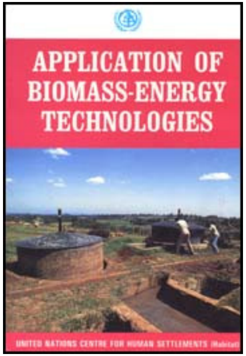

Application of Biomass Energy Technologies (HABITAT, 1993, 168 p.)

V. BIOGAS

A. Introduction

Biogas is produced by the anaerobic fermentation of organic material. Biogas production can be considered as being one of the most mature biomass technologies in terms of the numbers of installations and years of use in countries such as China and India. It has the potential for multiple uses, e.g., cooking, lighting, electricity generation, running pumpsets and other agricultural machinery, and use in internal-combustion engines for motive power (Bhatia, 1990). Biogas technology is currently receiving increasing attention due to a combination of factors. Anaerobic digestion can make a significant contribution to the disposal of domestic, industrial and agricultural wastes which, if untreated, could cause severe public-health and water-pollution problems. The remaining sludge can then be used as a fertilizer (providing there is no polluting contamination). It therefore

contributes to control of environmental hazards and recycling of nutrients whilst alleviating dependence on imported fuels (Gunnerson and Stuckey, 1986). When manure is used in digesters, the sludge actually performs better as a fertilizer since less nitrogen is lost during anaerobic digestion, the nitrogen is available in a more useful form, weed seeds are destroyed, and the sludge does not smell and does not attract flies or mosquitoes. Furthermore, it yields more useful energy than when burnt for cooking as is the common practice in many rural regions.

Biogas production systems are relatively simple and can operate at small and large scales in urban or very remote rural communities. Almost all current biogas programmes, however, are based on family-sized plants which lose significant economies of scale, are suited more for cooking than electricity generation, and often do not produce enough output just to supply this need. Community biogas plants are more economical and can provide enough electricity for pumping water lighting etc. However, there are social difficulties of organization and equity in the contribution of feedstock and the distribution of costs and benefits.

The basic designs of biogas plants - fixed-dome (Chinese), floating-drum (Indian), and bag (membrane) - have been used in a number of countries for many years. The designs reflect modest optimization for reduced capital costs and increased volumetric gas yields. Biogas can be used in internal-combustion engines using either the gas alone in an adapted petrol engine, or using a mixture of biogas and diesel in an adapted diesel engine. The main advantage of a diesel/biogas engine is the flexibility in its operation since it can operate as a dual-fuel engine using biogas and/or diesel. Usually, dual-fuel engines are so designed that when biogas is available the engine will utilize it, and when it is exhausted, the engine automatically switches over to diesel without any interruption. Diesel engines are reliable, simple to maintain, have a longer working life and higher thermal efficiency than petrol engines and are also more extensively used in rural areas.

Biogas technology has made some important advances in recent years, e.g., in China, Denmark and the United States. However, the technology of anaerobic digestion has not yet fully realized its promised potential for energy production. In industrialized countries biogas programmes have been hindered by operational difficulties, lack of basic understanding, and innovation. In some developing countries, development of biogas programmes has lacked urgency because of readily available and inexpensive traditional fuels such as fuelwood and residues. Lack of local skills, together with high costs, tend to be a significant deterrent to optimization and widespread acceptance of biogas technology (Hall and Rosillo-Calle, 1991).

B. India

In India, the history of biogas technology goes back to 1937, when experiments with anaerobic digestion were carried out using municipal sewage sludge. Experiments were then extended to cattle dung in 1939, and in 1946, a batch-type reactor was developed. In 1950, the floating-cover digester was designed, which was subsequently improved and propagated by the Khadi and Village Industries Commission (KVIC). This model is, thus, known as the "KVIC" or Indian type, extensively used in India and elsewhere the world.

The "multi-model multi-agency" approach adopted by the Department of Non-conventional Energy Sources (DNES), which has become a full-fledged Ministry (MNES) has greatly stepped up the propagation of family biogas plants (FBPs) in the country. In this approach, several NGOs have been recognized and encouraged as disseminators of FBPs, in addition to the traditional disseminators, such as KVIC and Rural Development Departments (RDDs) (Khandelwal, 1990; Moulik, 1990). With a planned crash programme beginning in 1984 and subsequently involving many NGOs (Moulik, 1990), annual targets exceeding 150,000 biogas plants in the country have been consistently recorded (Khandelwal, 1990). In response to several field-level problems, and low dung availability etc., the DNES has been funding and monitoring several R&D attempts to improve

efficiency of existing plants as well as to bring out alternative designs and fermentation concepts for alternate feedstocks. The number of biogas plants built in India is extremely low (3-9 per cent of the potential, as discussed below) and the percentage of satisfactorily functioning plants is equally low.

Table 6. Performance evaluation of biogas application in India

Location (Total, number X 1000, C7 Sample No.)	Distribution of plants (percentage)			
	Functional	Non-commissioned incomplete etc.	Defective	Operational problems
DNES 1991				
Bihar (62.8, 1671)	72.4	-	3.8	23.8
Himachal Pradesh (24.5, 520)	92.2	-	2.3	5.5
Karnatoka (72.6, 1495)	94.1	-	1.9	4.0
Maharastra (421.1., 2309)	92.5	-	1.1	6.4
UP (197.9, 1800)	60.6	-	11.8	27.6
Total (1403.6, 19,841)	84.3	-	4.0	11.7
C.S.V. Wardha	48.5		52	
I.I.M. Ahmedabad, Gujarat				
Janata plants	60		40	
KVIC plants	89		11	
KVIC	70		30	
C& Aud. General				
Harayana	41.85	53.15	4.0	

Himachal Pradesh	62.2	37.8		
Uttar Pradesh	89.6	10.4		
IRMA, Gujarat	40		60	
Directorate of Agriculture	64.3		35.7	

Table 7. Biogas for cooking and power-generation

					FBPs			**Commu**	
Villages	**Number of households**	**Population**		**Dung per day (kg)**	**Feasible number of households for FBPs**	**Population (percentage)**	**Cooking population (percentage)**	**Electr**	
								Ener	
		Human	**Cattle**					**Total (kWh)**	**Pe cap (kW**
Ungra	166	1010	478	151	24	13	36	69	0.0
Suggenahalli	155	726	325	1 463	13	9	34	47	0.0
Pura	87	463	248	1 116	15	16	41	36	0.0
Hosahalli	36	191	127	572	8	20	51	18	0.0
Malenahalli	86	547	500	2 250	44	51	70	73	0.1
Tattikai	85	622	380	1 710	42	70	47	55	0.0
Sirsimakki	81	611	448	2016	50	47	56	65	0.1

Currently with nearly 1.5 million biogas plants in the country, monitoring the spread and efficiency is being carried out at many levels involving the state governments, the DNES's own monitoring offices and by independent agencies commissioned by the DNES. In addition, several independent surveys carried out by various research, educational, developmental and financial institutions also exist in the form of published articles, reports and surveys. However, there are wide variations among them, possibly because of differences in criteria used. An excerpt of these surveys, presented in table 6, shows that, barring two locations, most biogas plants had a performance rating above 60 per cent. The national-level performance reported by DNES shows a good performance of 84 per cent. However, more details are needed to evaluate these data.

The biogas potential has been estimated differently and varies according to the feasibility criteria adopted. Consequently the estimated potential family biogas plants varies from a low value of 15 million (Khandelwal, 1990), to a medium value of 23 million (Moulik and Mehta, 1991) and a high of 40 million (DNES, 1992). The maximum potential for utilizing biogas for cooking/power generation has been estimated in table 7. The bovine population in different states varies significantly along with average dung yield (TEDDY, 1991). As a result, in the states of Haryana, Himachal Pradesh and Rajasthan, 44 to 55 per cent of the rural population could meet their daily cooking needs through this energy technology. In most other states, 24-33 per cent of the rural cooking-energy needs can be met through biogas, thus reflecting its large potential in the country. It is also evident that in most states basic rural energy services (characterized by constant year round demand), such as domestic lighting, water supply and flour milling, among others, can be met through biogas systems. It is, however, acknowledged that it might not be possible to realize this high potential.

The target set for the year 2000 is 12 million units with an estimated budget of $7 billion (Dec. 1988 $). There are indications, however, that in the coming decade the subsidy policy of the Government for the biogas programme will be reduced significantly - from 40

per cent of the total investment in the 1985-1990 plan to 25 per cent in 1990-1995 and to 10 per cent in 1995-2000 (Sinha and Kandpal, 1990). Since electricity is heavily subsidized and the electricity tariff is only one fifth of the real cost of providing electricity in rural areas, the farmer will usually opt for an electric motor instead of a diesel engine or a dual-fuel (biogas/diesel) engine. It is worth noting that

> **"presently the main motivation of farmers for adapting a dual-fuel engine (usually meaning better-off farmers who could afford $15 to $20 for converting the existing diesel engine to a duel-fuel engine) is to provide a back-up power source for their irrigation systems to guard against inadequate electricity supplies and diesel shortages" (Bhatia, 1990, p. 582).**

1. *Family biogas plants* (*FBPs*)

The family biogas plant (FBP) implementation programme in the country is mostly carried out by state-level rural development bodies which rarely transcend the state boundaries in this matter. Presented below are case studies in four different states of the country, representing different agroclimatic situations, designs of biogas plants adopted, promotional techniques etc. These case studies have been chosen based on availability of a reasonably holistic analysis of the techno-economic parameters. The four states chosen are Maharashtra, Bihar, Himachal Pradesh and Karnataka. The techno-economic and management aspects are discussed later.

The approach and methodologies pertaining to diffusion of FBPs are generally uniform throughout the country. The approach of the programme is broadly promotional and therefore incorporates a significant subsidy component, financed through the apex governmental body, the Department of Non-conventional Energy Sources (DNES) and implemented through the state-level Rural Development Departments (RDD). A promotional approach becomes necessary in the existing mixed economy and dual society,

because over 50 per cent of rural households neither have the purchasing power nor are capable of articulating demands for a conventional market economy (Krishnaswamy and Reddy, 1988, unpublished studies). This necessitates alternative technology-transfer mechanisms. A flow chart representing this action programme is presented in figure 3. The entire programme is a target-oriented programme, where targets fixed by the RDD to *zilla parishats* (ZP, the nodal agency) is further distributed among blocks (*taluks*) where the block development officer (BDO) is the responsible official. The promotion of the biogas plants begins at the village level wherein the *gram sevaks* motivate potential beneficiaries and receive applications for onward transmission to the BDO. The BDO is responsible for their scrutiny for the satisfaction of the feasibility criteria and size selection, sanctioning of subsidy and assistance in obtaining required bank loans. The extent of subsidy provided depends upon the backwardness (socially) and the geographic location (DNES, 1992). Following the sanctioning the NGOs, entrepreneurs and skilled masons are enlisted to supervise and construct these plants on a turnkey basis.

Normally the beneficiaries are free to choose from six different designs and models approved by the DNES for the purpose of taking advantage of the subsidy. Both types of plants, namely the Indian floating-drum type (KVIC) and the Chinese fixed-dome types, and their variants are promoted by the programme (Khandelwal, 1990). All these biogas plants have been designed mainly for use with cattle dung as substrate, though other slurrifiable animal dung can also be utilized. The main technical features of these two types of plants are listed in table 8 which shows that while fixed dome plants are cheaper they are found to have low reliability in the field owing to several technological and diffusional constraints discussed later. Currently there is greater thrust in the promotion of the latest fixed-dome design (Deenabandu, improved “Shanghai” design).

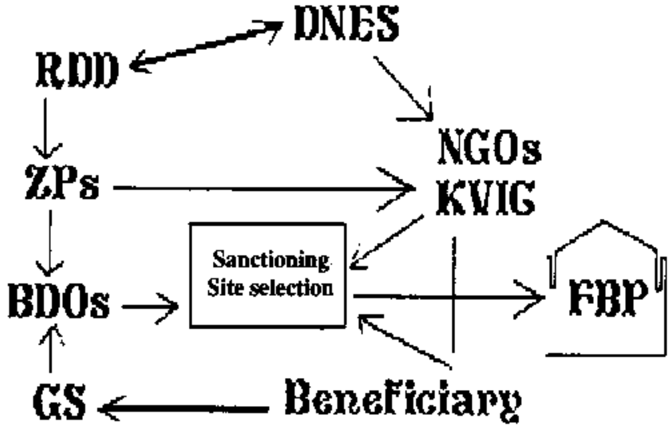

Figure 3. FBP diffusion pattern

Table 8. Main technical features of fixed-dome and floating dome and floating-drum biogas plants

Fixed dome	Floating drum
• masonry of concrete structure entirely	masonry digester with steel, plastic or composite based gas holder
• low costs	high costs (20-30 per cent higher)
• low maintenance	frequent maintenance
• low reliability	high reliability
• high masonry and supervisory skill required	low masonry and fabricating skills
• variable gas pressure complicates	constant gas pressure simplifies appliance design and

appliance design	usage

Greater attention is currently being focused on fixed-dome plants since they are cheaper and are being diffused through several voluntary agencies which offer a two year warranty and a follow-up programme (Veena Joshi et al, 1992). During the construction of biogas plants the following steps are involved (in close coordination with the BDO and supervisor):

- **Selection of appropriate sites;**
- **Excavation for the digester (mostly by the beneficiary);**
- **Procurement of materials required (cement, sand, bricks, burner etc.);**
- **Construction and installation;**
- **Commissioning, use and maintenance of the biogas plants.**

All these steps play an important role and impart several constraints on the diffusion as discussed later.

The management of the technology at the national level is effected through the governmental machinery and a few NGOs. Its implication, effectiveness and alterations needed are discussed later. At the FBP user's level however, the management is restricted to operation and maintenance of the devices and plants as well as storage and deployment of manure after they are installed. The routine operation and maintenance involve the following:

- **Daily feeding and slurry removal;**
- **Cleaning and upkeep of plant, pipelines and devices;**
- **Frequent painting of the gas holder (mild steel, (MS) floating-drum design);**
- **Minor repairs to plants.**

All major repairs require the services of a skilled mason or biogas supervisor.

2. *Results*

(a) *Maharashtra*

The state of Maharashtra accounts for the largest number of biogas plants constructed (421,000, DNES (1992)). The state is centrally located in the country and is less subject to gross temperature fluctuations leading to less fluctuating gas yields. Maharashtra also was one of the largest promoters of the biogas programme accounting for nearly half the annual rate of biogas plants being built in the country and amounting to approximately 1000 plants per district annually. While both designs of plants coexist in the state, the Deenabandhu model has received greater attention in the recent past (Dyal Chand, 1988, 1989). The very rapid dissemination rate of biogas plants has been characterized by an approach to target fulfilment and laxity in adhering to the feasibility criteria established for sanctioning, namely, bovine holding and family size). This is the possible reason for non-commissioning of over 50 per cent of the biogas plants built during the study years. It is also reported that about 30 per cent of the plants are underfed leaving only 4 per cent of them optimally functioning (see tables 6 and 8). The adoption pattern indicated that the probability to "commission" and successfully operate biogas plants increased with the land- and bovine-holding size. Therefore the large-sized plants had greater chances of being commissioned due to the fact that they were sanctioned to households having larger bovine-holdings as well as possible access to resources. Conversely, the smaller plants led to poor adoption because they were being aimed at the lower economic groups who did not have enough cattle, a crucial feasibility criterion which had been overlooked.

(b) *Bihar*

In Bihar, the majority of the biogas plants have been constructed in the plains. The prevailing agro-climatic conditions of Bihar suggest that there would be seasonal fluctuations in gas yields and efficiency caused by the extreme climate. Moulik and Mehta

(1991) report a high degree of functional plants (89 per cent) sampled in 21 districts of Bihar. The major failure pattern among the non-functional plants is presented in table 9. While both types of plants exist, the dissemination programme is dominated by the fixed-dome plants. Irrespective of the design, nearly 39 per cent of the failures could be attributed to lack of adequate training in operation and maintenance. About 53 per cent of defective plants were structural failures due to inadequate knowledge and training in FBP construction. Seasonal variations in plant performance were gauged by measuring the time for which gas was used for cooking and lighting purposes. While lighting use seemed to be constant irrespective of the season, marked shortages in gas for cooking were felt in winter. The authors conclude that the construction of biogas plants in the state has been stalled by the lack of adequately trained masons necessitating additional follow-up programmes to reduce failures.

Table 9. Cash-flow statement (August, 1989), Methan Community Biogas Plant

Income (Rs)		Expenditure (Rs)	
Gas connections:		Salaries:	
		Plant operator	6 000
		(8 × 25 Rs/day × 30 days)	
Users	11 200	Driver	1 000
(280 × 40 Rs)		Supervisor	1 000
Occasional users	370	Diesel	1 200
(37 × 10 Rs)		Machine oil	600
		Repair charges	500
Total 11 570			10 300

(c) *Himachal Pradesh* (*HP*)

Kalia and Kanwar (1991) studied the performance of FBPs during 1987-1988 from a sample survey (5 per cent, 553 plants of the 10,093 installed) in six districts of HP. They reported a high functionality rate of 82 per cent as well as low gas yields in winter (see tables 6 and 8). Of the 553 plants, 11.5 per cent were found to suffer from different modes of failure. All plants installed in the state were of the fixed-dome "Janata" model type. Though plant sizes ranged from 2 to 6m^3, over 65 per cent them were of 3-m^3 capacity. Background information collected indicated that the literacy rate among the biogas users in the sample was high (76 per cent). About 18 per cent of the biogas plants were constructed for households belonging to backward sections. Most beneficiaries had income levels well above the state's average. The cost of plants in this state seems to be strongly influenced by accessibility to construction materials and, on an average, were 12-45 per cent higher than costs recommended by the DNES. Owing to low winter temperatures, the gas production levels fall to 50 per cent of the rated capacity. The 2-m^3 size plants seem to be the least affected by the low temperatures. From these results the authors suggest that the 2-m^3 size is the optimum and most efficient.

(d) *Karnataka*

Karnataka has many distinct agro-climatic zones and offers a good location for studying the application of biogas plants in contrasting situations. As a part of this study a sample survey of 50 biogas plants in the Western Ghat region (Sirsi, Uttara Kannada district) and of another 50 plants installed in a semi- arid region (Kunigal, Tumkur district) were carried out. While 6-m^3 and 8-m^3 floating-drum plants were popular in Sirsi, both fixed-dome and floating-drum plants have been installed in Kunigal. Biogas plants constructed in Sirsi were generally over-sized and cost about 20-30 per cent more than recommended prices. The plant users had a high level of income, high literacy and exhibited a high

degree of motivation. These were probably the reasons for the absence of the non-functional FBP in the sample. Most plants were well maintained and repaired within 2-3 months of the occurrence of faults. There was little relation between the land-holding size, income levels, adult bovines, family size, time required between awareness and installation etc. In order to overcome the maintenance problems of the MS gas holders, most plant owners were switching to FRP gas holders at the time of major gas holder breakdown.

In Kunigal, the fixed-dome biogas plants designed and installed locally have exhibited a high degree of failure (70 per cent). The major cause of failure was identified as gas leakage through the dome. However, all floating-drum plants installed were functioning well in the sample.

3. *Community biogas plants* (*CBPs*)

In contrast to the FBP programmes mentioned earlier, the community biogas plants (CBPs) and institutional biogas plants (IBPs) are diffused through a separate programme due to the amount of funding and expertise required. From 1972 to date, about 494 large-scale biogas plants (Venkata Ramana, 1992) have been constructed among which 254 are claimed to be CBPs (although many do not exist today). There is little information available on 224 of the CBPs and only partial information on 34 of them. As in the case of FBPs, 40 per cent or more of these plants have, possibly been, closed down and about 10 per cent not commissioned due to having been built without proper feasibility studies. Another 6 per cent are being run for demonstration purpose and are virtually institutional biogas plants (IBPs). Among the rest, 34 per cent have severe problems of inadequate dung supply. Most CBPs are in Punjab (16) and Gujarat (4) (Venkata Ramana, 1992; Singh, 1988). In all these plants gas has been supplied for cooking except for the case of Pura village, where gas is now being converted into electrical power after having passed through the cooking-gas supply phase. Four CBPs are reported to be working satisfactorily

at present, three of which are in the Gujarat state characterized by a very high cattle to human ratio and existence of successful milk cooperatives. The success of the Pura plant in a semi-arid tract of the country may however be attributed to: (a) the gas being converted to electricity where felt needs like water supply and reliable domestic illumination are strong binding forces; and (b) continuous monitoring and involvement of research scientists (of ASTRA).

From the literature available it appears that there has been a learning phase between 1972 and 1987 wherein most biogas plants constructed have been abandoned for one or several reasons. All success reports about CBPs are after this period. It has been analysed that there are three categories of CBPs and, consequently, three case studies representing each of them have been outlined below.

> **(a) Successful CBPs operating continuously and located in areas where dung availability is high, such as in Gujarat and Punjab. Nevertheless, in spite of high dung availability, the cooking needs of only 50 per cent of families are being met**
>
> **(b) "Problematic/sick" CBPs where problems are related to inadequate dung input 70 per cent of the CBPs fall into this category. There is, however, very few data available for plants in this category. The case study of Pura, phase 1, is therefore cited in which the authors were involved and the gas produced was supplied for cooking during that period. It is, therefore, considered suitable for this category of CBPs.**
>
> **(c) CBPs used for energy services other than cooking (Pura, phase II).**

(a) *Community biogas plant at Methan Village, Gujarat* (Venkata Ramana, 1992)

(i) *Approach*

With the confidence developed by the successful on-going milk cooperative, a community biogas plant system was planned for the cooking-gas supply. The entire capital cost was borne by DNES and the installation work was executed through a private firm of consultants on a turn-key basis. The dung required for the initial charging of the plants (600 tons) was contributed by the villagers and was paid for by the contracting firm.

All the members of the village contribute dung to the system daily, and in turn, get the digested slurry back on a pro-rata basis. The gas users are charged at a flat rate of Rs. 40/month. There are some 40 migratory families who use the gas only for a few months. When their connections are not in use, they are charged only Rs. 10/month.

The daily operation of the plant has been entrusted to a contractor who supplies a minimum of eight labourers to feed the plant remove the slurry and clean the plant

(ii) *Technologies*

***Biogas plants:* There are eight biogas plants with a total gas capacity of 630 m^3/day. Six of them are of 85 m^3/day capacity, and the remaining two are of 60 m^3/day. All of them are of the conventional Indian (KVIC) design. The plants are spread over three sites in the village to ensure a uniform pressure in the gas distribution system. Each of the sites measure 50m X 50m approximately. The biogas plants are fitted with mechanical stirrers for mixing the inlet dung slurry.**

***Piping:* Underground piping of a total length of 40km has been installed for the gas distribution from the plants to the individual households Fourteen water traps have been built at various points of the piping to remove the condensed water.**

***Number of biogas stoves:* Initially in 306 households, currently in 326 households.**

(iii) ***Capital cost.*** **Rs. 1,919,000 (1987).**

(iv) ***Results***

Since its commissioning in April 1987, the system has run more or less continuously without any major problem. A supervisor and a driver remove the dung from households to the plant daily on a trolley, attached to a tractor. Complete cooking-fuel requirements of 326 out of the 600 families, i.e., 54 per cent, are being met with biogas. The drudgery of collecting firewood by the women belonging to these 326 families and their exposure to smoke has been avoided and hence there has been an improvement in health and quality of life. Furthermore, nearly 13 tons of fresh cattle dung is being transformed to an excellent fertilizer everyday. In addition, 10 of the villagers namely, one supervisor, one driver and eight plant operators, have been employed in their own village. It has been proved that the villagers, by forming a cooperative society, can manage the decentralized energy systems in the village environment successfully.

(v) ***Management***

A registered society, The Silver Jubilee Biogas Producers and Distributors Cooperative Society (SJCS), was established with all the biogas beneficiaries as members. A sum of Rs. 100 per household was charged as share price towards membership of the SJCS. In addition, a sum of Rs. 301 was collected as a connection fee from each beneficiary, with an assurance that the money would be utilized within the village. These sums of money formed the capital base for the Society.

The Society maintains such documents as resolutions of the meetings, cash bills and pass books, share capital register, ledgers and stock registers, accounts etc.

(b) ***Pura Community Biogas Plant*** **(*****First Phase*****) (*****KSCST, 1983, 1984*****)**

(i) *Location*

Pura village, in Kunigal Block, Tumkur district, Karnataka State.

(ii) *Approach*

The energy consumption and requirement patterns of some six villages in the block were studied. After analysing the data, Pura village was selected for installing the biogas plant. Several discussions about the proposed community biogas system were held with the village community so as to ensure its support for the system.

The main approach adopted was: (a) priority was given for cooking needs because cooking alone accounts for 91 per cent of the energy consumed in Pura; (b) to supply gas to all the households to enable the whole community to benefit; (c) to supply gas free of cost because firewood, their cooking fuel, was gathered at zero cost; (d) all households owning bovines should contribute dung to the plant to ensure maximum community participation; (e) dung supply would not be paid as the gas would be supplied free of cost; and (f) digested sludge should be returned to all the dung suppliers on a pro-rata basis. Finally, a "public utility" approach, e.g., having salaried employees, was adopted like in an urban setting unlike the traditional expectation of "voluntary labour" in rural areas.

The complete cost of the system was borne by the sponsors, the Karnataka State Council and Technology (KSCST), and the gas supply system started operating on 1 June 1982. Intensive training had earlier been imparted to the plant operators and the village women were trained in cooking with biogas. Regular joint discussions of all involved in the scheme, namely the project team, village leaders and beneficiaries, were maintained, with a frequency of at least once a month, about the status of the project. Accounts of dung and sludge were maintained to build the confidence among the beneficiaries/participants.

(iii) *Technologies*

Biogas plants: **The biogas digesters were of the Indian floating-drum type (Rajabapaiah et al, 1992). However, the detailed dimensions were based on the cost-minimization theory developed earlier and on realistic residence times that had been observed under similar conditions and low-cost construction techniques were utilized. The salient features of the modified design are: (a) the volumetric ratio (gas produced/unit volume of the digester) is high, i.e., 0.5 compared to 0.2-0.3 in conventional fixed-dome and floating-drum plants; (b) the plants have a better performance rating compared with the original KVIC plants, producing 14 per cent more biogas at the ambient temperature in spite of the 40 per cent reduction in the digester volume; (c) the plants are shallower and wider compared with the conventional ones, thereby accelerating the rate of gas release from the production zone to the gas holder, hence, the modified plants are easier to construct wherever the ground water table is high; and (d) the plants are 40 per cent cheaper than conventional plants.**

The Pura plants are capable of digesting a maximum of 1.25 tons of cattle dung/day and delivering a maximum of 42.5 m^3 biogas/day as well as 1.2 tons/day of sludge. In order to increase the reliability of the system, it was decided to construct two plants (each with half the rated gas production capacity) with a common inlet tank, instead of a single plant.

Sand-bed filters: **These filters enable: (a) transporting digested sludge from the biogas plant back to the homes and compost pits; (b) the use of the filtrate which contains some anaerobic micro- organisms, to mix with the input dung thereby marginally enhancing gas production; and (c) a reduction in the water requirement for charging biogas plants (Chanakya and Deshpande, 1993).**

The 11 filters constructed at the village can, together, handle as much as 1.7 m^3/day of slurry. Each filter of 4 m^2 area (4m × 1m), consists of three layers; 5 cm of gravel at the bottom, 3 cm of sand in the middle, and a wire mesh on top. The digested slurry effluent is

poured to a height of 10 cm above the wire mesh. The maximum recovery of water from the filter is about 70 per cent. The filtered and dried sludge was returned to the dung suppliers at the rate of 600 gms for each kg of dung delivered to the biogas plant.

Piping: **A network of underground PVC rigid piping consisting of different diameters, ranging form 65 mm to 15 mm, and totalling 1500 m in length, was installed to connect the households to the plants.**

Burners: **Low-cost biogas burners made out of discarded tins, costing Rs. 15 each and one tenth of the cost of biogas stoves then available in the market, were developed, fabricated and installed in all the households.**

(iv) ***Results***

At best, the gas could be supplied for only about 1 hour/day, leaving most of the households cooking unfinished even for the morning meal. It became clear that dung alone was not sufficient to meet the complete cooking energy requirements and other feed-stocks had to be explored. However, on the organizational side, the project provided the following insights: (a) the merits of the slurry filtration and of the non-monetization of dung and filtered sludge rather than buying dung and selling sludge; (b) the advantage in running the system with trained and salaried employees just as in any urban public utility which does not depend on voluntary labour, (c) the importance of training the households in the safe and efficient use of gas; (d) the crucial role of periodic maintenance of the system; and, above all, (e) the complete participation of the community.

After two-and-a-half years of trouble-free operation, the villagers did not want to lose the system despite the disappointments as regard the amount of gas, and they requested the project team to utilize the established infrastructure and divert the gas to non-cooking purposes such as electricity generation. This is detailed in section VI. B.

C. China

For over 50 years the Chinese have struggled to develop and diffuse biogas technology. At present, China has about 5 million family biogas plants in working order. Although over 7 million have been constructed in the past, many of them were poorly built with inadequate mixtures of earth, sand and lime. This was mainly because during the 1950s and 1970s "quality" was sacrificed at the altar of "quantity" which has left a lasting impression in farmers' minds of digesters never producing much gas. Today, about 25 million Chinese people use biogas mainly for cooking and lighting. A further 10,000 large- and medium-size biogas digesters are working in food factories, wineries, livestock farms etc. Biogas produced in large enterprises is transferred to centralized biogas supply stations, biogas motive power stations (422 with an installed capacity of 5849 HP) or biogas electric power stations (822 with a total of 7836 kW).

The Bureau of Environment Protection and Energy (1991) estimates that about 54 per cent of the energy requirements (equivalent to about 282 Mtcoe) of the 900 million rural population comes from over 560 Mt of biomass, mainly in the form of straw and firewood although this is probably a conservative estimate. Continued reliance on traditional patterns of biomass supply and use to meet rural household fuel needs may result not only in greater disparity between supply and demand, but also in greater disruption of local agricultural and ecological systems. Improved efficiency of biomass production and use thus has become imperative (World Bank, 1985). Additionally, energy shortages may be one of the fundamental motives for the continued development of biogas. The use of human excrement in digesters rather than spreading it on the field (as is usual in China) can destroy more than 90 per cent of the intestinal parasites and other pathogens thus making the nutrient recycling process far more hygienic. This is because the Chinese digestion plants have a long retention time of about six months (Rajabapaiah et al, 1992). In addition to animal and human dung, about 2 Mt of straw is digested each year (Daxiong et al, 1990; Zong 1989).

Daxiong et al (1990) carried out an economic analysis of 58 biogas plants in Tongliang, Sichuan, and compared this with data produced by other researchers in 242 biogas plants in Hubei. Their analysis shows a high rate of return on investment in biogas and short payback periods of between one and four years (see table 10). Capital costs vary from 15 to 40 yuan per m^3 of digester capacity, and the annual gas output varies from about 30 to 40 m^3 per yr for each m^3 of digester. The annual value of this biogas in terms of savings in coal, kerosene, burned biomass, labour and fertilizer varies from about 7 to 16 yuan. If operating costs are included, the internal rate of return (IRR) varies from 59 per cent to 114 per cent.

Biogas plants in China have been subsidized and/or received low-interest loans. Since 1980, the State has allocated more than 10 million yuan every year for the development of biogas, which represents 200 yuan for each plant constructed every year. This money is spent in improving biogas equipment, promotion, standardization, servicing, training, research on new technology etc. Standardized production techniques and equipment have significantly improved the reliability and quality of biogas supply; there are 116 biogas research centres in China today (Daxiong et al, 1990; Anon., 1991).

The more recent opening-up of the economy to financial incentives is beginning to have a major effect on the biogas programme. Until 1983, when a peasant built a digester the State and local government provided two thirds of the money and also guaranteed the supply of building materials. Since 1983, there has been a move towards financial self-reliance which has resulted in a reduction in subsidies from two thirds to one third which, in turn, has led to a decrease in the construction of biodigesters. Although the rate of return remains high, the increase in the initial capital outlay is a disincentive to users. For example, Sichuan province which before 1983 built an average of 250,000 biodigesters annually, constructed only 81,000 in 1983 (Daxiong et al, 1990).

Socio-economic changes in China are also affecting biogas production. For example, rural

migration to the more-economically-developed areas has resulted in peasants not having sufficient organic matter to fill their biogas digesters (since they produce fewer pigs); also, since biogas production is labour-intensive, there are not enough people (particularly young people) to take care of the biodigesters. Additionally, due to improving living standards, a growing number of peasants prefer to buy privately-sold coal than to use biogas, because it saves time which can be spent on more lucrative work (Daxiong et al, 1990).

Tabel 10. Economic analysis of biogas plants in Tomgliang

Locations:		**Tongliang**	**Hubei (1)**	**Hubei (2)**	**Hubei (3)**
Year		1993		1993	
Sample size (number of plants)		58	76	70	%
Average pit size (m^3)		6.6	8.0	5.2	8.0
Costs		Unit cost m^3 (yuan)	Cost per m^3 (yuan)	Cost per m^3 (yuan)	Cost per m^3 (yuan)
	Quantity per digester				
Cement (kg)	440				
Crushed stone (tons)	2.5				
Sand (tons)	1.5				
Coating (kg)	1				
Rolled steel, etc (kg)	3				
Total materials		13.39	17.67	17.18	8.57
Work days					

-skilled	17	1.5	3.86	9.9	3.02	3.76
-unskilled	26	1	3.94			
Other expenses			2.43	4.09		0.95
Other equipment				7.79	2.02	1.69
Total capital costs			23.6	39.35	22.22	14.97
Total operating costs (yuan/year × year)[a]			3.87	45.3	40.5	36
Total costs including operating costs for 15 years			62.3	84.65	6172	50.97

Notes:

[a] Life = 15 years

The costs of construction of biogas plants are difficult to compare between countries and over time due to the importance of controlled prices in China. The capital costs in Tongliang and Hubei vary from 15 to 40 yuan per 1 m^3 of digester capacity, and the annual gas output varies from about 30 to 45 m^3 yr from each m^3 of digester.

The value of this gas in terms of savings in coal, kerosene, burned biomass, labour and fertilizer varies from about 7 to 16 yuan/m^3 digester capacity. This represents a pay-bach period of between about 1 and 5 years. If the daily operating costs are included, the internal rate of return varies from about 59 to 14.2 per cent.

In the 1975-1978 period, each biogas plant cost about 80 yuan as compared with

156 yuan for a 6.6 m^3 plant in 1983, although this involved twice as much labour (80 work days/plant in 1988) and the output from each digester averaged only 151 m^3 compared with nearly 300 m^3 in the current plants.

***Source:* Daxiong et a. 1990.**

This changing situation seems to indicate that production and management of biogas will become more centralized and industrialized in both rural and urban areas and will be used as part of an integrated production system. In this way, advanced technology could be used to increase production and financial returns and thus will have greater appeal to peasants. As living standards improve so will the demand for energy. Since commercial energy production in China cannot keep pace with the expected rise in consumption, adequate energy supplies in rural areas cannot be guaranteed. Hence, biogas appears to be a very viable energy source.

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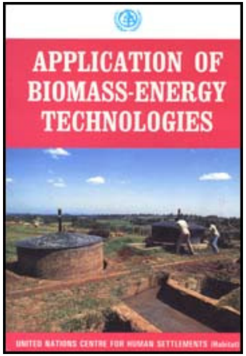

Application of Biomass Energy Technologies (HABITAT, 1993, 168 p.)

VI. CONVERSION OF BIOMASS INTO ELECTRICITY

A. Gasification

Usually, electricity from biomass is produced via the condensing steam turbine, in which the biomass is burned in a boiler to produce steam, which is expanded through a turbine driving a generator. The technology is well-established, robust and can accept a wide variety of feedstocks. However, it has a relatively high unit-capital cost and low operating efficiency with little prospect of improving either significantly in the future. A promising alternative is the gas turbine fuelled by gas produced from biomass by means of thermochemical decomposition in an atmosphere that has a restricted supply of air (Larson and Svenningson, 1991). Gas turbines have lower unit-capital costs, can be considerably more efficient and have good prospects for improvements of both parameters.

The basic principles of gasification have been under study and development since the early

nineteenth century, and during the Second World War nearly a million biomass gasifier-powered vehicles were used in Europe. Interest in biomass gasification was revived during the "energy crisis" of the 1970s and slumped again with the subsequent decline of oil prices in the 1980s. The World Bank (1989) estimated that only 1000 - 3000 gasifiers have been installed globally, mostly small charcoal gasifiers in South America.

Biomass gasification systems generally have four principal components:

> **(a) Fuel preparation, handling and feed system;**
> **(b) Gasification reactor vessel;**
> **(c) Gas cleaning, cooling and mixing system;**
> **(d) Energy conversion system (e.g., internal-combustion engine with generator or pump set, or gas burner coupled to a boiler and kiln).**

When gas is used in an internal-combustion engine for electricity production (power gasifiers), it usually requires elaborate gas cleaning, cooling and mixing systems with strict quality and reactor design criteria making the technology quite complicated. Therefore,

> **"Power gasifiers worldwide have had a historical record of sensitivity to changes in fuel characteristics, technical hitches, manpower capabilities and environmental conditions" (Sanday and Lloyd, 1991, p. 14).**

Gasifiers used simply for heat generation do not have such complex requirements and are, therefore, easier to design and operate, less costly and more energy- efficient. All types of gasifiers require feedstocks with low moisture and volatile contents. Therefore, good-quality charcoal is generally best, although it requires a separate production facility and gives a lower overall efficiency.

In the simplest, open-cycle gas turbine the hot exhaust of the turbine, is discharged

directly to the atmosphere. Alternatively, it can be used to produce steam in a heat-recovery steam generator. The steam can then be used for heating in a cogeneration system; for injecting back into the gas turbine, thus improving power output and generating efficiency known as a steam-injected gas turbine (STIG) cycle; or for expanding through a steam turbine to boost power output and efficiency - a gas turbine/steam turbine combined cycle (GTCC) (Williams & Larson, 1992). While natural gas is the preferred fuel, limited future supplies have stimulated the expenditure of millions of dollars in research and development efforts on the thermo-chemical gasification of coal as a gas-turbine feedstock. Much of the work on coal-gasifier/gas-turbine systems is directly relevant to biomass integrated gasifier/gas turbines (BIG/GTs). Biomass is easier to gasify than coal and has a very low sulphur content. Also, BIG/GT technologies for cogeneration or stand-alone power applications have the promise of being able to produce electricity at a lower cost in many instances than most alternatives, including large centralized, coal-fired, steam-electric power plants with flue gas desulphurization, nuclear power plants, and hydroelectric power plants.

It appears that the BIG/GT technology could be available for commercial power generating applications before the turn of the century. According to Williams and Larson (1992), efficiencies of 40 per cent or more will be demonstrated in the mid-1990s, and by 2025 these could reach 57 per cent using fuel-cell technologies being developed for coal. Gasifiers using wood and charcoal (the only fuel adequately proved so far) are again becoming commercially available, and research is being carried out on ways of gasifying other biomass fuels (such as residues) in some parts of the world (Foley and Barnard, 1983). Problems to overcome include the sensitivity of power gasifiers to changes in fuel characteristics, technical problems and environmental conditions. Capital costs can still sometimes be limiting, but can be reduced considerably if systems are manufactured locally or use local materials. For example, a ferrocement gasifier developed at the Asian institute of Technology in Bangkok had a capital cost reduced by a factor of ten (Mendis, undated). For developing countries, the sugarcane industries that produce sugar and fuel

ethanol are promising targets for near-term applications of BIG/GT technologies (Ogden et al, 1990).

Gasification has been the focus of attention in India because of its potential for large-scale commercialization. Biomass gasification technology could meet a variety of energy needs, particularly in the agricultural and rural sectors. A detailed micro- and macro-analysis by Jain (1989) showed that the overall potential in terms of installed capacity could be as large as 10,000 to 20,000 MW by the year 2000, consisting of small-scale decentralized installations for irrigation pumping and village electrification, as well as captive industrial power generation and grid-fed power from energy plantations. This results from a combination of favourable parameters in India which includes political commitment, prevailing power shortages and high costs, potential for specific applications such as irrigation pumping and rural electrification, and the existence of an infrastructure and technological base. Nonetheless, considerable efforts are still needed for large- scale commercialization.

B. Pura village, India

In India, there has recently been increasing interest in large community-sized digesters, of which around 25 are now in operation nationwide. An example of one of the few successful community biogas plants can be found in Pura village, some 100 miles west of Bangalore. The Centre for Application of Science and Technology to Rural Areas (ASTRA) at the Indian Institute of Science at Bangalore helped to build the community plant. As explained earlier, despite careful planning and execution, the plant was initially subject to many problems. However, ASTRA learnt a lot from this first effort and used the experience and recommendations of the villagers to redesign the plant to meet different requirements (Reddy et al, 1990).

As of April 1991, the population of Pura village was 463. Before the biogas system was

installed, only 45 per cent of the homes were electrified from the grid (Rajabapaiah et al, 1992), and this often did not provide enough electricity to power their lights.

Although the team from ASTRA had assumed that gas for cooking would be a priority, the villagers of Pura actually put clean drinking water first. It had been calculated mat the digester could supply enough gas to power a generator to supply electricity which could then be used to pump water to a reservoir. However, the villagers, understandably, wanted assurance that other people would supply dung before they handed over their own. At the same time, ASTRA wanted the assurance that people would supply dung before it set up the water pump. There seemed no way out of this impasse, and the biogas project stopped in 1984. Meanwhile, other developmental project work by the ASTRA team within the village continued, and it was eventually able to overcome many of the problems and revive the project.

It was possible to set up the biogas plant in the first place because the villagers had nothing to lose by participating in the project. Women already collected the dung for use as fertilizer, the project merely "borrowed" this dung and returned an equivalent quantity of better-quality slurry. However, to make it successful required the establishment of community involvement in the organization and running of the scheme. According to Rajabapaiah et al, (1992),

> **"The crucial administrative step in Pura was establishing a scheme for dung collection and sludge return based on a delivery fee (of Rs. 0.02 or 0.1586 US cents per kilogram), which goes primarily to the women. This ensures the involvement of women who are the principal beneficiaries of the water supply and the electric lights."**

Once villagers experienced the benefits of the gas - clean drinking water from taps, a reliable source of electricity, improved fertilizer etc. - they were willing to take

responsibility for the running of the digester, and ensuring that the benefits were distributed fairly. A village development society (*grama vikasa sabha*) was established involving the traditional community leaders. Pura had not had a village committee since before colonial days. They achieved an outstanding 93-per cent collection of dues from 1988 to 1991. Equity is maintained by keeping records of the weight of dung delivered and compost received for each family. These records are displayed publicly for all to see. The system appears to work well (Hall and Rosillo-Calle, 1991; Rajabapaiah et al, 1992).

The biogas system still consists of two plants with a common inlet tank connected to a dual-fuel engine. Between September 1987 and April 1991, the engine ran for about 4521 hours, and an 80 per cent diesel replacement rate was achieved. The project is now managed by the villagers and employs two village youths to operate the biogas plant and the electricity and water distribution systems, while maintaining plant records and accounts. Their salaries are provided by the project sponsor, the Karnataka State Council for Science and Technology (Rajabapaiah et al, 1992).

In September 1987, the water-supply system began operating consisting of a 3 HP pump lifting water from a 50 m depth to an overhead tank from which it is distributed by gravity to nine public taps, the location of which was decided by the villagers. This saved the villagers travelling 1.6 km for water collection and caused an increase in per capita consumption of water, although the villagers have restricted access to the water supply to keep the consumption to a reasonable level. By September 1990,29 private taps had been installed in households for which the owners pay a tariff. Excess electricity is used to power domestic lights (currently 103 X 20 W fluorescent tubes), for which the recipients also pay (Rajabapaiah et al, 1992).

The economics of production are highlighted in table 11. From September 1990 to April 1991, the revenues from lighting and private water taps covered 93 per cent of the expenditures apart from the workers' salaries. The biogas system is operated for about 4.2

hrs/day with a dung input of 291 kg/day and a unit cost of energy over $US0.25/kWh. However, the system is capable of handling 1250 kg dung/day (the amount of dung actually produced in the village) and operating for 18 hrs/day which would reduce the unit cost considerably. The income from lights and private water taps currently covers only about half of the recurring expenses, but as demand for electricity and supply of dung increases, and costs fall, this will become more economic. When the hours of operation reach 6 hrs/day, at current tariff charges, the system will cover all of its operating expenses and the surplus can be used to return the capital investment. At 15.1 hrs/day, the unit cost of electricity is lower than that from a central power station. Extra gas can be used, for example, for cooking or to provide power for local industries, thereby increasing living standards even further. There are plans under consideration for a dairy development scheme, selling milk and providing more dung.

Table 11. Economic analysis of a biogas electricity system, Pura village, India

Capital costs ($US at 1989 rates)	
Biogas plant	2 554
Piping etc.	166
Send filters	83
7 horsepower diesel engine	754
5 kva three-phase generating set	1 563
Accessories, tools etc.	415
Engine room	331
Total	5 866
Average monthly expenditure Sept 1990 to April 1991	
Labour	20.98
Diesel	10.19

Diesel	10.19
Dung	8.14
Repairs	2.08
Uncollectable[a]	1.52
Miscellaneous	1.67
Total	53.90
Average monthly income, Sept. 1990 to April 1991	
Lights[b]	18.41
Private water taps[c]	5.51
KSCST grant[d]	29.98
Total	59.32

Notes:

1989 $US1 = rupees (Rs.)

[a] Loss of income from inoperational lights and/or taps.
[b] 81 lights at RS.5/month = Rs.405/month = $18.40/month
[c] 25 taps at Rs.5/month = Rs. 125/month = $5.68
[d] Rs.660/month to pay the salaries of the two workers

***Source:* Rajabapaiah et al, 1992.**

Rajabapaiah et al, (1992) believe that

"The Pura biogas plant is held together and sustained by the convergence of

> **individual and collective interests and that Non-cooperation with the community biogas plant results in a heavy individual price (access to water and light being cut off by the village), which is too great a personal loss to compensate for the minor advantages of non-cooperation to collective interests."**

Residents now realise that biogas has raised their standard of living by making their lives more comfortable at a relatively low cost, so they will ensure that the system is maintained; this is a good illustration of the meaning of sustainable development. One resident is quoted as saying "The grid provides government power, but biogas provides people power, which is far more reliable".

People in Pura village are now thinking of building a wood gasifier to provide producer gas as a supplement to its supply of biogas. Their gasifier would be similar to the successful project in the nearby village of Hosahalli -the next case study - which provides electricity for lighting and water pumping. They are establishing an energy forest to grow the feedstock and ASTRA is confident that the villagers will follow it through, having seen a nearby success of a gasification system and the benefits of electrification.

C. Hosahalli village, India

The ASTRA group in Bangalore (Ravindranath et al, 1990; Ravindranath and Mukunda, 1990) had carried out studies, at the micro-level, of biogas and producer-gas-driven electricity generating sets in the village of Hosahalli in Karnataka State. They believe that

> **"The field experiments at Hosahalli village have demonstrated so far the technical feasibility of a decentralized electricity generation system based on wood gasifier and biogas technology for meeting various energy needs of remote rural settlements" (Ravindranath et al, 1990 p.1975).**

The wood gasifier provides gas to drive a 7 HP dual-fuel engine (80 per cent woodgas and

20 per cent diesel) and a 5 kVA 3-phase generator. The life of the engine has been taken to be 20,000 hours, after which the engine has to be replaced The cost of the system is based on an operating time of 15 hours/day. Table 12 shows the operational and capital costs of a 3.7 kW wood system for generating electricity. The operational cost considering diesel and labour is Rs. 1.22 per kWh if wood is free, and Rs 1.54 if wood is to be purchased. The capital cost amounts to Rs. 63,600; in contrast, the capital cost of an equivalent engine running on diesel is estimated to be around Rs. 39,600.

According to Ravindranath and Mukunda (1990), at the current level of operation for lighting only for 4 hours/day, the wood-gasification system would be economic only if electricity is priced at Rs 3.5 per kWh. However, if the gasification system operates beyond 5 hours/day, the unit cost of energy becomes cheaper than the diesel system. The economic viability could be improved further by: (a) matching of the gasifier-diesel engine capacity (5 kW) since currently a 3.7 kW generator is connected; and (b) by diversifying the use of the gasifier system for meeting other energy needs such as pumping water which would lead to increased capacity utilization. At present, a subsidy is still required at this stage of development, but there is a strong possibility that the system will become economically viable in the near future. It should be noted that the centralized electricity-generation and distribution systems are also subsidized in the district. For comparison, the present subsidized price of grid-based electricity is Rs. 0.65/kWh.

An important aspect of this project is that the villagers are prepared to pay over twice as much for their electricity (Rs. 1.3/kWh) because: (a) the supply is reliable; (b) it provides ancillary benefits (clean drinking water, flour mill etc.); (c) quality of supply; and (d) of emergence of self-reliance (the formation of a village management committee) (Ravindranath, in press).

D. Mauritius

Mauritius is dominated by the production of sugar, which represents around 88 per cent of the cultivable area. Sugarcane accounts for nearly 20 per cent of the country's gross domestic product (GDP) and over 40 per cent of its export earnings. The economy is thus quite sensitive to fluctuations in domestic sugar production and world sugar markets. Almost 60 per cent of total energy requirements in Mauritius (excluding wood fuels primarily used for cooking) are met by bagasse-fired generation of power and steam in the sugarcane industry. Bagasse is playing an increasing role in power supply and currently provides around 10 per cent of Mauritius' electricity requirements. Woody biomass supplied approximately 63 per cent (3.5×10^6 GJ) of all the energy required for household cooking in the country in 1988. There is a potential for producing 10.2×10^6 GI, using the by-products of the sugar industry and to a lesser extent solar energy.

Table 12. Costs of a 3.7 kW woodgasfier system for generating electricity, Hosahalli village, India

Details of wood gasfier	
Capacity	5kW
Annual fuelwood requirement	5.1 tons
Land area required	1 ha
Productivity, 6000 trees	6.4 t/ha
Wood requirement	14 kg/day
Load (1.3kg wood per kWh)	10.74 kWh/d
Kerosene	1121/yr
Capital cost (Rs)[a]	
Gasifier	28 600
Engine	28 600

Voltage stabiliser + accessories	6 000		
Wood cuter	3 000		
Building	5 000		
Energy forest	5 000		
Total	636 000		
Operational costs (Rs.)[b]			
Input	**Quantity per kWh**	**Cost per kWh**	**Cost per month**
Diesel	130 ml	0.52	167
Labour - wood preparation	0.37 h	0.7	225
Total cost	-	1.2	392
Wood (if purchased)	1.3 kg	0.32	103
Total cost	-	1.54	495

Notes:

$1 = 17.2 Rupees (Rs.) (January 1990).

The economic analysis of the wood gas-based electricity system was carried out using a discounted cash flow (DCF) technique, namely, net present value (NPV) method as follows:

NPV - Present value of life cycle benefits Present value of total life cycle costs. Total life-cycle benefits were calculated from the sale of electricity. The unit cost of sale of energy (Rs/kWh) was computed by setting NPV = 0 and solving for the cost of energy. The unit cost of energy was calculated taking a discount rate of 12 per cent, for the wood and gas-based system and then compared with a diesel-based

system of similar capacity.

[a] Life of gasifier 50,000 hours; annual maintenance cost 5 per cent, and operational level 20 hours/day.

[b] Cost per month is calculated considering the current energy consumption of 10.74 kWh per day. Labour is priced at Rs. 15 for 8 hours, and wood is freely available from the energy forest Its market price is Rs.0.25/kg of twigs.

Source: **Revindranath et al, 1990; Ravindranath and Makunda, 1990**

According to Baguant (1990) the Flacq United Estate Limited (FUEL) is the largest sugar estate in Mauritius with an annual average production of 700,000 tons of fresh cane, and 79,000 tons of sugar. FUEL was among the first sugar estates to produce excess steam for production of electricity for sale to the national grid in the mid-1950s. In 1982, the FUEL sugar estate installed a dual-fuel, bagasse and coal furnace to produce electricity all year-around and substantially increase its output. Bagasse is used at the rate of about 35-40 t/hour and coal at about 14 t/hour. A boiler with capacity of 1101 steam/h, 42 bars pressure, 440°C and a condensing turbine coupled with a generator of 21.7 MW led to an average production of 75×10^6 kWh of excess electricity (30×10^6 kWh produced solely from bagasse during the crop season and 45×10^6 kWh from coal). This represents about 12-15 per cent of the total electricity requirements of Mauritius.

In 1989, the electricity output by FUEL increased to 94×10^6 kWh (26x10 from bagasse and 68×10^6 from coal) representing about 16 per cent of the country's total requirements and resulting in over 80 per cent of the electricity being sold to the grid. Unfortunately detailed economic costs of production are not yet available fdor the updated plant following negotiation with the electricity boards, but some available information is set out

in table 13.

E. The Philippines

In August 1980, the Government of the Philippines raised the price of fuels, doubling the price of diesel within two years. This adversely affected the farmers who pumped water for irrigation and caused severe economic difficulties. The Government's response was to look for alternative energy sources and gasifiers were chosen due to the extensive R and D experience of the University of Philippines in this field (Foley and Barnard, 1983).

Attempts to introduce gasifiers on a large scale began in 1981 when the Government, with assistance from USAID, embarked on an ambitious programme which initially planned to retrofit 1150 diesel-pump-powered irrigation systems converting them to gas/diesel fuel operations with charcoal-fed gasifiers. This involved 495 irrigator's service associations (ISA) with a total membership of over 26,000 farmers and covered over 46,000 ha The Government's main agency in promoting the use of the gasifiers was the Farm Systems Development Corporation (FSDC). Bernardo and Kilayko (1990) carried out an analysis of the gasifier programme. The results were very disappointing, with just 1 per cent (three out of 248 plants) still being used in 1987; and over 80 per cent in need of repair. The gasifier programme thus failed to achieve its objectives in reducing farmers' dependence on diesel fuel and in improving their financial position. The causes of this unsatisfactory outcome are claimed to arise more from institutional and management problems than from any inherent weakness in the technology itself.

Table 13. Capital costs of FUEL'S dual-uel thermal power plant, Mauritius

Input	Capital cost ($US thousands (1989))
Bagasse conveyor (300m^3)	93

Bagasse conveyor (300m^3)	[illegible]
Boiler (300m^3) (110t/hr, 440 C)	2 150
Chimney/scrubber	80
Turbo alternator (21.7 MW)(27125 MW; 6600 V)	1 550
Accessories etc.	500
Power-house crane etc.	70
Building	67
Total	**4 810**
Technical Data	
Effective power generation	18 MW
Electricity production 1989: From bagasse during crop season	27 MkWh
From coal during intercrop	57 MkWh
Coal used (tons)(at 3.5 per cent moisture - 28.1.GJ/t)	49,500
Bagasse used (tons)(at 50 per cent moisture - 9.9 GJ/t)	185,000

***Source:* Baguant, 1990.**

According to Bernardo and Kilayko (1990), success required a “fit” between the technology, the users and the implementing agency. Many farmers did not view their irrigation systems as a means of improving their productivity and profitability, but largely as a type of insurance against inadequate rainfall. Therefore, they saw little value in gasifier-powered pumps. The gasification programme was imposed from above with little understanding of the users' needs. The method of financing also failed to provide clear economic signals to the farmers, and failed to acknowledge the financial realities of the farmers' lives. Many farmers did not know how much the gasifier was costing them, and

they frequently did not realize that its costs were covered by a loan rather than a grant. As projects failed, this clearly affected their ability to meet loan repayments.

The half-hearted support of the FSDC area officers and their more general financial difficulties created serious problems in implementation, and the FSDC were generally unable to enforce minimum requirements of its projects with many consequent failures. Additionally, the failure of the ISAs to observe proper maintenance practices ultimately resulted in engine failures, and even permanent damage to engines. Poor maintenance reduced the life expectancy of the gasifier which, in turn, raised the annual capital cost charge significantly. An additional problem was that inflation had a very negative effect on farmer's living standards forcing them to cut down on production inputs, one of which was irrigation - not a priority for many farmers despite FSDC's objectives.

As indicated in table 14, the use of gasifiers could have resulted in significant savings in fuel costs; however, this was not so. Solely on the basis of the cost of fuel, running a 50 HP diesel motor on 50 per cent diesel and 50 per cent charcoal produced only minor savings in 1982 and 1985, and losses in 1983 and 1984. This was partly because charcoal prices increased by 600 per cent from 1977 to 1985 and charcoal was, on occasion, more scarce and expensive than diesel due to increasing household and industrial demand. The greatest savings occurred in 1987 when charcoal prices fell faster than those of diesel. Charcoal gasifiers thus did not completely displace the use of diesel oil. The farmers found it inconvenient to procure two types of fuel without obtaining sufficient benefits for their extra efforts. The implementing agency was inadequately funded and was subject to unrealistic installation targets imposed by the political system. This case highlights the considerable difficulties involved in setting up and running an infrastructure necessary to carry out repairs and supply spare parts to support new technologies. It illustrates the even more difficult problem of ensuring an adequate supply of raw material (charcoal) at acceptable prices (Bernardo and Kilayko, 1990).

Table 14. Estimated costs of gasification using wood chips and charcoal, the Philippines

	FCSD project proposal (woodchip) (P)	Actual field costs (charcoal) (P)
I. Without gasifier		
Amortization for irrigation	23,619	23,619
Diesel fuel	69,504	70,590
Lubricant	6,950	7,059
Repairs and maintenance	9,920	negligible
Operating hours	1,200 hrs	600 hrs
Total	109,933	101,268
Cost per hour	91.66	168.78
II. With gasifier		
Amortization for irrigation loan	23,619	23,619
Amortization for gasifier	6,745	6,745
Amortization for woodlot	4,266	-
Diesel fuel	20,851	35,295
Lubricant	6,950	7,059
Woodchip labour	7,047	-
Repairs and maintenance	11,470	negligible
Charcoal fuel	-	17,036
Operating hours	1,200 hrs	600 hrs
Total	80,948	89,754

Cost per hour	67.46	149.59
III. Savings		
Total	29,045	11,514
Savings per hour	24.2	19.1

Notes:

Philippines pesos (P); $1=P18.12

Information based on a field survey of 53 farmers' units involved with gasifiers in Panay Island in 1985, later supplemented by information available countrywide in 1987. By 1985, some 319 charcoal-fed gasifiers were installed under a government programme.

This table indicates that given the field conditions, the use of gasifiers could result in significant savings in fuel cost.

***Source:* Bernardo and Kilayko, 1990**

F. The South Pacific

The island States of the South Pacific are generally dependent on imported fossil fuels. Due to the high oil prices in the early 1980s and plentiful indigenous biomass resources (on the larger islands), there was considerable interest in installing biomass gasification units for electricity production and crop drying. Available resources include residues from over 600,000 ha of copra plantations and almost 44.5 million ha of forested areas (Sanday and Lloyd, 1991). The main impetus for the introduction of power gasifiers into the South Pacific region was the European Community-funded Lome II Pacific Region Energy Programme (PREP) in 1983/84. This proposed, and budgeted for, 17 gasifier projects, but finally, only two were installed, both considerably reduced in scale, capacity and cost

relative to the original proposals. Other gasifier units were also installed privately in the region. Sanday and Lloyd (1991) of the Energy Studies Unit (ESU) at the University of the South Pacific carried out a survey and monitoring programme of all power and heat gasifiers. They found that of the 16 power gasifiers installed altogether, only one was known to be still operating satisfactorily, the rest having ceased operation. Similarly, for the "Waterwide" heat gasifiers installed in Papua New Guinea, only 20 out of 80 were still in use in January 1990, and most of the other documented heat gasifiers in this region were also expected to have shut down.

The operational problems were thought mainly to be due to flaws in original designs resulting in shortened plant lifetime. The systems installed experienced severe operational and design problems that should have been solved prior to installation in remote sites. To Sanday and Lloyd (1991, p. 17) it seemed

> **"that the Pacific Islands have been used as experimental stations for technologies that have not been proven in industrial countries". (Furthermore,) "gasifiers have often quickly deteriorated resulting from mismanagement of operational and maintenance procedures, and the persisting hostile operational environment."**

Most of the manufacturers were external to the region, some based as far away as Europe. Therefore, there was a lack of spare parts and skilled technicians to carry out maintenance and repair work. This situation was exacerbated by the fact that five of the six manufacturers who supplied systems to the region in the last decade went out of business. There was also a lack of infrastructure support within the region as personnel trained in gasifier technology were extremely scarce, so ordinary mechanics and technicians were often called on to carry out repair work with limited success. Since the gasifier locations were scattered amongst different islands it was difficult and costly to locate maintenance services and they could not be promptly available. Information on the technology was limited and usually in the form of papers for academics and other

technical personnel rather than being designed for potential end-users.

The availability of biomass feedstocks may have been over-estimated originally, and the quality these feedstocks and their erratic supplies resulted in intermittent gasifier operation with some systems being periodically shut down. The shortages due to lack of fuelwood supplies were "compounded by domestic cooking receiving priority, difficulties associated with land availability and ownership, and soil salinity problems when replanting programmes were used" (Sanday and Lloyd, 1991, p. x). Also, lacking were schemes to collect scattered fuel and the failure to implement tree replanting programmes. Furthermore, the "Waterwide" heat gasifiers experienced problems with smoke contamination affecting the quality of dried agricultural products and causing heavy financial losses; this was mainly due to improper use.

Repetitive breakdowns and lack of maintenance support meant gasifier operators usually preferred to choose diesel systems which had been proved to be relatively successful and user-friendly in such situations. Furthermore, initial capital costs of gasifiers were high and unable to compete with equivalent diesel sets at current diesel fuel prices. All the problems experienced appear to have discouraged further developments towards implementation of gasifier technology in the region. Most success was found with small wood and husk-fuelled gasifiers installed in Papua New Guinea for agro-drying applications. The single power gasifier that was still operational, a BECE unit in Vanuatu, connected with a school, was successful due to "the availability of wood fuels, the commitment of the operators and the school management and the fortune to have a very gifted and enthusiastic support staff as one of the teachers at the school."

G. Indonesia

Rice husks are one of the most widely available agricultural residues in Indonesia, but they have few uses. They are a significant potential energy source if reliable conversion

technologies can be developed. In Indonesia in 1986, milled rice production was over 26 Mt and 6.5 Mt of rice husks were subsequently produced - husks are estimated at 20 per cent of unmilled paddy weight Use of 25 per cent of these husks (about 1.8 Mt) and a similar amount of available straw would yield about 3.6 Mt of energy feedstock which could produce an estimated 155 or 300 MW electricity depending of the amount of capital invested in the facility (USAID, 1988). Research and development work in gasifier technology has expanded considerably in Indonesia, and has been supported by the Government In 1987, the Government mandated that 10 gasifiers, manufactured in Indonesia, should be placed in field operation to help demonstrate their technical and economic viability.

This case study is based on a system designed by Manurung and Beenackers (1990). Their continuous, small-scale down-draft rice-husk gasification system appears to have overcome many of the previous problems related to the gasification of rice husks. Based on laboratory experience the first unit (10 kWh) was installed in a village, 100 km east of Bandung, West Java, in 1986. This was followed up by two scaled-up versions each with a capacity of 35-40 kWh. One powers a 1000 kg/hr rice mill and the other provides 10 kWh of electricity for 320 rural consumers.

Typical performance of these field units (called Gasifier I and II) are illustrated in table 15. Diesel fuel replacement up to 70 per cent was achieved; the rice husk to electricity conversion is about 2.4 and 2.0 kg/kWh for Gasifier I and II, respectively. The economic analysis shown in part C of the table is based on Gasifier II only, and demonstrates the pay-back period (PBP) and the net present value (NPV) of the investment. In addition, the economics of the gasification unit are compared with those of a conventional diesel-engine generating set of the same capacity. The costs are based on 1989 economic data and on the present actual performance of Gasifier II for that year.

Under present conditions, according to Manurung and Beenackers (1990), the operating

costs of the dual-fuel plant were lower than the plant revenues, resulting in a positive income, with a pay-back period of 7 years compared with 8 years for the full diesel plant. Since the diesel costs for a full diesel plant are 66 per cent of its operating costs, and only 22 per cent for a dual-fuel plant the economics are particularly sensitive to the price of diesel, and also to load capacity, total annual operating hours and the level of diesel substitution. If applied to rural electricity production, economic feasibility appears to be good with capacities of 30 to 50 kWh and upward, under Javan conditions of 1989.

H. Mali

Chinese-built rice-husk gasifier power plants (160 kWh) were installed in the early 1970s, according to Mahin (1989), at two rice mills at Dogofiri and N'Debougou. These have operated successfully since then with more than 55,000 hours operating experience, although economic analyses of these plants are not easily available. In 1986, with the assistance of GTZ (German Agency for Technical Cooperation), an additional Chinese-built gasifier was installed nearby at the rice mill in Molodo which processes about 20,000 t/yr of rice. The plant produces about 1 kWh for each 2.5 kg of rice husks used in the gasifier. It generates up to 160 kW of power. The total annual operating costs were DM146,877 (or DM0.26/kWh) which is 54 per cent of that of a diesel- engine plant. The GTZ study (Mahin, 1989) indicates the difference in capital cost between the diesel and the gasifier plant. Investment costs of the gasifier power plant could be recovered in less than four years. Table 16 provides a summary of cost of the rice husk-fulled gasifier power plant at Molodo.

Table 15. Gasification of rice husks, Indonesia

Parameters	**Gasifier I**	**Gasifier II**
(a) Typical daily operation data		
Operating time	18.00-24.00	18.00-24.00

		04.00-06.00
Electricity generated (kVA)(kW)	12(9.6)	18(15)
Diesel fuel consumption (I/day):		
100 per cent diesel fuel	40	42
dual-fuel operation	12.0	12.6
Lubricant oil consumption	81/60 hr	81/20 hr
Rice husk consumption (kg/hr)	23.3	30.0
Temperature of outlet gas (K)	673	603
Temperature or gas entering the engine (K)	303	308
Lower heating value of gas (kJ/m^3)	not measured	4,300
Filter cleaning	once in 2 weeks	once in 2 weeks
Tar in gas at gasifier outlet (g/m^3)	1.7	3.8
Tar in gas after dry filter (g/m^3)	0.37	1.00
(b) Parameters relevant to economic analysis		
Diesel oil replacement (percentage)	70	70
Rice husk to electricity energy conversion factor (kg/kWh)	2.4	2.0
Lubricating oil cost (Rp/dm^3)	900	2,500
Rice husk price (Rp/kg)	7.5	7.5
Electricity delivered price (Rp/10 W/month)	2,000	1,000
Transmitted electrical power (kW) Diesel oil price (on site) (Rp/dm^3)	4.5 250	5.0 250
Operator salary (Rp/month)	30,000	25,000

Operator salary (Rp/month)	30,000		25,000	
(c) Economics of generating electricity using dual-fuel and full diesel				
	Dual-fuel		**Full-diesel**	
	Rupiahs	**Percentage**	**Rupiahs**	**Percentage**
Investment:				
Gasifier	5 000 000	27		0
Diesel engine	13 000 000	70	13 000 000	96
Building	500000	3	500 000	4
Installation	200000	1		0
Total	8700000	100	13 500 000	100
Operating costs:				
Labour	306 000	7	180000	4
Maintenance	639 840	14	336 960	7
Rice husk	583 200	13		0
Diesel oil	1 010 880	22	3 369 600	66
Sub-total	2 539 920		3 886 560	
Depreciation	1 962 500	44	1 187 500	23
Total expense	4 502 420	100	5 074 060	100

Production cost (Rp/kWh consum.)	347	392
Production cost (Rp/kWh gen)	116	131
Sales income (Rp)	5 404 320	5 404 320
Cash flow (Rp)	2 864 400	1 517 760
Economic variables:		
Gasfier lifetime (years)	8	8
Engine lifetime (years)	12	12
Building lifetime (years)	8	8
Daily operating hours (hr/day)	8	8
Annual operating hours (hours)	2 592	2 592
Load level (kW)	15	15
Diesel consumption (1/hr)	2	5
Husk consumption (kg/hr)	30	33
Registered load (kW)	5	5
Electricity consumed (kWh/yr)	12 960	12960
Electricity generated (kWh/yr)	38 880	38 880
Diesel price (Rp/l)	250	250
Husk price (Rp/kg)	8	-
Operator wage (Rp/hr)	63	63
Labour wage (Rp/hr)	44	44
Load factor	1	1
Electricity price (Rp/kWh)	417	417
Interest (percentage)	12	12

***Notes:* $US1=Rp 1750**

Capital cost for a gasifier of 15 HP is $US 3000; the price of higher capacities is calculated by:

Capital cost (× HP) = Capital costs (15HP) * (x/15) (10×0.3)

Interest rate is 12 per cent per annum

Gasifier economic life is 7 years

Engine derating due to oil replacement is proportional to the percentage of oil replacement

Mechanical power to run a rice meal is 27 kW per ton of rice milled per hour 250 kg husk is produced per ton of rice, of which only 25 per cent is needed to power the mill

***Source:* Manning and Beenackrs, 1990.**

I. Brazil - potential

Although this paper is involved in the analysis of established bioenergy projects, it is also of value to examine the potential for electricity production in the north-east region of Brazil, as assessed by Carpentieri et al, (1992), since this has implications for other developing countries. The north-east region has a low population density, an economy heavily dependent on agriculture, and an energy consumption about half the national average. Over 90 per cent of all electricity produced in Brazil, and virtually all that is produced in the north-east is hydroelectric. To meet projected growth rates for electricity consumption in the north-east up to 2015 would require a capital investment in new

power plants (all hydroelectric) in excess of £40 billion. It is planned to develop essentially all remaining hydroelectric potential in the Northeast by 2005, and costs will rise as less favourable sites are developed. However, the hydroelectric potential will inevitably be exhausted and alternative electricity sources must be found. One option under consideration is importing electricity from new hydroelectric projects to be located in the Amazon river basin. But this would be expensive, environmentally controversial and would involve little direct long-term investment or job creation in the north-east.

In 1982, the Division of Alternative Energy Sources of the Hydroelectric Company of Sao Francisco (CHESF), responsible for production and transmission of bulk energy in the north-east initiated studies on alternative advanced technologies for converting biomass into electricity. There are three potential biomass resources in the north-east mat could be utilized for electricity production: sugarcane residues, plantations, and the residues of other agricultural products. Of these, the first two show most promise for large-scale use as plantations are well established. In fact, both plantation industries in Brazil are recognized as world leaders.

In this region practically all woodfuel comes from natural forests with devastating environmental effects. Efforts to establish plantation have been quite successful in Brazil as a whole with over 40 per cent of all charcoal now being derived from this source (Abracave, 1992), and plantations are estimated to cover 4 to 6 million ha (mostly used by steel and paper and pulp producers). Large investments have been made in plantation technology and techniques resulting in a great improvement over the last 15 to 20 years. CHESF carried out a biogeoclimatic assessment to evaluate the potential for wood-plantation energy, considering only land area judged to be sub-optimal for agriculture (CHESF, 1990). It estimated that 50 million ha (a third of the land area of the north-east) was available for plantations with productivities ranging from 6 to 44 m^3/ha/yr of wood, and that the total plantation production potential is about 1340 million m^3/yr of wood

which could produce 12.6 EJ/yr. This compares with a total energy use in the north-east of about 1.1 EJ. Cost estimates range from 7.3 c/kWh for condensing steam turbine technology (CST) down to 4.3 c/kWh for gas turbine/steam turbine combined cycle technology (GTCC). Over 86 per cent of the wood production would be at an average cost less than $1.35/GJ (Carpentieri et al, 1992).

Table 16. Economic analysis of a rice-husk-fuelled gasifier

Details of rice mill at Molodo	
Mill capacity	20,000 t paddy
Operating season (24 hrs, 5500 h/yr)	230 days/yr
Energy requirements - electric motor	110 kW/h
- auxiliary equipment	12 kW/h
Cost of diesel power (DM)	
Capital cost	370 000
Annual costs	43 030
	198 000
	10 000
	7 000
	15 000
	570 000 kWh
Total annual operating costs	273 030
Unit cost	0.48/kWh
Details of the gasifier power plant:	
Rice-husk consumption	250-350 kg/h

Rice husk consumption	250-350 kg/h
Lubricating oil	0.41 l/hr
Diesel oil engine (every 600 hrs)	
Maximum energy generation (1 kWh for 2.5 kg of rice husks)	2001
	160 kW
Cost of the gasifier power plant	
Capital costs:	
Purchase price of gasifier	490 000
Transport and insurance	40 000
Assembly and installation	60 000
Building and structure	150 000
36 kWh standby diesel generator	40 000
Total costs of installation	780 000
Annual costs:	
Annual capital cost (amortization period 13 years at 11.73 per cent)	85 877
Lubricating oil	19 000
Standby generator	5 000
Repairs and maintenance	12000
Labour	25 000
Total annual operating costs	146 877
Unit cost	0.26/kWh

***Note:* $US1=DM 1.70**
***Source:* Based on Mahin, 1989.**

Sugarcane, on the other hand, is already widely grown in Brazil and some sugarcane processing facilities are already selling small quantities of electricity produced from bagasse to utilities. The present biomass energy production potential in the north-east from the area of cane planted in 1989 is estimated to be 174 PJ/yr. Looking at a future scenario, the average cost of producing the electricity with STIG technology is around 4.0-4.4 c/kWh. This would be competitive with marginal costs of anticipated new hydroelectric supply. If tops and leaves are also used, the bioenergy available could be increased by up to 75 per cent, and off-season jobs baling and transporting the *barbojo* would be created (Carpentieri et al, 1992).

Carpentieri et al, (1992) constructed two alternative scenarios for the production of electricity in the Northeast to the year 2015, these are summarized in table 17. The "Hydro" scenario is based on CHESF plans for continued expansion of the hydroelectric system; while the "Biomass" scenario is "intended to be a plausible scenario of how biomass could be incorporated into the utility system." Both proposals include the initial installation of 4100 MW of hydroelectric power at a single site, Xingo I. The Biomass scenario then assumes sugarcane CEST systems (including *barbojo*) begin to make a contribution in 1987 such that half of the total potential is installed by 2000 at 320 MW/yr. From 2000, STIG systems come on line at the rate of 280 MW/yr until 2010 when the full electricity-generating potential of sugarcane is realized. Plantation activity is assumed to begin in 1994 with stand-alone power stations first coming on line in 2000 based on GTCC technology with an installed capacity of 250 MW, and annual additions will increase up to 1000 MW of new supply in 2015 (this is supplied by only 4 per cent of CHESF's assumed potential fuelwood in the north-east).

Table 17. Comparison of alternative electric system scenarios in north-east Brazil, 1990-2015

	Hydro scenario	Biomass scenario

		Hydro	Cane	Wood	Total
Generating capacity:					
Added MW, 1990-2015	16,745	3,909	2,480	4,494	10,883
Total MW in 2015	23,957	11,112[a]	2,480	4,494	18,806
Number of generating units	27	14	50[b]	75[b]	140
Electricity generation (GWh):					
Total in 2015	103,555	52,875	17,214	33,465	103,555
Added, 1990-2015	72,975	22,295	17,214	33,465	72,975
Total (percentage of estimated potential) [c]	0.21	0.1	0.42	0.024	0.052
Capital requirements:					
Total ($million), 1990-2015	26,666[a]	4,491	3,609	6,568[e]	14,669
Average investment ($/kW)	1,592	1,149	1,455	1,462	1,348
Cost of electricity production in 2015:					
Average system cost (C/kWh)	3.7	1.9	5.3	4.3	3.2
Marginal cost of new supply (C/kWh)	6.7	5.5[f]	4.4	4.3	4.3
Employment:					
New jobs created, 1990 to 2015	25,131	5,864	96,764[g]	55,463h	158,091
Investment ($US 1988) per job	1,061,000	766,000	37,300	118,400	92,800
New land area required in north-east region					
Total (km^2)	4,787[i]	447	-[i]	22,740k	23,187
Percentage of total north-east area	0'.03	0.03	0.00	1.46	1.5

***Notes:* For more information of scenarios, see text.**
Assumed electricity demand growth rate 5 per cent year.

[a] The only hydroelectric sites assumed to be added to the existing hydro capacity in the biomass scenario are Xingo I, Sacos, Pedra do Cavalo, Araca, and Itapebi.

[b] The number of cane-processing sites in the north-east is currently about 120, only a fraction of which would be exporting electricity by 2015 under the scenario considered. The number of wood-fired generating sites is estimated assuming an average capacity of an individual plant to be 60 MW. (In practice, individual units might be clustered into modules of 4 or 5 units each).

[c] The total ultimate hydro GWh potential is estimated based on a total MW capacity potential of 113,300 MW, which includes the potential in both the north-east and north regions. The total ultimate wood and cane potentials are taken to be 1400 TWh and 41 TWh respectively.

[d] Includes an additional amount of $300 per kW for transmission from plants in the north to the north-east.

[e] The total investment includes plantation-establishment costs totalling $611 million incurred during the years 2010 to 2015. Because of the 6-year period before the first harvest, the plantation investments during these years do not lead to any electricity production until the period 2016 to 2021. The assumed plantation-establishment cost is $213/kW. This assumes an average yield of 33 m^3/yr per planted hectare, conversion to electricity at 40 per cent efficiency, an implanted (natural-vegetation) equal to 43 per cent of the planted area, and a capital investment of $689/hectare.

[f] Estimated average cost of power from building and of operating the 7 hydropower plants in north-east region that are not included in the biomass scenario.

[g] The number of currently seasonal jobs that would be converted to full-time jobs.

[h] Includes 13,099 jobs associated with establishing and maintaining plantations during the period 2010 to 2015. These plantations would not be harvested until after 2010. See note [e] above.

[i] Land area flooded by new hydro facilities in the north-east region only. The area that would be flooded in the north region is an additional 7700 km^2

[j] Zero additional area is required for electricity from sugarcane, since the total planted area is assumed to remain at today's level.

[k] Only 70 per cent of this area would be active plantation. The balance would be left in "natural" from. The total includes 8870 km^2 of plantation area that would be established between 2010 and 2015, but which would not be harvested until the period 2016 to 2021. See note[e] above.

***Source:* Carpentieri et al, 1992.**

Total new land required by the Biomass scenario would represent only 1.6 per cent of the total land area of the north-east. Since the biomass facilities are smaller and greater in quantity they offer more security and can follow demand more closely. The Hydro scenario would contribute 25 GW between 1990 and 2015 compared with 15 GW in the Biomass scenario. Average unit investment costs would be 25 per cent higher for the HYDRO case,

the total required capital investment would be twice as much, average electricity production costs will be higher, and marginal production costs will be substantially higher. This scenario assumes "a reasonable commitment from government, utilities, industry and relevant R&D organizations, and the support of the population in general." (Carpentieri et al, 1992).

The energy potentially available from other agricultural residues in the north-east is estimated to be about 145 PJ/yr, which is equivalent to about 10 per cent of primary energy consumption in this region. Since these sources are widely dispersed and lack any infrastructure for energy use, they are of more importance for use locally, in a decentralized manner (Carpentieri et al, 1992). The Brazilian Government is promising to introduce a new policy across Brazil that will mandate the State-controlled electricity utilities to enter into long-term contracts to buy cogenerated power. This will encourage further the growth of biomass electricity production from residues.