Biogas generation: developments, problems, and tasks - an overview

E.J. DaSilva

Division of Scientific Research and Higher Education, Unesco, Paris, France

Introduction

In recent years, biogas systems have attracted considerable attention as a promising approach to decentralized rural development. Developed and developing countries and several international organizations have shown interest in biogas systems with respect to various objectives: a renewable source of energy, bio-fertilizer, waste recycling, rural development, public health and hygiene, pollution control, environmental management, appropriate technology, and technical cooperation. Within the context of the UNEP/Unesco/ICRO microbiology programme, which is sponsored jointly by the United Nations Environment Programme, Unesco, and the International Cell Research Organization, several workshops have already been held in Yogyakarta, Manila, Mexico City, Singapore, and Bangkok, in an attempt to catalyze the applications of this acknowledged low-cost, non-waste-producing technology that is increasingly being deployed to manage the environment and to ameliorate the search for substitute sources of fuel, food, and fertilizer (1 - 4). Early in 1979, in joint co" operation with IFIAS and ESCAP/UNIDO, a workshop will be held at Bandung to deal specifically with village micro" biology and the integrated biogas farming system. In this context, it is hoped that this activity on "The State of the Art of Bioconversion of Organic Residues for Rural Communities," a UN University joint World Hunger-Natural Resources activity receiving Unesco and UNEP/Unesco/ ICRO Panel support, will be making a significant contribution to the application of bioconversion processes for rural communities.

The utilization of microbial activity to treat agricultural, industrial, and domestic wastes has been common practice for a half century. Treatment includes the aerobic, activated sludge process and the anaerobic or methane fermentation method; the latter is simple, does not require imported know-how or components, is suited to small family or village-scale digestion, and is the only process utilizing waste as a valuable resource. Of great importance to the developing countries, the use of methane has, until recently, been restricted because of public antipathy or because other, cheaper energy sources were available. But, biogas technology today is a sufficiently significant producer of energy to command the attention of a fair number of countries (5) and agencies.

What is biogas?

Methane is the main constituent of what is popularly known as biogas. A colourless, odourless, inflammable gas, it has been referred to as sewerage gas, klar gas, marsh gas, refuse-derived fuel (RDF), sludge gas, will-o'-the-wisp of marsh lands, fool's fire, gobar gas (cow dung gas), bioenergy, and "fuel of the future." The gas mixture produced is composed roughly of 65 per cent CH_4, 30 per cent CO_2, and 1 per cent H_2S. A thousand cubic feet of processed biogas is equivalent to 600 cubic feet of natural gas, 6.4 gallons of butane, 5.2 gallons of gasoline, or 4.6 gallons of diesel oil. For cooking and lighting, a family of four would consume 150 cubic feet of biogas per day, an amount that is easily generated from the family's night soil and the dung of three cows. In addition, rural housewives using the biofuel are spared the irritating smoke resulting from the combustion of firewood, cattle dung cakes, and the detritus of raw vegetables (Figure 1).

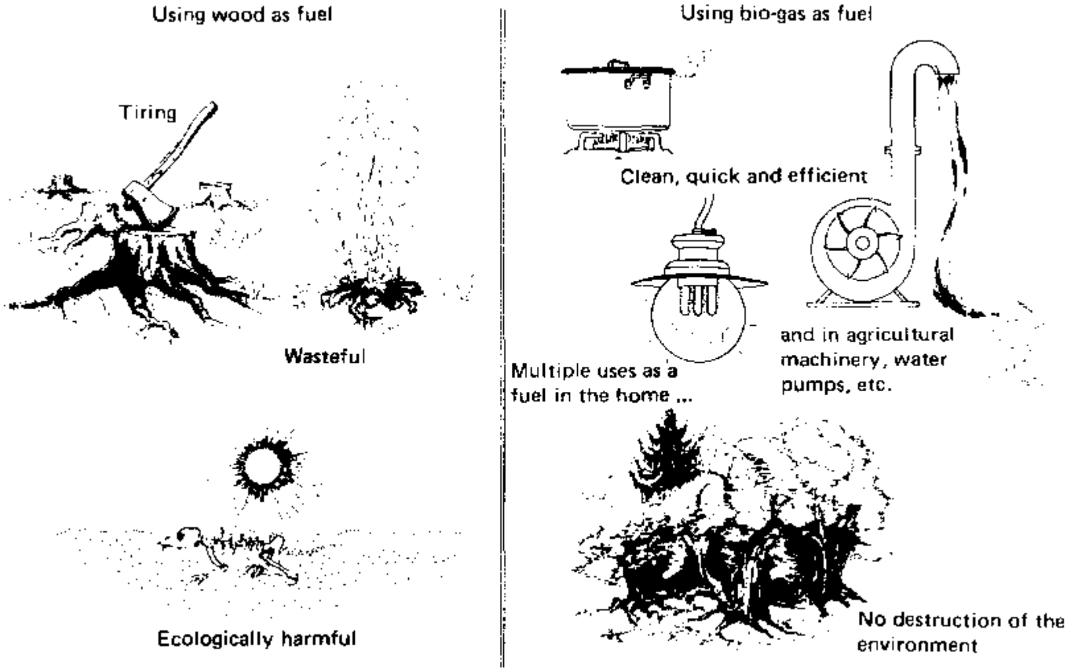


Figure 1. The Attributes of Biogas as a Fuel vs. the Disadvantages of Wood (Source: Bio-Gas Newsletter, August 1976)

Microbiology of CH_4, or bio-methanogenesis

Anaerobic digestion technology or the methane-generating bioconversion yields both fuel (biogas) and organic fertilizer (sludge), products that are the final result of microbial action on cellulosic and other non-chemically processed organic residues. These substrates are obtained through a series of degradative steps that involve a variety of bacteria (6 11). In the first step, complex polymeric organic substrates - proteins, carbohydrates, and fats - are transformed by non-methanogenic bacteria into essentially non-methanogenic substrates like butyrate, propionate, lactate, and alcohol. Through a second step that involves the acetogenic bacteria, the composition and identity of which still remain to be determined, these compounds are transformed into methanogenic substrates, i.e., acetate, H_2 and C1 compounds that are converted into CH_4 and CO_2 by the methane bacteria, obligate anaerobes that multiply in a neutral or slightly alkaline environment.

That the smooth cooperation of the three groups of bacteria has to be well regulated is exemplified by Bryant's discovery (12) of two mutually inter-dependent species existing in a symbiotic association that was formerly considered a pure culture under the name of Methanobacillus omelianskii. The association is comprised of two symbionts: an acetogenic organism and a methanogenic organism. The acetogen produces acetate and H_2 and CO_2, thereby disrupting the process of auto-inhibition with the acetogen, which succumbs to the H_2 it produces.

Again, it is necessary that both aspects of the anaerobic digestion process - liquefaction and gasification - be well balanced. If the methane bacteria are absent, the digestion process may only succeed in liquefying the material and may render it more offensive than the original material. On the other hand, if liquefaction occurs at a faster rate than gasification, the resultant accumulation of acids may inhibit the methane bacteria and the bioconversion process as well.

The biogas plant – some technical considerations

The biogas plant consists of two components: a digester (or fermentation tank) and a gas holder. The digester is a cube-shaped or cylindrical waterproof container with an inlet into which the fermentable mixture is introduced in the form of a liquid slurry. The gas holder is normally an airproof steel container that, by floating like a ball on the fermentation mix, cuts off air to the digester (anaerobiosis) and collects the gas generated. In one of the most widely used designs (Figure 2), the gas holder is equipped with a gas outlet, while the digester is provided with an overflow pipe to lead the sludge out into a drainage pit.

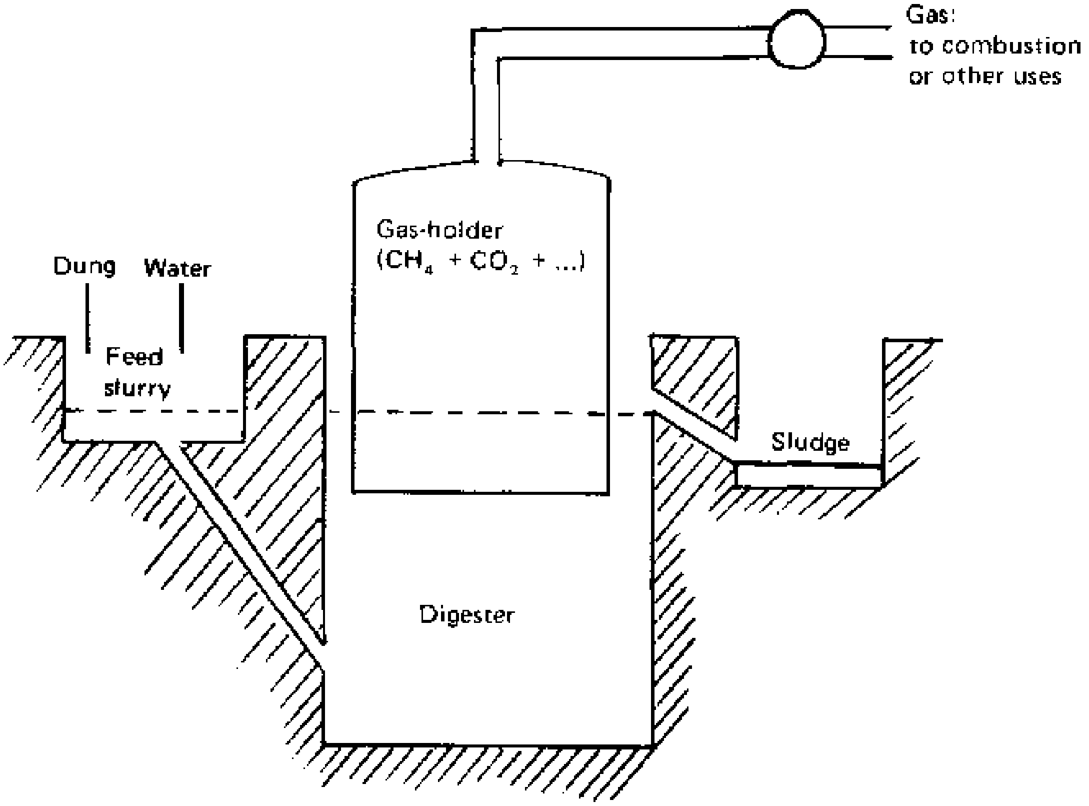


Figure 2. Diagram of Gobar-Gas Plant Used to Obtain Methane from Dung by Anaerobic Fermentation (After Prasad et al. [20]1

The construction, design, and economics of biogas plants have been dealt with in the literature (13 - 21). For biogas plant construction, important criteria are: (a) the amount of gas required for a specific use or uses, and lb) the amount of waste material available for processing. Fry (17)

Singh (21), and others (1, 3) have documented several guidelines for consideration in the designing of batch (periodic feeding) and continuous (daily feeding) compartmentalized and non-compartmentalized biogas plants that are of either the vertical or horizontal type. In addition, Loll (18) has recently dealt with the scientific principles, process engineering, and shapes of digestion reactors, and with the economics of the technology.

Digester reactors are constructed from brick, cement, concrete, and steel. In Indonesia, where rural skills in brick making, brick laying, plastering, and bamboo craft are well established, clay bricks have successfully replaced cement blocks and concrete. In areas where the cost is high, the "sausage" or bag digester (14) appears to be ideal (Figure 3). The digester is constructed of 0.55 mm thick Hypalon laminated with Neoprene and reinforced with nylon. The bag is fitted with an inlet and an outlet made from PVC. Even if imported from the United States, the cost of the digester and the gas holder (both combined in one bag) is only 10 per cent of that for a concrete-steel digester. Another advantage is that it can be mass produced and is easily mailed. In rural areas, the whole installation is completed in a matter of minutes. A hole in the ground accommodates the bag, which is filled two-thirds full with waste water. Gas production fully inflates the bag, which is weighted down and fitted with a compressor to increase gas pressure.

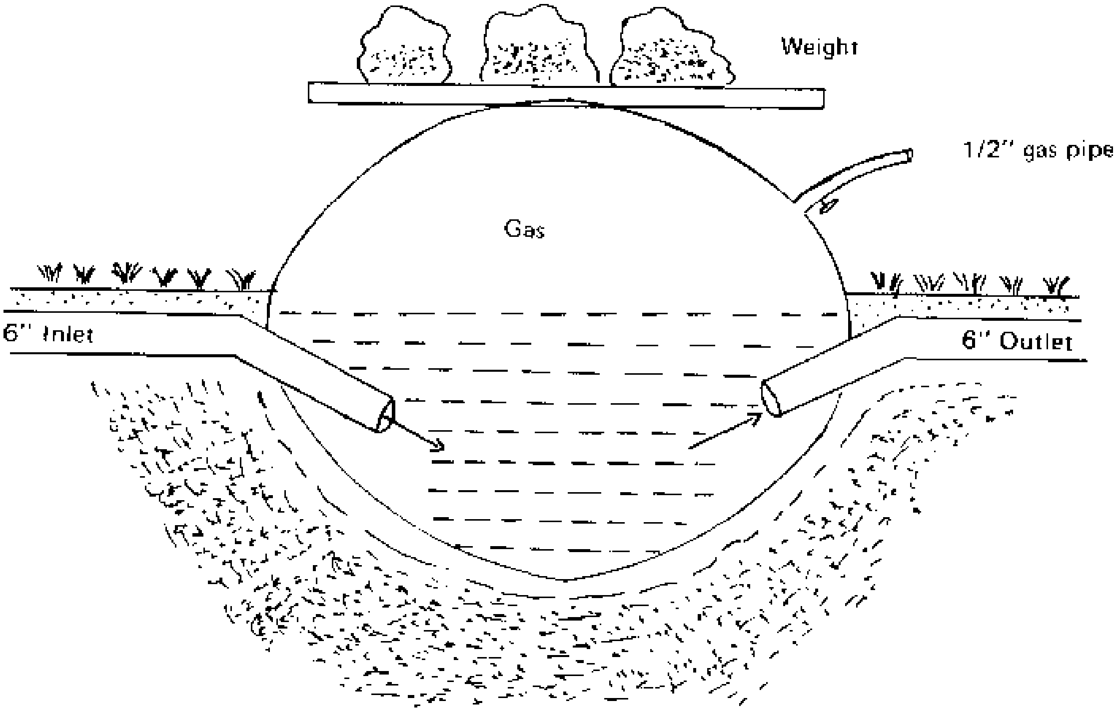


Figure 3. Diagrammatic Sketch of the "Sausage" Bag Digester Made of Hypalon Laminated with Neoprene

Environmental and operational considerations

Raw Materials (19)

Raw materials may be obtained from a variety of sources - livestock and poultry wastes, night soil, crop residues, food-processing and paper wastes, and materials such as aquatic weeds, water hyacinth, filamentous algae, and seaweed. Different problems are encountered with each of these wastes with regard to collection, transportation, processing, storage, residue utilization, and ultimate use. Residues from the agricultural sector such as spent straw, hay, cane trash, corn and plant stubble, and bagasse need to be shredded in order to facilitate their flow into the digester reactor as well as to increase the efficiency of bacterial action. Succulent plant material yields more gas than dried matter does, and hence materials like brush and weeds need semi-drying. The storage of raw materials in a damp, confined space for over ten days initiates anaerobic bacterial action that, though causing some gas loss, reduces the time for the digester to become operational.

Influent Solids Content (16, 19, 21)

Production of biogas is inefficient if fermentation materials are too dilute or too concentrated, resulting in, low biogas production and insufficient fermentation activity, respectively. Experience has shown that the raw-material (domestic and poultry wastes and manure) ratio to water should be 1:1, i.e., 100 kg of excrete to 100 kg of water. In the slurry, this corresponds to a total solids concentration of 8 - 11 per cent by weight.

Loading (14, 19)

The size of the digester depends upon the loading, which is determined by the influent solids content, retention time, and the digester temperature. Optimum loading rates vary with different digesters and their sites of location. Higher loading rates have been used when the ambient temperature is high. In general, the literature is filled with a variety of conflicting loading rates. In practice, the loading rate should be an expression of either (a) the weight of total volatile solids (TVS) added per day per unit volume of the digester, or (b) the weight of TVS added per day per unit weight of TVS in the digester. The latter principle is normally used for smooth operation of the digester.

Seeding (14, 19)

Common practice involves seeding with an adequate population of both the acid-forming and methanogenic bacteria. Actively digesting sludge from a sewage plant constitutes ideal "seed" material. As a general guideline, the seed material should be twice the volume of the fresh manure slurry during the start-up phase, with a gradual decrease in amount added over a three-week period. If the digester accumulates volatile acids as a result of overloading, the situation can be remedied by reseeding, or by the addition of lime or other alkali.

pH (14, 19)

Low pH inhibits the growth of the methanogenic bacteria and gas generation and is often the result of overloading. A successful pH range for anaerobic digestion is 6.0 - 8.0; efficient digestion occurs at a pH near neutrality. A slightly alkaline state is an indication that pH fluctuations are not too drastic. Low pH may be remedied by dilution or by the addition of lime.

Temperature (13,14,19, 21)

With a mesophilic flora, digestion proceeds best at 30ºC - 40ºC; with thermophiles, the optimum range is 50ºC - 60ºC. The choice of the temperature to be used is influenced by climatic considerations In general, there is no rule of thumb, but for optimum process stability, the temperature should be carefully regulated within a narrow range of the operating temperature. In warm climates, with no freezing temperatures, digesters may be operated without added heat. As a safety measure, it is common practice either to bury the digesters in the ground on account of the advantageous insulating properties of the soil, or to use a greenhouse covering. Heating requirements and, consequently, costs, can be minimized through the use of natural materials such as leaves, sawdust, straw, etc., which are composted in batches in a separate compartment around the digester,

Nutrients (13,17,19, 21)

The maintenance of optimum microbiological activity in the digester is crucial to gas generation and consequently is related to nutrient availability. Two of the most important nutrients are carbon and nitrogen and a critical factor for raw material choice is the overall C/N ratio.

Domestic sewage and animal and poultry wastes are examples of N-rich materials that provide nutrients for the growth and multiplication of the anaerobic organisms. On the other hand, N-poor materials like green grass, corn stubble, etc., are rich in carbohydrate substances that are essential for gas production. Excess availability of nitrogen leads to the formation of NH3, the concentration of which inhibits further growth. Ammonia toxicity can be remedied by low loading or by dilution. In practice, it is important to maintain, by weight, a C/N ratio close to 30:1 for achieving an optimum rate of digestion. The C/N ratio can be judiciously manipulated by combining materials low in carbon with those that are high in nitrogen, and vice versa.

Toxic Materials (13,14,19)

Wastes and biodegradable residue are often accompanied by a variety of pollutants that could inhibit anaerobic digestion. Potential toxicity due to ammonia can be corrected by remedying the C/N ratio of manure through the addition of shredded bagasse or straw, or by dilution. Common toxic substances are the soluble salts of copper, zinc, nickel, mercury, and chromium. On the other hand, salts of sodium, potassium, calcium, and magnesium may be stimulatory or toxic in action, both manifestations being associated with the cation rather than the anionic portion of the salt. Pesticides and synthetic detergents may also be troublesome to the process.

Stirring (13,14,17 - 19, 21)

When solid materials not well shredded are present in the digester, gas generation may be impeded by the formation of a scum that is comprised of these low-density solids that are enmeshed in a filamentous matrix. In time the scum hardens, disrupting the digestion process and causing stratification. Agitation can be done either mechanically with a plunger or by means of rotational spraying of fresh influent. Agitation, normally required for bath digesters, ensures exposure of new surfaces to bacterial action, prevents viscid stratification and slow-down of bacterial activity, and promotes uniform dispersion of the influent materials throughout the fermentation liquor, thereby accelerating digestion.

Retention Time (19, 21)

Other factors such as temperature, dilution, loading rate, etc., influence retention time. At high temperature bio-digestion occurs faster, reducing the time requirement. A normal period for the digestion of dung would be two to four weeks.

Developments and processes for rural areas

Two years ago, the Economic and Social Council of the United Nations adopted a survey, presented in 1978 to the Committee on Science and Technology for Development, listing the on-going research and development in unconventional sources of energy. From the point of view of the developing countries, it is heartening to note that the "use of farm wastes to produce methane" has also been identified in the United Nations World Plan of Action for the Application of Science and Technology to Development.

The Economic and Social Council for Asia and the Pacific, moreover, adopted the Colombo Declaration at its thirtieth session, which determined that the most urgent priorities for action are in the fields of food, energy, raw materials, and fertilizers, and that these priorities would be best met by the integrated biogas system (IBS).

An integrated system aims at the facile generation of fertilizer and acquisition of energy, production of protein via the growth of algae and fish in oxidation ponds, hygienic disposal of sewage and other refuse, and is a tangible effort to counteract environmental pollution. The heart of the system is the biogas process; it has the potential to "seed" self-reliance in relatively primitive economies (14, 22, 23). Allied benefits include the development of rural industry, the provision of local job opportunities, and the progressive eradication of hunger and poverty (Figures 4 - 7).

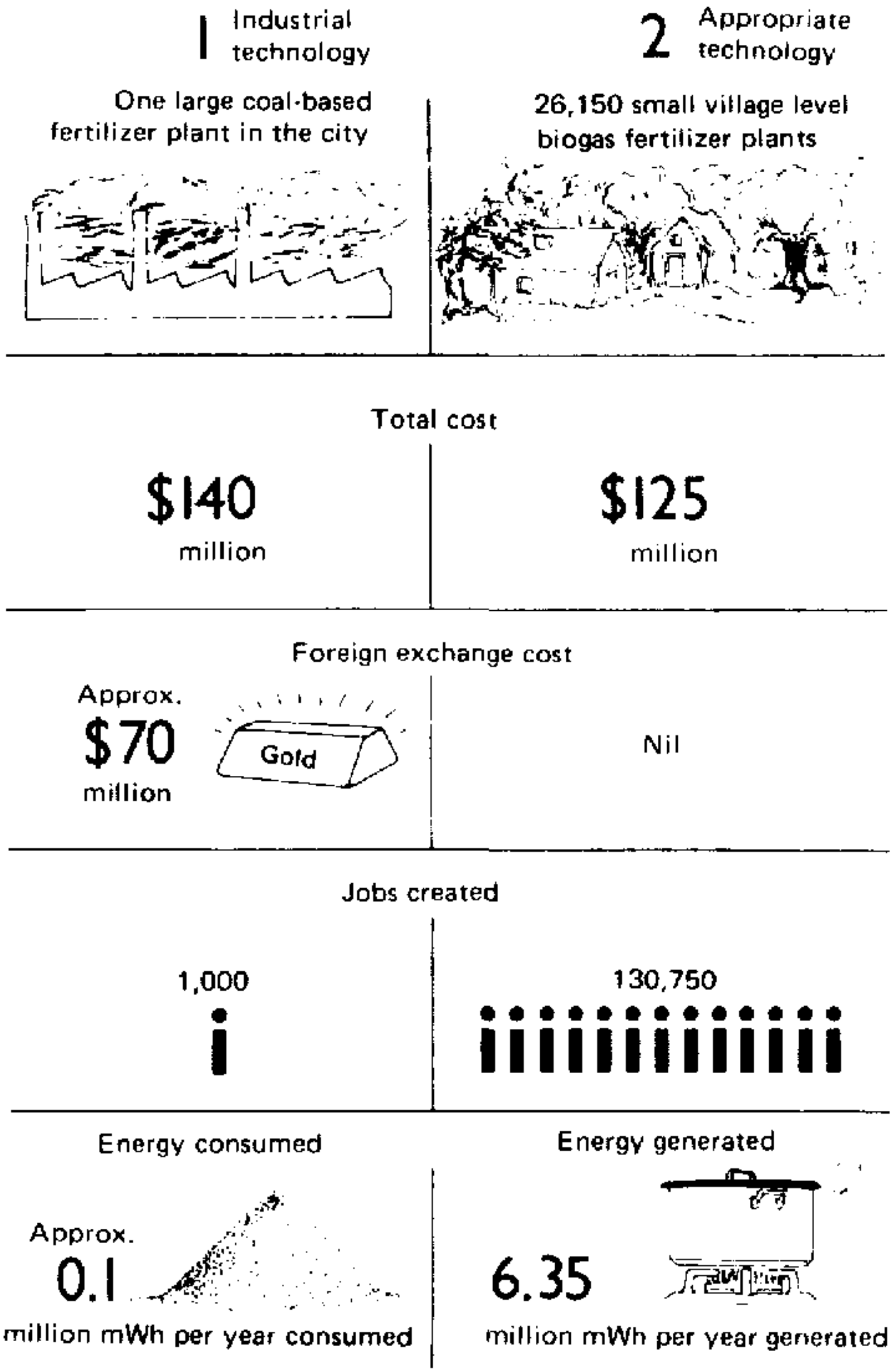
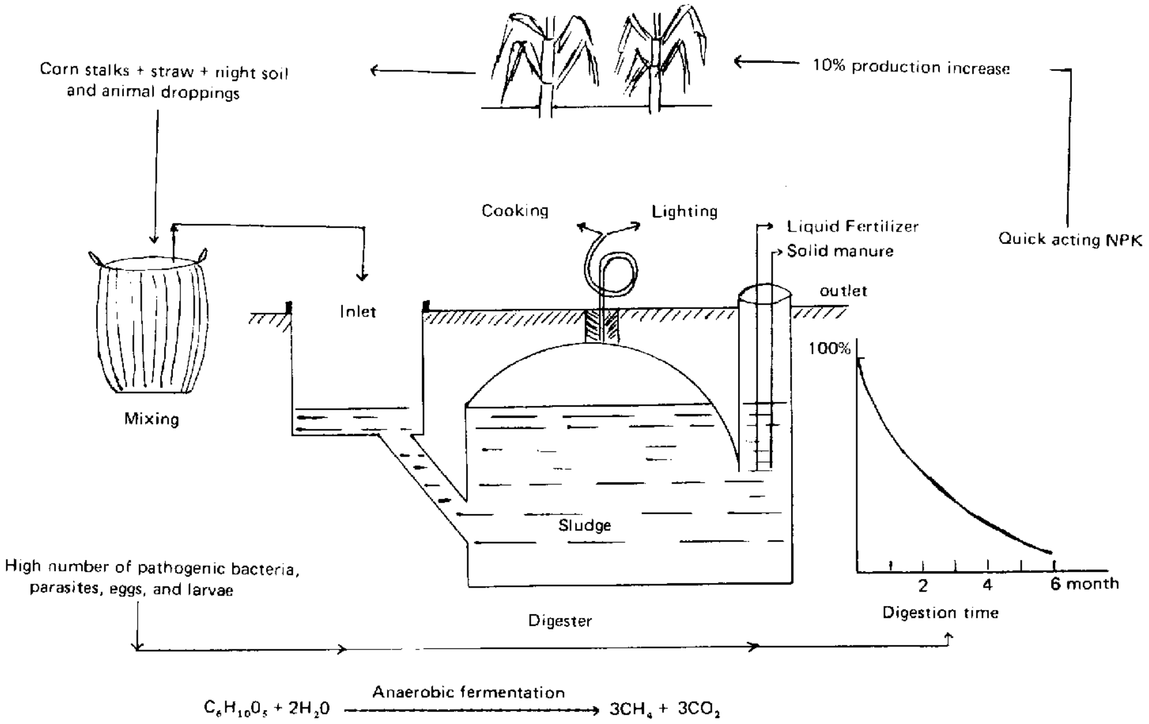


Figure 4. Two Ways of Increasing Fertilizer Production Target: 230,000 tons of nitrogen fertilizer per year. (Adapted from A.K.N. Reddy, Uniterra, Vol. 1, 1976)



$$C_6H_{10}O_5 + 2H_2O \xrightarrow{\text{Anaerobic fermentation}} 3CH_4 + 3CO_2$$

Figure 5. Biogas Cycle in China (Source: FAO Soils Bulletin 40, Rome, 1977)

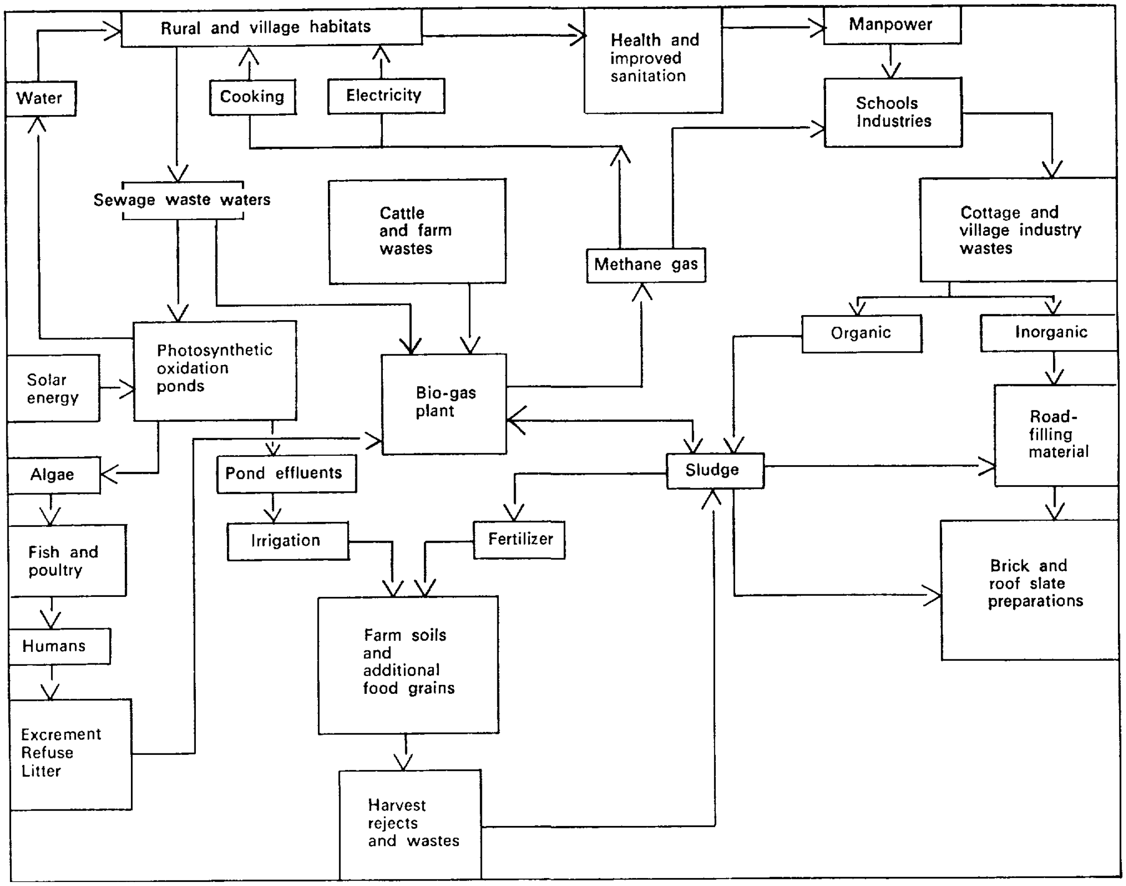


Figure 6. Interactive Loop of Rural or Village Farming System Based on Biogas or Methane Economy

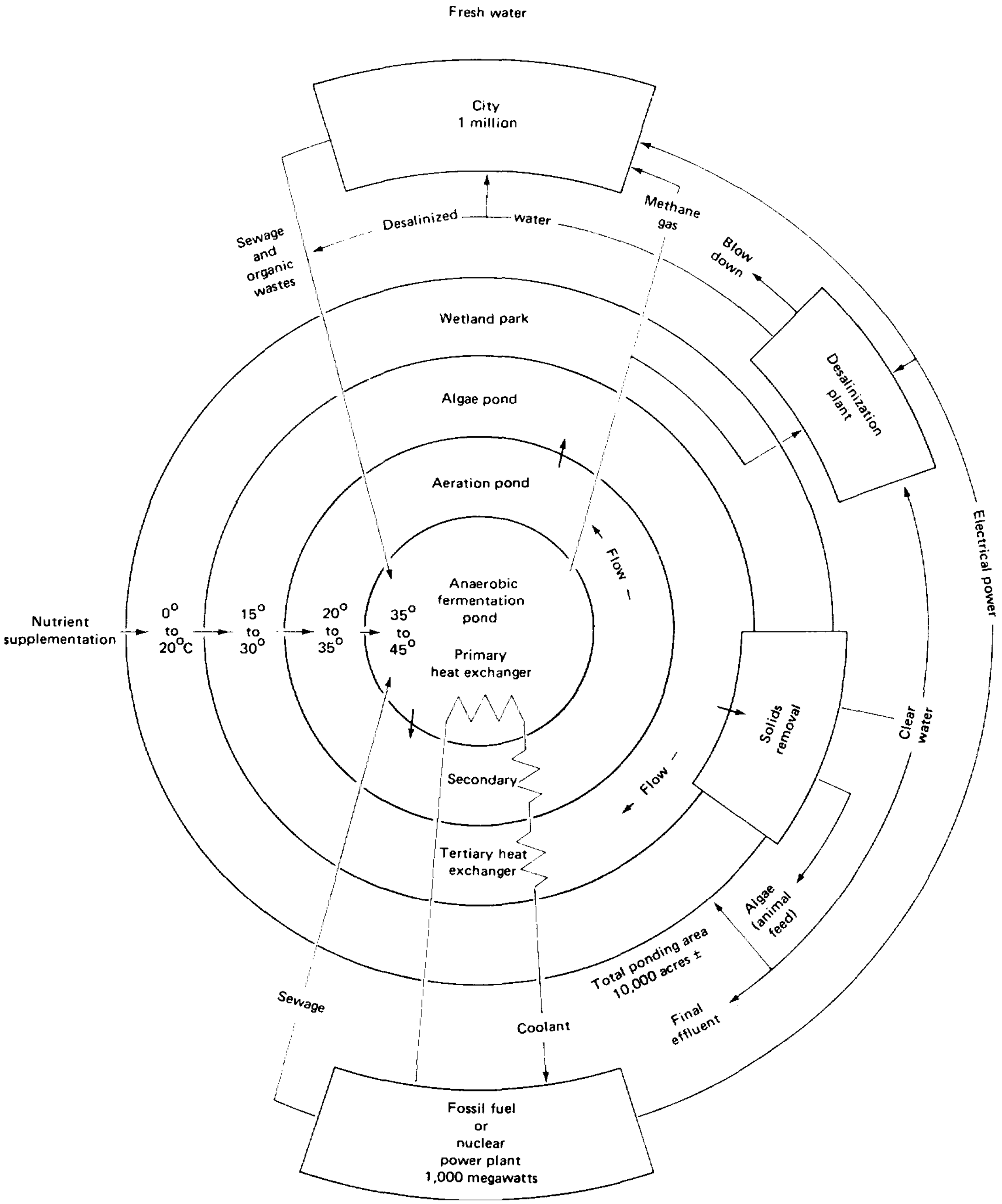


Figure 7. A Proposed Integrated Nuclear Cooling and Organic Waste Disposal System (After W. Oswald, University of California)

The coupling of a photosynthetic step (24 - 26) with digestion provides for the transformation of the minerals left by digestion directly into algae that can then be used as fodder, as feed for fish, as fertilizer, or for increased energy production by returning them to the digester process (Figure 8).

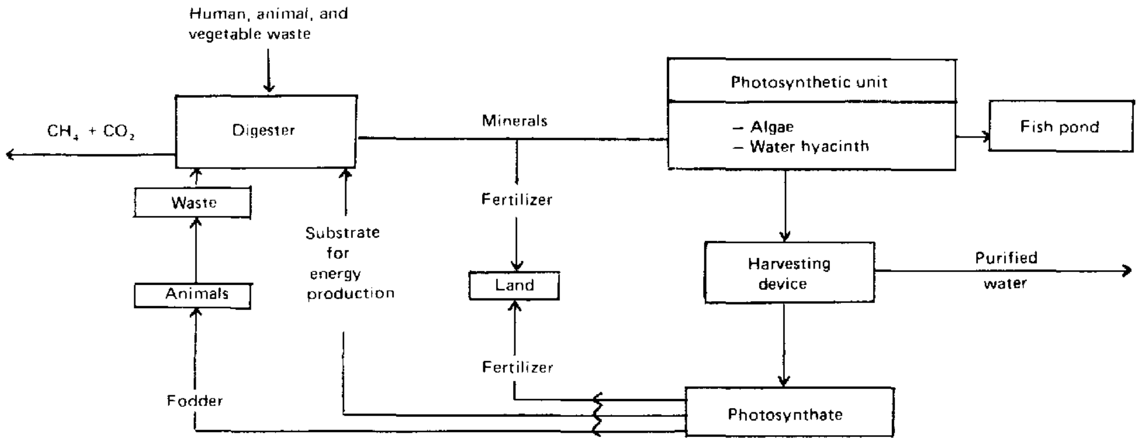


Figure 8. Simplified Scheme Indicating Various Combinations of Digestion and Photosynthesis for Fodder, Fertilizer, and Fuel Production (After J.W.M. LaRivière, J. Sci. Soc., Thailand, 1977)

The IBS aims at putting back into soil and water what has been taken from them, and increasing the amounts of nutrients by fixing CO2 and N2 from the atmosphere into the soil and water through photosynthesis by algae. Involving low cash investments on a decentralized basis, the implementation of IBS provides employment to the whole work force without disruption of the rural structure. Furthermore, it is an apt example of soft technology that does not pollute or destroy the physical environment. At the College of Agriculture of the University of the Philippines, preliminary work on a small scale has begun. In England, an Eco-house (Figure 9) has been built by Graham Caine on the Thames Polytechnical Playing Fields at Eltham, southeast of London. Results on the project, however, are not yet available.

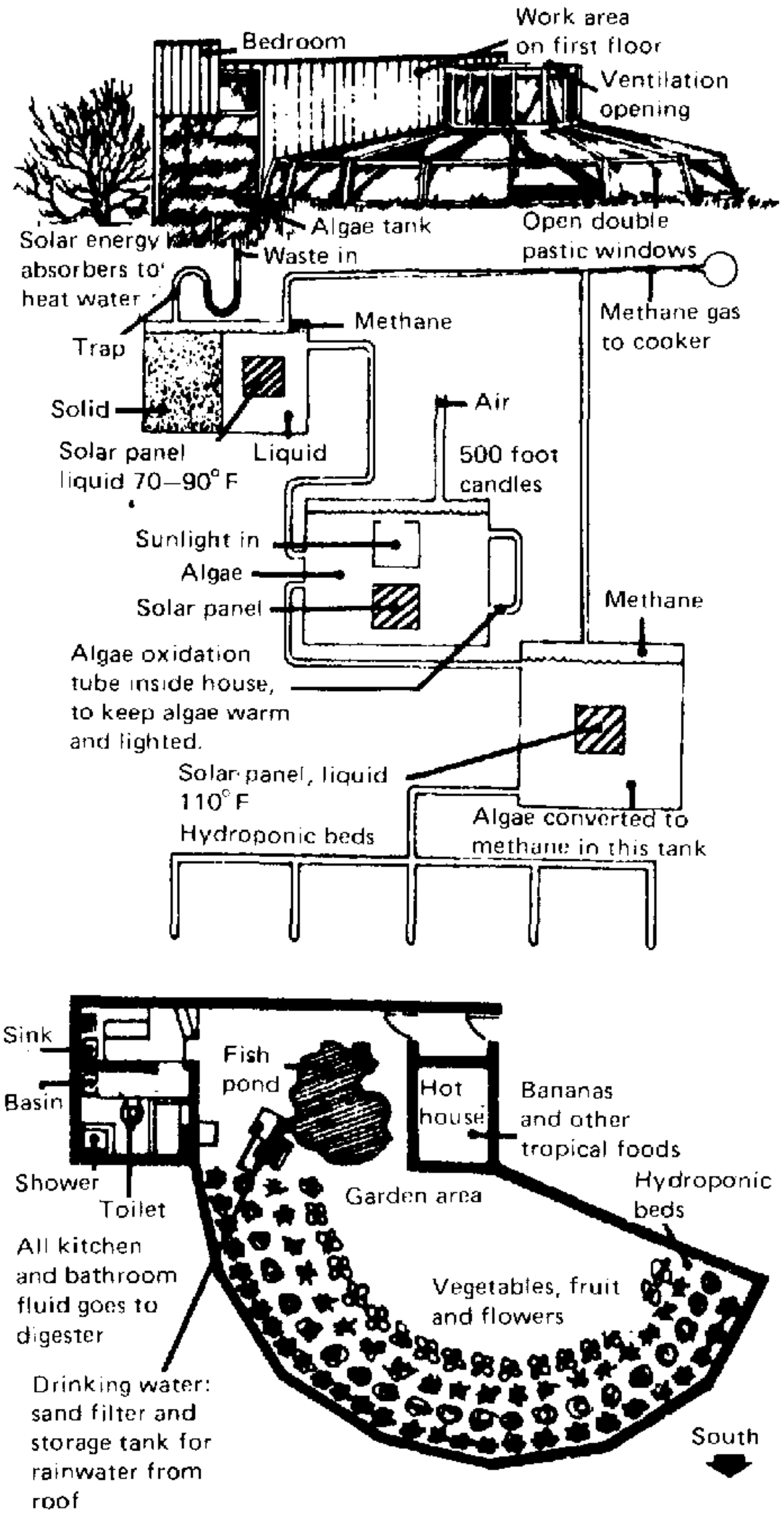


Figure 9. Graham Caine Eco-House (Reprinted with permission from Mother Earth News, No. 20 [March 1973], p. 62)

Cost-benefit analyses

There is no general answer to the economic feasibility of biogas production. National economic considerations play an important role. In Korea, wood is in short supply (27) and domestic fuel substitutes like rice and barley straw, and coal and oil could be conserved; wood could be a foreign-exchange earner in the field of handicrafts. In India, transportation costs of coal and oil to the rural areas is high and an extra burden on an already poor farmer.

The consumption of commercial and non-commercial energy for the whole of India, as determined for the period 1960 - 1971 by the Fuel Policy Committee Report, is provided in Table 3.

TABLE 3. Consumption of Commercial and Non-Commercial Energy in India

Year	Coal (M Tons)	Oil (M Tons)	Electricity (Billion kwh)	Firewood (M Tons)	Cow dung (M Tons)	Vegetable waste (MTons)
1960 - 61	47.1	6.75	16.9	101.04	55.38	31.08
1965 - 66	64.2	9 94	30.6	111.82	61.28	34.41
1970 - 71	71 1	14 95	48.7	122.75	67.28	37.77

Sources: Report of the Fuel Policy Committee,1974; S.N. Ghosh, Invention Intelligence 12:63 (1977).

The rural share in the energy consumption of electricity and coal is not considerable because, as the Report of the Panel of the National Committee of Science and Technology on Fuel and Power indicates, the large towns and cities with populations of 500,000 and more accommodate only 6 per cent of India's total population but consume about 50 per cent of the total commercial energy produced in the country.

In the villages, however, kerosene is used for lighting, but it is clear that with increasing population, biogas generation seems to offer solutions in the areas of fuel availability, electricity, fertilizer for cash crops, and would provide other socio-economic benefits.

On the other hand, cost-benefit analyses of methane generation vary widely, depending upon 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. Several factors have been listed in the economics of biogas generation (14, 17 - 19, 28). An appropriate example is the fact that a village-model gas plant, which cost Rs 500 some years ago, cost Rs 1,500 in 1974 and Rs 2,000 in 1977. Hence, a significant problem is whether rural people who cannot spend Rs 2,000 can cope with increasing inflationary and digester construction material costs.

The Khadi and Village Industries Commission has helped to tackle the problem through rural community co-operation and a scheme of subsidies and loans to encourage individual families, groups of families, institutions, and communities to construct biogas plants. An analysis of cost and income for a plant producing $3m^3$/day is given in Table 4. The net annual income of approximately US$60 shows that the capital investment of US$340 can be recouped in about six years. There are also incidental advantages of hygienic improvement, the absence of smoke and soot in gas burning, convenience in burning, and the increased richness of manure.

TABLE 4. Cost-Benefit Analysis of Khadi and Village Industries Commission Plant (in US dollars)

a. Capital cost	
Gas holder and frame	$ 93.5
Piping and stove	$ 34 7
Civil engineering construction (tank, inlet and outlet, etc.)	$210.1
Total	$338.3
b. Annual expenditure	
The interest on investment at 9%	$ 30.4
Depreciation on gas holder and frame at 10%	$ 9.3
Depreciation on piping and stove at 5%	$ 2.0
Depreciation on structure at 3%	$ 6.3
Cost of painting, once a Year	$ 6.7
Total	$ 54,7
c. Annual income	
Gas $3 m^3$ per day at \$1.5 per $29 m^3$ (1,000 cu.ft.)	$ 50.3
Manure (7 tons, composted) with refuse 16 tons at $4 per ton	$ 64.0
Total	$114.3
d. Net annual income (b - c)	$ 59.6

Source: ESCAP Document NR/EGNBD/4, 20 - 26 June 1978

Health hazards

Health hazards are associated with the handling of night soil and with the use of sludge from untreated human excrete as fertilizer.

In general, published data indicate that a digestion time of 14 days at 35ºC is effective in killing (99.9 per cent die-off rate) the enteric bacterial pathogens and the enteric group of viruses. However, the die-off rate for roundworm (Ascaris lumbricoides) and hookworm (Ancylostoma) is only 90 per cent, which is still high. In this context, biogas production would provide a public health benefit beyond that of any other treatment in managing the rural health environment of developing countries.

Bottlenecks, considerations, and research and development

Bioconversion of organic domestic and farm residues has become attractive as its technology has been successfully tested through experience on both small- and large-scale projects. Feeding upon renewable resources and non-polluting in process technology, biogas generation serves a triple function: waste removal, management of the environment, and energy production. Nevertheless, there are still several problems (14, 19, 20) that impede the efficient working of biogas generating systems (Table 5).

TABLE 5. Considerations Relating to Bottlenecks in Biogas Generation

Aspect	Bottlenecks	Remarks
Planning	Availability and ease of transportation of raw materials and processed residual products	Use of algae and hydroponic plants offsets high transportation costs of materials not readily at hand. Easily dried residual products facilitate transportation.
	Site selection	Nature of subsoil, water table, and availability of solar radiation, prevailing climatic conditions, and strength of village population need to be considered.
	Financial constraints: Digester design; high transportation costs of digester materials; installation and maintenance costs; increasing labour costs in distribution of biogas products for domestic purposes	Use of cheap construction materials, emphasizing low capital and maintenance costs and simplicity of operation; provision of subsidies and loans that are not burdensome.
	Necessity to own or have access to relatively large number of cattle	Well-planned rural community development, ownership and biogas distribution schemes necessary.
	Social constraints and psychological prejudice against the use of raw materials	Development of publicity programmes to counteract constraints compounded by illiteracy; provision of incentives for development of small-scale integrated biogas systems.
Technical	Improper preparation of influent solids leading to blockage and scum formation	Proper milling and other treatment measures (pre- soaking, adjustment of C/N ratio); removal of inert particles: sand and rocks.
	Temperature fluctuations	Careful regulation of temperature through use of low-cost insulating materials (sawdust, bagasse, grass, cotton waste, wheat straw); incorporation of auxiliary solar heating system.

	Maintenance of pH for optimal growth of Methanogenic bacteria	Appropriate choice of raw material, regulation of C/N ratio and dilution rate.
	C/N ratio	Appropriate mixing of N-rich and N-poor substrates with cellulosic substrates.
	Dilution ratio of influent solids content	Appropriate treatment of raw materials to avoid stratification and scum formation.
	Retention time of slurry	Dependent upon dilution ratio, loading rate, digestion temperature.
	Loading rate	Dependent upon digester size, dilution ratio, digestion temperature.
	Seeding of an appropriate bacterial Population for biogas generation	Development of specific and potent cultures.
	Corrosion of gas holder	Construction from cheap materials (glass fibre, clay, jute-fibre reinforced plastic) and/or regular cleaning and layering with protective materials (e.g., lubricating oil).
	Pin-hole leakages (digester tank, holder, inlet, outlet)	Establishment of "no leak" conditions, use of external protective coating materials (PVC, creosotes)
	Occurrence of CO_2 reducing calorific value of biogas	Reduction in CO_2 content through passage in lime-water
	Occurrence of water condensate in gas supply system (blockage, rusting)	Appropriate drainage system using condensate traps
	Occurrence of H_2S leading to corrosion	On a village scale, H_2S removed by passing over ferric oxide or iron filings
	Improper combustion	Designing of air-gas mixing appliances necessary
	Maintenance of gas supply at constant pressure	Regulation of uniform distribution and use of gas; removal of water condensate from piping systems; appropriate choice of gas holder in terms of weight and capacity
Residue utilization	Risks to health and plant crops resulting from residual accumulation of toxic materials and encysted pathogens	Avoid use of chemical industry effluents; more research on type, nature, and die-off rates of persisting organisms; minimize long transportation period of un-dried effluent
Health	Hazards to human health in transporting night soil and other wastes (gray-water)	Linkage of latrine run-offs into biogas reactors promotes non-manual operations and general aesthetics
Safety	Improper handling and storage of methane	Appropriate measures necessary for plant operation, handling, and storage of biogas through provision of extension and servicing facilities

Rural communities using the integrated system are appropriate examples of recycled societies that benefit from low-capital investments on a decentralized basis and such communities are attuned to the environment. The technology thus seeded and spawned is, in essence, a populist technology based on "Nature's income and not on Nature's capital."

Biogas generated from locally available waste material seems to be one of the answers to the energy problem in most rural areas of developing countries. Gas generation consumes about one-fourth of the dung, but the available heat of the gas is about 20 per cent more than that obtained by burning the entire amount of dung directly. This is mainly due to the very high efficiency (60 per cent) of utilization compared to the poor efficiency (11 per cent) of burning dung cakes directly.

Several thousand biogas plants have been constructed in developing countries. A screening of the literature indicates that the experience of pioneering individuals and organizations has been the guiding principle rather than a defined scientific approach. Several basic chemical, microbiological, engineering, and social problems have to be tackled to ensure the large-scale adoption of biogas plants, with the concomitant assurances of economic success and cultural acceptance. Various experiences suggest that efficiency in operation needs to be developed, and some important factors are: reduction in the use of steel in current gas plant designs; optimum design of plants, efficient burners, heating of digesters with solar radiation, coupling of biogas systems with other non-conventional energy sources, design of large-scale community plants, optimum utilization of digested slurry, microbiological conversion of $CO2$ to $CH4$, improvement of the efficiency of digestion of dung and other cellulosic material through enzyme action and other pre-digestion methods, and anaerobic di gestion of urban wastes

We may summarize some of the research and development tasks that need to be undertaken as follows.

In basic research:

a. Studies on the choice, culture, and management of the micro-organisms involved in the generation of methane.

b. Studies on bacterial behaviour and growth in the simulated environment of a digester (fermentation components: rate, yield of gas, composition of gas as a function of variables - pH, temperature, agitation - with relation to substrates - manure, algae, water hyacinths).

In applied research:

a. Studies on improving biogas reactor design and economics focusing on: alternative construction materials in stead of steel and cement; seeding devices; gas purification methods; auxiliary heating systems; insulator materials; development of appropriate appliances for efficient biogas utilization (e.g. burners, lamps, mini tractors, etc.).

b. Studies for determining and increasing the traditionally acknowledged fertilizer value of sludge.

c. Studies on quicker de-watering of sludge.

d. Studies on deployment of methane to strengthening small-scale industries, e.g., brick-making, welding, etc.

In social research:

a. Effective deployment of the written, spoken, and printed word in overcoming the social constraints to the use of biogas by rural populations.

b. Programmes designed to illustrate the benefits accruing to rural household and community hygiene and health.

c. Programmes designed to illustrate the need for proper management of rural natural resources and for boosting rural crop yields in counteracting food and feed unavailability and insufficiency.

d. On-site training of extension and technical personnel for field-work geared to the construction, operation, maintenance, and servicing of biogas generating systems.

e. Involvement and training of rural administrative and technical personnel in regional, national, and international activities focusing on the potentials and benefits of integrated biogas systems.

Table 6 shows a number of the benefits of biogas utilization, set against the related drawbacks of presently used alternatives.

Present problems	Benefits of Biogas
Depletion of forests for firewood and causation of ecological imbalance and climatic changes	Positive impact on deforestation; relieves a portion of the labour force from having to collect wood and transport coal; helps conserve local energy resources
Burning of dung cakes: source of environmental pollution; decreases inorganic nutrients; night soil transportation a hazard to health	Inexpensive solution to problem of rural fuel shortage; improvements in the living and health standards of rural and village communities; provides employment opportunities in spin-off small-scale industries
Untreated manure, organic wastes, and residues lost as valuable fertilizer	Residual sludge is applied as top-dressing; good soil conditioner; inorganic residue useful for land reclamation
Untreated refuse and organic wastes a direct threat to health	Effective destruction of intestinal pathogens and parasites; end-products non-polluting, cheap; odours non-offensive
Initial high cost resulting from installation, maintenance, storage, and distribution costs of end-products	System pays for itself
Social constraints and psychological prejudice to use of human waste materials	Income-generator and apt example of self-reliance and self- sufficiency

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Discussion summary

The question arose as to whether retention time in the biogas fermentation could be reduced by mixing. There seems to be very little in the literature on the subject, and, although information is now becoming available from the United States National Academy of Sciences and the Economic and Social Commission for Asia and the Pacific (ESCAPI, much more is needed. There is a great deal of information on domestic sludge, and it is now possible to treat dissolved residues, e.g., potato, in continuous anaerobic processes.