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BIOGAS TECHNOLOGY IN DEVELOPING COUNTRIES: AN OVERVIEW OF PERSPECTIVES

by

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PREFACE

In undertaking the publication of this issue, the editors have no intention of producing yet another state-of-the-art review on biogas, thereby contributing superfluously to the already prolific literature on the subject.

Our purpose is to introduce for the first time a critical review. However, while the authors present in the review their own judgements on some points, they still try to report objectively various conflicting and controversial opinions expressed in the literature. Results obtained in various countries in trying to implement biogas schemes vary considerably - from outstanding successes to bitter failures, leading to much controversy and confusion.

It seems therefore imperative to try to clarify the situation by challenging some current views on biogas technology. Considering the magnitude of the topic, the coverage of this review has been deliberately narrowed to family-size systems in developing countries.

It is hoped that this publication will stimulate some useful insights, and set the topic in a realistic perspective, avoiding over-optimism on one hand and over-pessimism on the other.

The Editors

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Biogas Technology in Developing Countries : An Overview of Perspectives

by

D.M. Tam
N.C. Thanh

I. INTRODUCTION

Biogas, also called "marsh gas", "bihugas" (Germany) or "gobar gas" (India), is a product of anaerobic fermentation of organic matters, and consists of about 60-70 per cent methane, 30-40 per cent carbon dioxide, and a small amount of other gases such as hydrogen, hydrogen sulphide, carbon monoxide, etc.

I.1 The Reason

Biogas technology has been known for a long time, but the interest in it has tremendously increased - mainly because of the increasing costs and the rapid depletion of local traditional fuel sources and of world fossil fuels. The interest in biogas technology has also been stimulated by the promotional efforts of various international organizations and foreign aid agencies through their publications, meetings, visits, etc., in which proponents are dominant over opponents - if any. As a consequence, implementation programs for biogas production have been carried out, 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 doubt. All of these may discourage those who tempt to implement a biogas program in their locations. At the same time, much enthusiasm - and over-optimism - still prevail. While these attitudes are needed for a good start, they may cause misconceptions with regard to biogas technology, and so may engender even more failures.

For these reasons, the authors realize the need of bringing out this review, even though there are innumerable publications on biogas technology.

I.2 The Purpose

This review is an attempt to formulate some realistic perspectives on biogas technology. The authors have tried their best to be neither over-pessimistic nor negative in putting the technology on the "surgery table". It is considered 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.

I.3 The Scope

This is not a review of the technical aspects per se, which have been well covered in the current literature. Rather, it gives an overview from some angles focusing on the technology. It is impossible to cover all aspects of such a vast topic. The authors have deliberately narrowed their coverage as follows:

- Geographically, attention is paid to developing countries where high priorities are numerous but resources are limited and the technology is still at a low level.

- Scale-wise, the review discusses specifically family-size systems; due to their inherent complexity and their impacts on various disciplines.

- The authors have refrained from dealing with biogas technology as a component of integrated systems of waste recycling and waste management. Covering such systems would be akin to "putting all one's eggs in one basket" and thus diluting the main theme.

II. THE TECHNOLOGY IN A NUTSHELL

This Section briefly describes biogas technology as it stands nowadays. For more details, other documents may be referred to (Bryant, 1979; Chaudhry & Saleemi, 1980; Chengdu Institute of Biology, 1979; Eggeling et al., no date; Eggeling & Stephan, 1981; ESCAP, 1975; ESCAP 1980; FAO, 1978a; FAO 1978b; Pyle, 1976; van Brakel, 1980; van Buren et al., 1979; van Velsen, 1981).

II.1 The Process

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 her 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 complete anaerobic fermentation process is depicted in Figure 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 catalyze 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 acid.

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

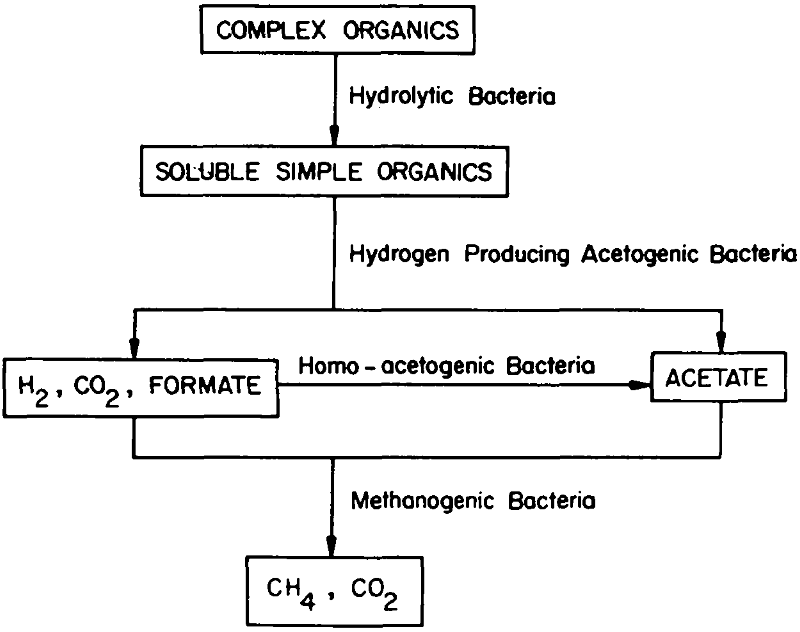

Figure 1 Biogas Production Process

Table 1 : Optimum Conditions for Biogas Production

Parameter	Optimum Value
Temperature, °C	30–35
pH	6.8–7.5
Carbon/Nitrogen Ratio	25–30
Solids content, %	7–9
Retention Time, days	25–35

II.2 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 organics into CH_4, CO_2, H_2, H_2S, etc. The optimum conditions for the process are described in Table 1. In the conditions cited, although the temperature is a controllable parameter, in practice it is not economically - or even technically - feasible in rural Asia to bring the temperature to the optimal value. 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 developing countries have their pH values in the neutral range.

Some types of wastes such as cattle, sheep and horse dung have a C/N ratio near the optimum value. Others, such as human excreta and pig waste, have C/N ratios of about 3 and 13, respectively (Van Buren et al, 1979). 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.

Most of the waste materials have solids contents much higher than the desired levels of 7-9 per cent, thus some amount of water should be added. Normally one part of waste requires about 1-1.5 parts of water. This may involve a constraint where water is scarce or difficult to get.

Retention time decides the extent at which the waste is digested. The longer the time, the larger the volume of gas produced from a given amount of waste, and the smaller the volume of gas from a given digester volume, and vice versa. Thus, if the available amount of input material 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 fear that if the loading is too high, it may flush out the microorganisms quicker than they can multiply does not materialize, since in practice it is desirable to exploit as much as possible the gas production potential from a limited amount of waste, and also since the digesters are not well mixed, and hence the solids retention time is higher than the hydraulic retention time.

II.3 Potential Gas Production

The potential gas volumes produced from wastes vary depending on the source, and can be expressed based on a head count (Table 2) or on a fixed weight (Table 3). Expressing the gas production from a number of animal head may lead to a serious error in the assessment of gas potential, whereas basing the gas production per unit weight of animal, although it is more accurate, is not practical in field work. It goes without saying that the gas volume produced from a given type of waste also varies widely depending on innumerable factors.

II.4 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 machines. For the latter, dual-fuel engines are usually adopted, so that they can be alternatively run with conventional fuels or with biogas.

Table 2 : 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 3: 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).*

The requirements of gas for various purposes are presented in Table 4. One m^3 of biogas can serve one of the following purposes (van Buren, et al., 1979):

- Lighting, with an equivalence of a 60-100 watt bulb for 6 hours
- Cooking 3 meals for a family of 5-6 persons
- Driving a 3-tonne lorry 2.8 km
- Running a 1-hp motor for 2 hours
- Generating 1.25 kW of electricity

Table 4 : Biogas Requirements for Various Purposes (Shah, 1978)

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

Tables 5 and 6 present a comparison between biogas and various commercial fuels.

II.5 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" (Figure 2), and the floating gas holder known as the "Indian digester" (Figure 3). The latter is also called the "KVIC digester" since it was developed by the Indian Khadi & Village Industry Commission. The digesters currently used in Asia are slightly modified forms of one or the other of these two main types (ESCAP, 1980). Table 7 briefly describes the main features of the two types.

Table 5. 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	" "	11
Charcoal, kg	6930	" "	28
Soft coke, kg	6292	" "	28
Coal gas, kg	4004	Standard burner	60
Electricity, kWh	860	Hot plate	70

Table 6: Relative Value of Biogas Compared with Other Energy Sources (Eggeling et al., no date)

Relative Calorific Value	Relative Monetary Value
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

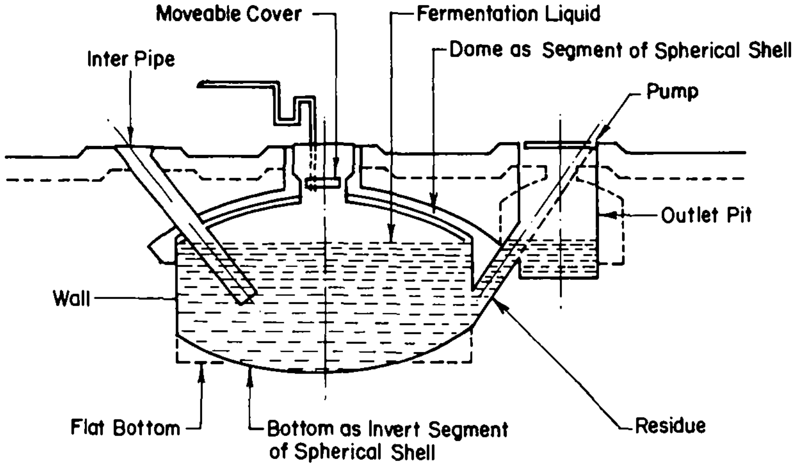

Figure 2 The Chinese Digester Design

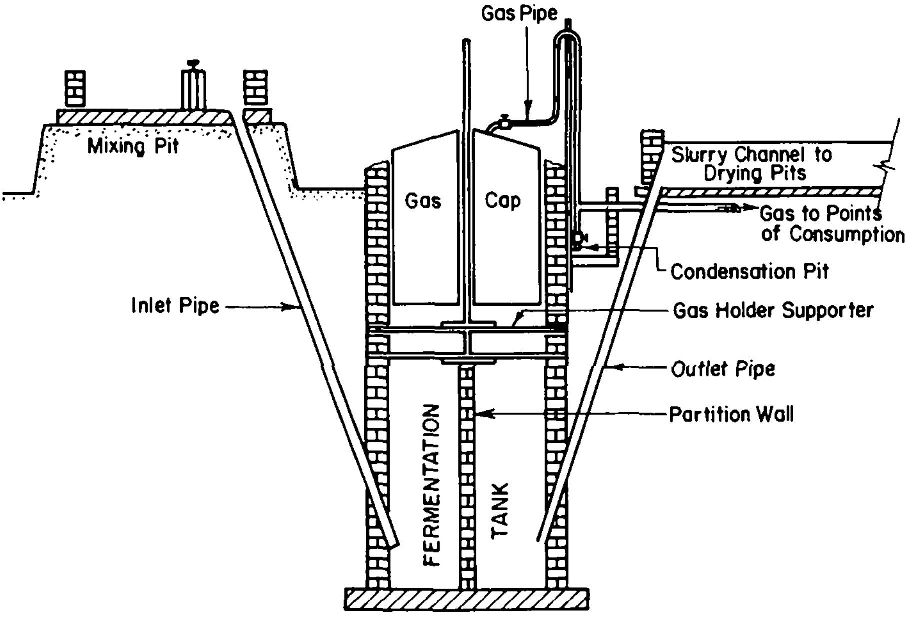

Figure 3 The Indian Digester Design

Table 7 : 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 – Gastight is a problem for bad lining	– In floating metal drum – Height of drum indicates gas volume – Drum needs regular painting to prevent corrosion – No problem in gastight
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

Modified designs exist for both Chinese as well as Indian types (Chiranjivi, 1978; ESCAP, 1980; Garg et al., 1980).

II.6 The Status of Biogas Technology

Presently the development and application of biogas technology in developing countries are in variable stages. This Section will present the status as reported in the recent literature, mostly published after 1978. For the literature during and before 1978, the reader may refer to Barnett et al. (1978), ESCAP (1975), FAO (1978a and 1978b).

The People's Republic of China: According to Thery & Dang (1979), the New China News reported in 1978 that there were 7 million digesters in operation in the summer of 1978. Subsequent reports (Lovejoy, 1980; Wu, 1980; Chen & Li, 1980) still gave the same figure. Ma (1981) put the figure of small digesters at 7,140,000, and claimed that these digesters produced 400,000,000 m^3 of biogas a year. In Sichuan, about 20,000 large digesters operate diesel engines to generate electricity. Another source (Yang, 1980) reveals that according to incomplete statistics, there are 700 small biogas power stations and 600 small electricity generating plants using biogas; and Chen & Li (1980) give more specific figures: 715 and 617, respectively.

The medium-term aim is to build 40 million plants in the areas in which about 70 million families live with serious fuel shortage problems (Eggeling & Stephan, 1981).

The New China News' forecasting of 20 million digesters in 1980 and 70 million in 1985 (Thery & Dang, 1979) does not seem to be realistic.

The Fiji Islands: Several digesters have been built with some success. The cost of the digesters is too high for the average small farmer since concrete and steel are used (Chan, 1982).

India: The latest report (Myles, 1983) indicates that India has to date 126,000 family-size digesters. According to Deshpande (1980), despite the fact that India has one-fifth of the total bovine population of the world, biogas technology has not made a big headway in the rural economy, due to many handicaps which have prevented its widespread adoption.

Nevertheless, the Government of India has launched a national program for constructing 400,000 digesters, and about US$ 55 million have been earmarked for this purpose.

Republic of Korea: During the period 1969-1975, 28,944 family-size digesters were built in this country. By 1979, many of these plants were no longer used (Park, Park & Lim, 1979).

Nepal: According to IDC (1981), approximately 750 family-size digesters and some community plants were in operation by 1980. Technical, financial and social problems impede the promotion of biogas technology in Nepal and permit only a small exploitation of the theoretical biogas potential. The digesters are mainly of the Indian design; recent activities are concentrated in the manufacture of locally modified Chinese plants to be used in cold climates by solar heating (Steiger, 1981).

The Philippines: A number of household biogas units have been built privately or with assistance from the National Science Development Board. Documentation for these existing systems is lacking, but it is generally believed that the units are all functioning as intended (Terrado, 1982).

Taiwan: In 1973 there were said to be nearly 7,500 family-size biogas units on the island, most using pig waste (Subramanian, 1976).

Thailand: As of 1979, there were 221 biogas digesters with volumes varying between 4.7-5.3 m^3 and an average gas capacity of 1.2 m^3/day (Sermpol et al., 1979). Various problems have resulted in more than a half of the digesters being abandoned, mostly after 2 years of operation.

Other Countries

ESCAP (1975) and Subramanian (1976) report extensively on the status of biogas technology in Asia, and DaSilva (1980) presents a global view of the activities of national governments and international agencies in biogas technology. Some newer information is presented below.

Cameroon: Some small digesters have been started, using pig and poultry wastes (Wesenberg, 1982).

Egypt: A national demonstration project for the development and application of biogas technology has been undertaken since 1979 (El-Halwagi, 1980).

Ethiopia: Some digesters have been built but many of them have been out of operation at one time or another. A Working Group to coordinate activities related to the development of biomass technology was established in 1978. Research activities and results, implementation work, and cost analysés have been reported (Megersa, 1980).

Central America: Some experimental digesters of the Taiwanese design have been operated, but further research work is required before biogas technology can be disseminated to the people in this region (Calzada, 1980).

III. THE BENEFITS OF BIOGAS TECHNOLOGY

Much has been said with enthusiasm about the numerous benefits of biogas technology. It is often stated that biogas technology can offer a great potential to solve a variety of problems. For instance, Eusebio & Rabino (1978) have calculated that if 60 per cent of animal wastes in Southeast Asia is collected and utilized for biogas production, the region could save the equivalence of 8.9 billion liters of petroleum with an estimated value of US$ 858 million (Table 8). This amount would have cut down 15 per cent of the total imports of mineral fuels, lubricators and related products in the region. The potential of biogas technology in some countries has also been estimated and is presented in Table 9.

Table 8: Approximate Energy Yields from Animal Wastes in Southeast Asia[1]
(Adapted from Eusebio & Rabino, 1978)

Country	Manure Collected[2] tonnes/d	Energy Equivalent[3] kl/yr	Savings in Petroleum Imports	
			10^6 US$[4]	%
Burma	49,100	890,400	86	3,581.67
Indonesia	55,900	1,247,900	120	47.56
Kampuchea	18,200	328,400	32	62.16
Korea	7,500	175,300	17	1.26
Laos	11,100	224,500	22	296.85
Malaysia	5,800	187,700	18	4.26
Philippines	58,000	1,141,900	110	14.32
Singapore	2,000	73,500	7	0.36
Thailand	65,000	1,281,700	124	17.83
Oceanic	189,000	3,338,900	322	228.82
Total[5]	461,634.38	8,890,063.655	858.2	4,315.09

[1] Including water buffalo, cattle, pig and poultry wastes. Data in 1975.

[2] If only 60% is collected. Rounded figures.

[3] Rounded figures.

[4] Based on 1 barrel of oil = US$ 11.51 in November, 1975. Rounded figures

[5] Original figures.

Theoretically, the potential of biogas technology is quite impressive. In the case of India, if the country's potential (shown in Table 9) is realized by 1990, biogas could supply India with energy 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 biogas technology in realistic perspective.

III.1 Biogas as a Substitute for Firewood

For rural populations of developing countries - numbering some 200 million people or half of the world population - as much as 80 to 90 per cent of their energy needs are for cooking and heating, and these needs are overwhelmingly provided for by burning wood. This is performed on an open fire or on very inefficient stoves, and no more than 5-10 per cent of the calorific value of the wood is recovered as useful heat.

Table 9 : 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). – 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 petro a year.	Agarval, 1979 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. – Theoretical potential of fresh dung: 28 million tonnes per annum.	Shrestha, 1981 IDC, 1981

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

Surveys have revealed that in rural areas, some 50% of the energy requirements of a typical household is for the task of cooking (Skrinde, 1981). Another survey in an area in Bangladesh (Islam, 1980) indicated that 93% of the fuel energy used was for cooking. Hall et al. (1982) also indicate that firewood is a main source of fuel energy in many rural areas of Asia and Africa. Table 10 shows this trend, country-wise, in some regions of Asia. 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 forest 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), 275-365 kg in India (Makhijani, 1977), 0.7-0.86 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 the world. From data supplied by the World Bank in 1980, Hall et al. (1982) estimate that the forest areas per capita in Bangladesh, Kenya, India, Nepal and Thailand are, respectively, 0.03, 0.06, 0.1, 0.3 and 0.4 hectare, against the average of 0.74 hectare for all developing countries. According to Hall et al., these data are almost certainly overestimates. Even so, they indicate the urgent need for developing countries to fulfill their energy requirements. The result is that rural families must spend hours a day and travel further and further to collect firewood. In some cases, women and children - on whom this burden customarily falls - have to travel 10-15 km a day in their search for wood (Lovejoy, 1980). In fact, they are still fortunate to have wood to search for. 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 aerial photos shows that the forest area of Nepal has declined from 60 to 30 per cent 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 due to the fact that the natural regeneration rate of forest in Nepal is slow, about 70 kg of biomass per capita per annum.

It has been believed that collecting firewood causes forest destruction, and biogas technology is, therefore, looked upon as a means to at least partially curb this problem. It is estimated that a 100-cubic feet (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 biogas technology. Thus, where firewood is still readily available to rural people, the development of biogas technology is slow. 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, as discussed at length by Sharatchandra et al. (1981). It is suggested (ESCAP, 1979) that the common claim that deforestation is caused by people cutting trees for firewood does not seem to hold everywhere. It has been found that villagers in Bangdung, Indonesia, for their fire gather mainly twigs and branches that are found within a few kilometers from their villages. The alarming deforestation in Java is primarily caused by the pressing need for more agricultural land to feed an expanding population. Similarly, Makhijani

(1977) stated that much - if not most - of the soil erosion caused by cutting trees is the result of the commercial lumber operations of government and industry, which indulge in thoughtless clearance of large areas.

Table 10 : Contribution of Firewood to Total Fuel Energy Requirements in Some Countries

Country	% Contribution[1] to	Remark	Reference
Bangladesh[2]	6.8 rural areas	Data 1974–75. Including homestead wood, forest and cut firewood.	Islam, 1980
India	41 rural areas	Data 1970–71. Including charcoal.	Revelle, 1976
Indonesia	70–75 whole country	93% of firewood is for home cooking.	Wiersum, 1979 (secondary source)
		Equivalent to 800 x 10^{12} kJ	Mubayi et al., 1980
Nepal	86.8 whole country	Data 1975–76. Firewood consumed equivalent to 6.2 million tonnes of coal.	Shrestha, 1981
Peru	rural areas	Equivalent to 138 x 10^{12} kJ	Mubayi et al., 1980
Sri Lanka	60 whole country	Supplies are fast dwindling. No effective program for afforestation.	Amaratunga, 1980
Sudan	rural areas	Equivalent to 60 x 10^{12} kJ	Mubayi et al., 1980
Tanzania	rural areas	Equivalent to 320 x 10^{12} kJ	Mubayi et al., 1980
Thailand	?	The whole country consumed in 1970 23.4 million m^3 of firewood and 15.6 million m^3 of charcoal.	Pisit, 1979
	?	Firewood is forecasted to substitute for 65 million liters of crude oil by 1986.	Gosling, 1982 (secondary source)
		Equivalent to 440 x 10^{12} kJ	Mubayi et al., 1980

[1] *Based on energy value*

[2] *61.2% of fuel energy consumed in rural areas come from crop residues*

Another aspect of the problem, illustrated by the situation in Bangladesh, refutes the idea that there is some positive benefit of forestation alleviation by means of biogas technology. 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) is not available to the poorer households.

The benefit of biogas technology derived from saving firewood seems, therefore, not always to be clear. The main criticism of biogas technology is centered on the high cost of the digester relative to the low return from the fuel obtained. Although advocates for biogas technology estimate that biogas is twice as cheap as firewood (Ansari & Yasin, 1980), one 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, biogas technology 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 biogas technology, 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 it has the advantage of being a generally familiar commodity.

III.2 Biogas as a Substitute for Animal Dung

Animal dung constituted 5-10 per cent of the requirements for kitchen fuel in rural areas of India at the beginning of this century. This figure rose to 25 per cent by 1930, 45 per cent by 1950 and 70 per cent at the present time (Khan, 1980). Prasad et al. (1974) estimated that 45 per cent 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 per cent 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. Newer estimates (Deshpande, 1980) show that more than 265 millions tonnes (apparently fresh weight) of cowdung are burnt away annually by farmers as fuel for cooking.

A similar picture can be seen in Pakistan where 70 per cent of the fuel used in the villages is animal dung, and this constitutes about 70 per cent of the cattle and buffalo dung produced (Shah, 1978c). 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.

The latter point has had increasingly serious implications because the phenomenal increase in the prices of petroleum products in the world market in the 1970's also understandably led to a similar increase in the prices of chemical fertilizers. Figure 4 (DaSilva & Doelle, 1980) clearly depicts the cost of scarcity in oil-importing developing countries. During the period 1971-1974, while the yearly import value of chemical fertilizers increased consistently from US$ 533 to $ 1,450 (nearly three-fold), the amounts only fluctuated between 4.6 to 5.8 (20 per cent) million tonnes.

Type		*1971*	*1972*	*1973*	*1974*
Nitrogen	Million tonnes	2.3	2.5	2.6	2.0
	Million U.S. $	311	341	462	900
Phosphate	Million tonnes	1.0	1.2	1.4	1.1
	Million U.S. $	126	183	275	380
Potash	Million tonnes	1.3	1.5	1.8	1.8
	Million U.S. $	96	101	138	170

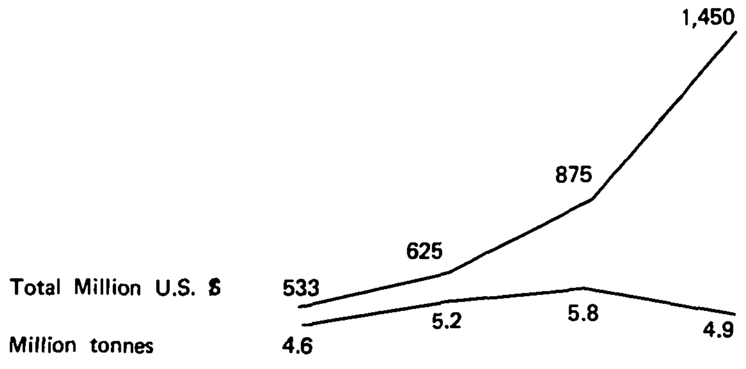

Figure 4: The Cost of Scarcity: Imports of Manufactured Fertilizers by Developing Countries

Although about half of the available dung is degraded in the generation of gas, the useful heat of the gas is about 20 per cent more than the useful heat obtained by burning directly the entire amount of dung. This is mainly due to the 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, due to the following factors:

- The scale of animal dung saving is small as compared with the enormous cost. India, for example, has set a target of building 100,000 family-size biogas units each year during the period of 1975-1985, at a cost of US$ 200-400 apiece (Makhijani, 1976). Even if this target were to be reached (more likely it will not), this would mean that by 1985 only 2-4 per cent of India's cattle herd would be involved.

- This benefit is meaningless to rural people since animal dung is normally obtained free, whereas the gas has to be produced at a cost.
- As stated previously, the saving of animal dung is traded off with aggravated deforestation. The benefit cannot be considered significant if there is such a trade-off.

III.3 Biogas as a Substitute for Fossil Oil

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 per cent, whereas the bill for these commodities 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 per cent of households use kerosene oil lamps for lighting (Amaratunga, 1980). It was hoped that biogas technology could partly help 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 per cent of the total energy needs. If compared with the total energy needs of the whole country, the proportion is much less, and should be lower than 0.1 per cent.

III.4 Biogas to Reduce Drudgery

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. Biogas technology 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 per cent of the population in rural Nepal are jobless, according to Shrestha, 1981) - people still have much free time. Similarly, where conventional fuels are plentiful or readily available, the benefit derived from 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).

III.5 Biogas as a Means of 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 or handling if the waste is used as a fertilizer. Table 11 indicates the losses of nitrogen from various traditional methods of waste handling in developing countries. From this Table, there is an implication that the hot and wet conditions in the tropics are not favorable for nitrogen conservation by these methods.

Table 11: Nitrogen Remaining in Different Handling Methods (After Taiganaides, 1978)

Handling Methods	% N Remained
Deep pit storage, liquid spreading	34
Open lot surface storage, solid handling & spreading	40
Bedded storage, solid handling & spreading	65
Incorporation within 7 days, warm & dry soil	50
Incorporation within 1–4 days, warm & dry soil	65
Incorporation within 7 days, warm & wet soil	70
Incorporation within 1–4 days, warm & wet soil	85
Incorporation within 7 days, cool & wet soil	90

The amount of nitrogen in various types of wastes are presented in Table 12. 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 (Table 11); but nitrogen is not lost from a biogas digester. In fact, from scanty information it is known that the nitrogen level is reduced during fermentation, and the degree of reduction reported by Chen (1978) to be 5 per cent, by the Chinese Institute of Soil and Fertilizer (1979) to be 3-10 per cent (depending on the input mixtures), and by Iannotti (1979) to be 2.7 per cent (Table 13). With this information, the common belief that a biogas digester produces fertilizer should be reconsidered, and this point will be taken up in more detail below.

Table 12 : 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)

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 - for example, calculations based on the influent and effluent concentrations, instead of on the total amounts of input and output. In a closed digester where there is no known process of nitrogen fixation, an increase of total nitrogen amount is inconceivable. Rather, a digester is just able to increase the amount of nitrogen available to 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 and valid (Bhatia, 1977) since digested 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 such as fruit trees or forests. In this case, the higher proportion of nitrogen in organic forms in the raw waste may result in some nitrogen being carried over from one season to another, whereas the nitrogen in ammoniacal form in digester effluent will volatilize within a short time. The overall result in this comparison may very well that raw wastes are better than digested wastes.

Table 13 : Nitrogen Transformations in a Digester
(Percentage Figures in Brackets)

Input Material	Influent		Effluent		Unit Expression	Refs.
	Total N	NH_3	Total N	NH_3		
Nightsoil	1.049	0.62	1.009 (–3.8)	0.86 (+38.7)		Li, 1982
Pig manure	109	59.2	106 (–2.7)	79.4 (+34.1)	g/d	Iannotti <u>et al.</u>, 1979
Pig manure hay = 4: 1	17.55	–	15.8 (–10.0)	– –	g/jar	Institute of Soil & Fertilizer (1979)
Pig manure : cattle manure : hay = 1: 1: 1	23.71	–	22.68 (–4.3)	–	g/jar	"
Pig manure : cattle manure : feces = 3: 1: 1	37.23	–	36.23	–	g/jar	"

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 work has been recommended (ESCAP, 1980) as a "demonstration" method to show laymen that biogas technology has great benefits, and this may be misleading.

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. Unfortunately, data regarding these aspects are not sufficient to determine the benefit. It has been said (Eggeling et al., no date) that nitrogen escaping from digested slurry after more than 10 days of storage amounts to about 10-15 per cent. ESCAP (1980) indicates that the "nitrogen effectiveness" of digester effluent which is spread and ploughed is 85 per cent that of dung which is spread and ploughed immediately. No details are given on whether this "effectiveness" is assessed on perennial vegetation or short-lived crops. In the latter case, the effectiveness of fresh dung is very limited, and therefore the figure of 85 per cent is not very meaningful. 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 per cent, depending on the climatic conditions. In the tropics, the loss is likely much higher. Shah (1978c) says that if the slurry is dried, essentially all of the ammonia is lost. This is reasonable since digester effluent needs a long drying period due to its high water content, about 90 per cent. Table 13 shows that ammonia constitutes 75 to 85 per cent of the total nitrogen in digester effluent. Hence, according to Shah, the loss of nitrogen from the drying of digester effluent could be extremely - and unfavorably - high.

It can be concluded that biogas effluent as a fertilizer should not be construed as a full benefit of biogas technology. 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 nutrients in the waste to forms more readily available to plants, other methods should also be considered, rather than blindly adopting biogas technology. This consideration will be dealt with in Section III.7.

III.6 Biogas as a Pathogen Inactivation Method

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 have been observed to live up to 37 days while 99 per cent of filarias die within 30 days in summer. The viability rates of Ascaris ova - which is the most resistant of all parasites - range from 63-93 per cent after 10-90 days to 20 per cent 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 hookworm ova are killed quickly in a digester, the latter surviving for no more than 9 days (Sichuan Institute, 1979), and being removed by 90 per cent within 30 days in winter; whereas Shigella and Spirochetes die within 2 days (FAO, 1978b). Para-typhoid B bacilli - one of the most persistent enteric bacteria - survive for a period of 44 days in a digester (FAO, 1978a).

Based on these data and others, it has been claimed that biogas technology is a method for pathogen destruction and could contribute to sanitation improvement in rural areas of developing countries. It is true that significant improvement in public health is observed in the regions where biogas technology has been introduced. But building a digester solely for this purpose is not a logical reason. Thermophilic composting, which is carried out at higher temperatures (50-60 °C) and with less water content (40-50 per cent) in a period equivalent to the retention times of the Indian digester, should do a much better job.

III.7 Biogas Technology vs Composting

From the considerations on nutrient conservation and pathogen inactivation discussed above, the important matter now is to compare the performance of waste handling methods that are common in rural areas of developing countries in relation to these aspects. Before the introduction of biogas technology, composting is probably the only waste recycling option in rural developing countries whose eventual purpose is fertilization.

Nitrogen Conservation

Without going into elaborate details of the composting process, it suffices to say that - based on data from various sources compiled by Gotaas (1956) - a correct composting process can help conserve from 85 to 90, and possibly 95 per cent of the nitrogen in the raw materials. Also, it has been reported (Tuan & Tam, 1981) that as much as 95 per cent of the nitrogen contained in human excreta can be conserved by closed, thermophilic composting in field conditions using soil powder, mud, hay, dead leaves, etc. as bulking agents. These sources of information show that a biogas digester is not superior to a correct composting method as far as nitrogen conservation is concerned. In other respects, biogas technology has more disadvantages: it is more costly, more difficult to operate and maintain, requires more space and water, and digester effluent is more difficult to handle and transport than compost.

The comparison between digester effluent and compost is not necessarily concerned only with NPK contents. Compost is well known for its beneficial effects in fertilization due to its chelating agents, growth hormones, increasing the ability of the soil medium to retain plant nutrients, increasing the water holding capacity of soil, and improvement of soil structure. Apparently no information is available to indicate whether biogas digester effluent is able to render these benefits, or to what extent it can do so.

Of course, the comparison does not end here. The fertilizer value of the product at the point of its end-use is a decisive factor. For instance:

(a) The surface application method could be more favorable with digester effluent since available nutrients can leach quickly to the soil and are held there, whereas surface-applied compost would lose more nutrients through volatilization due to its low water content.

(b) Compost, when matured, can be stored as it is in a closed heap and is taken out gradually for use. Storing in this way will cause little nitrogen loss. For digester effluent, drying will lead to substantial nitrogen losses (Section III.5).

(c) Vogtmann & Besson (1978) compare anaerobic digestion with composing, based on the concept of total nitrogen loss, that is, the loss during the process and on application. According to them, some of the concerns over the loss of nitrogen during composting farmyard manure as compared with that in anaerobic digestion are not justified. The total nitrogen loss from anaerobically digested farmyard manure under practical conditions is probably as high as the nitrogen loss during composting. In the latter case, data compiled by Vogtmann & Besson show that the nitrogen loss after application can be neglected and only the loss during the process should be considered.

Théry (1981) makes some remarks on the evaluation of the benefit of bio-fertilizer, based on an observation that:

(a) on the one side, the value of the bio-fertilizer is much higher than that in fresh farmyard manure (ICAR, 1976); and

(b) on the other side, an opinion that the anaerobic digestion method should be compared to another method - scientific composting - and not just to the status quo represented by traditional farmyard manure (Bhatia, 1977).

From this divergence of methodology in comparative analysis, two studies arrive at very contradictory conclusions; the first one calculating highly favorable cost/benefit ratios, and the second rejecting the public program for the promotion of biogas technology. While Bhatia observes that there is no accurate and properly quantified information on the basis of which one can say that digester slurry is of significantly better quality than scientific compost manure, Thery cautions against using laboratory data in this kind of comparison.

Théry (1981) further gives a hypothesis to explain why the Chinese - being the most experienced practicians in aerobic composting - should switch to anaerobic digestion. The explanation is that, whatever the relative performance of aerobic composting and anaerobic digestion in the laboratory, in the field the Chinese peasants have considerably greater success with the latter than with the former; and so no consensus of a priori theoretical evaluation could prove the benefit of biogas technology as the massive "vote" of the real rural China does.

In fact this hypothesis seems to be over-simplified due to the following factors:

- The extent to which peasant enthusiasm for anaerobic digestion was a result of intensive promotional influence on the part of government authorities is difficult to estimate.

- The Chinese authorities, when educating their people to switch from composting to biogas technology, had a good reason to do so: biogas technology can alleviate the problems of fertilizer and fuel, the severity of the latter has been so often stressed in the literature by the Chinese (Ma, 1981; Yang, 1981; Wu, 1981).

- More than 70 per cent of the digesters in China are located in Sichuan Province alone. People in other provinces still practise mainly traditional composting. It is not known whether, apart from climatic conditions, there are any other factors that forestall a wider application of biogas technology in other provinces.

- Whereas Bhatia talks of "scientific composting", Théry uses the term "aerobic composting". It has been known (Vogtmann & Besson, 1978) that nitrogen loss from aerobic composting is quite substantial as compared with anaerobic digestion and so Thery has a justified argument. On the other hand, Bhatia may have meant by "scientific composting" the process whose main purpose is to conserve nitrogen, and thus he also has a valid point. It is interesting to note that another term, "closed composting", is also used (Tuan & Tam, 1981) to describe a process in which a 5-7 cm thick layer of mud covering the compost heap is formed to conserve nitrogen. Such a process is aerobic at first due to the presence of oxygen pockets in the heap, and anaerobic later when the oxygen is consumed.

Pathogen Inactivation

Gotaas (1956), when analyzing the typical temperature curves of a compost heap and the thermal death points of a number of pathogenic bacteria, parasites and parasitic ova, indicates the improbability of pathogen survival in composting. It is seen that the highest thermal death points of pathogens are appreciably lower than the maximum temperatures found inside the composting pile. The magnitude and duration of the high temperatures (50-60 °C for several days), populations of microorganisms, the antibiosis which is characteristic of a mixed compost and the low water content (40-50 per cent) - all very adverse to pathogens - provide a sound basis for believing that no pathogens, parasites, or parasitic ova survive the composting process.

Few data on pathogen destruction in composting at field scales exist in the literature available to the authors, except that experiments in China indicate that 96-100 per cent of *Ascaris* eggs are destroyed in aerobic composting (McGarry *et al.*, 1978). This level of inactivation is much higher than that in a biogas digester.

The discussion above and some salient points of the comparative analysis between biogas technology and composting are summarized in Table 14.

Table 14: Comparative Analysis of Biogas Technology and Compost

	COMPOSTING	BIOGAS PRODUCTION
Process Conditions :		
[1]Materials added	Vegetation	Water
Temperatures	50–70 °C	Ambient
Period	6–8 weeks	4–7 weeks
Nitrogen loss	5–15%	3–5%
Cost	Low	High
Space required	Small	Large
Operation	Traditional	Innovative
End Product :		
[2]Weight	Reduced	Increased
Water content	40–50%	88–92%
Humus content	Abundant	Not much
Pathogen destruction	Good	Moderate
Transport	Easy (light & dry)	Difficult (heavy & liquid)
Further handling	Not necessary	Drying usually needed
[3]Storage	Easy, no loss of nitrogen	Difficult, with loss of nitrogen

Notes :

[1] *Addition of materials : for composting to regulate the C: N ratio and moisture, and reduce the bulk density – may not be necessary if these parameters are right; for biogas production to reduce the solids content – compulsory.*

[2] *For composting, about 50–60% of the original weight; for biogas, about twice the original weight.*

[3] *For composting, the end-product can be left at the site and taken out bit by bit for use when needed; for biogas production, the effluent should be taken out of the digester and when exposed to the air will lose its nitrogen through volatilization.*

IV. ECONOMICS

Economic analyses of biogas technology have been carried out by many authors (Adisak, 1980; ESCAP, 1981; French, 1979; ICAR, 1976; KVIC, 1975; Li, 1982; Moulik & Srivastava, 1975; Pisit, 1979; Prasad et al., 1974; Sermpol, 1979; and Tyner & Adams, 1977), and have been reviewed by others (Bhatia, 1977; Barnett, 1978; and Mazumdar, 1982).

IV.1 Economic Feasibility

As seen from the literature, it is clear that there is no general answer to the economic feasibility of biogas technology. 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 per cent of the capital cost, this percentage rises to about 58 per cent for a digester in the Philippines producing daily 28-42 m^3 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 for India (Moulik & Srivastava, 1975). It is interesting to note that the discrepancies reported in the literature are mainly due to:

(a) the difference in local conditions, and/or
(b) the difference in the data - and "guesstimates" - used in the economic analyses.

In the first instance, the sharp contrast of the short payback time in China and the long one in Thailand is due to the fact that in the studies in Thailand, it is assumed that (i) the iron gas holders are not maintained by painting, but are replaced every 2 years (Sermpol et al., 1979); and (ii) there is no use of the digester slurry (Sermpol et al., 1979; Pisit, 1979). In China, the maintenance cost is much lower and the value of digester slurry is fully accounted for.

The second instance can be illustrated by the treatise of Moulik & Srivastana (1975). In this study, the results calculated from the data supplied by KVIC and from those collected by the authors have some discrepancies, especially for digesters of small sizes. For example, the payback periods of a digester with a gas capacity of 60 cft (1.7 m^3) per day at the discount rates of 10, 13 and 15 per cent are, respectively:

- From KVIC data: 9, 10 and 16 years.
- From Moulik's & Srivastana's data: 13, 23 years and infinity (that is, the investment cannot be recovered).

Even the economic feasibility of biogas technology has not reached a general concensus. While many researchers are in favor of biogas technology, others come to the conclusion that the monetary benefits do not outweigh the costs incurred by an individual household (Makhijani, 1977). It is further claimed that the benefits of biogas technology will accrue to the society as a whole rather than to the individual household which adopts biogas technology.

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 most dubious investment from the point of view of everyone except their manufacturers.

IV.2 Economic Assessment

In an economic assessment, many factors have to be considered, as outlined in Table 15. Although this Table is by no means exhaustive, it is clear that many of the factors listed cannot be expressed in monetary terms.

Table 15 : 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

Bhatia (1977) suggests that an economic appraisal - from the point of view of society - of investment in a biogas unit would require quantification and evaluation of primary and secondary benefits, as well as the direct and indirect costs associated with the installation of the plant. These benefits and costs are presented in Table 16.

Table 16 : A Framework for Social Benefit-Cost Analysis (Adapted from Bhatia, 1977)

Benefits	Costs
A. Primary 1. *Biogas as a source of fuel* 2. Digested slurry as fertilizer B. Secondary 1. Convenience of cooking with a clean fuel 2. Reduction in uncertainty of energy supply 3. Renewable source of energy 4. Reduction in imports 5. Local employment 6. Possibility of using human wastes & vegetable residues 7. Health improvement	A. Direct 1. *Capital* – Land – Construction – Materials (gas holder, pipes, appliances...) 2. Operating & Maintenance – Input materials – Water – Labor – Gas holder painting, pit repairs... B. Indirect 1. Depriving poor sections of animal dung 2. Management problems 3. Inconvenience of mixing cowdung with water and feeding the slurry

Bhatia further implies that the evaluation of gas used in cooking should be based on a comparison with the most economic traditional energy source, which, in the case of India, is soft coke. Firewood results in high environmental costs and cannot be recommended for large-scale use in cooking. Similarly, the use of cow dung as manure is more economic (from society's angle) than its use as fuel. It is in this context that the evaluation of gas used for cooking fuel is done in terms of "economic costs" of soft coke, rather than the equivalent of kerosene, electricity, or cow dung cakes.

For the evaluation of digester slurry as fertilizer, Bhatia suggests that in a situation where a major proportion of wastes are used as fertilizer, the evaluation can be done in terms of incremental analysis - i.e., the evaluation of additional quantity of manure and additional nutrients available from scientific compost.

In fact, it is not known whether this analysis as a whole is incremental or decremental. As already discussed in Section III.7, while compost may have less nitrogen than digester slurry, it contains much more humus which has various beneficial effects on plants and soils. For this reason, it is difficult to say whether the overall benefits of biogas technology over composting is positive or negative.

Not only the methodology in economic assessment is controversial (for example, see Section II.7), but there is not sufficient data in the literature based on which one can have even a rough guidance. Santerre & Smith (1982), when trying to apply a method to measure the appropriateness of biogas technology, have to give many estimated values in their analysis. The use of their approach, in which biogas technology is divided into five sub-systems analogous to the sub-system components of the nuclear power fuel cycle, is said to provide a detailed and reproducible framework for analyzing the resources exploited and the products provided by this relatively complex technology. Limited as it is by the available data base, the presentation of such a methodology nevertheless suggests important areas for more detailed studies.

As a general guideline, Figure 5 shows the chief costs of the two types of fixed-dome and floating-drum digesters. The Figure is based on a political-economic situation to be found, for instance, in India and many African countries. The planning costs shown are to be understood as administrative costs of self-financed biogas programs. It should be noted that the system of commune work in the People's Republic of China makes any cost comparison with other countries an unsolved problem (Eggeling et al., no date).

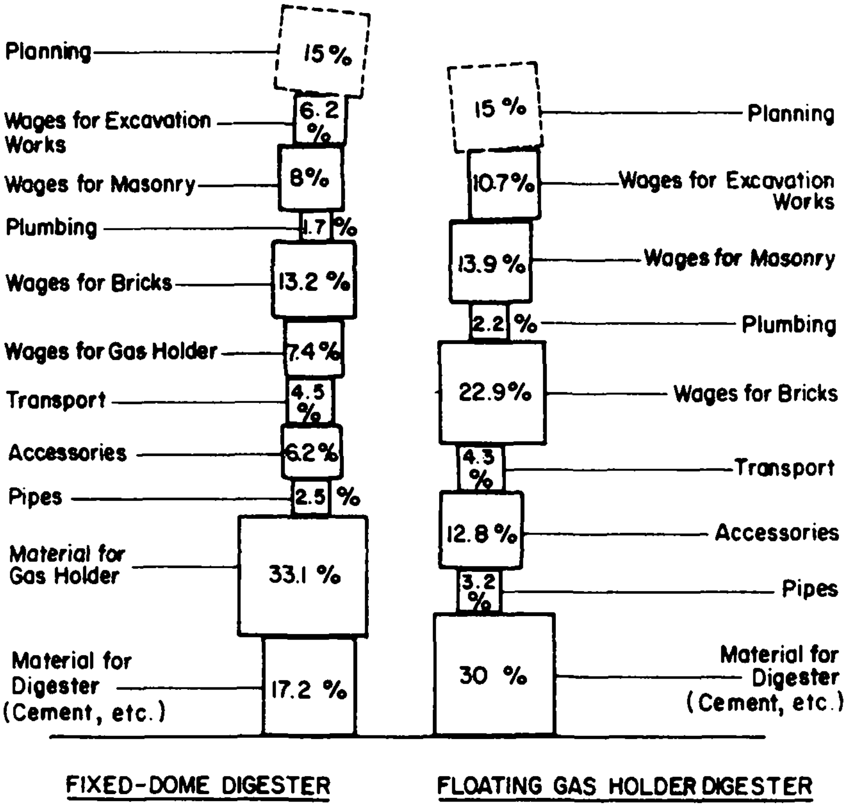

Figure 5. Classification of Cost Fractions (Eggeling et al., No Date)

All in all, biogas technology seems to have good economic viability as compared with some processes that appear as the most likely candidates for processing organic materials into fuels (Table 17). Muyabi et al. (1980), caution that this Table is intended for descriptive purposes rather than for comparison of these processes. It is interesting to note from Table 17 that biogas is more costly than charcoal produced by pyrolysis, possibly because the social or ecological costs of each process are not considered.

IV.3 Some Problems in Assessment

In the state of uncertainty and complexity, economic assessment should be carried out specifically for local conditions on a case-by-case basis. Although an exact methodology in economic analysis is difficult to agree upon universally, some errors or weaknesses that have been committed all too frequently in the past can be pinpointed to serve as general guidelines (Shah, 1978b; Shelat & Karia, 1977; Subramanian, 1976).

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

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. The common assumption of all the 365 days of a year for the normal operation of a digester may lead to serious errors. Seasonal variations in many parameters - such as those in gas production (summer vs winter, and close-down time for maintenance or repair), 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) - should be considered. 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.

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 use.

6. The basis of evaluation of the gas produced is of significance. For example, in places where the 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 (Shelat & Karia, 1977).

7. It has been observed that some of the present evaluations of 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

Table 17 : Biomass Conversion Technologies
(Muyabi 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.*

manure is fed into the digester, only its incremental value can be taken into account. This is in line with Bhatia's (1977) argument.

8. The evaluation of digested slurry is not as straightforward as it is supposed to be. Any loss in its fertilizer value during drying and/or storage has so far not been critically assessed. The fertilizer of slurry should be ascertained not only when it comes out of the digester, but also at the point of its end-use (Section III.5). Furthermore, the slurry is not a saleable product everywhere; and assuming a price for it, particularly when it is in liquid or semi-liquid form, is not easy. The best way to assess the benefits arising from the use of slurry would be to measure it - again, double accounting should be avoided - in terms of extra output of crops, algae, or fish. But reliable data on such benefits cannot be obtained during the planning stage.

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 parameters may cause substantial discrepancies, which in turn may cause a whole carefully planned program to fail.

V. SOCIO-ECONOMIC ASPECTS

Although biogas technology 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.

V.1 User's Perception Toward Biogas

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 in his mind, that is to try to solve his immediate problems, for the sake of survival.

In this ruthless struggle, all the benefits that have been discussed become meaningless to the poor, uneducated peasant. As one author (Reddy, 1977) puts 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 cooking 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 rural Nepal - and quite likely in rural areas of other developing countries - where much of the labor force is employed, traditional sources of energy (eg. firewood and animal dung) are available almost "free of cost" to the people, although their social cost, even though it may be high (eg. less time for education and entertainment), is still affordable. But alternative renewable energy sources, although they have low social costs, are too costly to 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, indeed, that he expresses his opinions and feelings. In an intensive survey in Thailand (Sermpol et al., 1979), more than 50 per cent of biogas users stated that the motive of biogas technology adoption was to please the government officials who came to them to promote biogas technology.

The indifferent attitudes described are more conspicuous with biogas technology 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 can be used to buy a small pump, or for a down payment to acquire a small farm tractor (Sermpol et al., 1979). These machines are considered by the farmer to be more important than biogas technology since it can bring additional cash within one crop season.

V.2 Long-term Benefits vs Short-term Priorities

The average capital investment for a digester in Thailand (Sermpol et al., 1979) is 2,675 Baht (about US$ 130). From this investment, the owner can get daily 1.2 m^3 of biogas, which is equivalent to 1 kg of charcoal, or a mere 3 Baht. Similarly, the investment cost of a digester in India is Rs. 400 (US$ 500), whereas the return is equivalent to 2-3 liters of kerosene per day (Skrinde, 1981). From the villager's viewpoint, these returns are either too low in relation to other uses of handy resources, or hard to quantify, and hence there is some hesitation in adopting biogas technology. 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 on their available income of a social and agricultural nature. 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 per cent of the villages are said to be 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 biogas technology 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 biogas technology to the Chinese peasants.

V.3 Unequitable Distribution of Benefits

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 65 cft (1.8 m^3) daily 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 represents about 10-12 per cent of the rural population

(Agarval, 1979). Another estimate shows that less than 5 per cent 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, in field conditions such a plant may produce an amount of gas sufficient for cooking only. The hope that more people will participate in biogas technology may not be justified since (i) a plant of such a scale may not be economically attractive, (ii) less benefit (without the benefit of lighting) means less incentive for adopting biogas technology; and (iii) families owning less animals are more reluctant - or even if they are not, have less resources to join the scheme.

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

It is evident that biogas technology depending solely on animal wastes as input materials will deprive the poor majority of a chance for raising their living standards.

V.4 Social Acceptance

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 discontinued due to the opposition of 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 the Philippines, Korea and 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; Shelat & Karia, 1977; 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 biogas technology.

V.5 Ownership of Waste Materials

Major obstacles can be readily seen from the ownership of waste materials. Traditionally, the institutional structure is arranged in the village such that the wastes are available for those who need them, without regard to the distribution of animal ownership. Biogas technology 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 from exerting their income rights. From free sources, the wastes will become a priced commodity like land, animals, etc. The loosers will be the poorer families who have to seek alternative sources of energy and fertilizers.

VI. SOME UNANSWERED QUESTIONS

VI.1 What Purpose(s) Does Biogas Serve Best?

While there are clamorous praises on biogas as a cooking fuel, an 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 to produce a high-grade fuel for cooking, while 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 foreign exchange requirements are much smaller in the case of biogas than either diesel or electricity; and also the capital requirements are much lower than those for supplying electricity or for finding, refining and distributing oil.

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

Reddy & Prasad (1977) also claim that biogas is so valuable an energy resource that one must examine whether there are any better end-uses for it than cooking. But this must only be considered in a perspective where, if not biogas, some other alternative source will be provided to meet the energy requirement for cooking and lighting. In many rural areas of developing countries where the shortage of traditional energy sources has become critical, this idea can hardly be realized. But in places where biogas technology 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.

VI.2 Household Direct Lighting or Community Electrification?

Rural electrification in India is well known to be an uneconomical proposition; the plans are for "zero" financial return for 5 years followed by 5 per cent return after 15 years, and extremely low load factors of 1 to 14 per cent. For this reason and others, only about 6.6 per cent of the total number of villages in India were electrified by 1977. Even where these villages had been electrified, the total energy supplied was only of the order of 0.2 kWh per capita per day, while the energy consumption was estimated to have been one kWh per capita per day. In Thailand, due to the high investment costs, distribution problems and low returns, about 81 per cent of the villages lack electricity (Pisit, 1979). Only 20 per cent of the population have access to electricity, the lion's share of which goes to urban areas.

Reddy (1977) calculated that if all wastes generated from the village (human and animal excreta, agricultural residues, etc.) were to be collected at 75 per cent efficiency to produce biogas, the energy amount obtained would not only surpass what was provided by rural electrification, but also satisfy the current energy consumption.

Gas electrification also brings about an improvement in efficiency (Table 5). 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 an average it takes only 750 liters of gas to produce one kWh of electricity, enough to light 25 40-watt bulbs (Saubolle & Bachmann, 1980). And wiring a house is cheaper and safer than installing gas pipes. For these reasons, community electrification using biogas from a central digester has been considered.

In a preliminary consideration 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. Thus the matter takes a different turn, which will be discussed in the next section.

VI.3 Community Plants or Family Units?

Advocates for community plants have cited various reasons, such as :

(a) 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.

(b) Due to the economies of size (Table 18), a communal plant can reduce the investment cost and therefore is more affordable.

(c) A plant owned by a community can have a better chance of receiving technical and financial support from outside the village.

(d) Community plants provide a possibility for bringing the benefits of biogas technology within the reach of poorer sections of rural communities.

(e) A community plant can provide a service that is normally not feasible with individual plants, such as mechanization and electrification.

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

Table 18 : Scale Economy of Biogas Digester – KVIC Design
(Adapted from ESCAP, 1981)

Gas Capacity/day		Initial Cost[1]		Net Present Value[2]		Payback Period, year[3]		Benefit/Cost Ratio[3]
cft	m^3	total	per m^3	total	per m^3	without subsidy	with subsidy	
60	1.7	2330	1370	106	62.3	–	20	0.94
100	2.8	3020	1065	2104	744.0	8	5	1.20
150	4.2	3360	791	5004	1178.2	4	4	1.49
200	5.7	4175	737	5004	883.6	4	3	1.59
250	7.1	4800	678	9921	1401.5	4	3	1.70
300	8.5	5000	588	12939	1523.1	3	2	1.83
500	14.1	8500	600	22321	1576.5	3	2	1.90

All monetary units are in Rs. US$ 1 ≃ 9 Rs. Figures are rounded

[1] *Including costs of gas holder, civil construction, and pipeline and appliances.*

[2] *At discount rate of 13%, with 20% subsidy deducted from initial costs.*

[3] *At discount rate of 13%*

- The fact that community plants have "clear-cut" economies of scale in comparison to family-size digesters is not a universal phenomenon.

- A community plant needs elaborate and extremely expensive management mechanisms for collecting and/or buying input materials, and distributing and/or selling gas and slurry. Likewise, costly distribution networks and special pumps to move gas through them may offset the economy of scale inherent in the actual digester itself.

- While each household owner can manage to find water for his family-size plant, fetching and transporting dozens of tonnes of water required for a community plant every day may be a problem.

- Such plants require great managerial talents from skilled technicians for their maintenance and operation.

- Efficient administrative and organizational structures are crucial to community programs. In many places, weak structures have created the "Tragedy of Commons", when individualism leads to irresponsibility and indifference towards the "common" things.

- Similarly, feuds and fractionalism, which are dominant realities in the social life of developing countries, can have an undesirable impact.

Generally, according to the arguments from the opponents, there is no assurance that community plants would be more desirable than family ones.

Ironically, while China promotes mainly family-size plants (Shian et al., 1979; Thery, 1981), appropriate technologists in India (Agarval, 1979) have argued that only large community plants can benefit the Indian rural poor. In Pakistan it is also suggested (Islam, 1980) that biogas technology may be made viable if it is considered at the 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 coupled with internal combustion engines would be economical in an Egyptian setting (El-Din et al., 1980). Several surveys (Moulik & Srivastana, 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, and the difference in local conditions. 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 the same school of thought, Makhijani (1977) stated that merely building community plants would not solve the basic problems. This would be akin to "electrifying a village", in which only a few can afford the connection.

At best a communal plant can serve "communal" purposes such as lighting and cooking for a school or a clinic. In this case, there is a benefit due to the fact that (i) the per capita gas consumption in communal establishments is smaller than in separate households : if meals are prepared for a greater number of persons at the same time, the per capita gas requirement for cooking will be reduced; (ii) a large-size plant also has a demonstration role due to its impressive appearance and hence can help convince the local people to follow.

VII. PROBLEMS & CONSTRAINTS

From the discussion up to now, the rate of failures in the implementation of biogas technology in various regions of Asia is already hardly surprising. But this is not the end of the disappointed performance of biogas technology. This Section will outline some common bottlenecks that have been encountered.

VII.1 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 per cent of the total investment cost. This is the common reason of failures where the Indian design is adopted (Sermpol *et al.*, 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 a lack of skills and equipment as in Thailand (Sermpol *et al.*, 1979); and also due to the fact that it is extremely difficult to lift the heavy gasholder out of the digester pit (ICAR, 1976).

VII.2 Seasonal Variations 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).

VII.3 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) since this task (i) requires removal of H_2S to prevent corrosion of the gas cylinder, and possibly of CO_2 to increase the capacity; (ii) is technically feasible only where a large amount of gas is produced; (iii) incurs high investment costs for a bottling plant and high operating costs for transporting heavy cylinders.

VII.4 Short Supply of Water

To supply 2 m^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).

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

VII.5 Short Supply of Feeding Materials

This should not be a reason for 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 et al., 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 manure has already been reused in agriculture. For this reason, the cost of manure is quite expensive and a farmer cannot afford to buy manure when the amount of manure available on his farm is insufficient. The same situation exists in Sri Lanka where farmers pay as much as US$ 12 for a tonne of cattle manure. The demand for cattle manure is so great in one area that it is sometimes transported from as far away as 150 km (Amarasiri, 1978).

In other cases, there is not a lack of animals per se, but just inefficient collection of animal wastes. Biogas technology requires a change in animal husbandry methods from free grazing to confinement, which incurs some cost to the animal owners, who have to harvest grasses and transport them to their confined animals. Increasing mechanization of rural farms has aggravated 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.

VII.6 Lack of Space

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

VII.7 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 is 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.

VII.8 High Investment Costs

As stated earlier, Asian farmers have no steady income and they get their money only twice or three times a year; and at the same time they have pressing demands on their available income of a social and agricultural nature. Whichever need comes earlier gets the funds. Consequently, it is a well-known fact that most rural families in developing countries cannot afford a family-size digester, the more so with the Indian design. In India, at a time when 60 per cent of the population had an average per capita consumption expenditure of less than one Rs. per day, a biogas plant with a gas capacity of 1.7-2.8 m^3/d cost 3,000 Rs. (Reddy, 1977).

It has also been pointed out (Subramanian, 1976) that if the sum for the capital cost of a digester is invested elsewhere, the annual interest at the rate of 15 per cent can cover the annual expenses even on liquefied petroleum gas.

VII.9 Administration and Organization

Yadava (1980), when reviewing the working of the biogas plant program in India, analyzed the main bottlenecks/problems encountered. Briefly, they are:

* Inadequate technical help
* Lack of follow-up services, and of monitoring of feedbacks
* Too much time lag - about one and a half years - between the submission of the application and the actual installation
* Lack of demonstrative efforts
* Lack of proper coordination

VIII. PROSPECTS FOR IMPROVEMENT

Much research and development work is required to render biogas technology more applicable and feasible. This section does not try to give a list of research requirements, which have been well covered elsewhere (Dandekar, 1980; DaSilva, 1980; ESCAP, 1975; Mazumdar, 1982; Moulik & Srivastava, 1975; Prasad et al., 1974 Sathianathan, 1975; Shah, 1978b; Subramanian, 1976). Rather, the prospects considered most promising are presented. Section VII was intended to serve as a checklist of current problems - especially those concerning administration and organization - whose remedial measures are apparent. These aspects, therefore, will not be repeated here.

Recommendations for measures to improve the technology of biogas production have been given (ESCAP, 1980; Prasad et al., 1974).

Various aspects for improvement have been pinpointed as follows:

(a) Reduction of digester size and cost
(b) Alternatives to cement and steel
(c) New design of digester
(d) Economics of different digester sizes
(e) Distribution and storage of gas
(f) Design of latrine-cum-biogas digesters
(g) Solar energy application

VIII.1 Optimization of Digester Size

Current digesters are built with a retention time of 50-60 days and they may have been over-designed as far as optimization is concerned.

Prasad et al. (1974) calculated that the digester volume can be cut to one-fifth of the current size. However, in order to achieve such a drastic reduction in digester size it is essential to collect basic data on:

* the fermentation rate as a function of temperature, pH, viscosity and mixing;
* the resulting gas yield and composition; and
* the choice and management of microorganisms for optimal methane production.

A scrutiny of the IARI and KVIC literature on the design of digesters showed that such basic design data had yet to be collected, and the plants were merely "put together" rather than "designed" for optimum conditions (Prasad et al., 1974).

Recently, research work has been oriented more rationally toward optimizing the design. It has been shown (Subramanian et al., 1979) that minimization of the cost of the gas holder in the Indian design leads to the narrow and deep digesters of conventional plants. If instead the total capital cost of the gas holder plus the digestion chamber is minimized, the optimization leads to wide and shallow digesters. These plants are not only 25-40 per cent cheaper, but their performance is slightly higher than conventional plants.

It should be noted that reducing the digester volume leads to reducing the retention time, and hence increasing the loading rate. This has some implications, namely:

* More input materials to be fed to an existing digester, which may be not practical where the availability of the materials has already proved to be a constraint;

* The same amount of input materials to be fed to a digester with an optimum design, which leads to a smaller volume of gas obtained from a given amount of waste;

* Shorter retention times cause a less extensive biodegradation and a lower rate of pathogen dieoff.

VIII.2 Media-Packed Digester

This concept arises from the bottleneck in the slow specific growth rate of methanogenic bacteria, with the result that the volume efficiency of the digester is limited. Improved digesters will therefore have to be designed so as to accumulate the active methanogenic biomass within the system. Clarification of the digester effluent and recycling of the settled biomass is a possibility but raises problems, such as:

(a) Variable settling properties of the methanogenic bacteria and their poor resistance to this treatment method (Melchior et al., 1982).

(b) The operation of a digester may become too complicated to be accepted by the user.

Media-packed digesters offer an alternative, in which the active biomass is attached to an inert carrier. Also known as the "anaerobic filter", the system can be operated downflow or, more often, upflow. Laboratory and pilot-scale systems have been reported (Colleran et al., 1982; Kasemsan, 1978; Le Roux et al., 1979; Scott & Genung, 1981; Sumaeth, 1980) to work satisfactorily, with the following results:

* Rapid start-up with a minimum of operating problems;

* A stability to the variations in operating conditions, which is particularly attractive in the context of farm-based operation.

- A better tolerance of adverse effects such as pH variations, high levels of volatile fatty acids and ammonia, and shock loadings.

- The volumetric loading can be increased, which means that the hydraulic retention time can be decreased; therefore

- The digester volume can be reduced; and this leads to

- *A reduction in investment cost*

The media are not necessarily expensive or have to be imported from outside the village. For example, small bamboo rings have been used in a pilot-scale digester, resulting in a reduction of the digester volume by about 50 per cent in comparison with conventional designs (Sumaeth, 1980).

Nevertheless, potential problems for full-scale applications exist. Some of them can be cited (Kasemsan & Weyrauch, 1978) as:

(a) difficulty in - and the cost of - waste distribution;

(b) excessive sludge sloughing off from a digester with a large cross section; and

(c) the overall process of scaling-up the size.

VIII.3 Phase Separation

Another bottleneck is considered to be due to the rate-limiting of the hydrolytic phase in the process. There is nowadays a tendency to split digestion systems into tow steps, in which the fermentation can be optimized separately.

Two-phase operation can bring about various benefits, such as:

- higher solids destruction efficiencies, and greater gas production rates and yields over those of conventional high-rate digestion systems (Ghose & Bhadra, 1981; Ghosh & Klass, 1978)

- a better reliability than single-phase systems for a wide variety of substrates (Melchior et al., 1982);

- large savings in the capital and operating costs (Colleran et al., 1982)

- the process can be used with a high suspended solids content (Colleran et al., 1982) and so less water will be needed to mix with the input material.

The construction of a partition wall in the digester chamber will also have additional advantages (Shah, 1978a), namely:

- the mixing of the fresh feeding material with the partially digested slurry is more thorough;

- the possibility of short-circuiting is eliminated;

- * the upward flow of the slurry in the first compartment and the downflow in the second compartment insure maximum time for the digestion of each batch of fresh feed; and

- * most of the scum formed is left over in the first compartment, and the incidence of blocking the outlet pipe decreases.

Since the partition wall is subjected to equal pressure on both sides, its thickness can be small and thus the incremental cost for such a wall is small. Furthermore, with the resulting higher gas production efficiency, the total volume of the digester could be relatively reduced and the construction materials can offset the incremental cost of the partition wall.

VIII.4 Construction Materials for the Gas Holder

As already mentioned, the steel gas holder in the Indian design constitutes 40-50 per cent of the total cost of a plant.

Various materials have been tried as a substitute for steel to build the gas holder. Experiments in India have demonstrated the suitability of ferrocement and galvanized iron. It is claimed that ferrocement especially possesses the following advantages (Sharma & Gopalaratnam, 1980):

(a) the technology involved is labor-intensive and calls for only moderate skills;

(b) the material has low thermal conductivity, and as a result the gas production rate is fairly uniform in all seasons;

(c) it has high resistance to corrosion;

(d) due to the ease of construction, any accidental damage can also be easily repaired;

(e) constituent materials that are required for construction are readily available in most developing countries; and most of all

(f) low cost: based on the experiments at the Structural Engineering Research Centre, India, ferrocement gas holders cost only half as much as steel gas holders.

Nevertheless, ferrocement depends too much on the skill of the laborers, and hence close and competent supervision is required. Furthermore, since the work is done manually, the final weight of a ferrocement gas holder is unpredictable.

Instead of using a floating gas holder incorporated with a digester, a separated balloon can be used to store the gas. At a community plant generating electricity in Foshan, China, balloons made of 0.28-mm thick PVC film, each with a capacity of 120 m^3, have been successfully used (Chen et al., 1978). The characteristics and benefits of the balloons are given as follows:

- * The materials making the balloons are cheap and easy to obtain. The cost of a 120-m^3 balloon is only 450 yuan, as compared with 12,500 yuan for a floating gas holder on a water tank.

* The gas pressure in the balloon is controlled by a safety valve at a maximum level of 3 cm of water column.

* Consequently, the demands on construction of the digester are less severe. For example, the roof of a 47-m^3 digester is made of concrete with a thickness of only 5 cm.

* Also, as the pressure of the gas system is very low, it is easy and cheap to fabricate absolutely reliable stop valves and safety valves.

VIII.5 Materials for the Digestion Chamber

A totally different approach to the reduction of the costs of plants based on the current design is to develop alternatives to cement and steel.

As far as cement is concerned, there seems little doubt that carefully constructed earthwork digesters can serve the purpose (Prasad et al., 1974). It may be necessary, however, to use a suitable lining of perhaps creosote or PVC.

Again ferrocement as a constructional material can be considered. A laboratory-scale digester built with ferrocement has yielded more gas than conventionally constructed units. It is calculated that a 3.5-m^3 capacity ferrocement digester can replace the conventional 5-m^3 plant (Swamy et al., 1981). There is no reason given for the improvement in gas yield, but possibly it is due to the effect of insulation.

There is a great need for alternative materials that allows mass production so that the user can buy a ready-made unit for direct and prompt installation and operation.

The use of bag digesters may have a potential. These digesters can be made of 0.55-mm thick Hypalon, laminated with neoprene and reinforced with nylon (Figure 6). The advantages of this type of digester are:

* Mass production capability.

* Easy transportability.

* Constant gas pressure.

* Low cost. Even if imported from the United States, the cost of a unit is only 10 per cent of that for a concrete-steel digester (ESCAP, 1975). In the Fiji Islands, a bag digester with a volume of 1,000 gallons (3.8 m^3) cost US$ 500 in 1975, but a concrete digester with the same volume cost $1,500 in 1978 (Chan, 1982).

* In rural areas, the whole installation is complete in a matter of minutes.

Misgivings regarding the use of bag digesters are:

* A fear of explosion (Maramba, 1980): an accidental puncture may be big enough to cause an explosion if there is an open fire (say, a lighted cigarette) nearby;

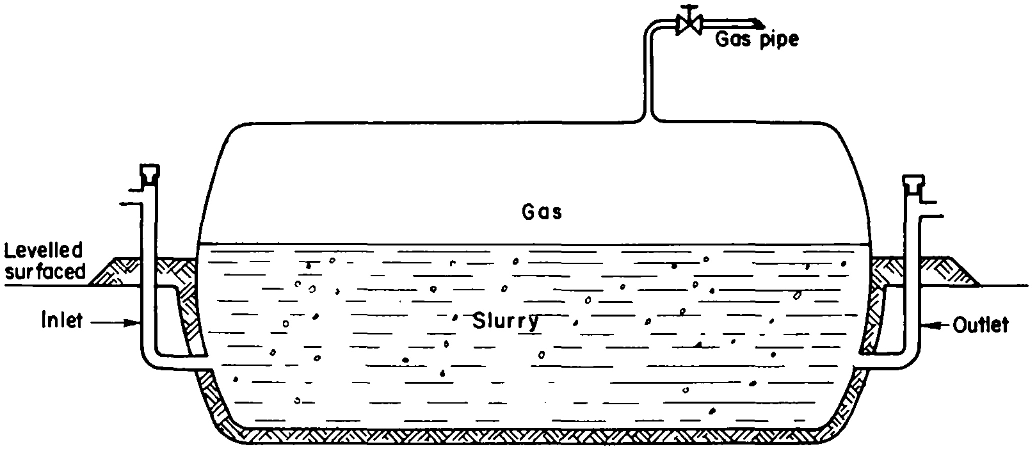

Figure 6. Flexible Bag Type Combined Digester / Gas Holder

- * Rodents have been known to bite and destroy the plastic bag (ESCAP, 1980).
- * It is difficult to repair any leak (Chan, 1982).
- * There is no provision for removing scum and stirring the slurry.
- * Its life span is short due to its low resistance to ultraviolet rays (ESCAP, 1981).

In 1974, the Union Industrial Research Institute, Hsinchu, Taiwan, invented the red mud plastic (RMP) for building biogas digesters. It is claimed that the total investment in this type of digester can be recovered within 5 to 9 months.

The characteristics of RMP are as follows (Hong et al., 1980):

a) Primary materials: red mud and wastes from the aluminum industry.

b) Physical properties: resistant to erosion by acid, alkali or salt solution.

c) The 1.2 mm-thick RMP digester can be used for at least 20 years. No leakage has been detected after several years of using this digester.

d) Broken parts can be easily repaired. The area around the broken part should be cleaned and patched with a piece of RMP using a strong adhesive.

e) The digester costs NT$ 300 (US$ 1 = NT$ 36) for each pig. Seven head of pigs provide sufficient fuel during warm seasons for a household of 5.

Figure 7 shows a typical RMP digester.

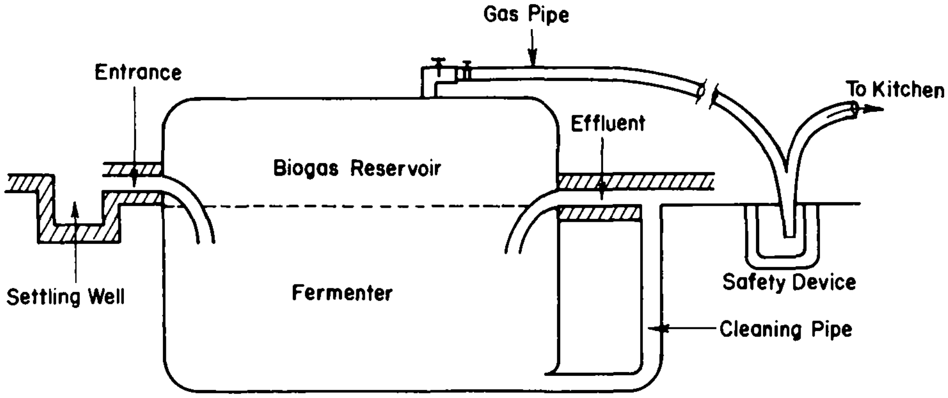

Figure 7 Typical RPM Digester

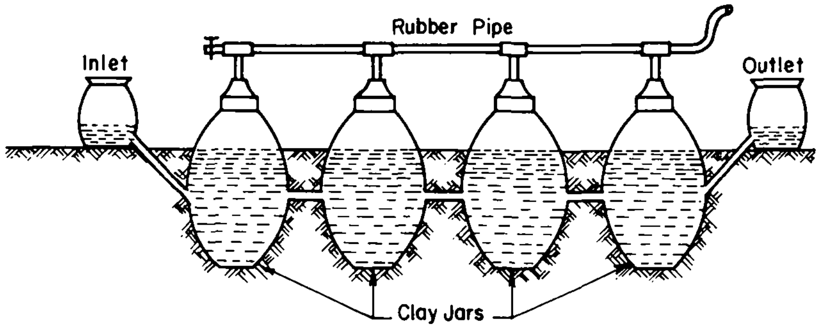

Figure 8 Digester Made of Clay Jars

The use of clay water jars as digesters has recently gained attention. The Centre of Science for Villages in Wardha, India, has developed a prototype made of clay jars added together in series (Figure 8). The jars can be inter-connected with 7.5 cm-thick clay pipes, and in this way the total capacity of the system can be increased to any required size. It is claimed (Gupta, 1982) that a digester consisting of ten 300-liter jars costs Rs. 650 (about US$ 70), less than one-fourth of the cost of the KVIC digester and even cheaper than the Chinese design.

It should be noted that that not all of the possible alternative construction materials can be satisfactorily applied anywhere. Subramanian (1976) observes that a number of unsuccessful attempts have already been made to use bamboo, wood, plastics and other materials in place of cement and steel. Moreover, French (1979) states that - based on his calculations - even if the use of cement and steel were reduced to zero, the system would still have a negative net present value in both financial and economic terms. Nevertheless, successes here and there show that alternative materials definitely have a promising role. Careful pre-application testings and correct use are compulsory when any new material is tried.

VIII.6 Gas Appliances

An example of cost versus efficiency trade-offs can be found with the gas burner (Lovejoy, 1980). Chinese burners for cooking and lighting are usually made of fired clay. Although their combustion efficiency is not high (less than 40 per cent), their cost is low (less than US$ 2). Indian burners, with a combustion efficiency of around 60 per cent, are made from cast iron with gunmetal injectors, and cost $ 12-15. However, in this area there now appears to be a convergence of the two approaches, with the Chinese developing more efficient clay burners, at the same time as the Indians are marketing lower cost but efficient porcelain burners.

VIII.7 Heating

If a low-cost and practical heating method can be devised, biogas technology will be applied more widely in cold regions. Unfortunately, it seems that heating may not be economically - and even technically - feasible for family-size digesters in rural areas.

But for community plants, heating could be seriously considered. Park, Park & Lim (1979) ran a 137-m^3 digester in winter conditions (the average of maximum ambient temperatures was 2.5 °C) and, by heating to control the slurry temperature at 35 °C, they obtained a gross gas production at the rate of 1.6-1.8 m^3 per m^3 of digester. This is a remarkable achievement if one compares this with the data presented in Table 7. Moreover, it was found that only 14 per cent of the heating energy was lost, and the energy requirement for heating was about 32 per cent of the total gas production. This still left about 1.1 m^3 of gas per m^3 of digester, that is, about twice to three times the gas production rate in the Indian design without heating.

Economic analysis is required to find out the affordability of heating, at least for community gas plants. In this respect, it should be observed that in cold seasons, the gas is regarded as being more valuable than at any other time, since alternative sources of energy are more difficult to find while the energy requirement is higher than in warm seasons. In this situation, it is very likely that additional costs for heating can well be afforded.

Research on applications of solar energy to digester heating has been initiated. Hills & Stephens (1980) have tried out two solar collectors - the breadbox and solar pond - for heating the influent, and conclude that the solar pond appears more suitable for farm use. Reddy et al. (1979) used a transparent cover to trap heat losses and recover this energy to heat a water pond formed on the roof of the gas holder. The operation of such a model, even under the worst conditions (cloudy sky), shows a significant improvement in terms of cost-benefit. For a family-size (1.7 m^3 gas a day) digester incorporated with a solar heater and a solar still, the incremental costs were under 10 per cent, whereas the improvement in yield was 11 per cent, besides producing an extra amount of distilled water.

Apart from creating a source of heat - whether from solar energy or biogas itself - the heat requirements for digesters can be reduced. Examples of operational procedures which accomplish this are (Hollingdale, 1980):

- Recycling of the supernatant or effluent to use as dilution to the feeding material. Since the total solids in the effluent are substantially lower than those in the influent, the effluent can be recycled to quite a considerable extent while adjusting the make-up water volume to maintain the required solids loading. If a 30 per cent recycle is applied, there is approximately 20 per cent reduction in the heating requirements.

- Applying a high solids level in the influent. The higher the level, the less make-up water is required. From 10 to 11 per cent of total solids in the influent should be possible.

- Optimizing the operating temperatures. For example, running a digester at 25 °C instead of 35 °C would reduce winter heat requirements by about half. Of course, the gas production will be reduced, and in order to optimize it under these circumstances, a wider study of gas demand patterns would be required.

Among the points presented above, it is considered important to recover as much heat from the effluent as possible (Mills, 1979). This becomes easier as continuous loading is approached. With efficient heat recovery, the heat requirements of a digester should be such a small proportion of its output that fluctuations between net summer and winter output will be minimal. This should still apply in extreme climates where the input is still likely to be pumped from a livestock building above 0 °C despite ambient temperatures of -20 °C. Under these conditions, it has been found that for a 50-m^3 digester, the ratio of input heat to loss heat is still 6:1 (Mills, 1979).

It should be noted that in the practical units operated at field scale, energy balances have not been as good as in theoretical models. This may be partly overcome by:

(a) improving insulation. This is not necessarily costly. For example, rice husks - which have been used to preserve ice in many rural areas - can be a good insulating material.

(b) reducing head loss by constructing an underground digester.

At larger scales, heat loss becomes relatively less important as the volume/surface ratio increases. This should make control of heat loss easier and more affordable for community-size plants.

IX. A CASE STUDY: BIOGAS TECHNOLOGY IN CHINA

It has become a widely-accepted fact that among countries adopting biogas technology, the People's Republic of China has set a phenomenal example of success. This Section will give an analysis of how and why.

To the Chinese, there is nothing such as "waste"; waste is only a misplaced resource which can become a valuable material for another product. At least this tradition gives a direction in the implementation of vast programs of waste recycling.

IX.1 Historical Review

The practice of biogas production goes back as early as 1936. During the years 1936-37, 4 digesters were built at 3 different places in an effort to generate electricity from biogas. Unfortunately, these innovations were not valued by the government at that time.

After the founding of the People's Republic of China, the development of biogas technology was promoted mainly to solve the shortage of fuel. The program has gone through four phases as described below.

- 1957-1967 Period: During this period, the time of the Great Leap Forward, attempts at instantaneous modernization through the use of simple, small-scale technologies were made. But only a small number of biogas digesters were actually built in some southern provinces, and even these were soon abandoned. The reasons for the setback were insufficient experience (Eggeling & Stephan, 1981) and undue haste in extension (Yang, 1980).

- 1968-1974 Period: Under the pressure of the energy crisis aggravated by the population growth, the construction technology for water-pressure type digesters was improved to a practical stage through repeated experiments in Sichuan Province. Between 1970 and 1972, peasants in two counties in Sichuan Basin built the first few hundred digesters. Thanks to the encouragement and financial subsidies of the government, further progress was remarkable: the number of digesters built in Sichuan surpassed 30,000 in the spring of 1974 and 120,000 in the fall of the same year; by the end of the year there were 209,000 digesters in the province, and in 1975 the number of digesters built or under construction reached 410,000 (Smil, 1977).

- 1975-1978 Period: Under the slogan "small, local, operated by the masses", the adoption of biogas technology was popularized throughout the country. This phase culminated in a national conference for experience exchange on the propagation of biogas technology in April 1975. Between April 1975 and June 1978, the number of biogas plants increased to 7 million.

- 1979-Present Period: At the end of 1978, a national inquiry on the existing biogas plants was conducted and gave evidence that 30-50 per cent of the plants had serious problems. 2 million plants having problems were replaced (Eggeling & Stephan, 1981). In the Third Conference in 1979, biogas was declared the "principal alternative" to cope with the fuel crisis of Chinese villages.

The figure of 7 million family-size digesters in China has been reported since 1978 up to the present time. Apparently there are no updated statistics. The Chinese government plans to build one million digesters a year (Wu, 1980), and, if the rate of construction in the early 1970's can be maintained, it is likely that this goal can be fulfilled. Therefore, up to the time of this writing, the number of digesters in China may already have reached the 10 million mark.

It seems that the development of biogas technology has not been achieved evenly all over China. Among the 7 million digesters, 5 million are in Sichuan Province, mainly due to the favorable climate in this province.

IX.2 Existing Favorable Conditions

Even before the launch of biogas technology in China, some favorable conditions already existed in the country, and together they have rendered biogas technology a viable proposition and brought about successes. Briefly, they are:

(a) There is a real need for alternative sources of energy. The Government - if they wish to save firewood for the forest, and animal dung and crop stalks for the land - would have to supply 390 million tonnes of coal a year for rural households, and this would scarcely be possible (Yang, 1980).

(b) Waste recycling has for long been a traditional practice in Chinese society; there is no social or religious aversion toward the use of any kind of waste.

(c) Some social features peculiar to China, which might not be characteristic for other countries, such as: no migration, strict birth control, particular habits of work, equality in the ownership of small land and small herds of livestock; all of these factors facilitate planning and ensure that the benefits are widely and speedily diffused.

(d) Some economic structures also are favorable to the implementation of biogas technology, such as the decentralization of industry, in which most districts now have their own mini-cement plants.

IX.3 Desperate Need for Alternative Energy

The fuel shortage is a big problem in China. It is estimated (Ma, 1981) that every rural family is short of cooking fuel for three months a year. The magnitude of the problem is staggering: 500 million people in the Chinese countryside do not have enough fuel to cook their meals or heat their water or home (Anon., 1982). Firewood, grasses and plant stalks still constitute the main source of fuel, with about 220 million tons of plant stalks and 50 million m^3 of firewood being consumed annually (Yang, 1980).

IX.4 Use of Locally Available Constructional Materials

A variety of construction materials, none of which is imported, can be used. For small digesters, the Chinese always prefer low-cost and accessible materials: rocks in the mountainous regions, pebbles from river beds, bricks in the plains.

A traditional Chinese building material is a mixture of clay and lime, compacted and cured until hardened. The active substances in clay soil - such as activated silicon oxide and aluminium oxide - react with the calcium hydroxide in hydrated lime and change into a chemically stable and insoluble gel matter of hydrated calcium silicate and calcium aluminate which make the lime-clay hard and strong (Shian et al., 1979). Lime-concrete is also a traditional Chinese building material. The commonly used composition of lime-concrete is lime:sand:crushed stone = 1:3:6 (by volume).

Cement and reinforced structures are normally used only for large community units (Smil, 1977). Recently cement concrete has been propagated for the construction of the digestion chamber, but thanks to a special technique of walling, it is possible to manufacture pre-stressed shell structure constructions at low cost.

This construction principle, when applied to the Indian design, has led to a reduction of 50 per cent of the masonary work (Eggeling & Stephan, 1981).

The diversity of building materials to adapt to local conditions are reflected clearly in the Chinese manuals (such as the one by the Southwest Architectural Designing Institute, 1980), in which different designs using different materials - and therefore different methods - are described.

Accessories are also simple. To save scarce metals, the gas outlet pipe is often made from tough plastic, and the conduit pipes are made either from a flexible synthetic material or from natural rubber (Smil, 1977).

IX.5 Diversified Use of Feeding Materials

Practically any type of waste suitable for anaerobic digestion is used: animal dung and human excreta, agricultural residues, grasses, aquatic weeds, industrial wastes, mud, etc. This diversification allows flexibility in operation and widens the feasibility of biogas technology.

As far as waste collection is concerned, no change is necessary when biogas technology is introduced. Animal dung and agricultural residues are customarily collected and reused, mainly through composting. Human excreta is removed by an organization which gathers and transports it for subsequent use in agronomy and aquaculture. Thus, the introduction of biogas does not represent more than a further intermediate step in the recycling process; it is not necessary to organize and set up a new collection system. This aspect is very important for the implemention of biogas technology (Eggeling & Stephan, 1981).

IX.6 Manpower Development

Technicians are trained through training courses combining theory with practice; the latter involves the construction of more than one digester from beginning to end. Usually the training course takes 15-30 days and is funded by the government (Chen & Li, 1980)

Frequent meetings are held in various places where experts are invited to give lectures, and thus the knowledge of biogas technicians is regularly updated.

There is at least one biogas technician working in every production team that uses biogas. A professional contingent is often established in the communes, and production brigades are employed to build digesters in batch for the peasants. The members of the contingent are, of course, trained personnel.

IX.7 Community Education

The government mobilize propaganda and publication departments at all levels to popularize fundamental knowledge on biogas technology. Numerous publications are brought out. Radio and television propagate and introduce the meaning and importance of biogas utilization, present experiments on biogas and their results, and discuss problems. Scientific movies are produced in some provinces.

IX.8 Public Participation

Extensive mass education brings awareness to the people, and consequently there is public participation. Thus, the policy for developing biogas technology in rural areas is to "rely mainly on the commune members' own efforts while making government and collective assistance subsidiary" (Yang, 1980). That is to say, in building a digester, the owner bears the costs of the materials required, while the production team is responsible for the labor cost, the Government helps train 2-3 peasant technicians for each production team, and the banks provide low-interest loans to poor owners.

Since the owner participates directly in the venture, he would naturally feel a sense of responsibility of ownership. The population's consciousness of self-support and the belief in self-reliance are considered important by the Chinese. The self-confident experimentation with biogas plants from below is indeed indispensable for their adaptation to local particularities (Eggeling & Stephan, 1981).

IX.9 Organization

A State Leading Group on biogas implementation is set up and consists of representatives from the State Commissions of Programme, Economics, Science & Technology, and Agriculture, and from the Ministries of Finance, Electricity, Light Industry, Farm Machinery, Chemical Industry, Health, and Commerce, together with the Army's General Logistics Department, the State General Supply & Marketing Cooperative, and the Agricultural Bank of China (Chen & Li, 1980).

An executive institution is set up under the Leading Group to handle day-to-day work.

Similar leading groups have also been set up in provinces, municipalities and autonomous regions, as well as in their subordinating countries and cities.

The above institutions may formulate policies, determine development programs, coordinate the efforts of all departments, sponsor training courses, and organize the supply of materials.

IX.10 Administration

The interest in biogas technology of different departments of the state administration - such as those in public health, forestry, agriculture, etc. - facilitates the implementation of biogas technology. This concentration of interests is shown by the setting up of biogas offices encroaching on various departments.

Of decisive importance for the propagation of biogas in China is the convergence of benefits of the three levels: household, collective and state. Each of three levels has benefits from - and consequently duties in - biogas programs. Private households and collectives contribute human/animal wastes and agricultural residues, respectively, and they in return receive the end-products. The state offers technical know-how, materials and/or credits, and is relieved of its duties in supplying traditional energy sources and in abating environmental/health hazards.

Based on the status quo of biogas technology development, the Chinese government has set up a policy of "strong leadership, active expansion, batch development, and steady advance" (Chen & Li, 1980). Biogas technology has been put on the agenda of all levels of the government, and specific policies and projects of development have been formulated. The major policies and measures taken are:

(a) Batch development proceeds in a planned way. It is realized that biogas technology concerns not only fuels but also aspects of fertilization, sanitation, as well as household affairs. Only when batch development (which involves at least a whole village or production team) is accomplished can the benefits of biogas technology be demonstrated and hence well accepted. Also, batch development creates a favorable situation in which financial, material and technical supports from the government can be concentrated. Once the process is accomplished, the location can serve as a model for others to follow.

This methodology is a result of "learning by mistakes". In the early stage of biogas technology development, digesters were scattered all over various experimental sites. This led to non-adoption since it could not improve the productivity and living standards of the whole team, it hindered proper technical instructions, all of which resulted in low performance of the digesters and low enthusiasm of the masses.

(b) Focus the development of biogas technology in areas short of firewood and prevalent in epidemic schistosomiasis. For example, a location in Sichuan Province was chosen to start a biogas technology program, and from there the technology later spread to other locations, thanks to the good example of the starting point. This not only solved the difficulty in firewood supply, but also reduced cases of schistosomiasis by 80 per cent (Chen & Li, 1980).

(c) Bring finance and constructional materials for biogas programs in line with the state and local government plans. A policy of "rely mainly on the finance of the family itself while making subsidies from the collective and the state subsidiary" is adopted. The portion of subsidy varies, depending on the financial status of the family. In addition, financial departments allocate a definite budget for the maintenance of the digester to ensure long-term good maintenance.

(d) Considerations are given both to the interests of the family and the collective. Policy concerning the distribution of raw feeding materials and digested slurry is set based on this principle, so that the digesters serve both the livelihood of the peasants and the production of agriculture.

IX.11 Research

Great efforts are made in the research on biogas technology. The Guangzhou Institute of Energy Conversion and the Chengdu Institute of Biology, both subordinated to the Chinese Academy of Sciences, together with the Chengdu Biogas Research Institute under the Ministry of Agriculture, are the major research institutes at the central level. In addition, research institutes under central ministries as well as universities also take part in the effort. In many provinces, districts and counties, there are also biogas research institutes or experimental stations. All the research institutes have close connections with the State and local offices of biogas.

Yearly meetings of biogas research institutes are held, where experts assess the results to see whether they are worth implementing. In addition, meetings of directors of biogas offices in major provinces and cities are held every year to exchange experience, discuss remedial measures for problems encountered, and plan for further development.

The Chinese have stressed (Eggeling & Stephan, 1981) that in China, practice is followed by research, while it is the reverse elsewhere. Thery (1981) also observes that in China, technological progress has been made not before but during the implementation.

The process of research could be best described by saying that it is a continuous one, from original design work during planning to remedial measures during implementation.

IX.12 Technology Transfer from China

Having reviewed the specific circumstances in China, it should be stressed that some of these may not be found - and may not easily be replicated - in other developing countries. Therefore, similar benefits from biogas technology should not be supposed to follow if biogas technology is adopted elsewhere.

IX.13 Another Side of The Story

In contrast to numerous praises for the success of the biogas program in China, the latest source (Anon., 1982) reveals that, according to a study carried out for the World Bank, nearly half of the digesters installed in China work only intermittently, if not at all. The study's author, Vaclav Smil, goes so far as to say that, rather than being a success, the program has been a "major disaster".

Some observations leading to this conclusion include:

* The digesters prove to be inefficient and commonly develop water and gas leaks;

* The haste with which the program is carried out, and the search for easy, instant benefits from the digesters;

* Many digesters are inadequately maintained and fail in their second year of operation.

The result of the failure is public disillusionment, and the number of new digesters being built has rapidly fallen off.

At the time of this writing, detailed information regarding this failure is not available, and therefore no decisive conclusion can be made.

X. CONCLUSION

Biogas technology, more than any other technology, is a delicate and complex issue. This paper just serves as a checklist of the main relevant aspects, to which there is still much to be added. Apparently successes, such as those in the People's Republic of China - if they are still believed to be successes (Section IX.13) - have not been achieved spontaneously or 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. But 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 in China still operating were kept running for eight months a year, they would contribute less than one per cent of China's rural energy use (Anon., 1982).

And, as pointed out in the paper, the benefits of biogas technology should not be taken for granted. Depending on the economic and social structures, the benefits may be small or great, and one benefit may be a trade-off for another. All of these factors will eventually decide the desirability of biogas technology. 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 assessed. Overlooking an essential factor may cause irreversible damage. After some years of implementation, it was discovered that more than fifty per cent of the total digesters built in one country had been abandoned. Fifty per cent of the owners interviewed said that the reason of non-use was the unavailability of input materials. In another country, most of the digesters were abandoned mainly due to their low performance in the winter. If the planning phase had been carefully worked out, these costly failures could have been avoided, or otherwise the resources used in implementing the biogas programs could have been diverted to alternative strategies to solve rural problems.

As expressed by Hall et al. (1982), the diffusion of new energy technologies is far from a simple process, and that it is likely to meet with any of the same problems that have hampered other rural development programs - such as those aimed at introducing high-yield crop varieties, irrigation systems, public health measures and population control. Therefore, when a system for biogas production 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, efficient 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. This could be achieved by watchful follow-ups and a preparedness for remedial measures. In some 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, and there is no one for the users to turn to for assistance in solving them; and finally when the officials revisit the sites, they can only express some frustration about reconsidering the technology.

Feedback monitoring requires an assessment of the whole scenario, besides a study on each component of this scenario. It has been pointed out that analyses in the past have often disregarded those effects that took place in parts of the system not immediately surrounding the project. Such effects have been called "second round" or "linkage" effects (Qurashi, 1980). As previously mentioned, an increase in the demand for animal wastes as a result of the introduction of biogas technology can induce the second round effects of reducing the availability of animal wastes to other existing users, and/or increasing the prices of the wastes. This gives rise to the inherent possibility of "chain reactions", with the subsequent results of accelerated deforestation, a larger gap between the rich and the poor, etc.

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 at any rate extensively covered in the literature (Eggeling & Stephan, 1981; ESCAP, 1975; ICAR, 1976; Lohani & Rajagopal, 1981; Moulik & Srivastava, 1975; Prasad *et al.*, 1974; Sathianathan, 1975; Shah, 1978a). It suffices to say that strong will and dedication - but not with a fanatic attitude - is badly needed for undertaking such a difficult endeavor. Only then can biogas technology be well accepted and well run, and fully show its potential benefits.

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