PGI/82/WS/21

Consolidation of information

A review of the literature on promotion of biogas systems

Pilot edition

General Information Programme and UNISIST

United Nations Educational,
Scientific and Cultural Organization

Paris,
November 1982

24-10-03
reclt streel,
unesio,

PGI-82/WS/21
PARIS, December 1982

CONSOLIDATION OF INFORMATION

A Review of the literature on promotion of biogas systems

Pilot edition

Prepared by
The Tata Energy Research
Institute

General Information Programme and UNISIST

United Nations Educational
Scientific and Cultural Organization

The present pilot edition is a photographic reproduction of the author's original manuscript prepared under a pilot project sponsored by the General Information Programme of UNESCO. The opinions expressed are not necessarily those of UNESCO or Tata Energy Research Institute and do not commit the organizations.

The Unesco Symposium on Information Analysis and Consolidation held in Colombo from 12 to 15 September 1978 recommended the establishment of pilot information consolidation units in selected priority areas and the distribution of their outputs for repackaging and adaptation for various categories of users.

In accordance with this recommendation, the Division of the General Information Programme of Unesco provided assistance to the Tata Energy Research Institute for the establishment of an information consolidation unit and for the preparation of information products consisting of evaluated, analyzed and consolidated information in three selected fields: biogas, windmills and cooking stoves.

At the end of Phase I of the Work Plan for 1980/81 agreed between Unesco and the Tata Energy Research Institute, the following pilot editions had been produced:

1. Biogas Handbook
2. Windpump Handbook
3. Cooking stoves Handbook
4. Review of the Literature on Promotion of Windpumps
5. Review of the Literature on Promotion of Biogas Systems

Phase II of the project involves the improvement of these pilot editions, their distribution and testing in the field, repackaging of the information for application by users at various levels and an evaluation of the results of the entire project at the end of 1983. In this context the opinions of the readers of these documents will be very useful. Comments should be addressed to:

Division of the General Information Programme
Unesco
75007 Paris

INTRODUCTION

Biogas generation is a simple and cheap method of decentralised energy production over a wide range of agricultural and climatic conditions in the developing countries.

Biogas systems have attracted considerable attention in view of their potential for waste recycling, pollution control and improvement of sanitary conditions, in addition to providing fuel and fertilizer. For instance, in India, a modest number of 1 million biogas plants constructed at an appropriate cost of Rs.300 crores, is expected to result in an annual saving of more than 4 million metric tons of fuelwood, over 22 million litres of kerosene and 3,42,210 metric tons of chemical fertilizers. The total benefit to the national economy in terms of current energy prices, is estimated to be about Rs.176.45 crores ($207 million).

With over seven million biogas plants already installed, China is reported to have made considerable progress in the use of biogas. In other countries similar family-size biogas plants are not found to be so successful. Alternatively, community-size biogas plants have been proposed. In spite of the economic advantages, community plants are beset with social and institutional problems, and their success depends upon careful planning, implementation and monitoring.

Experience elsewhere, for instance in the South Pacific, shows that the full potential of biogas can be realised only by an integrated biogas system. This system makes use of water and solar energy to treat human, animal and agricultural wastes by biological processes to produce at the same time methane gas as fuel, and the slurry which could be used to increase aquacultural output (algae, fish) before it is actually used as fertilizer to increase agricultural production. Such integrated systems appear to be highly promising.

However, further studies are required to investigate the economics of such systems, especially if they are to be successful in other agricultural systems and settlement patterns.

The development of biogas systems involves many disciplines that are scientifically complex, but the practical applications are within the capabilities of the ordinary farmer. However, effective implementation of biogas schemes is is dependent on policy framework, response of the people, economic viability and suitability of the organisational mechanism for the ultimate execution of the scheme.

This document is an indepth analysis of the various issues connected with promotion of biogas technology utilisation. It is based entirely on published literature, and its contents have been professionally evaluated. In view of the increasing fuel cost and the non-uniform energy prices throughout the world, no attempt has been made to recalculate the figures to demonstrate the present cost-benefits.

CONTENTS

PAGE NO.

LIST OF FIGURES AND TABLES

EXPLORING THE OPTIONS

Energy Consumption Pattern:

Non-commercial sources such as firewood, cattle dung, farmwaste, etc. provide for as much as 50% of the total energy requirements of nearly half of the world, comprising Asia, Africa and Latin America. The high prices of the fast depleting energy sources such as oil, coal, kerosene, etc. (as most of these energy sources have to be imported) and lack of proper transportation facilities in the rural areas have severely restricted the use of these commercial energy sources, increasing the dependence on locally available resources in the developing countries. (Ref. 38, 39)

Moreover, it is not possible to provide commercial energy on a national scale in many developing countries because of: (Ref. 39)

- high capital costs of commercial energy supply;
- high discount rates owing to shortage of capital;
- lack of skilled manpower in rural areas;
- decentralized energy needs of rural areas involving high transmission losses and inadequate demand to justify the setting up of local power plants of the conventional type;
- high transport costs of fuels such as coal and oil and lack of infrastructure, i.e. inadequate roadways, repair shops, carriers and communication facilities.

Developing countries which mostly have agrarian economies, high populations, and generally warm climates would benefit from an energy option which satisfies the following requirements: (Ref. 39)

- high output-capital ratio or rate of return;
- unit size appropriate to small-scale activities;
- labour-intensive rather than capital-intensive technology;
- self-help technology not requiring highly skilled labour; and
- use of locally available resources, which reduces transport costs.

Demand for fertilizer:

In addition to the increasing demand for energy, the demand for fertilizers too needs to be met by local resources, in developing countries, as the chemical fertilizers are increasingly moving out of the reach of the rural poor. Thus animal dung and agricultural waste, in addition to be being burnt as fuel, are being used for composting as well. Fuel and fertilizer, therefore, compete for the same resources and hence efficient utilisation of these resources has become a vital necessity. (Ref. 39)

Biogas technology:

Biogas technology is a promising option for the most efficient utilisation of the above resources. The technology involves the anaerobic fermentation of organic waste materials such as animal dung, human excreta, agricultural waste, etc. in a fermentation tank in the presence of micro-organisms to produce a gas called biogas, which contains about 60% methane and 40% carbon dioxide along with traces of other gases such as nitrogen and hydrogen sulphide. Biogas is a clean fuel useful for agricultural, domestic and cottage craft activities. The left-over sludge is rich in nitrogen and valuable as a fertilizer. Thus both the useful constituents of the waste materials, namely, carbohydrates and nitrogen, are appropriately utilized for fuel and fertilizer, respectively. (Ref. 39)

In dried dung, carbon burns with 11% efficiency in the customary fire, as opposed to 60% efficiency for methane obtained from biogas plants. Similarly, the digested sludge, which has 1.2-2 % of nitrogen is a better fertilizer than that obtained through composting of the same dung because composting involves losses and leads to products with only 0.75-1 % nitrogen. (Ref. 39)

Thus biogas technology as

- it requires relatively low investment;
- does not need highly skilled labour; and
- can be operated with local materials and self-help,

can be considered as the appropriate technology for rural environments. (Ref. 38)

Potential:

The quantities of biomass available world-wide are enormous and a wide range of these materials could be used for biogas production.

- Animal manure: Cattle population is an integral part of the rural environment in the developing countries. Normally about 10 kg. of dung is assumed to be available per day per animal. In addition, waste from piggeries, chicken farms, etc. can be used for biogas generation. However, not all the manures are readily available for energy purposes as the animals frequently graze over large remote areas and their manure cannot be easily collected. (Ref. 53)
- Human excreta: This is an important raw material for the production of biogas. Per capita contribution of human excreta is 190 g/day on wet weight basis or 38 g/day on dry weight basis. Per capita gas production works out to 0.25 m^3/day. (Ref. 51).
- Agricultural crop residues: There is no realistic estimation of agricultural crop residues available for biogas production. Crop residues such as wheat and rice straws and animal manure have been estimated at 4.2×10^9 tonnes annually. (Ref. 53)
- Aquatic plants: Water hyacinths, algae and some other aquatic plants under testing have shown a great potential for biogas production. (Ref. 17, 53)

Benefits:

In India for instance, the impact of full-scale adoption of biogas technology could mean that by 2000 A.D., almost 90% of the rural energy requirements in the domestic sector could be met (at present, this accounts for about 45% of the total energy consumption in India). The consequent reduction in firewood consumption would help to prevent deforestation. In addition, organic manure containing two million tons of additional nitrogen would be available every year to enhance solid nutrients, thus boosting food production and also helping to improve sanitation at the same time. Similar results are expected in other developing countries. (Ref. 39)

Advantages at individual level: (Ref. 17, 37, 39)

- Convenience of an efficient fuel for domestic energy needs.
- Elimination of smoke discomfort and its adverse health effects.
- Improvement in sanitation.
- Readily available manure for the fields.

Advantages at national level: (Ref. 17, 37, 39)

- Diversion of commercial fuels for industrial uses.
- Savings in investment and foreign exchange used for purchasing commercial energy and chemical fertilizer through the use of gas as replacement for diesel, and slurry as manure.
- Prevention of deforestation and its unavoidable consequences such as soil erosion, floods and climatic effects.
- Improved rural sanitation due to utilisation of dung and human excreta.
- Reduced air and water pollution.
- Improved health.
- Additional employment opportunities.

Quantified benefits per capita (in India): (Ref. 39)

- Availability of 6×10^6 Kcal/yr of energy in convenient form.
- Availability of 5.2 kg of nitrogen per year and consequently 52 kg of additional foodgrains per year

Thus biogas systems with respect to their immense potential for providing renewable sources of energy and biofertilizer, waste recycling, improving public health and hygiene, pollution control, environmental management are considered to be one of the most important alternatives for the developing countries.

The following schematic presentation of the biogas system is self-explanatory:

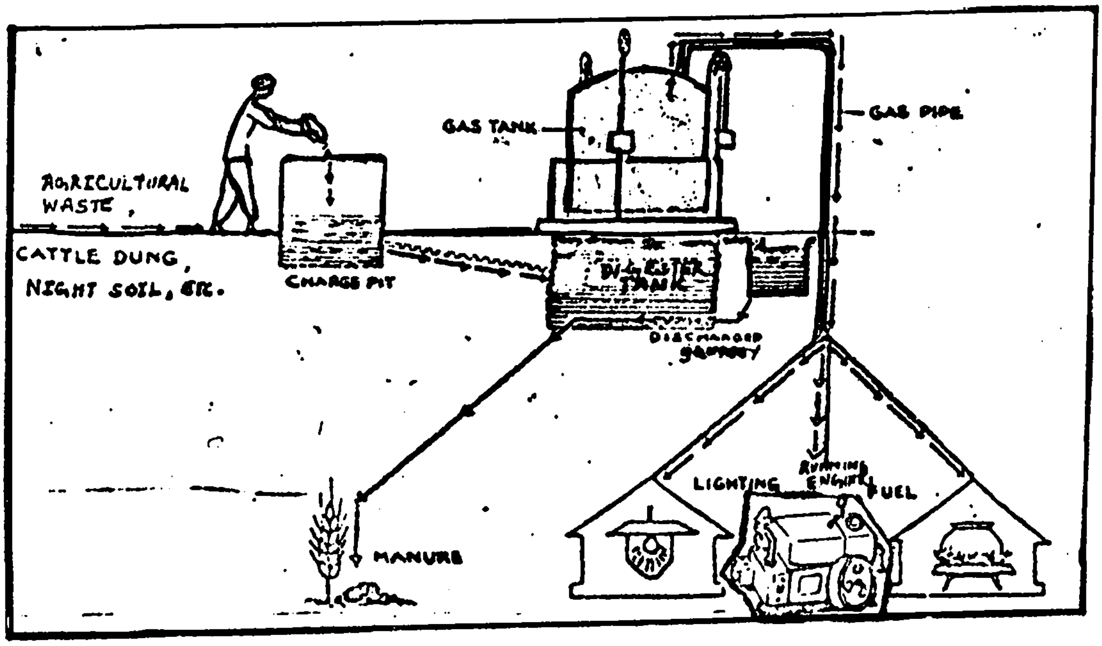

Fig. 1 : Biogas system

Integrated biogas systems:

Integrated biogas systems aim at the efficient generation of fertilizer and energy, production of protein via the growth of algae and fish in oxidation ponds, hygienic disposal of sewage and other refuse and a meaningful effort to keep the environment clean. The digester is the heart of the integrated biogas system because it treats the wastes sufficiently to allow the effluent to serve a useful purpose in the basins for algae and then in the fish ponds before it is absorbed in the soil by plants. (Ref. 13)

Addition of a photosynthetic step allows the minerals left by digestion to be incorporated into algae which can then be used as fodder, fish feed or fertilizer, or can be returned to the digester process to increase energy production. (Ref. 14)

Such a system involves low cash investments on a decentralised basis and is an apt example of "soft" technology that does not pollute or degrade the physical environment, and is appropriate for local skills and climatic conditions. (Ref. 11, 14)

The most important feature of integrated biogas development is its viability for small and large systems. All the byproducts can be utilised immediately and provide the farmer with the three elements (fuel, feed and fertilizer) essential to an integrated livestock-aquaculture-agriculture-industry system of closed cycle development (Ref. 10). The potential for the integrated biogas system is unlimited for the whole of the developing world (Ref. 11). The following is a schematic representation of the integrated biogas system.

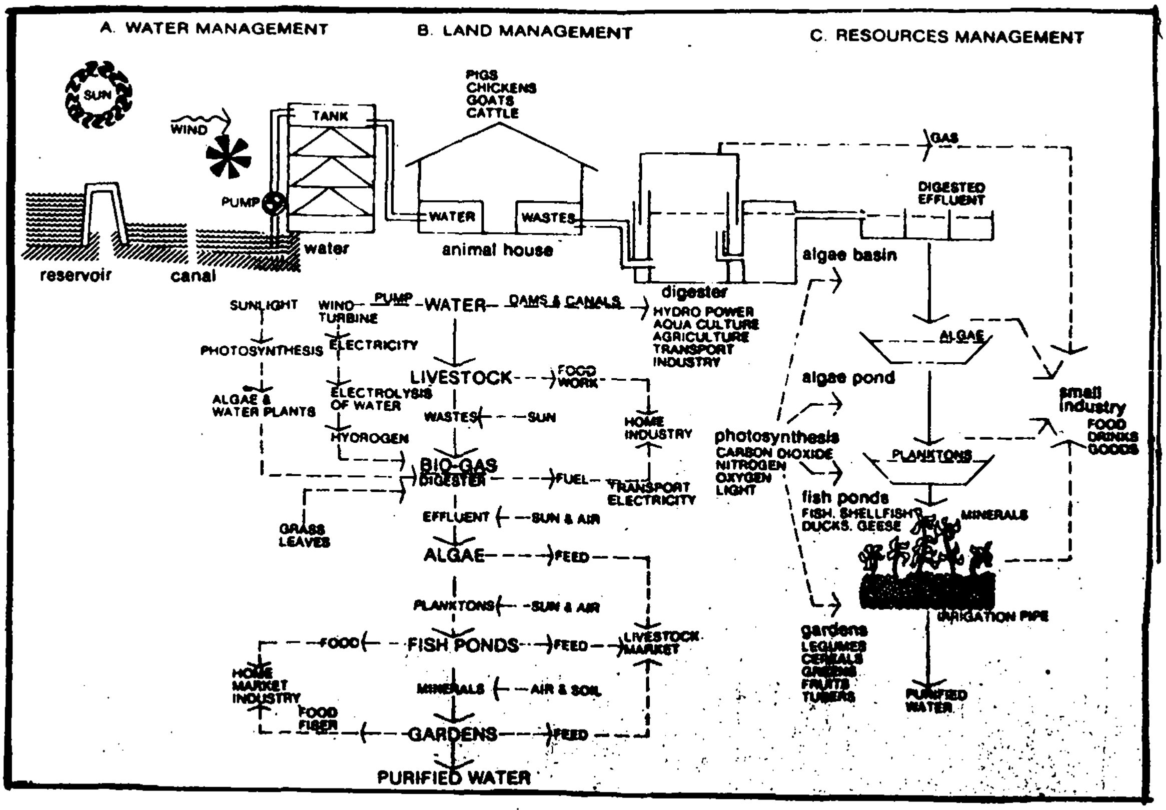

Fig. 2 : <u>Integrated Biogas System</u>. (Ref. 10)

BIOGAS SYSTEMS AND BENEFITS

Technology status:

- History:

  Even though biogas was discovered in the 17th century, it took more than 250 years for its first recorded practical application. The earliest plants, both for sewage disposal and gas recovery, were constructed in Europe and U.S.A. in the 1920s and 1930s respectively. China had its first plants in 1936. In 1946, Indian Agricultural Research Institute, New Delhi, set up an experimental biogas plant and in 1951, with the introduction of the semi-continuous plant combining the gas holder and digester in one unit, the real start of the use of biogas plants was made by IARI. (Ref. 32)

- Current status:

  During the last 40 years, more than 30 biogas plant designs, incorporating distinctive features either in the digester of gas holder have been developed in India, China, Thailand, Philippines, Taiwan, Pakistan and several other developing countries. (Ref. 32)

  Technology for the production of biogas is known and reliable, particularly where livestock is abundant. Currently over 7 million biogas plants are in operation in China and more than 80,000 in India. Most of these are family-size plants. There are few community plants operating in India, Philippines and China. (Ref. 32)

  In the last decade several highly industrialised countries have developed High Rate digestion plants for operation at lower and higher temperatures than the usual (30^{o}–35^{o}C)

- Biogas plant:

  A typical biogas plant consists of:

  - a digester in which the fermentation takes place, and
  - a gas holder which stores the gas produced.

Variations in different designs are found in several aspects of biogas plant construction and operation. (Ref. 32, 52)

- Digesters are usually designed for continuous-fed operation (Indian design).
- There are a few designs for batch-operation, especially for utilisation of agricultural waste (Chinese design).
- Gas holder in some plants is integrated with the digester as one unit (Chinese design).
- Others have the gas holder moving up and down on the digester (Indian design).
- There are several systems for stirring the sludge and breaking the scum.

- <u>Materials for construction</u>:

  Materials which are commonly used for construction of gas plants are bricks, cement, concrete and steel. In places where rural skills in brick-making, brick-laying, plastering and bamboo-craft are well established, clay bricks have successfully replaced cement blocks. Prototype plants have been set up using ferrocement, PVC, fibreglass, etc. for the gas holder. Plants can be constructed with relatively little know-how or equipment. (Ref. 13)

  A bag digester, made in the form of a sausage with composite rubber such as Neoprene reinforced with nylon threads, has been the big break-through in digester construction. It can be mass produced under supervision, easily transported and installed within one hour provided that the hole has been excavated beforehand and lined with sand. (Ref. 10, 11)

- <u>Feed Materials</u>:

  A wide range of organic matter is biodegradable by anaerobic fermentation. However, one single design is unlikely to cope adequately with all possible substrates because of the physical conditions and properties and different rates of fermentation that are involved: (Ref. 3,6,17)

  - cattle manure is the most commonly used raw material in India;

- use of human excreta and agricultural wastes is popular in China;
- piggery wastes are considered to be relatively easy to handle and are being used as feed in several countries;
- vegetable matter are said to have high potential for methane production per unit mass than that from cow manures;
- water hyacinth which has demonstrated a high potential as a source for biogas production is being experimented with on a large scale in India;
- Experiments are under way on the utilisation of a variety of agricultural wastes for the production of biogas.

- Use of biogas:

It is found very suitable for cooking and for lighting specially in unelectrified rural areas. A family of four would consume about 4.25 m^3 of gas per day for cooking and lighting purposes - an amount that is easily generated from the family's night soil and dung of three cows. (Ref. 17)

Several specially designed biogas burners and lamps are in operation in India and China. They can be fabricated indigenously. Many of them are available commercially. However it is more advantageous to use the gas to generate electricity and use it for lighting rather than use it directly. (Ref. 17)

Biogas promises to be a viable fuel for both petrol and diesel engines. Stationary engines located near the gas plant can be an economical and practical proposition. Research is under way in various institutions both in India and China on the use of biogas in internal combustion engines. (Ref. 15, 16, 22, 40)

- Status of biogas in various countries:

At present over 210 organisations in more than 40 countries of the world are engaged in varied biogas activities. These include research and development of more efficient and less expensive biogas plants and applications; financing the promotion of the use of biogas in the rural areas; and other activities.

Tables A and B in the Appendix indicate the status of biogas in various countries and also the biogas activities of various international organisations.

Economic analysis:

There is no universally valid assessment of the economic feasibility of biogas production. National economic considerations play an important role. (Ref. 13, 14)

In most developing countries wood for domestic fuel is in short supply and biogas systems would have a positive effect on both foreign exchange balances and conservation of biomass and also help to avoid the high cost of transporting coal and oil to rural areas. In the villages, kerosene is mainly used for lighting but with the increasing population and rising petroleum prices, biogas generation seems to offer much in the areas of fuel availability, fertilizer for cash crops and other benefits. (Ref. 14).

The economics of biogas production have been examined in India. Comparative costs are determined by four variables: (Ref. 54).

- the volume of gas and fertilizer slurry produced by a volume of cow dung compared to the fertilizer value of the dung if used in scientific composting;
- the value of the biogas in terms of the equivalent of kerosene, electricity or soft coke;
- the value of the manure;
- indirect costs and benefits.

Use of biogas could be considered not only for lighting and cooking but also for conversion into electrical or mechanical energy. (Ref. 54).

Assuming average production rates and methane concentrations, gas requirements for cooking thrice a day (about 1.4 m^3/day per family) could be supplied from the dung of three or four cows.

To supply the electric lighting needs of a family, averaging about 1 kWh/day by using biogas to operate an engine generator set (at peak load) would require 4-5 kWh/day of energy. This could be supplied by two cows.

This method of lighting is almost four times as efficient as a kerosene lantern even though the biogas technology requires much more capital investment compared to the purchase or home fabrication of a lantern.

The gas supplied by dung from one cow could provide energy at the rate of 1 kWh/d.

Biogas can also replace wood and charcoal for firing pottery. For small-scale pottery production, 8 m^3 of methane are required over a period of about five hours to fire earthenware to 1000°C in a kiln having a volume of 0.82 m^3. This volume of methane is equivalent to about 13 m^3 of biogas, which could be supplied by a four-day accumulation of dung of five cows. Larger production capacities for village industries could be scaled up according to needs.

The cost of supplying biogas for the above uses is shown in Table 1.

Table 1: Analysis of Cost of Supplying Cooking Fuel, Lighting and Mechanical Energy, and Electricity by Biogas (Ref. 54)

Variable	Value
Basic data	
Cattle dung, daily output per animal	
Biogas yielded by the dung of one animal	10 kg
per day	0.6 m^3
Energy content of biogas (60% methane)	6.4 kWh/m^3
Energy available daily from each animal	4 kWh
System lifetime	20 years
Conversion (peak) efficiencies:	
Internal-combustion engine	25%
Electrical generator	90%
Plant Cost	
Single-family plant (3 m^3)	$ 750
Financing costs (annual)[a]	
Single-family plant	$ 88
Motor generator set to provide 1 kWh/d	$ 742
Engine to provide 1 kWh/d mechanical energy	$ 440

Table contd.

Table 1 Contd.

Variable	Value
Sh 3 200 (d) at 10% (4h/d)	
Energy costs[b]	(per kWh)
Cooking and lighting directly by gas (20 kWh/d)	$ 0.012
Cooking and generation of electricity (1kWh/d)	$ 2.28
Cooking and generation of mechanical power (1kWh/d)	$ 1.45

a) Based on the ammortization of loan in equal instalments over the life of the plant at the rate of 10% per annum.

b) Not including cost of appliances or cost of collecting dung.

A family owning five animals would have at least 10 kg of dung (dry weight) per day, assuming a dung collection rate of 75%. (Ref. 39)

This can be beneficially used in three alternative ways - (Ref. 39)

composted to get fertilizer;
dried and burnt as fuel;
fed into a biogas plant to obtain both fertilizer and fuel.

To compare the three alternatives, the cost of obtaining (from the same quantity of dung) equal amounts of fuel and fertilizer from each one of the three alternatives, adding in supplementary purchases from the market where necessary, must be evaluated. (Ref. 39)

Thus, to get an amount of fuel and fertilizer equal to that obtained from a biogas plant, (Ref. 39)

- the family which burns the dung would need to buy not only fertilizer but also kerosene for lighting;

- a family which composts the dung would need to buy all of its fuel and also some fertilizer;
- a family which uses a biogas plant gets fuel as well as fertilizer richer in nitrogen than that obtained from composting.

The economic analysis of the three alternatives in India for those owning a sufficient number of cattle and farmland is summarised in table 2. (Ref. 39)

The cost of obtaining the same amounts of fuel and fertilizer is -

- $ 31 per year for biogas;
- $ 34.8 per year where dung is burnt;
- $ 41.4 per year where dung is composted.

(Calculations do not take into account the subsidy given by Government of India for setting up biogas plants).

Table 2: Economic Analysis of Alternatives for a Private Owner of Five Animals (dry dung = 3.65t/yr). (Ref. 39)

Item		Alternatives	
	(A)	(B)	(C)
1. Description of alternatives	Install a 1.8 m^3/day bio-gas plant and get fertilizer and gas for cooking and lighting	Utilize the dung for burning and purchase fertilizer and kerosene for lighting	Use dung for composting and purchase fuels and supplementary fertilizers
2. Investment (US. $)	200	-	-
3. Interest depreciation and maintenance costs ($/yr)+	31	-	-
4. Bio-gas generated (m^3/yr)	600	-	-
5. Effective heat obtained	1.905	1.296	-

Table Contd.

Contd. (Table 2)

Item	Alternative (A)	 (B)	 (C)
6. Fertilizer produced (kg N/yr)	52.6	-	29.9
7. Supplementary purchase ‡			
kerosene (kg/yr)	-	25	25
dung cakes (t/yr)	-	1.50	5.15
fertilizer (kgN/yr)	-	52.6	22.7
8. Annual costs	31	34.8	41.4

+ Based on interest of 12%, life of plant of 15 yr and cost of painting the drum of $ 5 per yr.

(Annual capital charge) = (initial investment)

‡ Based on :

1)

Calorific value	Efficiency of burning	Effective calories
Dung 3100-3300 kcal/kg	11%	345-365 kcal/kg
Bio-gas 4770 kcal/m^3	60%	2860 kcal/m^3

ii) Effective cooking energy needs amount to 1770 x 10^3 kcal/yr and can be obtained from either 615 m^3 of bio-gas or 5-15 tons of dung cakes.

iii) Either 25 kg of kerosene per yr or 46 m^3 of bio-gas/yr are required for lighting.

iv) 1 kg of dung when composted gives 0.56 kg of compost when no other agricultural waste is added with 2.0% nitrogen.

Based on prices of $0.12/kg of kerosene, $ 5.5/ton of dung cakes and $ 0.45/kg of nitrogen.

- <u>Economic benefits of biogas utilisation</u>:

  Efficient utilisation of biogas technology definitely has positive effects on the national economy. (Ref. 9, 16, 17)

  - Biogas generation is one of the cheapest methods of producing energy on the spot from readily available resources.
  - Utilisation of biogas reduces the consumption of commercial energy sources such as coal, kerosene, etc. which results in reduction of family fuel budget.
  - The uncertainty of energy supply is partially resolved as there is less dependence on imported energy.
  - Forest wealth of the nation is saved as there is considerable reduction in consumption of firewood.
  - Valuable organic fertilisers can be obtained and this in turn increases agricultural production and also reduces the dependence on chemical fertilizer.
  - Dependency on imported energy and fertilizer is reduced, resulting in big saving of foreign exchange.
  - An integrated biogas system which is based on the efficient utilisation of local manpower and resources provides an integrated livestock-aquaculture-agriculture economy for a self-reliant and more than self-sufficient society.

The benefits to the individual owner of a biogas plant are many, too, but none of them result in direct cash benefit. (Ref. 36)

- There is no incremental income to the family arising out of the investment on a gas plant. (Ref. 55)
- The family saves money on fuel and fertilizer. The money saved may be either consumed or invested in other spheres such as irrigation, drainage, crop storage, acquisition of machines, repayment of debts, purchase of more food, augmenting of cattle holdings, etc. (Ref. 55)
- The additional manhours available through the time otherwise spent for collecting fuel wood could be used for work on the field and for alternative employment. (Ref. 48)

- Cost benefit analysis:

The cost-benefit analysis of methane generation varies widely, depending on the uses and actual benefits of biogas production, public and private costs associated with the development and utilization of methane and on the technology used to generate methane. (Ref. 13)

An analysis of cost and income for a 3 m^3 plant is given in table 3.

Table 3 : Cost Benefit : An Economic Analysis of a 3 m^3 Gas Plant Conducted by Khadi and Village Industries Commission, India (Ref. 14)

a) Initial Cost:		US $
Gas holder and frame		93.50
Piping and stove		34.70
Construction		210.10
	Total	338.30
b) Annual expenditure:		
Interest on investment at 9%		30.40
Depreciation on gas holder and frame at 10%		9.30
Depreciation of piping and stove at 5%		2.00
Depreciation on structure at 3%		6.30
Cost of painting once a year		6.70
	Total	54.70
c) Annual Income:		
Gas 3m^3/day at \$1.50/29 m^3		50.30
Manure 17 tons composted with refuse 16 tons at $ 4/ton		64.00
	Total	114.30

The net annual income (c-b) = $60 which indicates that the investment can be recouped in about 6 years. (Ref. 13)

The ecological costs of harvesting additional amounts of firewood. to meet the increasing use of non-commercial fuels is considerable. Further the use of cowdung or vegetable refuses as fuel also implies ecological costs as it destroys a valuable source of nitrogen and depletes the fertility of the soil. An ecological cost-benefit analysis clearly favours biogas. (Ref. 14)

- Internal rates of return on biogas plants:

  The internal rate of return is found to range between 13.53% in 2 m^3 plants to 58.9% in 35 m^3 plants. Thus the average earning on the investment increased with an increase in the size of the plant.

  On comparing the internal rate of return from biogas plants with that from investment in alternative projects, it was seen that the rates of return from investment in tractors and lift irrigation projects was 18 and 28% respectively and that from investment in buffaloes was 14.29%. These figures indicate that investment in gas plants is favourable except for 2 m^3 - 3 m^3 plants. (Ref. 36)

  However, if the farmers do not perceive the benefits of gas in terms of kerosene equivalent, many of the smaller plants will not be able to fare better than competing investment opportunities.

- Community plants:

  Due to certain economic reasons, the family-size biogas plants are likely to have a limited impact in spite of personal gains and some national gains as well. (Ref. 4, 18, 29, 39)

  - Only those families having more than 5 animals and capable of investing $200-258 and also maintaining the plants can install plants of adequate size.

    But all rural families do not have this capability and thus direct benefits of biogas plants would be limited to a few families. In a community plant, the farm waste from smaller holdings could be put in, thus effectively utilising most of the collectable farm waste of the community.

- Size of the family plant is usually determined to provide enough gas to meet the family's needs even during the winter months when gas production is low. Hence if the excess gas generated has no seasonal use, the surplus would be wasted.

  In a community plant, this gas could go to other families.

- Due to the large size of a community plant, there would be an economy of scale in terms of land utilized, investment necessary and skilled man-hours required for operating and maintaining the plant. In case of the family plant, in spite of the simple technology involved, the efforts required for its efficient operation may be beyond what a farmer can handle himself. Also, a farmer who is hesistant to invest a large sum of money in his own private plant may not mind paying a small deposit and rentals required for getting gas from a community plant.

- Benefit-cost analysis of community plants:

Consider a hypothetical village community of 100 families (500 persons) and 250 animals with 14 families possessing 5 or more animals. The price of cow-dung cakes in the village is $55/ton, or $0.55/kg of dry dung. This should be the minimum purchase price of dung if the collectors are not to be worse off in selling their dung to the plant co-operative. (Ref. 39)

With 500 kg of dung, the gas production would vary from 85 m^3 per day in winter to 221 m^3/day in summer and would amount, on an average to 150 m^3/day. With additional cellulosic wastes, the average generation could be 170 m^3/day. This will be adequate to meet the domestic fuel needs of the village population for all but two or three winter months, when there will be a shortage of 20-40%. However, in a community plant, it may be possible to heat the plant in winter and hence not suffer a gas shortage. (Ref. 39)

With the price of dung fixed at $6.0/ton, the price of fertilizer at $250/ton of N and the price of home delivered biogas at $4.60/100 m^3 and $3.5/100 m^3 for gas used in the plant site kitchen, and given an interest rate of 12%, the annual profits are more than adequate to recover the cost of the capital investment is less than 15 years (expected life of plant). The community plants are seen to be economically viable and it should be possible to operate a village-level plant commercially. (Ref. 39)

Also, at the proposed prices, all households are better off with the adoption of village biogas plants than otherwise. (Ref. 39)

> The poor family pays $21 for fuel as compared to $25 at present.
>
> The family having 10 kg of dung/day, i.e. enough to set up its own plant, pays $28.45 for gas, $23.6 for fertilizers and receives $22 for sale of dung. Its net costs are thus $30.05/year which is less than $31 for installing its own plant.
>
> The family is also saved from the risks and trouble of installing and operating its own plant.

Table 4 works out the economics of community biogas plant on the above prices.

Table 4 : Economics of Community Plant of 170 m^3 of Gas/Day Capacity. (Ref. 39)

	Costs:	U.S. $
A.	Investment	
a)	Plant of 170 m^3/day capacity	4000
b)	Plant-site kitchens	500
c)	Plant-site washing facilities	200
d)	Compressor	300
e)	250 Cylinders	2500
f)	100 Burners	1000
g)	Delivery carts	500

Table Contd.

Table 4 (Contd.)

	Costs:	U.S. $
A.	Investment	
h)	Land and preparation for drying beds	1000
	Total investment costs	10,000
B.	Operating Costs per annum	
a)	Purchase of dung	
	500 kg at $6.0/ton per day	
	(6.0 x 365)/2=	1100
b)	Plant and compressor maintenance	400
c)	Staff	
i)	Manager/Accountant)	
ii)	Dung collection and Feeding)	
iii)	Gas Distribution)	1000
iv)	Water Procurement)	
v)	Kitchen Maintenance)	
	Total operating costs	2500
C.	Receipts Per Annum	
a)	Sale of Gas	
	49,500 m^3 of bottled gas at $4.60/100 m^3	2275
	12,600 m^3 of gas at $3.5/100 m^3	440
b)	Sale of fertilizer: 2.63 tons of N at $450/ton	1180
D.	Gross Annual Earnings (Receipts-Operating costs)	1395

Economic Viability of Integrated Biogas Systems:

The integrated approach to waste recycling and utilization is economically viable, particularly if the main objective is self-reliance at the village level. (Ref. 16)

While evaluating the benefits of the integrated biogas system, one must not forget that three important elements (fuel, feed and fertilizer) in the economic development of rural areas are available on the spot without any transport, storage, handling or other distributive costs. So besides saving the scarce foreign exchange of the nation, the farmer can expect a much higher income without having to depend upon inputs from outside.

The benefits from better sanitation and nutrition should also not be ignored.

Social benefits:

Biogas utilization benefits individuals, the community and the nation at large by helping to improve the standard of living of individual families and by ensuring self-sufficiency for smaller and remote units of society. (Ref. 6, 9, 17)

- The fuel burns with a sootless flame, providing for smokeless cooking which does not dirty the home or the vessels.
- Cooking with biogas is much faster and more efficient than cooking with traditional fuels such as firewood, thus reducing the drudgery of rural women's lives and sparing them time for developmental activities.
- Reduction in the time spent in cooking, finding fuels, chopping wood, collecting weeds and crop stalks or buying coal from distant places results in an overall improvement in the situation of women and children.
- There is considerable encouragement to establish artisan business, including related training installations, which improves employment and also stops the exodus to cities from villages for employment opportunities.

Apart from the social benefits, factors which motivate individuals to accept the biogas plant differ considerably. (Ref. 50)

- The richer sections may adopt it to enhance their social status, or to please government officials or political leaders propogating implementation of the plants.
- The poorer sections care very little about personal comforts and convenience and are rarely interested in community affairs. (Ref. 44)

- Only plants set up by an understanding of the fuel and manurial value have a greater chance of success.

Also, the acceptability of both family-type as well as community-type biogas plants is very much influenced by social and cultural habits, prejudices, religious beliefs, educational background, socio-economic status, settlement patterns of the individuals and the community. (Ref. 1, 50)

Any promotional activity undertaken to enhance the social acceptability of biogas technology must take into consideration all the above factors.

Environmental and health aspects:

Biogas systems designed to process animal and human excreta are expected to contribute to a cleaner and healthier environment. (Ref. 1, 4, 12, 15, 39)

- Elimination of smoke reduces the incidence of lung and eye diseases, especially among village women and children.
- Improved rural sanitation due to systematic collection and processing of animal dung and human excreta.

  This also leads to reduction in water-borne diseases caused by lack of sewers and sanitation.

  Published data (Ref. 13) indicate that a digestion time of 14 days at 35°C brings about effective destruction (99.9% destruction rate) of enteric bacterial pathogems and enteric veruses. However the destruction rate of round worms and hookworms is 90% which is also high. In this context, biogas production provides public health benefit superior to any other treatment in managing the rural health environment in developing countries.
- Aids to prevent deforestation and consequently soil erosion, floods and climatic effects.

Socio-techno-economic considerations:

For biogas to be a viable option for the entire community, the following factors need serious considerations: (Ref. 18, 19, 21, 27, 36, 37, 41)

- Ratio of cattle population: 0.5 cattle per person is required. Alternatively, the organic waste availability should be 1 to 2 kg/cap/day to meet cooking and lighting requirements. It should be noted that cattle dung contains more volatile matter than most other wastes.
- Temperature rates: The desirable range is 15° to 40° C for an adequate yield of gas.
- Cost of biogas: The cost of each family plant should not exceed $ 250 for a 2 m^3 plant, if free labour to maintain the plant is available. Alternatively, the total cost (capital, labor, maintenance of any plant - village or family-size) should compete with the cost of coal or kerosene imported to the villages. The cost then becomes 5 ¢/m^3 (assuming 14 ¢ per litre of kerosene). Of course, as kerosene prices rise, higher prices for biogas could be permitted.
- Agrarian society: If a need exists for fertilizers as well as for fuels, the chances of acceptance are higher in an agrarian society as compared to a nomadic or pastoral society. It also helps if a tradition exists for using dung.
- Village plants: The chances of success of a village or community biogas plant would be higher for villages with clustered dwellings rather than with dwellings scattered over large distances. If the houses are far apart, it may be advisable to have more than one plant in different parts of the locality as it would reduce the cost of piping the gas.
- Size of the village: Since it is possible to produce biogas from human excreta, municipal sewage and agricultural wastes, biogas plants are feasible, irrespective of the size of the village.

  However, if other fuel alternatives such as coal dust or wood, or charcoal exists, there may be less incentive for developing biogas resources. But the number of developing countries with other alternatives is rather small.

- For setting up a community plant -
  - There should be the ability to cooperate in a manner and on the scale required to run such a plant in the community;
  - The benefits of such a plant should indeed reach those members of the community who for various reasons are unable to install individual plants;
  - The economics of scale of such plants on the generation side should offset diseconomies on the distribution of gas and dung collection side;
  - Such a plant should be economically and socially (as distinct from financially) viable when credit is taken for the fuel provided for the generation of mechanical and electrical energy through gas for dual fuel engines;
  - For any given location of a plant, as the "command area" of the plant increases, distribution cost per connection will start increasing to the point where they fully offset economies on the generation side. This point depends uniquely on each particular location - on factors such as the configuration and density of houses around it, etc.
  - To charge a price for the gas, it would be necessary to check the daily or monthly consumption of each household for accounting which will require installation of gas meters in each household. This naturally will involve extra cost. The method of pricing too requires serious consideration as it involves a decision about charging people who may not be in a position to or be willing to pay for fuel.
  - Efficient management of the community plant would require careful supervision of -
    - making available sufficient money for building the plant;
    - collecting the required amount and type of dung socially acceptable to the community;
    - making available sufficient water in the dry season;
    - giving due credit and monetary compensations to persons supplying the dung;

- enticing people away from utilisation of the dung for purposes other than production of gas;
- deciding on time of distribution of the gas, on charges for the gas supplied either by installing a gas meter, or on the number, type and size of appliances in the household;
- distribution of the gas plant effluent;
- making the operation economically attractive, so that it may be easier to get people to undertake the responsibility, and the operation could be leased through auction;
- payments for maintenance and repairs; and
- priority for distribution of the available gas, in case of short supply.

PROMOTION CONSTRAINTS

The concept of biogas technology and its utilisation, in spite of its simplicity and obvious economic as well as public health benefits, is yet to reach the vast majority of the rural poor in the developing countries. In India, for instance, the 80,000 or more plants set up so far cater to about 2% of her rural population, and these for sure are not the ones who really need this technology. The situation is similar in most other developing countries. (Ref. 9)

The apathy of the policy-makers in formulating a national biogas policy and effecting its implementation with the help of a streamlined organisational network, unjustified prejudice on the part of the public and lukewarm promotional programmes coupled, with certain technical problems, are considered to be the factors inhibiting the use of biogas technology. (Ref. 1, 2, 5, 6, 10, 11, 17-19, 24, 35-37, 44, 50, 53)

- Technical problems:

  - Corrosion of the gas holder: (Ref. 1, 6, 17, 19, 24, 37, 45) The digester cover or the gas holder is usually made of steel and corrodes easily as it is in constant contact with the toxic substances present in the atmosphere and in the slurry. This problem is more pronounced in the coastal regions.

    The gas holder, thus, has a very short life compared to other parts of the plant, although it is the costliest component.

    The problem may be solved by painting the gas holder annually with anti-corrosive paints.

    Alternatively, materials such as fibreglass, ferrocement galvanised iron and plastics such as PVC, high density polyethylene, glass-reinforced polyester sheets, etc. may be used as substitute materials for the gas-holder.

Experiments in India have demonstrated the following advantages and disadvantages of the alternate materials: (Ref. 27, 41, 43). But of these materials only ferrocement and galvanised iron are found suitable.

- Ferrocement: The material has high resistance against cracking and permeability, it is lighter than steel and can be cast into sections as thin as 1 cm. It also has high resistance against corrosion and high impact strength, and gas holders require no special skill for fabrication.

  But gas holders are heavy, and loss of gas occurs due to seepage.
- Plastics: They do not corrode, have good resistance to mild acids and alkalies, good insulation to temperature variations, and flexibility.

  But they deteriorate due to weathering and are hazardous in case of fire. Also, they may easily break at the joints and the top seam.
- Fibreglass: This material does not get corroded, is lightweight, not adversely affected by ultra-violet rays, retains heat and is advantageous in cold weather, can withstand all temperature variations.

  But although the thickness of the fibreglass shell of the gas holder is functionally suitable it does not lend strength to the structure. The weight is not adequate to give propelling pressure to the gas.

  The Chinese type of design, with digester and holder fixed into one unit (made of cement-concrete), may be one answer to the corrosion problem.

- Seasonality of gas production:

Methanogenic bacteria are mesophilic in nature and reduction in temperature adversely affects gas production in low temperatures. (Ref. 6, 17, 37, 52)

The fall in gas production starts when the ambient temperature falls below 20°C.

To increase gas production in winter and in colder regions, the following measures have been suggested: (Ref. 6, 8, 12, 17)

- whole plants, including the gas holder, may be insulated with material such as straw;
- the green-house effect may be created around the gas plant;
- solar heated water may be used to prepare the input slurry;
- the whole digester may be heated with solar energy or biogas;
- by composting around the digester wall;
- by addition of urine, wheat straw, enzymes, water hyacinth, etc.

- Formation of scum: (Ref. 17, 37)

Presence of undigested material such as straw, water hyacinth leaves, coarse dung, animal bedding or clothing, sand and gravel in the fermenting slurry may cause scum formation on the surface of the slurry.

This inhibits gas production and also corrodes the gas holder.

Paper mixing of the slurry to disperse the floating material and regular agitation or semi-circular rotation of the drum may prevent scum formation.

It may be necessary to incorporate special stirrers or mixing devices in the plant designs.

- Water requirements of biogas plants:

For every kilogram of dung used to prepare the slurry 1 litre of water is required. (Ref. 17, 37)

Thus for every 2 m^3 gas plant in a village 45 litres of water are required.

This water demand is excessive in most of the rural regions, especially in the poorer areas.

Available data indicate a 40 per cent decrease in gas production when the water to dung ratio is reduced by about half. This reduction must be viewed against a possible 100% increase when the fermentation temperature is increased from 15°C to 27°C. (Ref. 45)

Thus, operation of biogas plants at higher temperatures will permit lower water supply requirements. (Ref. 45)

Alternatively, attention must be turned to achieving a "drier" process which requires less water for the fermentation. (Ref. 45)

Also, designs in which a settling tank permits re-cycling of a major fraction of the water/supernatent to the digester, may be considered. Such recycling of water will also reduce the volume of digested sludge to be handles for fertiliser production. (Ref. 55)

- Short supply of animal wastes:

This may not warrant the construction of a digester as the gas produced may not be adequate for the needs of the family.

To solve this problem biomass such as grass, leaves, algae, aquatic weeds and even garbage can be digested for biomass production, provided some human and animal waste is added to supply the bacteria required for the fermentation reaction. (Ref. 2, 11, 18)

- Availability of space near the point of use:

Most villages are densely packed with houses, with very little space for construction of gas plants near the houses where the gas is used. This is particularly true of the poorer sections of the villages. (Ref. 35)

- Storage of biogas:

Biogas with its 50-80% methane content cannot be liquified at ambient temperature, and hence cannot be bottled like LPG. (Ref. 45)

It can be stored in the gaseous state only at pressures of the order of 5,000 psi which would necessitate a cylinder of 0.1484 m^3 volume to store a month's cooking energy for a family of 5. To store or transport the energy equivalent of 16 litres of petrol or 14.5 litres of kerosene as compressed as at 2000 psi, it requires a cylinder of 1.6 m by 0.27 m in diameter weighing 63 kg (presuming removal of oxygen). It would hold m^3 of cleaned methane gas. Hence, LPG cylinders currently in use, which are designed for about 1500 psi, cannot be used. (Ref. 17, 45)

Thus special heavy cylinders needing special manufacturing skills would be required. Moreover, the amount of gas available at one place must be enough to justify installation of the requisite machinery for the bottling of the gas. (Ref. 45)

The cost of cleaning the gas of CO_2 and H_2S, compressing, purchasing special high pressure storage bottles and transporting them make the proposition of bottling biogas uneconomical. (Ref. 17)

- <u>Problems in utilisation of biogas:</u>

Non-availability of appropriate and efficient designs of biogas burners and lamps is a major constraint in biogas utilisation. Efficiency of existing burners is not very satisfactory. Also, because of low pressure, the distribution of gas to distant sites poses problems. (Ref. 6)

Attempts made by housewives to modify existing burners or make do with home-made burners lead to inefficient use and thereby more consumption of the gas. (Ref. 21)

Although lighting directly with biogas reduces the cost of electricity generation and distribution, the savings are offset by the need to purchase biogas lamps requiring regular servicing. (Ref. 20) High waste heat of biogas lighting renders it inferior to electricity in a warm climate. Mantle lighting in general is inefficient. A 40 watt gas lamp consuming 0.126 m^3 of gas will be required per hour to light six lamps. But with the same gas one kW of electricity can be generated which could energize 25 lamps of 40 watts each. (Ref. 49)

Experiments conducted indicate that biogas should be used as a supplementary fuel rather than as a sole substitute fuel for engines. (Ref. 40) Engines get hotter running with biogas, which means the cooling system needs to be in good repair. As gas pressure is slightly above the atmospheric pressure and the gas cannot be transported to a long distance, use of biogas is limited to stationary engines. (Ref. 15) Carbon dioxide (CO_2)

in the biogas lowers its calorific value but increases the knock resistance and this favourable reduces the chances of pre-ignition of the gas when it is compressed along with air in diesel engines. (Ref. 15, 22) Also, the presence of hydrogen sulfide (H_2S) which increases especially with the addition of biological waste other than cowdung, causes corrosion of engine components (Ref. 15, 22) However, both CO_2 and H_2S can be scrubbed off from the biogas by bubbling the gas through caustic potash or lime water or through a 10% aqueous solution of monoethanolamine (MEA) to remove CO_2,and using iron fillings to absorb H_2S. (Ref. 17, 40)

Conversion of diesel engines to biogas engines warrants major modification such as governor adjustments in the engine design, thereby excluding the presently existing designs from direct use and also necessiating the setting up of very large gas plants. (Ref. 40)

The work done on utilization of biogas in engines is mostly empirical and sporadic in nature. Much remains to be done in the direction of the design of an efficient carburettor within the reach of the small farmer. (Ref. 22)

- <u>Problems in utilisation of the slurry</u>:

Slurry, as it comes out of the digester is difficult to handle as it cannot be carried on the hand or in a basket - the usual modes of carrying things in the village. Hence it becomes necessary to have pits near the plant. When there is scarcely enough space for the plant alone, small cart tanker could be designed, but this would involve additional cost. Several methods have been suggested and tried out for transporting and storing the slurry for a short period. (Ref. 47, 48)

- <u>Additional technical problems</u>:

Certain problems such as rising up of digester floor with the rise of the ground water level, bursting of the digester with excessive gas pressure, clogging of inlet, outlet and central guide pipes and other problems in the day-to-day operation of the plant such as slow rate of gas production or too little gas in spite of the correct pressure, long and weak flames, pulsuating flames, poor light, etc. are often faced by the plant user. (Ref. 52)

Economic Factors:

The existing cost structure of biogas plants is prohibitive for a large majority of the rural population. There is no direct cash income from the investment in a biogas plant, which incidentally is the most crucial motivating factor for the rural families. This factor alone seriously limits the attractiveness of investment in biogas plants. (Ref. 31, 36) So far as fuel and fertilizer are concerned, family-size plants are uneconomic, besides requiring 5 head of cattle to operate it. (Ref. 16)

- High capital investment: Family-size biogas units cost $200-$300 to install an amount exceeding the incomes of all but the richest farmers. (Ref. 54)

  Also, after the initial investment, few have the money to carry out regular maintenance and repair work.

  Avoiding wasteful designs of plants, building digesters using locally available and low-cost materials suited to local conditions as is done in China, instead of using steel and cement which often needs to be imported, and increasing research and development to improve the fermentation process so as to reduce the retention time and hence make the digester smaller, have all helped to decrease the cost of the plant. (Ref. 3, 11, 46)

- Low economic return: For a small farmer the cost of biogas generation will always remain high, as the fuel represents not more than 20 per cent of the possible return on the capital invested. This will remain so unless the more important fertilizer value of the treated wastes that can change the picture of the depleted soil and polluted ponds in many villages into lush fields of food crops or aquatic life, is taken into account. Thus although there may not be any direct cash flow from biogas utilization, its indirect benefits need to be stressed. (Ref. 11)

- High opportunity cost: Individual farmers generally look at biogas as a substitute for firewood. But when they perceive the opportunity cost of firewood, family-size plants naturally seem uneconomic. (Ref. 36) One critic has even evaluated the cost of producing 1,000,000 BTU by biogas at $1.50 and by using firewood at $0.15, (without giving details) (Ref. 16)

Moreover, firewood, animal dung and agricultural waste when burnt directly to produce fuel need no capital investment unlike that required in producing biogas. (Ref. 35, 36)

The picture may differ when the manurial value of the digested slurry is taken into account. (Ref. 11)

- Inefficiency of financial assistance: To make investment in biogas plants more attractive, financial incentives are being provided, as subsidies and loans, by the national governments, financial institutions, rural development and voluntary agencies. (Ref. 28, 35, 36)

But this sort of financial assistance has its own limitations:

- Subsidies provided are considered to be too little and the interests charged on loans too high. (Ref. 36) Even with 15-20% subsidy a 2 m^3 plant is not viable to the poor individual. (Ref. 35)
- The criteria used for bank loans are often found disadvantageous to the poor who are really in need of it. (Ref. 35, 44)
    - Banks require a land mortgage, and marginal farmers and landless labourers are hardly in a position to satisfy this condition. (Ref. 50)
    - As the size of gas plant recommended for a loan and the subsidy is based on the number of cattle heads owned by the family, majority of the families may not be able to avail of them, as they do not own any cattle at all. (Ref. 35)

      Other factors such as family size, socio-economic status, potential to buy dung, etc. should be considered in recommending the plant size for a loan. (Ref. 35)
    - Biogas technology is location-specific. Hence estimates based on the data from the work done in one area is most often lower than the cost of labour and materials used for erecting the plants elsewhere. (Ref. 50)
    - Delay in disbursement of subsidies and loans costs, a lot to the owners in terms of money and time. (Ref. 35, 50)

  - To obtain loans, plant owners are required to submit bills of purchase of material, and in the experience of owners, it would cost them less if they bought the material without bills. (Ref. 50)
  - The subsidy raises the internal rate of return of plants of all sizes but much more for large plants than for smaller ones. Since the internal rate of return is quite high, for large plants, the rationale for giving subsidy can be questioned from the point of view of economics. Even if subsidy is given as a promotional measure without regard to the economics of the plants, the rationale of a flat rate of subsidy can still be questioned. The subsidy benefits the rich more than the poor. (Ref. 35)
  - Direct subsidies while causing many plants to be built quickly usually result in many of these plants going out of use within a few years. The situation may improve if the farmer was made to pay the full price and then subsidize the cost of the plant indirectly with low-interest loans. (Ref. 17)

- High cost of utilisation devices:

  Burners, stoves, lamps, etc. for utilising the gas cost much and are not readily available.

  Domestic cooking gas burners made of cheaper materials like ceramic and clay and the gas supply nozzle made of wood or bamboo may reduce the price. (Ref. 25)

- Non-availability of input material: Transporting dung and water from long distances besides causing inconvenience to plant owners increases the cost of labour. (Ref. 25, 35)
- Loss of time: Construction of gas plants take a lot of time and involve a lot of running around by the owners to collect the requisite materials, get sanctioned loans and subsidies, collect them, get the necessary technical helps etc. This time spent might have been used more fruitfully, on a more profitable basis. (Ref. 50)

- Availability and utilisation of alternate fuels: In places where firewood is still available, or in electrified villages, the need for biogas plants is not acute, mainly as the economic benefits at the individual level are not readily evident. (Ref. 35, 44)

  Also, at the present stage of hardware development of biogas technology, gas produced may not be able to meet all the requirements of a family, and biogas would have to be used in conjunction with other energy sources. This may discourage people from accepting the technology.

- Community plants: These plants lead to progressive cost-saving compared to single plants, but this again depends on organized communities which are ready and competent to run these plants. (Ref. 9)

  Lack of cooperation is the major bottleneck in the running of a community plant. Devising a satisfactory system of distribution and pricing of gas and of collecting charges is perhaps the most difficult test of ability to cooperate for mutual benefit.

  It is difficult to decide on the method of distribution of gas and manure and on the fixing of their price. (Ref. 35)

  Charging a price for fuel is not acceptable to the majority of villagers as they feel that fuel did not cost them anything earlier and that the gas used comes from dung contributed free. The fact that the slurry, obtained as a by-product during the anaerobic digestion of the dung, is available free and can be used as manure does not carry much weight as the 1) value placed on manure is insignificant. (Ref. 21)
  There also exist problems in the collecting of dung -
  - Very small quantities of dung are burnt discretely by some families. The temptation increases with the decrease in gas production.
  - Decrease in the number of animals from the estimated number.
  - Absence of labour/proper incentives for collection of dung. (Ref. 21)

Laying of pipes for gas distribution from a community plant tends to offset the economy of scale to a large extent. (Ref. 20) Small gasholders away from the plant, near points of maximum use, may be used, connected with small-diameter pipes with the plant, which will supply gas continuously.

Social barriers:

- Beliefs, prejudices, habits, attitudes of individuals:

  Prevailing prejudices associated with waste utilisation can make the whole project unacceptable. For example, there is much hesitancy regarding the use of human excreta as feed for gas plants as well as to use the gas from it for cooking purposes. (Ref. 16, 47) Cooking systems and food habits need modification and adjustment.

  Muslim societies, on account of religious beliefs do not wish to use piggery waste for the plants. (Ref. 50)

  In such cases promotion of utilisation of other feed materials such as cattle dung, and agricultural waste may improve the acceptability of the technology.

  People often find it difficult to change the habit of defeacating in the open fields. Having latrines at home is also often opposed by several villagers. (Ref. 35, 44)

  Unwillingness to prepare the slurry or attend to the plant daily often leads to abandoning of plants. The tribals and nomads consider this as a curb on their free movements. (Ref. 35, 49)

  Individuals often lack the entreprenaurial ability to do the running about associated with raising a bank loan, applying for subsidy, arranging for raw materials, supervising installation and undertaking preventive maintenance and repairs. (Ref. 20)

  Biogas is treated primarily as a source of gas for cooking and lighting. While these facilities are welcome conveniences, they, do not have a very high priority in the allocation of the individuals scarce money resources. (Ref. 2)

- Settlement pattern: The clustered pattern of housing in villages, particularly in the poorer sections, does not allow enough backyard space for installation of family-size gas plants whereas scattered settlements prove a hindrance to installation of community plants. (Ref. 1, 35, 44, 50)

  Clustered settlements often have better opportunities to gain an access to other energy sources. There would be more incentives for electricity supply and charcoal trading in clustered areas rather than in scattered settlements. Road-lined settlements have an easy access to other energy resources, especially electricity. Also, people here are more inclined to adopt the urban way of living, thus changing their energy-use pattern and limiting their accessibility to animal manure. (Ref. 1)

  Scattered settlements are difficult to serve with piped gas. Gas bags/containers have therefore to be deviçed. But these settlements have the advantage of having enough space near the home for locating both the gas plant and the cattle shed in close proximity, thereby saving time. (Ref. 1, 48)

- Educational background: The educational level of the prospective users influences biogas technology adaption significantly, as it helps to broaden the users attitudes towards technological innovation and improvement of living conditions, develops their logical evaluation of the technology, changes their social perception and to acquire the necessary knowledge needed for operation and maintenance of the biogas systems. (Ref. 1)

  Thus education plays an important role to eradicating the social prejudices and beliefs currently hampering the acceptability of the technology. (Ref. 1)

  Further, with sufficient technical knowledge there would be fewer cases of plant failures due to minor operational problems.

Health hazards: These are associated with the handling of night soil and from the use of sludge as fertilizer which has been derived from unheated human excreta. (Ref. 13)

Data Lacuna:

The economics of biogas utilisation is extremely location-specific and the economics of the system cannot be worked out in the absence of appropriate data. The data currently available is not only unreliable at the microlevel as the values assumed by different studies for similar parameters vary considerably and there is often overestimation of benefits and underestimation of costs. Further, these data are obtained from a narrow range of possible plant designs and socio-economic conditions and agricultural practices. (Ref. 3, 5, 50)

Organisational complexity:

- Need for adequate follow-up services and maintenance capabilities: Proper maintenance of plants is as crucial as the setting up of the gas plant. (Ref. 36)

  But most often, after-sales and maintenance services in developing countries are inaccessible to most plant owners. Inexperience and lack of personal involvement and incentive on the part of the people responsible for maintenance service often hold up repair of the plant leading to frustration to the owner and subsequently to the plant being abandoned. The service provided is often of poor quality at exorbitant charges and without any guarantee for the repair work. (Ref. 36, 49)
- Need for more workshop facilities: Most rural areas pathetically lack any kind of workshop facilities. As a result, parts of the plant have to be manufactured or repaired at distant towns and need to be transported, causing additional expenditure to the plant owner. (Ref. 35, 36, 50)
- Need for local design innovation: Through action research, plants to suit local conditions of feed-stock, soil conditions, temperature and local materials have to be devised. This is one of the factors in the success of the Chinese programme. (Ref. 48)
- Need for standardisation: A growing number of problematic plants are often the cause of dissuading people from setting up plants. But malfunctioning of the majority of the plants is not always due to inherent technical problems but the use of inferior quality

materials for the construction of the plants. The quality control mechanism lacks rigour. (Ref. 36) Absence of approved government laboratories for testing biogas appliances leads to defective utilisation devices. (Ref. 50)

- Need for an integrated biogas energy: In most countries different agencies, such as production agencies (fabricators, agro-industries), financial institutions (banks), voluntary organisations, trade organizations (fabricators, after-sales services bodies, suppliers of raw material), technical agencies (like Khadi and Village Industries Commission (KVIC), India), administrative and executing agencies (Ministries/departments of agriculture, rural development agencies, etc.) are involved in the biogas programme. (Ref. 35-37)

These organisations have nothing in common and are synthetically brought together, resulting in difficulties in the coordination of their activities. Moreover, each of these organisations has different levels of commitment and involvement in the scheme. For most of these organisations, promotion of biogas technology is just a peripheral activity. Each organisation follows its own operational procedure. (Ref. 36, 37)

Due to lack of clear definition and understanding of the activities of these bodies beneficiaries wishing to install the plants have to go from one office to another to get the work done. (Ref. 36)

Manpower alloted by different agencies participating in the scheme is totally inadequate. For instance, a district supervisor of the KVIC in India has to actively promote the gobar gas programme in his district through personal contacts, group meetings, demonstrations, etc. has to arrange for bank loans for the user, supervise the actual installation of the plant and so on. Thus, he is not often free to render the help and technical guidance expected of him to all. (Ref. 35)

The biogas scheme has to be operated on a wide-spread geographic area covering thousands of potential beneficiaries, and without adequate transportation facilities. Thus, the identification of target groups, monitoring of procedural requirements, supervision, technical guidance, provision of construction material and attending to complaints of plant owners assumes different magnitudes of problems for the various organisations. This leads to infrequent contact between plant owners and relevant agencies. (Ref. 36, 37)

A streamlined organisational network with a single focal point coordinating and controlling the activities of the various organizations responsible for undertaking construction, maintenance of biogas plants, financing of construction, carrying out further research and development and popularising the programme would provide a solution to the above problem. (Ref. 36, 46, 48)

- Need for clustered development: Also, one or two family digesters built in a locality are insufficient to demonstrate the advantages of biogas which has an impact not only on energy but also on aspects of fertilization and sanitation as well as household chores. Further, sparse distribution also hinders proper technological instruction which results in low quality digesters that in turn dampens the enthusiasm of the people and thus hampers generation of widespread support. (Ref. 46)
- Extension and training: Extension activities play an important role in the transfer of the technology to the rural masses. The activities of extension workers include coordination of activities at the community, district, state and national levels, intensive publicity campaign through the mass media, arranging for materials at fair prices, arranging for loans from banks, giving technical advice, demonstrating performance of gas plants, training artisans, educating people about plant operation, fabricating parts of the plant, efficient utilisation of gas, etc. (Ref. 50)

At present extension activities are sporadic in nature and too widespread geographically to make an impact on the rural people. Workshop facilities to help the extension workers in fabrication of various parts of the plant as well as appropriate literature for dissemination of information to the people are very much limited. Often, choice of the wrong site for demonstration purposes for instance choosing the houses of rich farmers or villages far from road or rail lines defeat the purpose of demonstration. (Ref. 50)

Absence of a sufficient number of trained workers for providing technical guidance for construction, operation and maintenance of the gas plants clearly indicates the inadequacy of the training programme in most countries.

In the experience of users, often a single efficient transfer agent, who may be a resident of the locality in which he serves, is more effective than government agents who lack personal involvement in the project or may not be aware of the social customs, prejudices, know the local language and are not always available in times of need. (Ref. 50)

One single agent or a group of transfer agents cannot be fully successful in the actual implementation programme unless and until the extension agencies operate very clearly with services for producing usable credit or subsidies, the necessary equipments and, perhaps more important, for providing reasonable, efficient support for maintenance and trouble-fre operation. (Ref. 50)

- Biogas plants market: There is no organization responsible for providing the necessary raw materials or component parts at fixed rates. The fabricators in general seem to have inadequate working capital and face financial difficulties. The infrastructure of fabricators and after-sales service units has not been well developed. Moreover, a sound marketing concept systematically organized, sustained, and extensive marketing efforts to popularize biogas plants have been seriously lacking. (Ref. 9, 35, 36)
  Due to lack of proper response from customers the fabricators are often in difficulty. Gas holders and other components ordered by users but not collected in time render them unsaleable. The fabricators are led to malpractises by using substandard material and charging higher prices. (Ref. 36)
- Information-flows: Lack of a centralized information base containing evaluated data on performance of biogas plants and on other aspects of the technology is a serious constraint to all involved in the various aspects of the technology. (Ref. 53)

CHINESE EXPERIENCE

One of China's recent achievements has been the production of biogas from agricultural and human wastes. What would be regarded in many countries at best, a efficient system of waste disposal has become in China, a comprehensive, controlled method not only for improving rural health but for recycling resources and supplying energy as well. (Ref. 46)

Although the Chinese have been experimenting with biogas since the 1950s, it was only in the 1970s, when the technology for construction of water pressure-type digesters was brought to the practical stage, that there was a movement to extend the technology throughout the Chinese countryside. (Ref. 9, 10). In the last decade about 7 million family digesters have been built, together with 715 biogas power stations and 617 biogas generator plants. (Ref. 46)

The failure of the Chinese attempt to introduce biogas technology in rural areas in 1950s is mainly attributed to the absence of a coordinated functional set up and the poor socio-economic condition of the Chinese rural people. But since then there has been inprovement in the Chinese rural economy and the reasons for the Chinese success since 1974 in biogas technology promotion as against the problems faced in other countries is discussed in the following paragraphs. (Ref. 25, 46)

- Technological aspects:

  A prerequisite to the development of biogas utilisation is an inexpensive and reliable digester and, over the past 20 years, considerable research has been done in China on various digester types. This has resulted in development of low-cost digesters suited to local conditions. However, these digesters are not free of problems such as high gas pressure, low gas production, etc. To overcome these problems, Chinese researchers have studied balloon and floating cover type digesters. Development of a low-cost floating cover is under research and a break-through on this would speed up biogas utilization.

Further research has been organized on new sources of raw materials for fermentation, raising the level of fermentation technology, and increasing the thermal efficiency of biogas digesters in order to establish a solid basis for the expansion of biogas utilization.

- Economical feasibility:

Through successive improvements in design, the construction cost has been reduced to a certain extent. A digester for a family of five costs about $30.00 for materials. Construction manpower is provided by the family itself and the production team (discussed later). The labour needed to build such a digester is about 30 man-days. The cost of the digester is much less than a bicycle ($100). Almost every Chinese family owns a bicycle, and so building family digesters is economically feasible. (Ref. 46)

- Financial support:

The Chinese government has adopted a policy of relying mainly on the financial capacity of the family unit aided by subsidies from the collective, and state subsidiary for the construction of family digesters. The subsidy percentage differs by area. Families needing further assistance receive larger subsidies or 1.8 per cent loans from the Agricultural Bank. Construction materials are supplied by the local government and the production team. In addition, the financial departments allocates funds for the maintenance of the digesters and for the technicians' expenses so as to ensure good digester management.

- Clustered approach:

The clustering of construction was found to be more readily supported by Chinese leaders and citizens because of advances in agricultural production and sanitation. Only when digester construction in China was clustered in a village or production team, could the many advantages of biogas utilization be demonstrated and thus made acceptable to farmers.

Advantages of clustered development were found to be many -

- Clustered development favoured concentrated financial, material and technological support from the government, which helped ensure the quality of digesters and advances in technology.
- Communes and production teams were found to be more willing to train their own biogas technicians to instruct in the application and maintenance of the digesters to increase efficiency.
- The organizations were also willing to formulate policies and adopt measures necessary to settle the problems that can arise in the implementation of biogas units.

- Management of biogas systems:

In China, manure-biogas managers oversee the supply of raw materials for digesters, carry digesters' sludge to the fields for fertilizer, inspect biogas production and instruct the commune members on how to operate the digesters.
Measures suited to local conditions have been formulated regarding collection of raw materials, payments, distribution of residues to commune members for digester operation as well as the return of the digested sludge for fertilizer.

- The raw material collected by the peasants is checked by the manure-biogas manager before feeding into the digesters and payment is made according to the quality and quantity of the material.
- Generally the production team allocates residues to the peasants free in terms of the size of the family, while the team owns the digested sludge.
- Fertilizer for private plots is supplied by the team based on the area of the plots.

- Effective integrated agency:

The state office of Biogas Utilization and Popularization, which is an executive institution set up under the State Leading Group on Biogas Construction (comprising of representatives from the various Commissions for State planning, economic, scientific and technological - Ministsies of finance, agriculture, electricity, light industry, farm machinery, chemical industry, commerce, medicine, together with the General Logistics Department of the People's Liberation Army, the State General Supply and Marketing Cooperative and the Agricultural Bank of China) is responsible for the day-to-day work.

Biogas leading groups have been set up in provinces, municipalities and autonomous regions, as well as in their subordinating countries and cities. Ongoing work is handled by the offices of biogas utilization and popularization under the direction of either the leading groups or organizations designated by the groups.

These institutions being governmental, may effectively formulate policy, determine development programme, combine the efforts of all departments, sponsors training courses and organize the supply of digester construction.

China has made significant advances in biogas research. Several biogas research institutes or experimental stations have been set up in many provinces, cities, districts and countries. All the institutes and universities engaged in biogas research have close connections with the state and local biogas offices which distribute research results.

The State Biogas Office holds meetings for biogas research institutions once a year to discuss research projects and coordinate activities. Significant research is appraised by experts to determine whether it should be made known generally. In addition, meetings for directors of biogas offices in major provinces and cities are held every year to exchange experiences, discuss approaches to problem-solving and to develop programmes for further research.

- Training and education:

China has recognized the need for proper training of techmicians prior to expanding biogas utilization in a certain area.

Student technicians receive training for 15-30 days in the basic theory of biogas generation as well as in the construction of digesters. The training is funded by the government. Meetings are held often for exchanging experiences to raise the skill of biogas technicians. Experts are usually invited to give lectures and exchange experiences in the courses.

At least one biogas technician works in each energy production team utilizing biogas. The technician supervises the construction and maintenance of the digesters, as well as their daily operation and management. Professional contigents are generally established in the peoples' communes and production brigades to build digesters.

In order to spread basic knowledge to the population at large, as well as to Staff Officials working at all levels of government, propoganda and publication departments at all levels of the Chinese government have been mobilized to publicize and popularize fundamental knowledge about biogas. Considerable popular literature have been published on the subject and radio and television programmes explain the meaning and importance of biogas utilization, describe biogas research and discuss various policy problems. Popular science films on biogas have been produced in a number of provinces. These efforts have helped increase the Chinese people's knowledge of handling, managing and operating biogas digesters. This knowledge is continually updated.

- <u>Government support</u>:

The rapid development of biogas in China in so short a period has been possible only because of strong government support and advocacy since the early stages of development of biogas technology and utilisation in the country. Biogas construction is considered as an important component in the modernization of Chinese agriculture, and is listed in the national economic programme.

Based on the status of biogas development and the need to modernize agriculture, the Chinese government has established a policy of strong leadership, active expansion, cluster development, and steady advance. Biogas construction has been put on the agenda of government at all levels, and specific policies and projects for development have been formulated. Financial, material and technological support have also been provided through effective institutions established by the Government.

PLANNING AND EXECUTION

Recognising the importance of biogas plants in the context of a developing economy and realising the significance of government support in the promotion of biogas technology, as clearly demonstrated by the Chinese experience, it is suggested that short-term and long-term programmes be organised at national, regional and global levels for the integrated development and promotion of the technology. (Ref. 16, 46)

NATIONAL LEVEL:

Developing countries are at different stages of development in respect of biogas technology and its utilisation. Further as the dominant motivations for biogas use vary between countries, it is the task of individual governments to recognize the motivating factors, keeping in mind the individual as well as the national points of view and draft the programmes accordingly to achieve the desired goals. (Ref. 16) The following aspects need to be considered: (Ref. 16)

- The Programme should be a part of an integrated rural development programme with long-term and short-term projects, with targets specified;
- Rural and local government institutions and other statutory bodies should be involved in the programme implementation;
- Grass-root organizations should be developed/strengthened for doing specific tasks relevant to the programmes;
- Adequate financial assistance and incentives for the programme should be provided while ensuring people's involvement in them.

- Framing a policy:

  As a large-scale adoption of biogas technology can only succeed with appropriate support from the government, a sound and realistic policy must be established at the national level. The formulation of this policy should take into consideration the following issues. (Ref. 1)

- short and long-term energy demands in rural areas;
- mechanization in farming practices, rural electrification policy;
- socio-economic and technical constraints of biogas technology in rural application;
- public health roles of biogas technology; and
- government's roles in the promotion of the technology.

The national policy will serve as a framework for concerned authorities in setting promotional goals and planning promotional programmes and strategies. (Ref. 1)

The probable programmes of action within a national programme are discussed below:

Programme of Action:

- Identification of potential areas:

  It should be remembered that the economics of the biogas system is location-specific and hence it is essential to identify rural areas having the right potential and socio-economic environment to maximise the benefit to an individual, a rural community and to the nation as a whole. (Ref. 3)

  Criteria for identification of such areas: (Ref. 3, 50)

- Inputs have low opportunity cost:
  - availability of large quantity of agricultural and industrial wastes;
  - social acceptability of the use of human excreta, traditional collection of cowdung;
  - availability of capital (at low cost), water and labour.

- Adequate efficiency of operation is feasible:
  - availability of adequate inputs;
  - no severe winter;
  - good plant design;
  - adequate fabrication and technical service facilities.

- High opportunity cost exists for alternatives to outputs:
  - limited supply of fuel and fertilizer, coupled with high-cost transportation;
  - large-scale use of cow dung as fuel;
  - scarcity of wood;
  - inadequate water to make use of chemical fartilizers;
  - insufficient cash to purchase other fuels and fertilizers;
  - use of gas close to the generator or existence of economic bottling facilities;
  - easy handling of the slurry at low-cost.

Formula for calculating the potential of a village is given in Appendix (pg. no. 75)

Research and development:

In the overall context of the village energy system the biogas option poses technological, economic and social problems which demand coordinated research and development not only by the technologist, but also by economists and sociologists. Further, the R & D work should be linked with the development of other energy resources of the rural areas - e.g. social forestry, agriculture, etc. (Ref. 16, 48) The major objective of the research and development effort on biogas technology should be to optimise the technology to reduce cost. (Ref. 21) Coordinated research work whether nationally or regionally undertaken in difficult to continue because continuity of research would require committment of resources, smooth synchronisation of which is a difficult task. Biogas research should be goal-specific. (Ref. 25)

Problems needing immediate investigation are indicated below: (Ref. 45, 50)

Technical:

- Technology of collection and necessary preparation of various fermentable materials other than dung poultry wastes, agricultural cellulosic waste available in different places.
- Management of plantations of algae, water hyacinth, etc., including techniques of harvesting and preparation.

- Study of fermentation parameters (rate, gas yield, gas composition, etc.) as a function of variables such as temperature, pressure, pH, viscosity, agitation, etc. for various input materials (dung, faeces, poultry and agricultural wastes, algae, water hyacinths, etc.) and in different zones in the region.
- Study of the fermentation chemistry and microbiology with emphasis on the choice and management of micro-organisms for optimum methane production.
- Optimisation of the fermentation process for villages where water is scarce, i.e. development of "drier" processes, and water re-circulation systems.
- Detailed chemical engineering design of the biogas plant with maintenance of optimum conditions for methane production.
- Research and development on alternative linings (polythene, creosote, earth work, etc.) for the digester.
- Research and development on alternative materials (ferrocement, treated wood/plywood, polythene, glass-fibre or jute-fibre reinforced plastic polythene with bamboo basket reinforcement, oil drums, stoneware, etc.) for the gas holder.
- Development of single gas purification methods, including utilisation of Carbon dioxide and Hydrogen sulphide.
- Incorporation of auxiliary heating systems using solar heating, for example.
- Incorporation of agitators to stir the fermentation mix.
- Study of safety hazards and design of safety procedures for plant operation and for handling and storage of methane.
- Studies on the efficient and optimum utilisation of the digested slurry and sludge, their enrichment and effect on crop yields.
- Studies on determining and increasing the fertilizer value of sludge. (Ref. 14)
- Methods of storage of biogas, including compression into cylinders, materials of construction of containers, e.g. balloons.
- Design and development of methane engines to drive electricity generators and vehicles, methane fuel cells and Humphrey water-piston pumps running directly on biogas.

- Design of efficient carburettor, optimization of biogas engine parameters for specific energy input. (Ref. 10)
- Studies on use of methane by small industries (brick-making, welding, etc.) (Ref. 14)
- Integrating biogas systems with solar and wind energy systems.
- Research and development work should lay emphasis on the growth of algae in water and plants on land, in order to capitalize on a natural phenomenon - photosynthesis. (Ref. 15)
- Emphasize utilisation of surplus algae that are not eaten and the wastes produced by the biological creatures in order to produce fuel, feed and fertilizer. (Ref. 16)

Socio-economic:

- Comparison of social costs and benefits of biogas plants and rural electrification in different regions.
- Comparison of social costs and benefits of solar energy plantation and use of the same amount of land and water for conventional agriculture.
- Comparison of social costs and benefits of a small number of large-size biogas plants vs a large number of small-size plants, taking into account economies of scale and village demography.
- Methodology and techniques for routine decision-making regarding optimum location(s), size(s) and number of biogas plants in a particular village depending upon its cattle and human population, distribution of houses, etc.
- Comparative economies of various ways of distributing biogas energy, viz. pipeline distribution of biogas, distribution of electricity produced from biogas and gas distribution in containers.
- Formulation of schemes for ownership, control and distribution of biogas and fertilizer to villagers and appropriate safeguarding of interests of non-owners of cattle.
- Nature of extension services required for popularisation of biogas plants.

- Cost reduction:

The family-size biogas plants, which are usually looked upon as substitute for firewood, can be made economically viable only by decreasing their installation cost. This alone can help to bring out a meeting ground between individual and social objective in promoting these plants. (Ref. 36)

This must be achieved by insisting on the use of cheaper and locally available material for construction of the plant, avoiding importing of any type of raw material either from another country or from different parts of the same country. Also, serious research and developmental efforts should be directed towards construction of more efficient but low-cost digesters and efficient digestion processes requiring less retention time. (Ref. 11, 25)

Another way of lowering the installation cost of digesters is by increasing the amount of subsidy. This however, goes against one school of thought that no subsidy of free, direct, monetary incentive should be given in the promotion of the biogas technology, so that the competitive position of biogas technology is not greatly distorted to make biogas technology more favourable than other energy sources. (Ref. 1)

But in general it is felt that increase in the subsidy would go a long way in increasing the acceptability of the technology, especially of family-size plants. (Ref. 35, 36)

A sliding scale of subsidies based on the size of the plant and the economic conditions of the owner may be devised, the smaller plant and farmer being entitled to a larger subsidy. Otherwise, it is felt that subsidies benefit the richer class only. (Ref. 48, 50) It may be necessary to provide subsidy to small and marginal farmers over and above the capital subsidy, with a view to making the project feasible and acceptable to them.

The gains from gobar gas plants are marginal and the payback period of the initial investment is long for small plants (2-3 m^3) particularly if the benefits are valued realistically. This implies a differential maturity period and rate of interest on bank loans, e.g. a larger maturity period and a lower interest rate from small plants and vice versa. (Ref. 35)

Since the average earning on money invested is very high in large plants, the need for subsidy on large plants may be questioned. If the subsidy is to be given on other economic grounds, it should be higher for small plants as the flat subsidy rate increases the rate of large plants much more than small ones. (Ref. 35)

Alternate suggestions made (Ref. 36) are as follows:

- An easily available package of essential services and technical facilities on a sort of turn-key basis, so as to attract potential customers, may be provided;
- A hire-purchase system can be introduced so that the burden of investing the total capital is not borne by the customers. Individual loan advances can be easily replaced by the more efficient institutional finances.

Also, operational procedures in providing loans and subsidies need to be simplified so that the time-lag between submission of the application and disbursement of the loan and actual construction of plants on the other hand is cut down to the minimum. This will reduce the additional financial burden on the plant owner. (Ref. 35)

- Exploiting potential:

It is generally felt that the utility and acceptance of the programme will be greatly enhanced if it meets some felt needs of the people and is economically viable either in itself or in association with other linked activities for the families which adopt it. (Ref. 2, 16)

Such an approach is possible if more emphasis is laid on the possibilities of meeting the manurial requirements of multicropped agriculture through the process of biogas digestion. (Ref. 2)

From the experience on small, pilot projects in Papua New Guinea, it is found that the benefit from biogas represents only 15-20 per cent of the total benefits obtained from what is referred to as an "Integrated Biogas System". (Ref. 16)

In such a system there is a choice between three main by-products:
(Ref. 16)

- fuel (methane) for domestic, industrial/commercial purposes,
- feed (algae, fish and aquatic plants) for livestock, and
- fertilizer for crops.

The yield of each of them can be varied to suit any given situation by varying the design of the system. (Ref. 16)

For example, in the tropical islands in the South Pacific, some coastal villages have plenty of fish but are short of vegetables, so the emphasis will be on a small digester to meet domestic and refrigeration needs (for fish preservation) and fertilizer for gardens. (Ref. 15)

Some inland villages are short of meat protein as their rivers are polluted, and then wildlife has disappeared because of forestry operations, so a bigger digester will be required to cope with the large quantity of animal wastes, with ponds for algae and fish culture for feed or food, and the effluent to be used to grow legumes and cereals, mostly for feed. (Ref. 16)

Some villages near the towns are short of land and want to have small industries such as bakeries, dairies etc. They will need intensive pig and chicken farms with as big a digester as possible to produce all the power they need for such industries and perhaps commercial production of algae and water plants to make the maximum use of the nutrients available. (Ref. 16)

Although it is known that all these developments are possible, too much neglect has been experienced in these fields. More research and development needs to be done to obtain the best conditions for maximum yields of fuel, feed and fertilizer from various kinds of animal and agricultural wastes so that the best system to suit any set of condition may be designed. (Ref. 16)

Promising integrated developments of biogas such as the Indian cattle-fuel-compost-fodder project, Operation Flood, the Fijian and Papua New Guinea pig-fuel-algae-fish crop projects should be fully investigated and improved upon. (Ref. 16, 31)

But to make the Integrated Biogas System work, it is necessary to have the full backing from all parties involved local farmers, agricultural officials and government. (Ref. 10)

- Community plants:

The choice between large and small biogas systems is highly context-specific and cultural and social factors enter into the policy arena. A system that is economically rational for a given village may be culturally inappropriate for others. Often, though community plants used to provide energy for cooking and lighting needs of a community have an economic edge, the distribution of land and animals makes the system beyond the reach of the poor. (Ref. 20)

- Operational scheme:

The following is a conceptual operating scheme for a community plant: (Ref. 39)

> Dung may be purchased daily for money and the fertilizer available sold to the sellers of farm waste at a fixed price in proportion to the farm waste sold by them. Those who cannot afford to buy gas may come to the plant sites to cook their meals at a community kitchen that is attached to the community gas plant in exchange of a few hours of service per week for the operation of the plant, such as collecting farmwaste, bringing water to the plant, maintaining cleanliness, etc., or for a price paid to utilize the burners for a certain time. One may even consider giving it free of cost if the situation permits and misuse is prevented. In fact, as a sort of development rebate, it is suggested that the gas may be suppled free for a couple of years until purchasing power picks up. (Ref. 45) Cylinders and gas burners may be rented out to users on payment of a

deposit of a fixed amount. Community kitchens may have to be provided for the very poor families who cannot afford this deposit.

- Guidelines for pricing policy: In fixing the prices of the various inputs and outputs, the following aspects should be kept in mind: (Ref. 39)
  - The price at which the dung is purchased for the plant should be a little higher than the present market price of dung so as to give an incentive to those who collect dung at present for consumption directly as fuel.
  - The price for a unit of gas should not exceed the price of an equivalent amount of delivered calories from an alternative source of fuel. Since 100 m^3 of biogas delivers 286,000 kcal and a ton of dung delivers 350,000 kcal, the price of 100 m^3 biogas should not exceed the price of 0.817 ton of dung. Even though biogas is a much more convenient form of fuel and many would be willing to pay relatively more for it than for example for dung cakes, this limit has to be observed for ensuring that even the poor are better off when using biogas rather than burning the dung directly.
  - The price of the fertilizer obtained from the plant has to be less than the price of equivalent nitrogen obtained from chemical sources.
  - The price charged for biogas should be such as not to cost the various rural households more than they currently spend on fuel.

The following are the alternative distribution strategies suggested for gas and manure: (Ref. 35)

- Given the norm of the amount of gas required per person per day, charge each household using the gas of the community plant according to its family size. This is at a disadvantage to the poorer family.
- Distribute the gas free to the poorest section of the community in which case the whole financial burden has to be borne by the relatively richer sections of the community.

- Distribute the gas free of cost to the poorer members in exchange for their labour in dung collection, slurry-making and other operations.
- Distribute the gas according to the family size and dung contribution. Each household should be given gas equivalent to its dung contribution free and should be charged for any excess requirement.

  Thus households owning less number of cattle and more family members will have to pay more - a disadvantage to the poorer sections of the community.
- If the plant owner buys all the dung it uses the manure can be sold at a fixed price to the community. Alternatively, it can be distributed according to the dung contribution of the households with a charge for enrichment of manure or by adopting the above alternatives for gas distribution.
- To avoid the problems of distributing and pricing of gas, the community can decide to use the gas for its common benefits - for street lignting, operating irrigation and drinking water pumps used by the whole community, lighting of public premises, etc.

Operating the community gas plant as a utility for the whole village (like water supply in some villages) has many advantages. Some of the problems connected with the collection of dung and distribution of gas and manure are solved by utilising the gas for industrial purposes - e.g. flour, rice or dal mill, fodder cutter, etc. It may be possible to add to the revenue collected in the village. The dung falling on village roads and common lands - which accounts for one-fourth of the dung production of the village, would belong to the community. This dung, together with human excreta from community latrines, crop residues and organic wastes, could become the basic feed-stock for the system, and be supplemented with dung purchased at a fixed price. (Ref. 48)

A percentage of the gas (according to the need) could be used for domestic purposes and the rest used for generating electricity - which could be sold or used for community-owned industry.

Composting of the slurry along with organic wastes (not needed for the plant) could add to the nutrient supply in the village, and provide employment to two or three people. (Ref. 48)

- Extension and education:

To acquaint users fully with the installation, functioning, maintenance and uses and benefits of biogas technology, an intensive educational programme needs to be integrated in the policy framework so that prejudices and ignorance of scientific processes do not stand in the way of promotion of the technology. (Ref. 1, 35, 36)

Any organized development of biogas technology must be based on the availability of adequate training facilities and of trained manpower. Thus the national governments should organize and implement regional, national and local training programmes for their professional and technical staff, and for promotional personnel and extension workers. (Ref. 53)

Training needs to be done at engineering, scientific, technical and extension levels. International workshops and practical field courses should be instituted, aimed at training people, at universities or other institutions, who will act as professors or teachers in the biogas programmes. (Ref. 53)

For universal introduction of the technology, a trained cadre of workers trained in both the technical and managerial (entrepreneurial) skills has to be developed from among the carpenters/ blacksmiths/masons of the rural areas. The presence of such a person on each production brigade or commune has helped considerably for the widespread adoption of the technology in China. (Ref. 48)

A network of decentralised agencies comprising suitably trained personnel could be set up at different levels - village, district, etc. (Ref. 6, 7)

Popular education and extension programmes should be used to raise people's awareness and stimulate their capability to develop the technology further. (Ref. 53)

Women need to be actively involved in the implementation of the programme as they are intimately involved in the utilisation of the gas for domestic purposes. Also, cooking practices and habits need to be suitably changed for efficient utilisation of the gas. Thus special educational programmes for them will brighten the chances of obtaining their approval and giving a momentum to the scheme. (Ref. 36, 49) The local leaders too should be involved in every aspect of the programme, including education, extension and training since their understanding and acceptance of the benefits of the technology will enhance the chance of its acceptance by the local residents. (Ref. 1)

Effective two-way communication link between top policy planners and the rural masses calls for increasing use of the mass media such as television, radio and newspapers. Other means of educating and informing people is by distribution of technical and non-technical literature in local languages, demonstration of the operation of biogas plants, use of biogas and residual slurry as manure. Informative, persuasive literature gives details of the economics and functioning of the plants, loan facilities, reasons for malfunctioning, production of manure, cost of maintenance need to be prepared and circulated widely. (Ref. 36)

Systematic campaigns for popularising biogas plants should be organised by government departments involved in the programme. (Ref. 5)

These campaigns should aim to arouse sufficient consciousness among potential customers about the macro-level national concern of energy-saving and environmental control as a process of seeding the market. (Ref. 36)

Active participation of voluntary organisations, students' groups, women's groups, farmer's associations should be sought and encouraged in the education, training and extension programmes. (Ref. 37)

- Industrial issues:

  The use of biogas technology is restrained by low level of industrialization in developing countries, to make maximum profit from the national resources available. To overcome this there is a need for the encouragement and/or the promotion of participation by national industrial enterprises in the implementation of the technology. Systematic organisation, and sustained and extensive marketing efforts must be developed. The infrastructure of fabrication and after-sales service units should be developed on a local level reachable by bicycle or public transport to guarantee a reliable and quick service for customers. Supply of materials and spare parts need to be channelised through government fair-price shops. Repairing charges should be standardized. Burners and stoves should be made easily available to the rural poor at fair price. (Ref. 5, 7, 9, 36, 53)

- Information-flows:

  Transfer of technology, both from one country to another and within a country, from the laboratory to the field, depends on a smooth flow of information from its point of origin to the point of utilisation. For this it is necessary to create a centralised information base which would be responsible for the following functions - (Ref. 53)

  - collecting and distribution of information on planning, evaluation, financing and operation of biogas technology;
  - promotion of the use of information throughout each country by organizing conferences, workshops;
  - promotion of standardization of equipment and techniques;
  - cooperation with similar centres in other countries in sharing local experience, techniques, etc.

- Organisational Infrastructure:

  As biogas is seen in connection with the following areas rural development, agriculture and forestry, energy supply industries, health service, education and culture, settlement planning, labour market policy and social welfare, it ought to be integrated into the respective ministries and administrations. (Ref. 55)

A national coordinating body must be set up to ensure cooperation of all the departments and for planning and reviewing the programmes. This centralised core agency should be entrusted with the task of promotion, propagation, development of hardware and also programmes of execution at the grass-root level. (Ref. 16)

It is necessary to form biogas expert groups with overlapping knowledge of the above areas on the different planning levels - central ministries and local administrations (in case of centralised systems) or different regional authorities (in case of decentralised systems) and planning boards of development projects. Aspecial biogas cell constituting experts from the above mentioned areas may be created. (Ref. 55)

At the local levels of administration, local bodies responsible for the above mentioned areas may be entrusted with the responsiblity of chanellising subsidies, coordinating with other financing bodies, government institutions, agecies at the local level, facilitating institutional financing, arranging for raw materials, appointment and demarcation of areas for the executing agencies, monitoring of the programme at the local level, maintenance of subsidy accounts and submission of progress and expenditure reports to the national agency. (Ref. 55)

The mechanism created should be responsible for: (Ref. 16)

- Extension and training:
  - setting up of an information and documentation centre on biogas technology;
  - setting up of a mobile exhibition unit to arrange for demonstration exhibition;
  - developing scientific demonstration kits for schools, colleges;
  - arranging training programmes for visits of technicians/ extension workers, periodical meetings/workshops, etc.;
  - offering scholarships and fellowships;

  - preparing a training manual for planning, design, construction, maintenance of plants, in local languages.
- Designing, fabrication, construction and operation of plants:
  - providing adequate workshop facilities and assistance;
  - ensuring timely supply of standard materials and equipments at standard price.
- Technological aspects and problems:

  Identifying institutions for -
  - undertaking activities to improve the productivity and economics of biogas plants;
  - undertaking research, development and design work relating to all aspects of the technology and construction of plants on a prototype scale;
  - setting up standards for the materials used in plant construction, testing of appliances, etc.;
  - standardization of technical terminologies involved, defining the parameters of designs and determination of the specifications of biogas plants and accessories;
  - collecting existing and available information on technologies and arranging for their dissemination in specified areas in collaboration with training and extension fields.
- Social and economic issues and approaches:

  Identifying institutions to -
  - undertake studies in depth of problems relating to social acceptability of biogas;
  - solve methods for assisting in greater acceptability of programmes;
  - undertake study of the cost aspect of the plant and suggest cost-reduction alternatives;
  - undertake study to establish an integrated programme for the biogas system in the development of feed, fertilizer and food.

REGIONAL LEVEL:

The multi-disciplinary nature of biogas technology involves expertise from different fields such as Microbiology, Biochemistry, different branches of Engineering, Agriculture, Social Sciences, etc. (Ref. 8, 24) The availability of experts in all these fields along with equipments and other physical facilities in one single institution is an ideal case, which is quite difficult to achieve. It may not even be possible to have experts in all the fields in a particular country. (Ref. 25)

This necessiates development of a regional programme in which a prime institution having experience in the technology could play a leading role in mobilising resources (experts, materials, equipments) in different fields to optimise the technology. (Ref. 25)

In case a single institution is not capable of providing inputs in all fields the leading institution can distribute the task according to the capability and commitment of participating institutions. (Ref. 25)

Such a leading institution can then act as a focal point, coordinating the activities of the national agencies working on biogas projects, thereby creating a network system. Such a system is expected to result in cooperative activities such as - (Ref. 16) exchange of scientists, technicians, experts, administrative heads from the different countries who wish to initiate/develop biogas programme as well as in those countries where the programme is making good; organising study tours, conferences, symposia, etc.; exchange of audio-visual aids, equipments, manuals; initiating action on standardization of technical terminologies, defining parameters of plant design, determining specifications of the plant and accessories; preparation of manuals, newsletters for exchanging information on various aspects of the technology, success and failures, research methodology for socio-economic evaluation of biogas technology, etc.

GLOBAL LEVEL:

At the global level, a global project may be considered which may incorporate mobilization of existing technology and transfer of the same to interested countries and also initiate integrated industrial/engineering and applied research adaptation, development and utilization with a view to evolving an improved biogas system on a package basis. (Ref. 16)

In view of the importance and urgency attached to biogas development programmes, it is imperative that certain projects of interest to developing countries may be accorded priority by the United Nations and other international organizations such as the Economic and Social Commission for Asia and the Pacific, the United Nations Development Programme and the World Bank. (Ref. 53)

As in the case of the global biogas programme (Ref. 51) the involvement of international agencies for the promotion of biogas may be in the following specific areas:

- These international bodies should assist governments, universities and research institutes to promote cooperative research, development and demonstration programmes in biogas between developed and developing countries as well as among developing countries;
- Research and development centres should be established involving at least two, or possibly more countries, with continuing international support to those developing countries where experience, expertise and infrastructure already exist, which are particularly suitable to each of these research and development needs;
- Scientific and technological information emerging from these programmes should be made freely available, particularly for the benefit of the rural poor.

REFERENCES

1. Applied Scientific Research Corporation of Thailand, Environment and Development Research Department. Final report on pre-feasibility study of the biogas technology application in rural areas of Thailand, submitted to International Development Research Centre. Bangkok, Applied Scientific Research Corporation of Thailand, April 1979.

2. Bahadur, Shahzad. "Role of biogas in rural development". Presented at : Workshop on energy for rural development held at Ahmedabad, December 27-29, 1979. 11 p.

3. Barnett, Andrew et al. Biogas technology in the third world : A multidisciplinary review. Ottawa, International Research Centre, 1978.

4. Biswas, D.K. "Towards better design of biogas plants for fuel and fertilizer". Bhagirath. Vol. 12, October 1975, p. 140-145.

5. Biswas, T.D. "Biogas in India – Retrospects and prospects". Presented at National symposium on biogas technology, and usage held in New Delhi, November 29-30, 1977. In : National Symposium on biogas technology and usage : Abstracts of papers and major recommendations. p. 13-18. New Delhi, Indian Agricultural Research Institute, 1979.

6. Biswas, T.D. "Biogas plants : prospects and limitations". Invention Intelligence, January-February 1977, p. 71-78.

7. Biswas, T.D. "Cow dung gas plant for energy and manure". Fertiliser News, Vol. 19, No. 9, September 1974, p. 3-7 and 33.

8. Biswas, T.D. et al. "Removal of carbon dioxide from biogas". Presented at : National symposium on biogas technology and usage held in New Delhi, November 29-30, 1977. In : National Symposium on biogas technology and usage : Abstracts of papers and major recommendations, p. 37-38. New Delhi, Indian Agricultural Research Institute, 1979.

9. Bremen Overseas Research and Development Association. German Agency for Technical Cooperation and Bremen Senate for Economic Affairs and Foreign Trade, Report on the International biogas-workshop held in Bremen, May 16-20, 1979. p. 7-22, 69-76, 197-281.

10. Chan, George. "Integrated biogas development : Fiji". In : Biomass energy projects - planning and management edited by Louis J. Woodman and Ralph N. Love. New York, Pergamon Press, 1981.

11. Chan, George L. "Socio-economic aspects of various biogas systems". Presented at ESCAP workshop on biogas technology and utilisation, held in Manila, October 13-18, 1975. 27 p.

12. Chawla, P.O. et al. "Note on stimulation of anaerobic fermentation of dung in the cow dung gas plant". Indian Journal of Agricultural Sciences, Vol. 39, No. 11, November 1969, p. 1040-1043.

13. De Silva, E.J. "Biogas : Fuel for developing countries - an overview". ASSET, Vol. 1, No. 11, November 1979, p. 10-16.

14. De Silva, E.J. "Biogas : Fuel for the future". Ambio, Vol. 9, No. 1, 1980, p. 2 - 9.

15. Dass, R.S. et al. "Biogas as a replacement fuel to diesel engines". Agricultural Engineering Today, Vol. 2, No. 2, March - April 1978, p. 14 - 19.

16. Economic and Social Commission for Asia and the Pacific. Biogas technology and utilization. Report - preparatory mission on biogas technology and utilization, New Delhi workshop on biogas technology and utilization, Manila workshop on biogas technology and utilization. Bangkok, ESCAP, 1975.

17. Economic and Social Commission for Asia and the Pacific. Guidebook on biogas development. New York, United Nations, 1980.

18. Eusuf, M. "Development of biogas in Bangladesh : Technological aspects". Presented at : Biogas workshop organised by Commonwealth Science Council and Khadi and Village Industries Commission, held in Bombay, September 8-10, 1980. 6 p.

19. Farvar, M. Tagh and Bajrachanya, Deepak. "Projects and problems of biogas technology as an appropriate technology for development in the rural areas - a critical appraisal". Presented at : Second international workshop on biogas technology and utilization held in Manila, October 13-18, 1975.

20. Ghate, P.B. "Biogas : A decentralised energy systems : A pilot investigation project". Economic and Political Weekly, July 1979, p. 1132-1136.

21. Ghate, P.B. Fatch Singh Ka Purva : Some preliminary feedback for further community biogas plants.

22. Gupta, R.K. and Iyer, N.V. "Use of biogas in diesel engines". Agricultural Engineering Today, Vol. 1, May-June 1977, p. 7-10.

23. Hayes, Peter and Drucker, Charles. "Community biogas in India". Soft Energy Notes, April 1980, 10-13.

24. India, Department of Science and Technology. Biogas technology and utilisation : A status report. New Delhi, Department of Science and Technology, Government of India. 1981.

25. Islam, M.N. "Policy issues in relation to biogas technology as a tool for rural development". Presented at : Biogas Workshop organised by Commonwealth Science Council and Khadi and Village Industries Commission held in Bombay, September 8-10, 1980. 17 p.

26. Jain, M.K. and Mishra, M.M. "Biogas plant : An alternative technology for energy and manure". Food Farming, and Agriculture. April 1978. Vol. 9, No. 10, p. 292-296.

27. Joshi, D.S. "Use of fibre glass for gasholder in biogas plant". Journal of Biowaste Treatment, Vol. 1, No. 1, 1981, p. 25-27.

28. Khadi and Village Industries Commission, Directorate of Gobar Gas Scheme. Gobar gas : Why and how. Bombay, Khadi and Village Industries Commission.

29. Khandelwal, K.C. Community biogas plant. New Delhi, Action for Food Production, 1979. (AFPRO publication no. 106).

30. Khandelwal, K.C. "Implementation of biogas programme at village level - a case study. "Presented at : National symposium on biogas technology and usage held at New Delhi, November 29-30, 1977 : *In National Symposium on biogas technology and usage : Abstracts of papers and major recommendations*. p. 44-45. New Delhi, Indian Agricultural Research Institute, 1979.

31. Khandelwal, K.C. "Write-up on the activities of Ministry of Agriculture, Department of Agriculture and Cooperation, New Delhi". *In Renewable Energy research in India*. Bombay, Tata Energy Research Institute, August 1981.

32. Maramba, Felix D. Sr. *Biogas and waste recycling : Philippines experience*. Metro Manila, Philippines, Maya Farms Division, Liberty Flour Mills, 1978.

33. Mehta, M.M. et al. *Biogas utilization in tractor diesel engines for stationary applications*. Faridabad, Escorts Scientific Research Centre, n.d. 12 p.

34. Moulik, T.K. "Promoting biogas technology in the villages : Experiences in Gujarat". Presented at : National Symposium on biogas technology and usage held in New Delhi, November 29-30, 1977. *In : National Symposium on biogas technology and usage : Abstracts of papers and major recommendations*, p. 52 - 53. New Delhi, Indian Agricultural Research Institute, 1979.

35. Moulik, T.K. and U.K. Srivastava. *Biogas plants at the village level : problems and prospects in Gujarat*. Ahmedabad, Indian Institute of Management, Centre for Management in Agriculture, 1975.

36. Moulik, T.K. et al. *Biogas system in India : A socio-economic evaluation*. Ahmedabad, Centre for Management in Agriculture, Indian Institute of Management, n.d.

37. Myles, Raymond and Singh, J.B. "Promotion of biogas plants for small and marginal farmers on individual and community basis". Presented at : AFPRO seminar on integrated approach to agricultural development held in Bangalore, October 3-5, 1979. 11 p.

38. Parikh, Jyoti K. "Renewable energy options : What could developing countries expect from them?". *Energy*, Vol. 4, No. 5, 1979, p. 989 - 994.

39. Parikh, Jyoti K. and Kirit S. Parikh. "Mobilization and impacts of biogas technologies". Energy, Vol. 2, no. 4, 1977, p. 441-455.

40. Parikh, P.P. and C.K. Jain. "Gobar gas as supplementary fuel for diesel engines". Urja, April 1977, p. 27-29.

41. Patankar, G.L. Plastics in setting up of a gobar gas plant. Bombay, Gobar Gas Research Division, Khadi and Village Industries Commission, n.d.

42. Patankar, G.L. Recent developments in gobar gas technology. Bombay, Khadi and Village Industries Commission, Gobar Gas Development Centre, 1976 - 1977.

43. Patankar, G.L. Substitute material for biogas holder. 1979.

44. Patel, Jashbhai J. "Gobar gas plant - fuel and manure from organic wastes". Presented at : FAI/FAO National Seminar on optimising agricultural production under limited availability of fertilizers. 13 p.

45. Prasad, C.R. et al. "Biogas plants : prospects, problems and tasks". Economic and Political Weekly, Vol. 9, nos. 32-34, August 1974, p. 1347-1364.

46. Ru-Chen, Chen. "Development of biogas utilization in China". Natural Resources Forum, Vol. 5, No. 3, July 1981, p. 277 - 282.

47. Sathianathan, M.A. Biogas : Achievements and challenges. New Delhi, Association of Voluntary Agencies for Rural Development, 1975.

48. Sathianathan, M.A. Biogas '81. New Delhi, Association of Voluntary Agencies for Rural Development, In Print.

49. Singh, K.N. "Extension aspects of cow dung gas plant". Presented at : National symposium on biogas technology and usage held in New Delhi, November 29-30, 1977. In : National Symposium on biogas technology and usage : Abstracts of papers and major recommendations, p. 48-51. New Delhi, Indian Agricultural Research Institute, 1979.

50. Subramanian, S.K. Biogas systems in Asia. New Delhi, Management Development Institute, 1977.

51. Subrahmanyam, P.V.R. "Digestion of night soil and aspects of public health". Background paper for the Workshop on Biogas Systems held in New Delhi, February 28-March 4, 1977.

52. Tata Energy Research Institute. Biogas technology handbook. Bombay, TERI, To be published.

53. United Nations Conference on New and Renewable Sources of Energy. "Report of the Technical Panel on Biomass Energy on its second session". Presented at : 3rd session of Preparatory Committee, held 30 March - 17 April 1981. (A/CONF-100/PC/28, 28 January 1981).

54. United Nations Industrial Development Organization. Appropriate industrial technology for energy for rural requirements. New York, United Nations, 1979, p. 58 - 62.

55. Private communication from the Agricultural Finance Corporation Limited, Bombay, 1980.

APPENDIX

Table A : Status of Biogas Activities Worldwide (Ref. 13)

Countries	Remarks
Algeria	R & D projects in experimental stage
Australia	Animal and crop residues used for fuel production
Bangladesh	Development of rural community-size plants for energy and fertilizer production
Barbados	Bioenergy and fertilizer production
Cameroun	Rural development
Canada	Fermentation of straw for methane production
China, People's Republic of	Fertilizer and energy production; family-sized plants
Congo	R & D projects under way
Cook Islands	Integrated biogas farming systems
Costa Rica	R & D projects
Ecuador	Biogas utilized in cooperative farms
El Salvador	Biogas generation from coffee wastes
Ethiopia	Rural development scheme
Fiji	Integrated farming system with algal and fish ponds for protein and fertilizer production
France	Manure used for methane and fertilizer
Guatemala	Biogas from piggery wastes and straw
Guyana	Bioenergy production
Honduras	Biogas as alternative to wood fuel
India	Biogas in rural households
Indonesia	Experimental and training activities
Iran	Promotion of public health programs through community-size biogas plants
Jamaica	Bioenergy production
Japan	Pollution control
Korea, Republic of	Feed and fertilizer production
Lesotho	Rural development
Malaysia	Biogas technology for rural electrification
Mauritiue	Cane sugar residue used for biogas
Nepal	Bioenergy and fertilizer production
Netherlands	Piggery effluents used for methane production
New Zealand	Animal and crop residues used for methane production
Nicaragua	Biogas used as fuel
Pakistan	Fertilizer production
Papua New Guinea	Fertilizer production
Philippines	Algal oxidation ponds; fertilizer production
Rwanda	Biogas for domestic use
Senegal	Rural electrification and domestic use
Singapore	Experimental and training activities
Sri Lanka	Rural development and energy centers
Thailand	Rural cooking and electrification
Trinidad	Energy and fertilizer from biogas
Tanzania	Fuel and fertilizer production
United Kingdom	Optimization of biogas from sewage sludge
Upper Volta	Village development scheme
USA	Development of mobile demonstration units for rural areas
Zambia	Biogas on family farms
Zaire	Laboratory experiments in progress

Table 8 : Biogas Activities of International Organizations (Ref. 13)

UN Agencies	Area and Remarks
Economic and Social Commission for Asia and the Pacific (ESCAP)	Projects on bio-energy technology and integrated biogas systems through workshops-Manila, New Delhi, Bangkok, Suva
Food and Agricultural Organization (FAO)	Compedium of technologies in agro-industrial residue utilization and world directory of research institutions Workshops, study tours and field projects on organic recycling including biogas production in Afghanistan, China, Nepal, Papua New Guinea and Indonesia
United Nations Development Program (UNDP)	National projects in Leosotho, Philippines and Tanzania
United Nations Environment Program (UNEP)	Environment management; Rural energy program, photosynthesis, village projects
United Nations Educational Scientific and Cultural Organization (UNESCO)+	Promotion of basic and applied microbiological research through training courses
United Nations Childrens Fund (UNICEF)	Provision of basic services to children via village and rural biogas systems
United Nations Industrial Development Organization (UNIDO)	Provision of information and assistance in mobilization of existing technology for integrated development
United Nations Institute for Training and Research (UNITAR)	Provision of specialized training
United Nations University (UNU)	Program on bioconversion of organic residues for rural development in improving agricultural yield and managing natural resources
World Health Organization (WHO)	Specialized technical bulletins in sanitation and composting technologies
Other Agencies	
Commonwealth Science Council (CSC)	Rural development and alternative energy program
Inter-American Bank (IDB)	Intermediate technology program on fuel production from agricultural and animal wastes for Central America
International Development Research Center (IDRC)	Support of research projects: social and economic evaluation of Biogas Technology

+ Activities carried out in close cooperation with other UN Agencies, as well as :

International Cell Research Organization (ICRO)

International Federation of Institutes for Advanced Studies (IFIAS)

ESCAP.

Useful data

- Table C : Availability of dung (green) per stable bound medium size animal : (Ref. 9)

Animal	Dung available per day
Buffalo	14 kg
Cow	10 kg
Calves	4 kg

- Table D : Production of biogas from different types of raw material : (Ref. 27)

Material	Amount of gas (m^3 /kg of fresh material)	
	Winter	Summer
Cattle dung	0.036	0.092
Night soil	-	0.04
Pig dung	0.07	0.10
Poultry droppings	0.07	0.16

- Table E : Quantity of dung required for various plant sizes : (Ref. 27)

Size of plant (gas production/ day) (m^3)	Amount of wer dung required (kg)	No. of animals
2	35 - 40	2 - 3
3	45 - 50	3 - 4
4	55 - 60	4 - 6
6	80 - 100	6 - 10
8	120 - 150	12 - 15
10	160 - 200	16 - 20

- Replacement value of different fuels by 1 m^3 of biogas (Ref. 6, 9)

1 m^3 of Biogas = Alcohol - 1.1 litres
= Butane - 0.43 kg
= Cattle dung cake - 12.30 kg
= Charcoal - 1.4 kg
= Crude oil - 0.6 litre
= Diesel oil - 0.52 litre
= Electricity - 4.7 kWh
= Firewood - 3.47 kg
= Gasoline - 0.8 litre
= Kerosene - 0.62 litre
= LPG - 1 lb
= Soft Coal - 1.6 kg
= Town Gas - 1.5 m^3

<u>Formulae for calculation of</u> -

1. Biogas potential 'P' of a village : (Ref. 44)

$$P = N_A X_D Y_D + N_p \; X \; N_S Y \; N_S + \sum W_i Y_i$$

where N_A and N_p = cattle and human population;

X_D and XN_S = average daily collected yield per unit weight of dung and night soil.

Y_D and YN_S = gas yield per unit weight of dung and night soil.

W_i = total daily available weight of fermentable cellulosic waste of type 'i'.

Y_i = corresponding gas yield per unit weight of the cellulosic waste 'i'.

(Parameters in the above equation will vary from place to place)

2. Annual capital cost 'c' of installation of biogas plant :(Ref.44)

$$C = \frac{i(I+i)\ ne}{(I+i)\ neI}$$

where C = annual cost
I = Investment
i = interest rate
ne= life span

3. **Annual maintenance cost 'M' of a biogas plant (Ref. 44)**

$$M = \frac{i}{(I+i)\ nm - 1}$$

where S = sum to be accrued at the end
of $nm = 2$ years for painting.

4. Annual labour cost 'L' (Ref. 44)

$L = n_L \times W \times 365$ where n_L = number of men required to operate the plant.

W = daily wage.