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Biogas Technology in Asia: The Perspectives

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ABSTRACT

This is an overview of some salient points and perspectives of biogas technology (BGT) in Asia. The current literature is reviewed regarding the ecological, social, cultural and economic impacts of BGT. It is suggested that the potential benefits of BGT should not be taken for granted. Depending on local conditions, the benefits may be great or small, one benefit may be a trade-off for another, or may be just an incremental rather than a full one. The literature indicates that the failures in biogas programs have reached an alarming rate, and caused dissatisfaction and doubt. In order not to repeat such failures, in-depth studies on local conditions and conscientious planning are urged.

INTRODUCTION

Biogas technology (BGT) has been known for a long time, but the interest in it has recently increased very considerably – mainly because of the higher costs and the rapid depletion of local traditional fuel sources and of fossil fuels. The interest in BGT has been further stimulated by the promotional efforts of various international organizations and foreign aid agencies through their publications, meetings, visits, etc., in which proponents are usually dominant over opponents – if any. As a consequence, biogas programs have been implemented in various parts of Asia, seemingly without proper planning and feasibility studies. Impressive successes from a country are taken as a good example to follow, with the hope that a similar result will be replicated elsewhere. Quite often it is not. Bitter failures have been reported at an alarming rate, and together with them, pessimism and doubts. All of these may unduly discourage those who attempt to implement a biogas program.

On the other hand, many expectations – and over-optimism – still prevail. While these attitudes are needed for a good start, they may cause misconceptions with regard to BGT, and so may engender even more failures.

For the above reasons, the authors realize the need of giving some insights into the perspectives of BGT. Trying not to be over-pessimistic or negative, the authors consider it is vitally important to perceive the technology as objectively as possible, so that processes of planning and decision-making can be properly carried out, and failures will be less likely to happen. Special attention will be given to family-size biogas systems in Asia, due to their inherent complexity and their wide-ranging impacts.

TECHNOLOGICAL BRIEFS

The Status

Biogas is a product of anaerobic fermentation of organic matters, and consists of about 60-

70% methane, 30-40% carbon dioxide, and a small amount of other gases. Presently the status of development and application of BGT in Asian countries varies, as has been reviewed by Barnett *et al.* (1978), ESCAP (1975), FAO (1978a & 1978b), and Tam & Thanh (1982). Briefly, there are about 7-9 million digester units in the People's Republic of China, 126,000 in India, 30,000 in the Republic of Korea, 8,000 in the Republic of China, 350 in Nepal, 300 in Thailand, 200 in the Philippines, and a smaller number in some other Asian countries.

The input materials for biogas digesters in Asia are the wastes that can be found locally, such as animal dung, human excreta, and agricultural residues. India, with its large horde of cows, uses almost exclusively cow dung as the input material, whereas the People's Republic of China, where two out of five pigs of the world stock are raised, relies mainly on pig excreta and, to a significant extent, on human excreta.

The Process

The complete anaerobic fermentation process is depicted in Fig. 1, and the four responsible groups of bacteria are briefly described below (Chen *et al.*, 1980).

1. *Hydrolytic Bacteria:* which stabilize carbohydrates, proteins, lipids and other minor components of biomass to fatty acids, H_2 and CO_2.

2. *Hydrogen-Producing Acetogenic Bacteria:* which catabolyze certain fatty acids and several end-products to acetate, H_2 and CO_2.

3. *Homo-acetogenic Bacteria:* which synthesize acetate using H_2, CO_2 and formate, or hydrolyze multi-carbon compounds to acetic acids.

4. *Methanogenic Bacteria:* which utilize acetate, H_2 and CO_2 to produce methane.

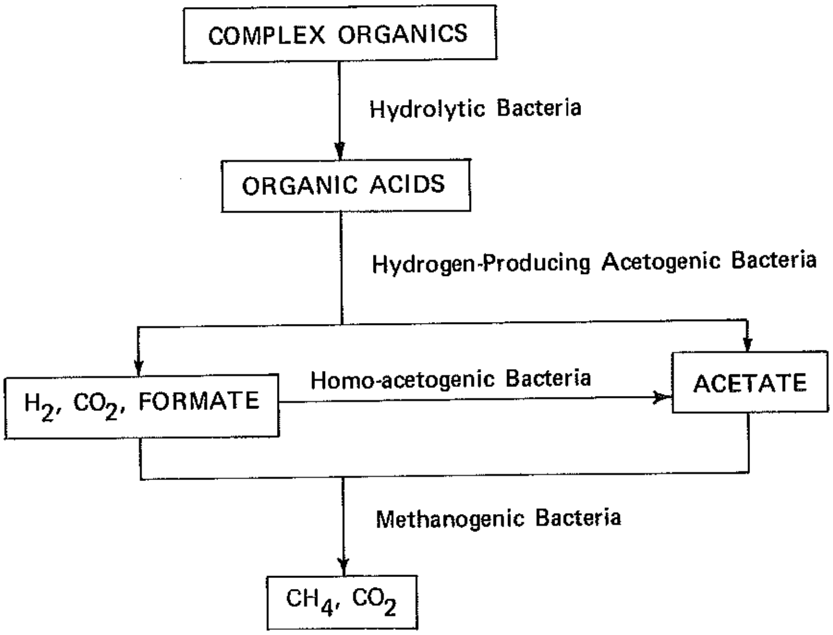

Fig. 1 Biogas production process

Optimum Conditions

Basically, the input materials are introduced into a closed digester, where, without the presence of free oxygen, the responsible microorganisms work successively to convert complex organic matters into CH_4, CO_2, H_2, H_2S, etc. The optimum conditions for the process are given in Table 1. In the parameters cited, perhaps the temperature is the most difficult – or costly – to control. The process virtually stops when the temperature drops below 10°C, and this is a major technical constraint for cold regions.

The pH is of no concern since the common input materials used in rural Asia have their pH values in the neutral range.

Some types of waste – such as cattle, sheep and horse dung – have a C/N ratio near the optimum value. Others – such as human excreta and poultry waste – have low C/N ratios. These sources should be mixed with materials of plant origin, which are high in carbon and low in nitrogen, to bring the C/N ratio to an optimum level.

Retention time decides the rate at which the waste is digested. The longer the time, the larger the volume of gas produced from a given amount of waste, and vice versa. Thus, if the available amount of input materials is limited, a bigger digester can be adopted to more fully exploit the gas potential; and where the waste is abundant, the waste can be fed at a higher loading rate into a small digester to maximize the gas production per unit volume of the digester. The optimum retention time depends on the temperature. The optimum range in Table 1 is for ambient temperatures during hot seasons of tropical climates. In practice, a longer retention time is usually adopted to cope with cool seasons.

Table 1
Optimum conditions for biogas production

Parameter	Optimum Value
Temperature, °C	30–35
pH	6.8–7.5
Carbon/Nitrogen Ratio	20–30
Solids Content, %	7–9
Retention Time, days	20–40

Biogas Digester Designs

There are in practice two main types of biogas plant that have been developed in Asia: the fixed-dome digester, which is commonly called the "Chinese digester" (Fig. 2), and the type with a floating gas holder known as the "Indian digester" (Fig. 3). The latter is also called the "KVIC digester" since it was developed by the Indian Khadi & Village Industries Commission (KVIC). Table 2 gives the main features of the two types. The digesters currently used in Asia sometimes are slightly modified forms of one or the other of these two main types.

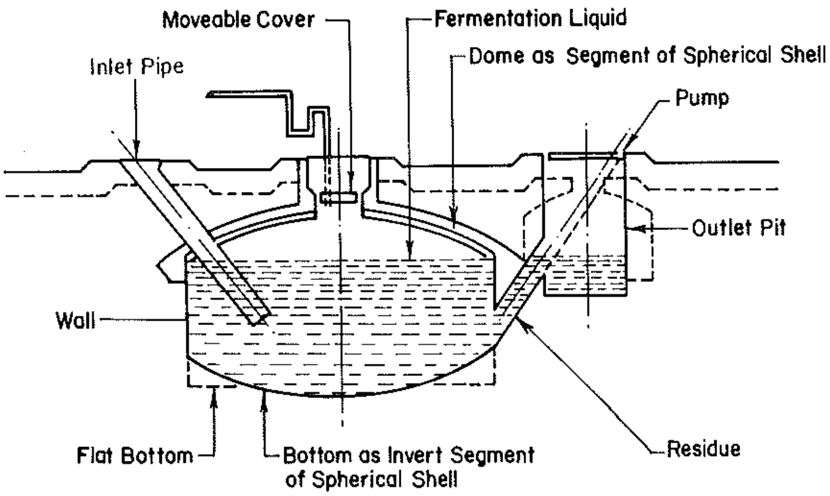

Fig. 2 The Chinese digester design

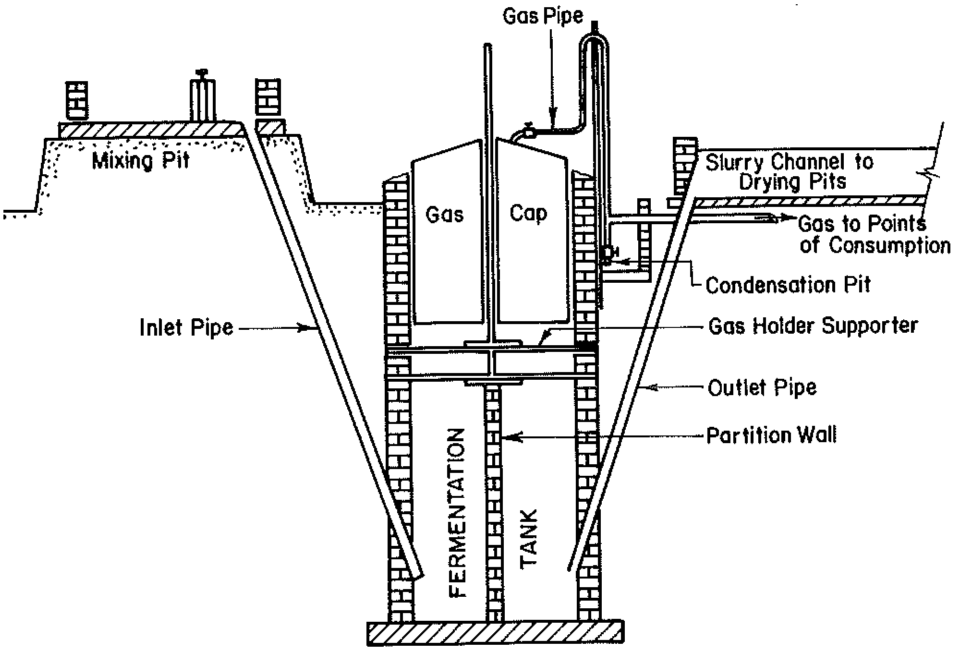

Fig. 3 The Indian digester design

Table 2
Summary of comparison between Chinese and Indian design
(Adopted from Anon., 1979 and Eggeling *et al.*, no date)

	Chinese Design	Indian Design
Construction Materials	– Several different materials – Usually locally available	– Masonry – May be brought from outside village
Construction	– Closed, underground masonry or concrete pit with adjacent inlet & outlet – Requires skill to build dome, careful lining to prevent gas leaks – Usually self-help	– Simple above-ground tank – Easy to build but hard to install where drum cannot be made or easily carried – Self-help possible, but gas holder has to be produced in workshop
Gas Storage	– In dome combined with digestion chamber – Manometer indicates gas volume – For use throughout digester lifespan with occasional linings – Gastightness is a problem with bad linings	– In floating metal drum – Height of drum indicates gas volume – Drum needs regular painting to prevent corrosion – No problem with gastightness
Gas Pressure	– High : up to 1000 mm water column – Varying according to gas use – Automatic release of excessive gas through manometer	– Low : 70–150 mm water column – Steady, due to floating drum – Automatic release of excessive gas through gas drum
Efficiency	– Low, due to gas escape through large inlets & outlets : 0.15–0.30 m^3 gas produced per m^3 digester per day – Stable through seasons, due to good insulation of underground construction	– Higher, gas escape insignificant : 0.30–0.60 m^3 gas produced per m^3 digester per day – Subject to seasonal variations, loss of heat through metal drum
Feeding Materials	– Mostly mixtures of animal wastes, human excreta, household refuse, agricultural residues	– Virtually only cow dung, occasionally agricultural residues
Operation	– Mostly batch loading, can be continuous – Effluent removal by pump or bucket – Labor-intensive for batch loading, emptying pit & removing effluent – No provision for mixing	– Virtually continuous loading – Effluent removal by gravity flow – Virtually no attention beyond mixing & feeding influent – Mixing by rotating drum
Maintenance	– Wall lining	– Drum painting
Cost	– Low, because no metal part	– High, due to metal drum

Potential Gas Production

The potential gas volumes produced from wastes vary greatly depending on innumerable factors, and can be expressed based on head count (Table 3) or on a fixed weight (Table 4). Expressing the gas production from a number of animal head may lead to a serious error in the assessment of gas potential, and basing it on the gas production per unit weight of animal, although it is more accurate, is not practical in field work.

Table 3
Average daily gas production based on head count
(Eggeling *et al.*, no date)

Source of Waste	Waste Production kg/d	Gas Production m^3/d
1 buffalo or European cow	15	0.50–0.74
1 zebu cow	10	0.25–0.40
1 calf	5	0.15–0.25
1 pig	2.5	0.50–0.10
10 chicken	—	0.02–0.04
1 latrine user	1	0.02–0.03
1 sheep/goat	—	0.02–0.04

Table 4
Average gas production based on waste amount

Source of Waste	Gas Production	
	m^3/1,000 kg animal*	m^3/1,000 kg waste**
Dairy Cattle	2.53	–
Beef Cattle	2.47	–
Cattle (Cows & Buffaloes)	–	22 – 40
Pig	2.69	40 – 60
Poultry	6.92	65.5 – 115
Pretreated Crop Waste	–	30 – 40
Water Hyacinth	–	40 – 50

* *of live weight. Data from Morris et al. (1975).*

** *apparently of fresh weight. Data from ESCAP (1980).*

Gas Uses

Biogas can be used for many purposes, but mainly for cooking and lighting in rural areas of Asia. For cooking, common burners used with natural liquified gas can be used with biogas, after minor modifications.

Biogas can be burned with a gas mantle to give a light bright enough to read by, or to be more efficient, can be used to produce electricity which lights electric light bulbs. The efficiency of appliances used with biogas still needs to be improved.

Biogas has been used to a lesser extent to run refrigerators, or vehicles and other engines. For the latter, dual-engines are usually preferred, so that they can be alternately run with conventional fuels or with biogas.

The requirements of gas for various purposes are presented in Table 5. Tables 6 and 7 present a comparison between biogas and various commercial fuels in terms of calorific value, thermal efficiency and monetary value.

Table 5
Biogas requirements for various purposes (Shah, 1978b)

Purposes	Specifications	Gas Required, m^3	Sources
Cooking	Per person	0.5/day	China
	Per person	0.34–0.43/day	India
	Per person	0.425/day	Nepal
	Stove 5 cm dia.	0.33	
	Stove 10 cm dia.	0.47	
	Stove 15 cm dia.	0.64	
Lighting	200–candle power	0.1	China
	40–watt bulb	0.13	India
	1–mantle	0.07–0.08	
	2–mantle	0.14	
	3–mantle	0.17	
Gasoline engine	Per hp	0.45	India (Engine efficiency 25%)
	Per hp	0.41	Pakistan (Engine efficiency 28%)
	Per hp	0.43	Philippines
Diesel engine	Per hp	0.45	Pakistan (Compression ratio 20)
Refrigerator	Per m^3	1.2	U.K.
Incubator	Per m^3	0.5–0.7	Nepal
Table fan	30 cm dia.	0.17	
Space heater	30 cm dia.	0.16	

Data are expressed per hour except as indicated

Table 6
Comparison of various fuels (KVIC, 1975)

Fuel	Calorific Value, Kcal	Burning Mode	Thermal Efficiency %
Biogas, m^3	4713	Standard burner	60
Kerosene, l	9122	Pressure stove	50
Firewood, kg	4708	Open stove	17.3
Cowdung cake, kg	2092	Open stove	11
Charcoal, kg	6930	Open stove	28
Soft coke, kg	6292	Open stove	28
Coal gas, kg	4004	Standard burner	60
Electricity, kWh	860	Hot plate	70

Table 7
Relative values of biogas compared with other energy sources
(Eggeling et al., no date)

Relative Calorific Values	Relative Monetary Values
1.0 m^3 biogas	1.0
3.6 kg firewood	–
1.5 kg charcoal	0.68
13.0 kg cowdung	–
0.5 kg butane	2.30
0.6 l kerosene	1.61
5.0 kWh electricity	2.12
0.5 l fuel oil	2.39

THE BENEFITS OF BIOGAS TECHNOLOGY

Much has been said with enthusiasm about the numerous benefits of BGT. It is often stated that BGT can offer a great potential to solve a variety of problems. For instance, Eusebio & Rabino (1978) have calculated that if 60% of animal wastes in Southeast Asia were collected and utilized for biogas production, the region could save the equivalent of 8.9 billion liters of petroleum with an estimated value of US$858 million. This amount would cut down 15% of the total imports of mineral fuels, lubricators and related products in the region. The estimated potential of BGT in some Asian countries is presented in Table 8.

Table 8
Estimated potentials of biogas technology

Country/Region	Potential	Ref.
China	– 1.400 billion tonnes of animal and human excreta are available. One kg, when fermented, produces 3350 kJ.	Ma, 1981
India	– 18,750,000 family-size biogas plants (1.7 m^3 of gas/d) and 560,000 community plants (142 m^3/d).	Agarval, 1979
	– 2,350 million cft (66.5 million m^3) biogas per day, equivalent to 4.12 million tons of coal a year or 1095 million gal (243 million liters) of petrol a year.	Chiranjivi, 1978
Korea, R.	– 311,981 m^3 of biogas produced in 1977 from cow, pig and chicken wastes. Equivalent to 1,095,400 barrels of kerosene, or 2,063 Megawatt-h.	Park, Lim & Park, 1979
South-East Asia	– Biogas from 60% of animal wastes produced in 1975 equivalent to 8.9 x 10^9 liters of petroleum.	Eusebio & Rabino, 1978
Pakistan	– 2,327 million m^3 of biogas produced from 50% of cattle dung, equivalent to 9.183 million barrels (1.25 million tons) of oil.	Hamid, 1980
Indonesia	– 15.975 million m^3 of gas per day	Nathan, 1982
Malaysia	– 1.962 " " " " " "	
Philippines	– 10.083 " " " " " "	
Singapore	– 0.680 " " " " " "	
Thailand	– 17.017 " " " " " "	
Nepal	– Theoretical potential of 790 million m^3 of gas, and economic potential of 116* million m^3 of gas. Equivalent to 3.21 million and 1.28 million, respectively, tonnes of coal.	Shrestha, 1981
	– Theoretical potential of fresh dung: 28 million tonnes per annum.	IDC, 1981

**This should probably read 316. The figure 116 may be a typographical error.*

Theoretically, the potential of BGT is quite appealing. In the case of India, if the potential shown in Table 8 is realized by 1990, biogas could supply India with an energy amount equivalent to nearly 44% of its projected electricity consumption, and reduce its projected consumption of coal by 15%, and of firewood by 79%. Although the investment required for such a program would be very high, about Rs. 66,000 million (about US$7,300 million), the benefits seem to be worth it. Are they? This section will deal with the main benefits of BGT in their right perspectives.

Interfuel Substitution

Biogas as a Substitute for Firewood

Data compiled from various countries have revealed that in the rural areas of Asia, substantial parts of the energy requirements of a typical household are for cooking (Skrinde, 1981; Tam & Thanh, 1982). As an extreme case, a survey in an area in Bangladesh (Islam, 1980) indicated that 93% of the fuel energy used was for cooking. A great portion of energy used for cooking purposes comes from firewood. For example, the contribution of firewood to total fuel energy requirements is 70-75% in Indonesia (Wiersum, 1979), 87% in Nepal (Shrestha, 1981), and 60% in Sri Lanka (Amaratunga, 1980).

With the population expansion coupled with the increasing need of fuel per capita, the use of firewood has accelerated deforestation at an alarming rate. Until recent years, forests had completely disappeared from most parts of China because the trees had been cut down for fuel (Revelle, 1976). In Nepal, about half a million hectares of forests are destroyed annually for firewood (IDC, 1981).

All of the above facts are hardly surprising, since the requirement of firewood per capita per year is about 250-300 kg in China (Eggeling & Stephan, 1981), 300 kg in India (Makhijani, 1977), 0.70-0.86 m^3 in Indonesia (Wiersum, 1979), and 700 kg or one m^3 in Nepal (IDC, 1981). A hectare of forest supports about 50 tonnes of wood (Prasad *et al.*, 1974), which can therefore supply firewood to about 160 persons. Probably a similar process of deforestation is now occurring in many other parts of Asia. It is estimated that the present forest reserves of India, at present annual rates of firewood consumption, can supply firewood for only 24 years (Revelle, 1976). A comparison of maps and photos shows that the forest area of Nepal has declined from 60 to 30% within 30 years. In 15 years, the Nepalese hill and mountain forests will be completely denuded at the current rate of tree cutting (IDC, 1981). This is because the natural regeneration rate of forests in Nepal is slow, about 70 kg of biomass per capita per year.

It is commonly believed that collecting firewood causes forest destruction, and BGT is, therefore, looked upon as a means to at least partially curb the deforestation. It is estimated that a 100-cft (2.8 m^3) biogas digester can save 0.3 acre (about 1,200 m^2) of forest per year. Ironically, deforestation, with the resulting scarcity of firewood, is an incentive for adopting BGT. Thus, where firewood is still readily available to rural people, the development of BGT is low. This is at least the case for Indonesia (Skrinde, 1981) and Thailand (Sermpol *et al.*, 1979).

But the problem of firewood is a rather complex one. The common claim that deforestation is caused by people cutting trees for firewood does not seem to hold everywhere. It has been observed that what many rural Asian families burn for cooking are not fallen trees, but the stalks from their crop residues (Islam, 1980), or twigs and small branches collected around their villages (ESCAP, 1979), or small brushes that are planted for fencing and for fuel (Dandekar, 1980). Much, if not most – of the soil erosion caused by cutting trees is the result, of the commercial lumber operations of government and industries, which indulge in thoughtless clearance of large areas of forest (Makhijani, 1977).

Another aspect of the problem, illustrated by the situation in Bangladesh, refutes the idea that there is a certain positive benefit of forestation alleviation by means of BGT. Here, it has been found (Islam, 1980) that there is little possibility of improvement of deforestation, because the households who can afford a biogas plant are also the owners of trees. So the trees which will be saved due to the use of biogas by richer households (who without biogas would not need firewood anyway) would not be available to the poorer households.

The benefit of BGT derived from saving firewood seems, therefore, not always to be clear. The main criticism of BGT is centered on the high cost of the digester relative to the low return from the fuel obtained. Although advocates of BGT estimated that biogas is twice as cheap as firewood (Ansari & Yasin, 1980), a critic evaluated the cost of producing 1,000,000 BTU by biogas at \$1.50, and by using firewood at \$0.15 (ESCAP, 1975).

In fact, BGT may have a negative effect on deforestation due to the fact that animal dung is traditionally free to those who collect it as a fuel source. With the introduction of BGT, the owners of animals will claim ownership of the dung produced by their animals to produce gas for themselves, and this will force poorer people to switch from dung to firewood.

There is even an implication (Wiersum, 1979) that an investment should be made in developing measures to ensure a sustained yield of firewood, since this has the advantage of being a familiar commodity.

Biogas as a Substitute for Animal Dung

Animal dung constituted 5-10% of requirements for kitchen fuel in rural areas of India at the beginning of this century. This figure rose to 25% by 1930, 45% by 1950 and 70% at the present time (Khan, 1980). Prasad *et al.* (1974) estimated that 45% of the domestic fuel requirements in Indian villages come from burning animal dung. A source quoted by Revelle (1976) revealed that about 4.68 million tonnes of dried cow dung were burned in India during 1970-71, of which 83% was consumed in rural areas. Another survey, also quoted by Revelle, gave the yearly per capita combustion of dung cakes in rural households as 87 kg during 1963-64. A similar picture can be seen in Pakistan where 70% of the fuel used in the villages is animal dung, and this constitutes about 70% of the cattle and buffalo dung produced (Shah, 1980). The use of animal dung as cooking fuel has an important implication since it is also valued as fertilizer, and the more it is burned in the home, the less it is applied to the field. Although one-fourth of the available dung is degraded in the generation of gas, the useful heat of the gas is about 20% more than the useful heat obtained by burning directly the entire amount of dung. This is mainly due to the very low efficiency of burning dung cakes against the much higher efficiency of burning biogas (Table 5). Thus gas conversion offers an efficient use of animal dung as a fuel, while still conserving the nutrients to be applied to crops.

In practice, the belief that using biogas for cooking can significantly alleviate the loss of nutrients from burning dung is likely to be an illusion. The reasons for this are:

- The scale of animal dung saving is too small as compared with the enormous cost involved. India, for example, has set a target of building 100,000 family-size biogas plants each year during the period of 1975-1985, at a total cost of about US\$30 thousand million (Makhijani, 1976). Even if this target were to be reached, this would mean that by 1985, only about 3% of India's cattle would be involved.
- This benefit is meaningless to rural people since animal dung can normally be obtained free, whereas the gas would be produced at a cost.
- As stated previously, the saving of animal dung is offset by aggravated deforestation.

Biogas as a Substitute for Fossil Fuels

Oil-importing countries are more and more burdened with their skyrocketing oil bills. A typical situation can be found in Pakistan, where, during the period 1971-1979 the amount of imported crude oil and petroleum products rose by less than 50%, whereas the bill increased 22-fold

(Shah, 1980). Kerosene is still a main source of energy for lighting in most rural areas of Asia. In Sri Lanka, about 90% of households use kerosene oil lamps for lighting (Amaratunga, 1980). It was hoped that BGT could partly help to save the reserve of foreign currency used for importing oil. In this respect, it should be noted that rural families in Asia usually light about 2-3 oil lamps for about 3 hours a day. Such a lighting regime would not require any substantial amount of oil as compared with the amount of oil used for agricultural and industrial purposes, for driving vehicles, and for the more sumptuous needs of urban areas. The kerosene consumption for a household in a survey area in Bangladesh is only about 1.06 gallons (less than 5 liters) per month (Islam, 1980). Even if all of the oil used for lighting in the rural areas of Bangladesh could be replaced by biogas, the amount of oil saved would be a small portion of the total amount of oil imported, which was more than 5 million tonnes during 1978-79 (Shah, 1980). The same situation prevails in rural India, where Revelle (1976) estimated that the energy used for lighting in 1970-71 was about 4.2% of the total energy needs. If compared with the total energy needs of the whole country, the proportion is much less, probably much less than 0.1%.

Drudgery Reduction

Where firewood is scarce, the collection and transport of firewood is very time-consuming. In China, this task requires up to 4 hours per day per family. BGT can eliminate this drudgery. Also, using biogas instead of firewood for cooking can reduce cooking time from 4-6 hours to 1.5-3 hours a day (Eggeling & Stephan, 1981). This can lead to more productive work, and is especially beneficial to women who can have more time for educational activities and entertainment.

In other situations where un or under-employment is still prevalent – about 63% of the population in rural Nepal are jobless, according to Shrestha (1981) – and people still have much free time, or where conventional fuels are plentiful or readily availble, such a benefit of time-saving may not be appreciated. It has also been remarked that the shift from firewood to biogas for cooking is a major change for village housewives. Whether this change – with all the associated problems of safety, handling, cooking practice, etc. – will be acceptable to them is a question which can only be answered in the field (Reddy & Prasad, 1977).

Nutrient Conservation

The nutrient element of concern is nitrogen since this element is lost if the waste is burned as a fuel, or can be depleted through volatilization, leaching, etc. during storage and handling if the waste is used as a fertilizer. The amounts of nitrogen in various types of wastes are presented in Table 9. Although at first glance the amounts seem to be negligible, full recycling of nutrients from wastes gives substantial benefits. Experience in Vietnam (Tuan & Tam, 1981) shows that the feces and urine collected for one year from a family of 4-5 persons – when applied to rice, corn or sweet potato – can offer an extra yield of 130-150 kg.

It is generally believed that in most handling methods of organic wastes today, substantial amounts of nitrogen are lost; but nitrogen is not lost from a biogas digester. In fact, from some sources it is known that the nitrogen level does reduce during anaerobic digestion, and the degree of reduction ranges from 3 to 10% (Iannotti *et al.*, 1979; Institute of Soil and Fertilizer, 1979; Li, 1982). With this information, the common belief that a biogas digester produces fertilizer should be reconsidered.

First of all, it should be pointed out that a biogas digester does not "produce" nitrogen. Oddly enough, there have been reports of an increase of nitrogen content in the digester effluent as compared with the influent. This must have been due to faulty analyses or calculations. In a closed digester where there is no known process of nitrogen fixation, an increase of total nitrogen is inconceivable. Rather, a digester is simply able to increase the amount of nitrogen available to

Table 9
Contents of nitrogen in some wastes

Waste	% Nitrogen on Dry Basis						
	General*	Burma	China	Fiji	India	Malaysia	Vietnam**
Human	5.5				5–7		7.0
Buffalo		1.4	0.3				1.7
Cow	1.7	1.4		1.8	1.4–1.8		1.3
Horse	2.3	5.5					
Pig	3.8	4.0	2.1	1.9		1.9	2.2
Goat		2.7		2.0			
Sheep	3.8		0.7				
Chicken		2.7	1.6	4.2		4.0	1.9
Duck		1.6					5.5

* *from Chaudhry & Saleemi (1980)*
** *from Tuan & Tam (1981)*
Other data compiled by Lohani & Rajagopal (1982)

plants. This could also be done with other waste handling methods such as composting.

Then, there have been various reports on impressive crop yield improvements as the result of applying effluents from digesters. Such a methodology in assessing the value of digester effluent as a fertilizer is a debatable matter. The usual comparison of the effects of digester effluents and influent on the yields of short-lived crops is not sound since digester wastes contain more available nutrients and hence should give better effects on short-lived crops. The situation would be different if raw and digested wastes were applied *gradually* at *low* loadings to perennial vegetation. In this case, the higher proportion of nitrogen in complex forms in the raw waste may result in some nitrogen being carried over from one season to another (Bhatia, 1977), whereas the nitrogen in ammoniacal form in digester effluent will volatilize within a short time. The overall result in this form of comparison – which is also biased – may very well be that raw wastes are better than digested wastes.

Still worse, comparing the yields of crops applied with digester effluent with those of crops not receiving any form of fertilizer is practically meaningless. Unfortunately, this kind of unscientific, greatly biased work has been recommended (ESCAP 1980) as a 'demonstration'' method to show laymen that BGT has great benefits.

The evaluation of digester effluent by measuring its nutrient composition immediately after it comes out of the digester is not appropriate. The application method, storage time and transport distance – among other factors – would have a direct effect on a benefit assessment of the end-product. Experience from Europe (Vogtmann & Besson, 1978) shows that nitrogen loss of anaerobically digested manure that is ploughed four days after application varies from 15 to 29%, depending on the climatic conditions. In the tropics, the loss is probably much higher.

As regards storage time, if digester slurry is dried, essentially all of the ammonia is lost through volatilization (Shah, 1980). Since ammonia constitutes 75-85% of the total nitrogen content in digester slurry, the total loss of nitrogen is, therefore, extremely and unacceptably high.

It can be concluded that biogas effluent as a fertilizer should not be construed as a full benefit of BGT. With or without a digester, a comparable amount of plant nutrients could be obtained from a given amount of waste. And if we wish to convert the nutrient in wastes to forms more readily available to plants, other methods should also be considered and compared, rather than blindly adopting BGT.

Pathogen Inactivation

Substantial portions of pathogens are removed from the effluent of a biogas digester.

For helminth ova, the physical mechanisms of removal are (i) floating to the surface where the ova adhere to the scums, and (ii) free settling to the bottom. Thus in the Chinese design without any mixing operation and with the outlet connected to the middle section of the digester chamber, a high removal of helminth ova is obtained (Sichuan Institute, 1979).

Long retention times – usually more than 40 days in the Indian design and several months in the Chinese design – are favorable for pathogen die-off. Schistosomes are observed to live up to 37 days, while 99% filarias die within 40 days in summer. The viability rates of *Ascaris* ova – which is the most resistant of all parasites – range from 63 to 93% after 10-90 days to 20% after 180 days (FAO, 1978a). This could cause a concern in the Indian design if mixing is performed and if the outlet pipe protrudes deep down to the bottom.

Because of anaerobic conditions, aerobic organisms such as *Leptospira* or hook worm ova are killed quickly in a digester, the latter surviving for no more than 9 days (Sichuan Institute, 1979), and are removed by 90% within 30 days in winter; whereas *Shigella* and Spirochetes die within 2 days (FAO, 1978b).

It has been observed that Para-typhoid B bacilli – one of the most persistent enteric bacteria – survive for a period of 44 days in a digester.

Based on these data and others, it has been claimed that BGT is a method for pathogen destruction and could contribute to sanitation improvement in rural areas of Asia. It is true that significant improvements in public health has been observed in regions where BGT has been introduced. But no one should build a digester solely for this purpose, just as one should not build it ~~not~~ for the sole purpose of nutrient conservation. Again, other prosesses should be considered and compared.

BIOGAS TECHNOLOGY VS COMPOSTING

From the considerations above, the important issue now is to compare the performance of nitrogen conservation among waste handling methods that are common in rural Asia. Before the introduction of BGT, composting is probably the only waste recycling option in rural Asia with the eventual purpose of fertilization. Tam & Thanh (1982) have given a comparative analysis of BGT *vis-a-vis* composting. Briefly, the arguments are:

* As far as nitrogen conservation is concerned, a biogas digester is *not* superior to composting. A closed composting process – the first stage of which is aerobic and the second, anaerobic – can conserve as much nitrogen as a digester.

* A concept of *total* nitrogen loss – that is, the loss (i) during the process *and* (ii) on application should be considered in the comparison. Based on this concept, some of the concerns over the loss of nitrogen during composting farmyard manure as compared with that in anaerobic digestion are not justified (Vogtmann & Besson, 1978).

* On application, the loss of nitrogen from compost is insignificant whereas this loss from digester effluent may be substantial.

- In other respects, BGT has more disadvantages: it is more costly, more difficult to operate and maintain, requires more space and water, and digester effluent in liquid form is more difficult to handle and transport than dry compost.
- With regard to pathogen inactivation, a biogas digester is worse than the composting process. In a compost heap, the temperature is higher, while the moisture is lower, and antibiosis, which is characteristic of composting, takes place all of these conditions have a very adverse effect on pathogens.
- Perhaps where labor-intensive work is not preferred and resources are available, BGT should be considered as a *convenient* – rather than an effective – means of nutrient conservation and pathogen inactivation.

SOCIO-ECONOMIC ASPECTS

Economic Assessment

In an economic analysis, many factors have to be considered, as outlined in Table 10. Although this Table is by no means comprehensive, it is clear that many factors listed cannot be expressed in monetary terms. In fact, there is no general answer to the economic feasibility of BGT. Data widely vary from country to country. For example, while it is reported (Sermpol, 1979) that the maintenance cost for a family-size plant in Thailand is about 23% of the capital cost, this percentage rises to about 58% for a digester in the Philippines producing daily 28-42m^2 of gas (Simpson & Morales, 1980). The payback time of a digester also varies greatly, from as low as 1.25 years in China (Li, 1982) to 7 years in Thailand (Pisit, 1979), and even as high as 16.7 years in India (Moulik & Srivastava, 1975).

Even the economic feasibility of BGT has not reached a general concensus. While many researchers are in favor of BGT, others come to the conclusion that the monetary benefits do not outweigh the costs incurred by an individual household (Makhijanai, 1977). It is further claimed that the benefits of BGT will accrue to the society as a whole rather than to the individual household which adopts BGT. An even less favorable impression is given by French (1979), who concludes that, based on his financial analysis, family-scale biogas plants of the sort used in India seem a dubious investment from the point of view of everyone except their manufacturers.

It can be seen from the available literature that quite often BGT is assessed alone, and seldom in comparison with other options for the same purposes. An interesting exception is the work done by Mubayi *et al.* (1980), in which BGT is assessed together with other biomass conversion technologies' (Table 11). Although Mubayi *et al.* caution that this table is intended for descriptive purposes rather than for comparison of these processes, such a work helps in giving broader insights into the option under consideration. For example, it has been observed that biogas is more costly than charcoal produced by pyrolysis. This conforms to some extent with the idea of Wiersum (1979), who advocates planting high-yield trees as a source of cheap cooking energy.

In the state of uncertainty and complexity (which has been dealt with in more detail by Tam & Thanh, 1982), economic analysis should be carried out specifically for local conditions on a case-by-case basis. Although an exact methodology in economic analysis is difficult to be universally agreed upon, some errors that have been committed all too frequently in the past can be pinpointed to serve as general guidelines (Bhatia, 1977, Shah, 1978a; Shelat & Karia, 1977; Subramanian, 1976).

1. Even with a given design and size, the investment can vary from place to place, even within the same country. For example, the cost of construction is dictated by many local conditions such as the soil properties, labor and material costs, etc. Hence all local factors should be studied in-depth.

Table 10
Factors to be considered in economic analysis
(Adapted from ESCAP, 1981)

1. Economic Factors	a. Interest on Loan
	b. Current/future cost of alternative fuels
	c. Current/future cost of chemical fertilizers
	d. Current/future cost of construction materials
	e. Saving of foreign currency
	f. Current/future labor cost
	g. Inflation rate
	h. Costs of transport of feeding materials and effluents
2. Social Factors	a. Employment created
	b. Better lighting : more educational/cultural activities
	c. Less time consumed for fetching firewood and for cooking
	d. Improved facilities in villages; thus less migration to cities
	e. Less expense for buying alternative fuels
	f. More time for additional income-earning activities
3. Technical Factors	a. Construction, maintenance and repairs of biogas plants
	b. Availability of materials and land required
	c. Suitability of local materials
4. Ecological/Health Factors	a. Improved health
	b. Forest conservation (Positive or negative)
	c. Environmental pollution abatement
	d. Improvement in yields of agricultural products

2. Some items such as the cost of land for the system and the cost of water used to dilute the feeding materials, although quantifiable, are usually neglected. In some cases, these factors are not as insignificant as they are thought to be.

3. Assessment based on documented data may cause serious errors. For example, the amount of dung produced by (generally speaking) cattle may vary from 4 kg a day for a calf to 30 kg for a buffalo. Hence, generalization on the number of animals required for operating a plant of a given size could be misleading.

4. Seasonal variations in many parameters – such as those in gas production (summer vs winter), in the amount of animal wastes collected (free grazing during summer vs confinement during winter), and in the cost of labor (planting season vs slack season) – are often ignored. The dangerous trend is that an over-optimist or an over-pessimist may choose a value in the range that he sees fit to support his idea.

Table 11
Biomass conversion technologies
(Mubayi et al., 1980)

Energy Product	Substrate	Process	Status of Technology	Maintenance Requirement	Sustainability of Substrate	Estimated Energy Cost (\$/10^9 J)
Methane	Crop residues Animal wastes	Anaerobic digestion	Well developed	Low	High	2–4[a]
Charcoal	Wood	Carbonization by kilns	Well developed	Low	Country dependent	2–6[b]
Charcoal, pyrolytic oil	Wood Crop residues	Pyrolysis	Available	High	High	1–3[c]
Methanol	Wood	Pyrolysis/ distillation	Available	High	Country dependent	8–10[d]
Ethanol	Sugarcane	Batch fetmentation	Available	High	Country dependent	18–20[e]
Ethanol	Crop residues	Batch fermentation	Research Stage	Medium	High	30–50[f]
SNG	Wood	Gasification	Development Stage	High	Country dependent	6–8[g]

[a] *Based on a 75 m^3/day community size plant. Does not include collection cost of wastes.*

[b] *Lower limit based on retail price of charcoal (1977) in Thailand and upper limit based on retail price of charcoal (1977) in Ghana.*

[c] *Lower limit based on production cost of a pyrolytic converter with one ton/day capacity. Upper limit based on production cost of a designed converter with six ton/day capacity in Ghana.*

[d] *Based on the economic feasibility of a plant of 100,000 gallon/day capacity at a feedstock cost of \$ 19/ton dry wood.*

[e] *Calculated selling price based on a feedstock cost of \$ 13.6/ton in Brazil*

[f] *Based on the economic feasibility of a plant of 75,800 gallon/day capacity at a feedstock cost of \$ 15/ton dry wood.*

[g] *Based on the economic feasibility of a plant of 6.4 x 10^6 SCF/day capacity at a feedstock cost of \$ 19/ton dry wood.*

5. Assessing the value of the gas should take into consideration some important factors, such as the methane content, and the efficiencies of gas gadgets and gas uses.
6. The basis of evaluation of the gas produced is of significance. For example, in places where people use wastes but not kerosene as fuel, valuing the gas at the market price of kerosene equivalent is not correct, since this over-estimates the benefits.
7. It has been observed that some of the present evaluations on biogas systems, while comparing the benefits with respect to existing practices, make the error of double accounting. For example, if the dung which is already used as a manure is fed to a digester, only its incremental value can be taken into account.
8. The evaluation of digested slurry is not as straightforward as it is supposed to be. The concept of *total* loss should be applied to ascertain the fertilizer value of digester effluent (whether it is used in liquid or dried form) at the point of end-use.
9. BGT should be assessed against – and compared with – other technologies offering similar benefits, such as planting of high-yield trees to supply firewood and green manure, electrification to provide lighting and pumping energy, or composting to produce fertilizer. In this way, the true benefits and any possible trade-offs can be identified.

The above points do not cover exhaustively the methodology for economic assessment. They are intended simply to illustrate the fact that crude assumptions on critical issues may cause substantial discrepancies, which is turn may cause a whole carefully planned program to fail. Amittedly there are not sufficient data in the literature based on which one can confidently assess the viability of BGT. Santerre & Smith (1982), when trying to apply a method to measure the appropriateness of BGT, have to give many estimated values in their analysis. Limited as it is by the available data base, their methodology nevertheless suggests important areas for more detailed studies.

Acceptance

Although BGT may offer various benefits, it does not necessarily mean that it will be accepted with enthusiasm. This Section will give an analysis from the user's point-of-view.

Due to his lack of knowledge and awareness, a villager cannot be expected to understand the benefits of deforestation control, nutrient conservation, or health improvement. Hard pressed with all the difficulties of his life, an uneducated and poor villager has only one thing on his mind, that is to try to solve his immediate problems for the sake of survival.

In this struggle, all the benefits that have been discussed become meaningless to the uneducated poor. As some authors (Reddy & Prasad, 1977) put it: "No poor family is naive enough to accumulate its total income over one and a half years to build one biogas plant when it can instead send a child out for a few hours a day to collect twigs and branches to meet its requirements for fuel at a 'zero' private cost".

Here, there is the matter of "social cost vs financial cost". Shrestha (1981) observes that under the prevailing socio-economic situation of Nepal – and quite likely in many rural Asian regions – where much of the labor force is unemployed, traditional sources of energy (eg., firewood and animal dung) are available "free of cost" to the people, although the social cost, even though it may be high (eg., less education for children and less entertainment for women), is still affordable. But alternative renewable energy sources, although they may have high social benefits, are too costly for rural people.

The conservative attitude of rural people is another matter to be considered. A land/animal owner may like to try something new, perhaps only out of curiosity. But a poor rural peasant is very hesitant to enter a new venture. Also, not being familiar with entrepreneurship practice, he is shy to contact a bank for a loan; and not being accustomed with social relations outside his village, he is not eager to ask for technical advice on the operation and maintenance of his digester, or for reparation work when his digester fails. It is seldom that he even airs his opinions and feelings. In an intensive survey in Thailand (Sempol, 1979), more than 50% of biogas users stated that the motive of BGT adoption was to please the government officials who came to them to promote BGT.

The indifferent attitudes described are more conspicuous with BGT since biogas does not bring in cash, and hence the benefits are hard to perceive. The investment cost for a family-size digester in Thailand (Sermpol, 1979) can be used to buy a smaller pump, or for a down payment to acquire a small farm tractor. These machines are considered by the farmer to be more important than BGT since it can bring additional cash within one crop season.

Acceptability of biogas may be hampered by religious convictions. Muslim societies, on account of their beliefs, oppose the use of pig waste as a feeding material (Sermpol, 1979; Subramanian, 1976). For instance, a plant in Indonesia using pig manure had to be abandoned due to opposition from Muslim villagers. In another case, the use of digested nightsoil as fertilizer was discontinued when a local witch doctor attributed sickness to the consumption of products grown with the digested slurry (Skrinde, 1981).

There is also much reluctance in some regions of India to use nightsoil as a feeding material as well as to use the gas produced from it for cooking. (Mazumdar, 1982; Moulik & Srivastava, 1975; Subramanian, 1976). The negative attitude toward the use of nightsoil varies from place to place, but when it occurs it is a major obstacle to the implementation of BGT.

Long-term Benefits vs Short-term Priorities

The average capital investment for a digester in Thailand (Sermpol, 1979) is 2,675 Baht (US$ 135). From this investment, the owner can get daily 1.2m^3 of biogas, which is equivalent to 1 kg of charcoal, or a mere 3 Baht (US$ 0.15). Similarly, the investment cost of a digester in India is Rs. 4000 (US$ 500), whereas the return is equivalent to 2-3 liters of gasoline a day. From the villager's viewpoint, these returns are either too low in relation to other uses of handy resources, or hard to quantify, and this leads to hesitation in adopting BGT. Asian farmers usually have no steady income, let alone a cash reserve. They get their money only twice or three times a year and at the same time they have pressing demands of a social and agricultural nature on their available income. Whichever need comes earlier will get the funds. As a result, the poor will not jeopardize meeting their immediate needs for any long-term goals, even if these may ultimately benefit them.

This attitude is consolidated further when the gas is not valued because of the availability of other sources of energy such as firewood nearby the house, or kerosene at the village market. In Korea, where 90% of the villages are supplied with cheap electricity – about US$ 2 per family per month – the high capital cost of a digester (about US$ 150) and low gas production in the winter both have adverse effects on BGT adoption (Subramanian, 1976).

Again, the cost of a digester is a crucial factor. In China, the construction materials cost a family about US$ 30 whereas the cost of a bicycle is $ 100 (Chen & Li, 1980). This clearly shows the affordability, and acceptability, of BGT to the Chinese peasants.

It can be concluded that most rural families in Asia cannot afford a family-size digester, the more so with the Indian design. It has been pointed out (Subramanian, 1976) that if the sum for the capital cost of a digester is invested elsewhere, the annual interest at a rate of 15% can cover the annual expenses even on liquefied petroleum gas.

Benefit Distribution

A family-size digester needs an input from 4-5 head of cattle in order to produce enough gas for cooking and lighting. Realistic data show that to set up a plant of 60 cft (1.8 m^3) gas capacity or more, one should possess at least 4 cows. This will limit the benefit of biogas to a small number of families who own enough cattle. In India, this number is about 10-12% of the rural population (Agarval, 1979). Another estimate shows that less than 5% of the village population in India own 4 or more animals. (Chiranjivi, 1978; Prasad *et al.*, 1978).

Although it has been suggested (Skrinde, 1981) that 2 or 3 cows could support a unit of 2-m^3 gas capacity, such a unit is still of doubtful value. The reasons are:

(a) Field conditions do not always produce such a high performance (Table 2). It is more likely that the dung from 2-3 cows produces an amount of gas sufficient for cooking only. Less benefit (without the benefit of lighting) means less incentive for adoption BGT.

(b) A plant of such a scale may not be economically attractive. A cost-benefit study (Moulik & Srivastava, 1975) has shown that, under existing technology, a digester of a size requiring less than 3-4 cattle to provide the necessary dung is not economically profitable.

(c) Families owning less animals are more reluctant – or event if they are not, have less resources to join the scheme.

BGT can cause far reaching effects in widening the gap between the rich and the poor. In India, a subsidy program for BGT was discontinued when it was found to have increased the effective price of dung, causing hardship to the poor.

It is evident that BGT depending solely on animal wastes as input materials will deprive the poor majority of a chance to raise their living standards.

Resource Ownership

Major obstacles can be readily seen from the ownership of waste materials. Traditionally, the institutional structure is arranged in the village so that the wastes are available for those who need them, without regard to the distribution of animal ownership. BGT will provide novel opportunities for the rich in the village to claim ownership of the wastes, and of their product – whether it is gas, electricity, or machine power. This will intimidate the poor, and in consequence they will lose their income rights. From free sources, the wastes will become a priced commodity like land, anmals, etc. The losers will be the poorer families who have to seek alternative sources of energy and fertilizers.

SOME UNANSWERED QUESTIONS

What Purpose(s) Does Biogas Serve Best?

While there are clamorous praises for biogas as a cooking fuel, one opinion (Makhijani, 1977) is that using biogas for cooking in India is basically an uneconomic proposition. The argument is that making a per capita investment of over Rs. 100 (about US$ 10) to produce a high-grade fuel for cooking, while irrigation pumps are idle for want of energy, is an unaffordable luxury. Makhijani further suggests that community biogas plants could be better used in irrigation, due to the following favorable factors:

(a) The cost of compressed methane is about the same as the cost of diesel and, in terms of useful energy, it is generally cheaper than unsubsidized rural electricity in India.

(b) The requirements for investment (especially for foreign exchange) are much smaller in the case of biogas than for either diesel or electricity.

(c) The number of new jobs would be 10-100 times greater than in a centralized electricity or fertilizer production scheme.

Reddy & Prasad (1977) also claim that biogas is so valuable as an energy source that one must examine whether there are any better end-uses for it than for cooking. In places where BGT programs have failed due to the availability of fuel, the programs could be revived to serve better purposes – for example, community electrification. This will be discussed in the next section.

Household Direct Lighting or Community Electrification?

At a pressure of 10 cm of water, a gas mantle burns about as brightly as a 40-watt electric bulb, which is better than most cheap oil lamps. Such a bulb consumes about 80 liters of gas per hour, so 25 mantles would require 2,000 liters of gas. On average, it takes only 750 liters of gas to produce one kWh of electricity, enough to light 25 40-watt bulbs (Bachmann & Saubolle, 1980). And wiring a house is cheaper and safer than installing gas pipes. For these reasons, community electrification using biogas from a central digester will be considered.

In a preliminary assessment of the items which should be considered in the costs and benefits of biogas plants vs rural electrification, Prasad *et al.* (1974) concluded that the former seems to be more favorable. In contrast, Tyner & Adams (1977) found that, on average, electricity generation using centralized power facilities is more cost advantageous than adopting decentralized systems based on biogas generation. However, in some situations, such as in isolated regions where the transmission cost is high, power generation from biogas may be a reasonable alternative.

An important factor to be considered is that electricity generation from biogas requires more materials that need to be brought from outside the village. This would increase the investment cost and complicate the operation and maintenance of high-technology facilities. The fact that community electrification using biogas has been adopted quite widely in China (Chen *et al.*, 1978; Li, 1982; Sichuan Provincial Office, 1980) does not necessarily mean that this option can be adopted elsewhere. In order to implement the scheme, community-size plants have to be built, and administered by the community as a whole. The feasibility of this concept is dicussed in the next section.

Community Plants or Family Units?

Advocates for community plants have cited various reasons, notably the following:

* The labor required for operation and maintenance of a community plant is considerably less than in individual plants, thus the responsible operator can be better trained for his job.
* Due to the economies of size, a communal plant can reduce the investment cost and therefore is more affordable.
* A plant owned by a community has a better chance of receiving technical and financial support from outside the village.
* Community plants provide a possibility for bringing the benefits of BGT within the reach of poorer sections of rural communities.
* A community plant can provide a service that is normally not feasible with individual plants, such as mechanization and electrification.

Opponents of community plants have also given many reasons to support their arguments, which can be summarized as follows (Agarval, 1979; Dandekar, 1979; French, 1979; Mathew, 1981; Santerre & Smith, 1982; Tyner & Adams, 1979):

- It is not always the case that community plants have "clear-cut" economies of scale in comparison with family-size digesters.
- A community plant needs elaborate and extremely expensive management mechanisms for collecting/buying inputs (i.e., wastes and water), and distributing/selling outputs (i.e., gas and fertilizer). Likewise, costly distribution equipment (e.g., gas piping or electrical wiring networks) may offset the economy of scale inherent in the actual digester itself.
- Such plants require great managerial talents from skilled technicians for their maintenance and operation. In many instances (Subramanian, 1976; Myles, 1983), a whole scheme has collapsed due to the replacement of responsible personnel.
- Furthermore, efficient administrative and organizational structures are crucial to community programs. Technical details can be worked out, such as the design of a rural energy center by Reddy & Subramanian (1979). The problem lies with organization and management. On the distribution side, some equitable and enforceable method should be devised for governing the flow of gas, electricity, fertilizer, etc., if a community plant is to be set up.
- There is even an argument (Tyner & Adams, 1979) that one may with some confidence predict a worsening of the internal distribution of resources and income within the village. In many places, weak structures have created the "Tragedy of Commons", when individualism leads to irresponsibility and indifference toward the "common" things.
- Psychologically, rural people in many regions have had bad experience from many co-operative schemes. Because of this, even blood-related families and members of a former joint family are reluctant to consider any joint ventures. Also, feuds and fractionalism, which are prevalent realities in the social life of developing countries, can have an undesirable impact.

Ironically, while China promotes mainly family-size plants (Shian *et al.*, 1979; Thery, 1981), appropriate technologists in India (Agarval, 1979; Basu *et al.*, 1983) have argued that only large community plants can benefit the Indian rural poor. In Pakistan it is also suggested (Islam, 1980) that BGT may be made viable if it is considered at homestead level for lighting purposes only and shared by households living in the homestead. In Egypt, a study reports that family-size units are uneconomical, but community digesters couple with internal engines would be economical in an Egyptian setting (El-Din *et al.*, 1980). Several surveys (Moulik & Srivastava, 1975; Subramanian, 1976) show that people are reluctant to accept such an idea.

Thus there is no general guideline for the choice between a family and a community plant, due to the inherent problems of the latter.

PROBLEMS & CONSTRAINTS

From the discussion already presented, it can be inferred that the rate of failures in the implementation of BGT in various regions of Asia is hardly surprising. In order to provide a more complete view of this situation, this section will outline some common bottlenecks that have been encountered.

Corrosion of the Gasholder in the Indian Design

The gasholder in this design has a very short life compared with other parts of the biogas plant, although it constitutes about 30-40% of the total investment cost. This is the common reason for failures where the Indian design is adopted (Sermpol, 1979; ESCAP, 1980; Prasad *et al.*, 1974). Although the gasholder can be well maintained for a relatively long time by regularly painting it, in practice this is not always possible due to the lack of skills and equipment as in Thailand (Sermpol, 1979); and also due to the fact tht it is extremely difficult to lift the heavy gasholder out of the digester pit (ICAR, 1976).

Seasonal Variation of Gas Production

During the period 1969-1975, 28,944 family-size digesters were built in the Republic of Korea, and they were welcomed by farmers at first. Some years later, many of these plants were no longer used, mainly due to problems associated with cold weather in winter (Park, Park & Lim, 1979).

No Suitable Method for Gas Storage

The problem of reduced gas production in the winter could be overcome if there were a method to store the surplus gas produced during the summer. Unfortunately, biogas cannot be liquified as LPG. Bottling biogas is not economical nor practical (ESCAP, 1980).

Short Supply of Water

To supply 2m^3 of gas per day – which is intended for cooking purposes for a family of 4-5 persons – about 50 kg of animal dung is needed per day, and this requires about 50-100 liters of water. In places where water is scarce or takes much labor to fetch, this additional requirement for water could well be an unacceptable burden to the user (ICAR, 1976). In a field survey (Dandekar, 1980) at a village in India, a woman expressed: "It's a fight to get enough water to drink for everyone Who is going to wage a battle to get more for this gas plant?"

French (1979) also observes that where woodlands are particularly scarce, water is likely to be scarce as well, and so BGT will be even less feasible than usual, precisely where firewood is dwindling more rapidly.

Short Supply of Feeding Materials

This should not be a reason of failure if there is conscientious planning. In fact, unavailability of animal wastes is the main reason for the failure of the biogas program in Thailand (Sermpol, 1979), and also contributes to the abandonment of a number of digesters in Korea (Skrinde, 1981). In Burma (Thant, 1978) and in Indonesia (Hodiono & Hartono, 1978), animal waste is already used in agriculture, and so manure is an unaffordable commodity to run a digester. The same situation exists in Sri Lanka, where farmers pay as much as US$ 12 for a tonne of cattle manure (Amarasiri, 1978).

In many cases, there is not a lack of animals *per se* but merely inefficient collection of animal wastes. BGT requires a change in animal husbandry methods from free grazing to confinement, which incurs some cost to the animal owners, who then have to harvest grasses and transport them to their confined animals. Increasing mechanization of rural farms has aggrevated the lack of animal wastes in rural areas, whereas modern animal husbandry which tends to aggregate a large number of livestock in a small area (usually semi-urban) will create problems of transporting the wastes to scattered biogas plants.

Lack of Space

Particularly in poorer sections of villages, houses are closely clustered, which means that there is no suitable backyard space for installing gas plants (Dandekar, 1980; Moulik & Srivastava, 1975; Subramanian, 1976).

Operating Problems

One opinion (Abeles *et al.*, 1980) is that too much effort in the past has been focused on the chemical and biochemical aspects of the fermentation processes and not enough attention given to the physico-mechanical characteristics. Thus operating problems such as scum formation, leakage, obstruction of the inlet, outlet and gas pipe have been frequently reported. These problems have discouraged the users and led to abandonment, especially where there is not sufficient extension work.

CONCLUSION

Biogas technology, more than any other technology, is a delicate and complex issue. The diffusion of new energy technologies is far from a simple process, and it is likely to meet with the same problems that have hampered other rural development programs. One has to bear in mind that even programs that have obvious benefits to the local people (like foodgrain or cloth co-opratives, jointly owned village industries, cooperation schemes in irrigation, etc.) have failed, and then ask oneself what the chances are of BGT (which has so many abstract benefits) succeeding.

This paper just serves as a checklist of the main relevant aspects, to which there is still much to be added. Apparently, successes that have been recorded have not been achieved spontaneously without initial failures. The technology itself is not enough, even if current plaguing technical problems can be solved – and there is much room for improvement (Tam & Thanh, 1982).

Most of all, it should be kept in mind that biogas technology is not a panacea to solve all problems at the same time. Even if the estimated 7-9 million digesters still operating in the People's Republic of China were kept running for 8 months a year, they would contribute less than 1% of China's rural energy use (Anon., 1982). As already pointed out, the benefits of BGT should not be taken for granted. Depending on the economic and social structures, the benefits can be small or great, and one benefit may be a trade-off for another. All of these factors will eventually decide the desirability of BGT. A careful, objective assessment of every aspect is essential during the planning phase.

On the other hand, many parameters can be quantitatively assessed, and all of them should be subjected to evaluation. Overlooking an essential factor may cause irreversible damage. After some years of implementation, it was discovered that more than 50% of the total digesters built in a particular country had been abandoned. 50% of the owners interviewed said that the reason for disuse was the unavailability of input materials. In another country, most of the digesters were abandoned mainly due to their low performance in winter. These costly failures could have been avoided if the planning phase had been carefully worked out. Alternatively, the resources used in implementing the BGT programs could have been diverted to other strategies for solving rural problems.

When a technology that is appropriate to local situations has been identified and the economic affordability has been proved, some other heavy tasks still lie ahead. These are – to cite only some of them – community education and motivation, good organization and administration, and possibly re-structuring the whole socio-cultural-economic set-up (such as changes in living habits and productive conduct, decentralization of the production of materials, rearrangement of dwellings, etc.).

Collecting feed-back and correcting any problem that arises during implementation is no less important. In the People's Republic of China, technical progress has been made not before but during the implementation stage (Thery, 1981). This must have resulted from watchful follow-ups and a preparedness for dealing with problems. In some other regions, promotional officials come to villages with an idea of "friendly persuasion," and go when the work is finished, leaving behind them a lot of problems that the users have no way of solving without assistance; and finally when the officials revisit the sites, they can do little more than write in their report under the heading "biogas technology reconsidered".

Feedback monitoring requires an assessment of the whole scenario, in addition to a study of each component in this scenario. Analyses in the past have often disregarded those "second-round" or "linkage" effects that took place in parts of the system not immediately surrounding the project (Qurashi, 1980).

The limited length of this paper does not allow for an elaboration of remedial measures and recommendations for actions to be taken – features which have been intensively covered in the literature. It suffices to say that strong will and dedication – but not with a fanatical attitude – is badly needed for undertaking such a difficult endeavor. Only then can BGT be well accepted and well run, and fully show its potential benefits.

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