 28.7 MJ/kWh of electricity generation. Thus, the electricity generation efficiency is low, in the range of 12.5 to 14%. The efficiency of conversion reported for the IISc Gasifier is in excess of 78% for the wood to gas and about 22% from energy input in the form of wood and diesel.

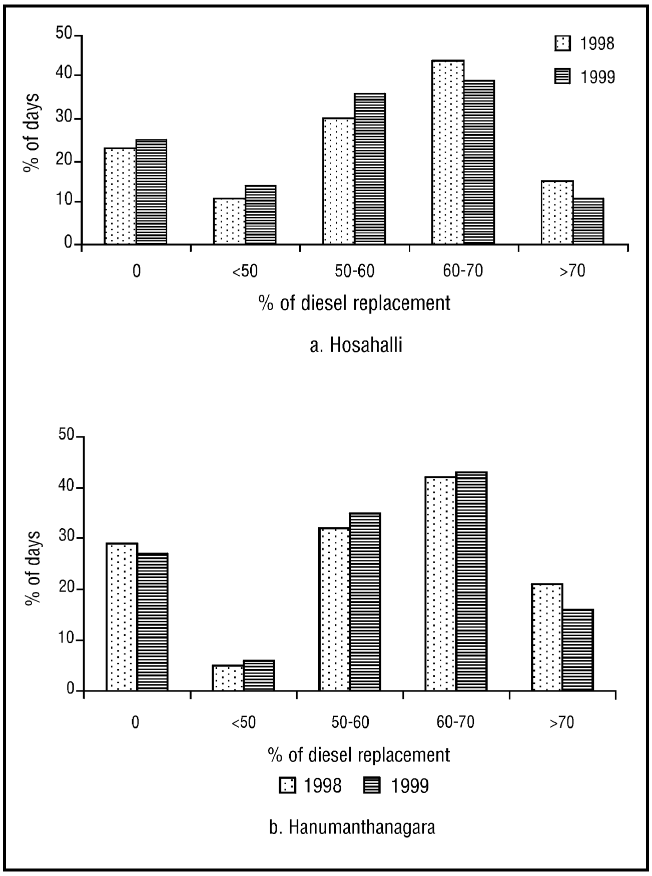

Figure 2. Diesel replacement (%) achieved in 1998 and 1999

6.4. Low diesel replacement and conversion efficiency

Diesel replacement, specific fuel consumption and conversion efficiency depends on the system, operation and maintenance parameters. Some of the factors contributing to the observed low diesel replacement and high specific fuel consumption leading to lower efficiency are as follows.

- The low plant load on the engine contributed to high diesel consumption. With an average load in the range of about 8kW, the engine is operating at around 40% of its capacity.
- Use of unsized and moist wood chips led to creation of air blocks in the reactor zone, leading to lower gas production and irregular flow of gas to the engine system.
- Lack of regular maintenance of gas pipeline and sand-bed filters.
- Improper operational conditions such as radiator leak, inadequate water in radiator, and inadequate air filter maintenance contributed to lower performance.
- Some engine- and alternator-related maintenance problems occurred after 2500 hours of operation in Hosahalli.

However, it is important to mention that it is possible to

Table 7. Payment of fee-for-service in Hosahalli and Hanumanthanagara

Village	Year	Total fee expected				Actual collection Rs/year	Percent recovery (%)
		Lighting Rs/year	Drinking water supply Rs/year	Flour mill Rs/year	Total Rs/year		
Hosahalli	1998	4005	3860	400	8265	4851	59
	1999	3930	3840	600	8370	4364	52
Hanumanthanagara	1998	3780	-	600	4380	1020	23
	1999	3420	2480	800	6700	5065	76
Total		15135	10180	2400	27715	15300	55

Note

Fee-for-service: lighting: Rs. 5/bulb point; water supply: Rs. 10/household; flour mill: Rs. 0.50 to 0.80/kg grain

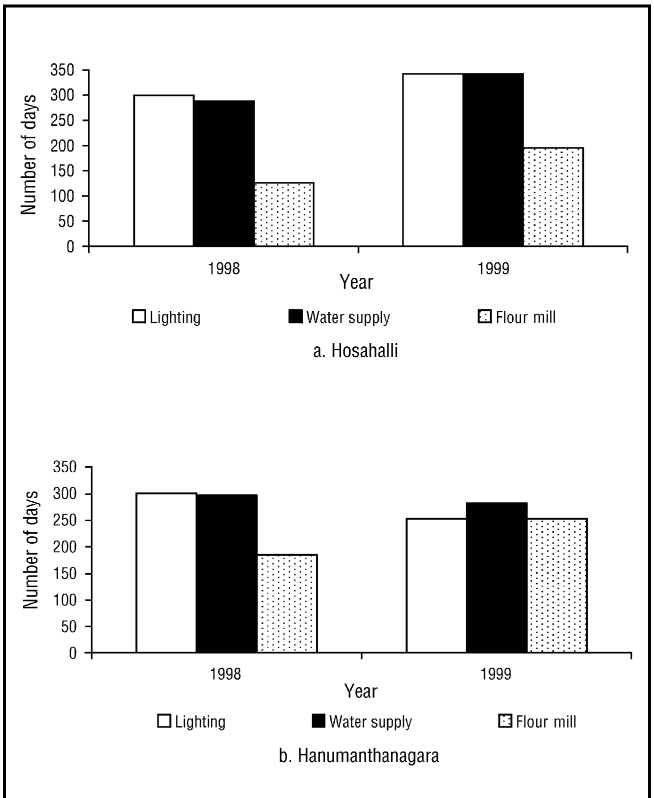

Figure 3. Number of days when lighting, pumping, drinking water supply and flour mill service was provided

mitigate these problems and some measures have already been adopted. The plant load factor is being improved through commissioning of the irrigation water-pumping activity. A mechanical wood chipper has been designed and its use will lead to near-uniform sized wood chips. Drying of wood will be done using the exhaust heat from the engine. A maintenance contract is being given to an entrepreneur to regularly check and rectify any maintenance problems. The skills of the operator may have to be enhanced so that he can correct some of the minor maintenance problems.

7. Services provided

One of the factors that contributes to the quality of life in rural areas is the quality and magnitude of use of energy for various services such as lighting, lifting water for domestic and irrigation purposes, milling grain, and agro-industries. The project aimed at not only generating electricity from bioenergy systems, but also integrating the energy end-use services such as lighting and pumping water for domestic use. The services also generate income to enable recovery of the capital, operational and maintenance costs. Residential and street lighting, lifting water for domestic use and flour-mill operation are the services that are fully operational in both the villages. The number of days these services were provided during 1998 and 1999 is given in Figure 3.

Lighting and domestic water supply was provided for over 80% of the days in both the villages. The flour mill was operated for a lower percentage of days as it was left to the entrepreneur, who operated the system depending on the demand for the service. The village communities wanted domestic water supply to be operated for all the 365 days of year as they do not have storage facilities. In urban areas in the region including Bangalore (the capital city of Karnataka state, with a population of 5 million), water is supplied only for 50% of the days in a year. It is important to plan for a water storage facility in each house in rural areas. Similarly, the electricity supply for lighting in rural areas connected to the grid is poor, with frequent failures and fluctuating voltage.

Thus, the reliability of drinking water supply and electricity for lighting from the decentralized power systems in both the villages is superior to the electricity supply from the grid system as well as even the urban water supply system in Karnataka.

8. Fee-for-service

The financial viability of rural bioenergy systems depends on recovery of investment, operational and maintenance costs. Households, farmers and industries should pay for the services. The approach adopted in the project villages is not to sell electricity and charge per kWh of electricity used, but to charge for the services provided. The rates for the services were fixed in consultation with the village community. The rate for lighting service is Rs. 5/bulb-point/month (for a 40W fluorescent light tube for 4 h/day requiring about 5 kWh/month). Water supply through private water taps is charged at Rs. 10/month/household. Milling of grain is charged at Rs. 0.5 to 0.8/kg of grain. The households agreed to the concept of *fee-for-service*. Recovery of *fee-for-service* in Hosahalli and Hanumanthanagara is shown in Table 7.

The project was implemented in two phases. In Phase I, the goal was to provide services such as piped water supply and electric lights to all the households and ensure 100% of the households derive benefits. During this phase lower tariffs were fixed in consultation with the village community. In Phase II, when irrigation water supply is provided, the incomes are likely to increase due to increased crop productivity as well as non-agro-based activities such as mulberry-based silkworm rearing. When the incomes go up, higher, indeed commercially viable, tariffs will be fixed. In Hosahalli as well as Hanumanthanagara the recovery of fee-for-service ranged from 52% to 76% during 1998 and 1999. Thus, it is hoped that the recovery of fee-for-service would improve in the years to come.

In India, energy supply is highly subsidized, particularly for rural areas [Ravindranath and Hall, 1995]. Electricity supply for irrigation water pumping is nearly fully subsidized. Electricity supply for domestic services such as lighting is also subsidized. Kerosene for domestic purposes such as lighting and cooking is partially subsidized. Given such a scenario, the recovery of fee-for-service in Hosahalli and Hanumanthanagara is very encouraging. When the irrigation water supply system is fully commissioned, leading to increase in income, the recovery of fee-for-service is likely to improve to near 100%. The long-term viability of rural bioenergy systems will depend on the success of fee-for-service at economic costs. This would depend on the increased incomes leading to increased repayment capacity and appropriate institutions to recover and manage the finances. Thus, there is a need for integrating the energy system with the end-use systems.

9. Management of the bioenergy systems

One of the key barriers to the spread of renewables is the absence of participatory institutions and enterprises for planning, implementation, operation, maintenance and management [Ravindranath et al., 2000]. A participatory approach was adopted for the planning, implementation and management of the bioenergy systems. The Hosahalli bioenergy project benefited significantly from a nearby on-going community biogas system-based rural electrification and water supply project in Pura village in respect of the implementation arrangements and management system [Reddy et al., 1995]. The institutions adopted and their functions are as follows.

- *Village assembly.* The village assembly, consisting of all adult men and women, meets periodically to take broad policy decisions and to select a small management committee. Some of the issues discussed include:
  - selection of operators;
  - sharing of water and electricity;
  - fixing rates for services;
  - allocation of land for energy forest;
  - forest protection arrangements;
  - selection of management committee; and
  - resolution of conflicts.

The village assembly has generally met once in 2 to 3 months to discuss the above issues. The assembly had to discuss several conflicts related to sharing of water, forest protection and recovery of fee-for-service.

The Hosahalli village community, particularly the farmers, initially agreed to share the water from the tubewell, even if they are situated on any farmland. However, one of the farmers was unwilling to share the water from the tubewell identified on his farm. But he was persuaded by the community to agree to share the water with other farmers. Similarly, forest protection, particularly from neighboring villages, was an issue. On a few occasions trees were felled by residents of neighboring villages and possibly by a few people of Hosahalli also. In the absence of legal documents and tenurial rights, the Hosahalli village community had difficulty in preventing extraction of wood by the neighboring village community. However, extraction has not affected supply of wood to gasifiers and the forest has regenerated.

- *Management Committee.* The management committee consists of 6 members selected by the village assembly, and has the following functions:
  - supervizing the operators and the operation of the system;
  - organizing distribution of services;
  - responsibility of informing about repairs/breakdown and putting systems back into operation after repairs;
  - collection of service charges;
  - protection of the power generation system and forests; and
  - procurement of inputs and supervision of accounts.

The management committee meets frequently and some of the responsibilities have been shared among the members of the committee.

- *Non-governmental organization (NGO) for interface between village community and other agencies.* Rural Development Training Society, a local NGO, acted as the agency for managing the system and for coordination with the implementation agency and the government. NGOs or entrepreneurs have to manage the rural bioenergy systems for sustainability. Self-help groups (SHG) of the village women were established by this NGO to create awareness and develop the culture of small savings. The experience of using the NGOs is still limited. The SHG has only recently been initiated. Its performance is yet to be monitored.
- *Operators.* In each village two persons were trained in the operation and minor maintenance of the power generation and end-use system. To generate electricity for lighting, pumping water for domestic use and flour-milling, one operator is employed. However, when fully operationalized to encompass power generation for irrigation water pumping, two or more operators may be needed.
- *Major institutional and social conflicts.* The Hosahalli

and Hanumanthanagara bioenergy systems have been in operation for nearly 12 and 3 years respectively. All the decisions on implementation, operation and management were largely taken through a participatory approach. However, the demonstration projects in Hosahalli and Hanumanthanagara were not without social and institutional problems and even conflicts. The major institutional and social conflicts encountered are as follows.

1. Land allocation for energy forest and forest protection. Land allocated by the Hosahalli village community was partly encroached upon and disputed by the farmers of a neighboring village. Forest protection was highly successful initially for 4 to 5 years. Extraction of trees by the neighboring village community occurred after that and particularly during 1998. The Hosahalli village community could not ensure protection, as it did not have any legal documents on the tenurial status. However, the forest vegetation has recovered and is growing. Clarity on land tenurial status and appropriate documents giving authority to Hosahalli will enable it to exclude others.
2. Sharing of irrigation water. The deep tubewells for extracting ground water for irrigation were located in private lands. Initially, the farmers had agreed to share the water equitably, no matter on whose land the tubewell points were located. However, due to intra-village conflicts, there was unwillingness to share the water. This problem was solved through discussion. All the three farmers on whose land the water source was located, agreed to share the water as a community resource.
3. Recovery of fee-for-service. Though there was complete agreement in the village assembly, some households failed to pay regularly, leading to conflicts and partial success of the fee-for-service concept. There was an improvement in the recovery during the later months of 1999.
4. Operator and management committee conflicts. The inter-family social problems of the village were reflected in the relationship between the operator and some of the members of the committee. The only solution is to get operators acceptable to all in the village, probably through an enterprise.
5. Repairs and maintenance of the systems. The village community is not equipped to undertake the repair and maintenance of the systems. This may not be a problem, if a large number of systems are installed in a cluster, as an entrepreneur could undertake maintenance contracts.

10. Impact of bioenergy system

The decentralized bioenergy systems have the potential to provide social, economic and environment benefits [Ravindranath and Hall, 1995]. Some of the impacts of the bioenergy systems in the two villages are presented in this section.

- Social benefits. Provision of piped water supply has reduced drudgery for women in fetching water, as earlier women used to fetch water from a far-off source. The quantity of water consumed is likely to have increased due to the convenience of private taps. Water comes from deep tubewells and is thus not contaminated. According to the women of these two villages, the health of the children has improved due to the use of safe water from deep tubewells. Electric lights in all the households of both the villages have contributed to increased silkworm-rearing and enabled children to study in the evenings. Women need not go walking several km to the neighboring village carrying grain for milling. Thus, the electric lights, piped water supply and flour mill have reduced drudgery and improved the quality of life, particularly that of women and children.
- Economic benefits. Forestry activities, operation and maintenance of power generation and end-use activities have created employment. When the irrigation system is commissioned, employment and incomes are likely to go up. Under the irrigation programme every farmer will get water supply for 0.2-0.4 ha. Farmers are likely to grow mulberry, which is a cash crop. Many farmers are likely to take up silkworm-rearing, creating additional employment and income. Farmers are encouraged to grow cash crops in the area to be irrigated and they are free to grow other crops in the rest of their land. Thus, all households are likely to derive employment and income generation benefits. The decentralized or renewable energy projects should include end-use as well as income generation activities as an integral component of the project.
- Equity. Equitable distribution of benefits is a unique feature of the bioenergy projects in Hosahalli and Hanumanthanagara. Every house is electrified, including thsoe of the poorest. Nearly every house has private taps for water supply. Every farmer will get irrigation water for about 0.2 ha. Every family has access to the flour mill.
- Environmental impacts. Degraded land (4 ha in Hosahalli and 8 ha in Hanumanthanagara) has been reclaimed with multi-species forestry, leading to conservation of soil and promotion of biodiversity. The land was an abandoned water storage tank, subjected to over-grazing, soil erosion and land degradation. There was no tree cover on the land. The village common land was being slowly encroached upon by farmers owning adjoining land, and but for the project all the land would have been encroached upon by now.

Kerosene consumption in both the villages has been avoided. Kerosene conserved annually is estimated to be 2.244t. Bioenergy is globally promoted as an important renewable energy technology for mitigating climate change. Bioenergy, based on sustainable supply of biomass from energy forests, is a CO_2-neutral energy option. Further, substitution of fossil fuels as observed in Hosahalli and Hanumanthanagara (kerosene substitution) could lead to a net CO_2 emission reduction. The bioenergy project in these two small villages in India has led to a CO_2 emission reduction of about 6t of CO_2 annually.

11. Conclusions and implications

The energy forest and biomass gasifier-based decentralized power generation systems in Hosahalli and Hanumanthanagara have demonstrated the technical and operational feasibility as well as the acceptance of alternative energy systems by the rural communities. If the bioenergy system is based on woody biomass, it is necessary and feasible, as shown in the case-study villages, to grow all the biomass feedstock required from dedicated energy or multipurpose forests, as well as to use crop residues. Woody biomass from the existing forests and village trees should not be depleted for energy purposes.

The economic viability of the system is yet to be proven. It depends on the capacity utilization as well as the efficiency of the operation and maintenance of the systems. The proposed commissioning of irrigation systems in both the villages during 2000 is likely to increase the capacity use of the power generation system as well as incomes of the households. The bioenergy project has also demonstrated the acceptability and feasibility of the fee-for-service concept, even though energy and services in the neighboring villages are subsidized by the government. There is a need for large-scale demonstration of the financial viability of bioenergy systems. Development of participatory institutions and entrepreneurship is critical for large-scale spread of bioenergy technologies. ■

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Publication schedule

Energy for Sustainable Development continues to redeem its pledge to maintain the new schedule for publication which started with Volume IV No 1, dated June 2000. We had decided to complete publication of Volume IV during this calendar year so that we could begin and finish each new volume during one calendar year. Consequently, although ***Energy for Sustainable Development*** will in future be a quarterly journal, we are completing publication of Volume IV before the end of 2000. We have already published Volume IV No 2 in August. The current issue, Volume IV No 3, is dated October 2000 and Volume IV No 4 will be published in December this year.