Bioenergy Systems Report

MARCH 1983: BIOENERGY FOR AGRICULTURE

INTRODUCTION

Previous Reports in this series have described efforts in many developing countries to expand the production of fuelwood, charcoal, and "biogas" from the anaerobic digestion of biomass for use as cooking fuels and for space heating in rural areas.

Energy is also urgently needed in these areas for the production and processing of farm products. The most common need is for mechanical energy to pump water for crops and livestock and to process grains. Energy for crop drying and for refrigeration of farm produce has a high priority in many areas. Mechanical and heat energy is needed in dairies, meat packing plants, feed mills, and other processing facilities. Many of these energy needs in the agricultural sector can be met with fuels derived from biomass.

This Report describes the use of biomass fuels in the production and processing of agricultural products. It will concentrate on two technologies for the production of gas fuels from biomass for use in engines and burners. Part One covers the generation of a fuel known as "producer gas" through the thermal gasification of biomass and the use of this gas to operate engines on farms. Part Two reviews the design and use of larger-scale anaerobic digestion systems and the use of biogas from these systems to provide mechanical power and heat energy needed in the agricultural sector.

The Reports in this series are sponsored by the Bioenergy Systems and Technology (BST) Project of the U.S. Agency for International Development. The BST Project includes several types of activities designed to assist USAID missions and governments of developing countries with the identification and development of bioenergy projects. This Report illustrates possible approaches to the development of projects for the use of biomass fuels for agricultural production and processing.

The design of an effective biomass energy project requires a number of choices among feedstocks, conversion processes, designs, equipment, and uses of the fuels as well as careful planning and management. The components must fit together into an effective total system. Designing such a system requires careful consideration of the availability of feedstocks, materials, equipment, and technical and management skills and of economic, institutional, and cultural factors which may influence the success of the project.

While many crucial decisions depend mainly on conditions at the proposed site, project designers should be able to draw heavily on the experience of others with similar bioenergy systems. In contrast with the extensive literature which is now available on the production of biomass fuels for domestic use, published information on biomass energy for agricultural production has been limited mainly to a relatively few technical reports on individual projects. Efforts to correlate technical experience among projects with similar purposes are rare, as are analyses of the non-technical factors influencing the design and viability of such projects.

The Editor and sponsors of this Report hope that it will contribute to the wider sharing of information on bioenergy projects for agriculture. However, the expanded use of biomass energy in developing countries

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requires not only a much wider exchange of technical information but also greatly expanded cooperation and collaboration among those who seek to develop biomass energy systems which will have a significant impact in developing countries. Support for collaborative research and development projects may be available soon under a new program which is being developed by the Agency for International Development.

Under this new program the BST Project could provide technical and financial assistance for cooperative bioenergy projects conducted by institutions in several countries. One type of collaborative project may involve coordinated activities to develop a type of bioenergy system which seems promising for a given region. Several institutions in the region would carry out segments of an agreed research and development program and share the resulting data and conclusions. BST support may also be available for collaboration between an institution in one country which already has extensive experience with a given type of bioenergy project and an organization in another country which hopes to acquire this kind of experience. A third type of collaborative effort may involve bioenergy research and demonstration projects which are jointly funded by AID and other international development assistance agencies. In a fourth type of project, BST would fund the collection, analysis, and dissemination of information on the experience of many institutions with a given problem such as the cleaning of producer gas for use in engines.

The AID Bioenergy Project is giving the highest priority to those types of bioenergy projects which could be widely duplicated within a given country or region and could thus have a considerable impact on the energy situation in that area. While most Project activities involve technical assistance, equal priority is given to economic, cultural, organizational, management, and other non-technical problems which must be resolved if the potential impact of a bioenergy option is to be fully realized.

Although project selection criteria have not yet been established, the BST Project staff would welcome suggestions or inquiries from institutions in developing countries which would be interested in joining a collaborative bioenergy research and development project. Dr. Paul Weatherly is the manager of the BST Project in the AID Office of Energy. Staff support for the Project is provided by a team from the Tennessee Valley Authority, an integrated resource management agency in the seven-state Tennessee River watershed. Mr. Edward Storey is coordinator of the TVA team, which is based in Rosslyn, Virginia, in the AID Office of Energy.

Other BST activities hve included field reconnaissance and prefeasibility studies, educational workshops, study tours, publications, and other information transfer activities. Bioenergy assessments or feasiblity studies have been provided or scheduled in Costa Rica, Honduras, Ecuador, Morocco, Kenya, Sudan, and Pakistan. The BST Project is currently supporting the development of wood gasification projects in Costa Rica and Honduras and is actively considering a biogas project in Pakistan and a project for the utilization of cotton stalks for fuel in Sudan. AID has also provided assistance for major programs in the Philippines to produce electric power from wood and to operate irrigation pumps and fishing boats with gasifiers.

All correspondence concerning BST Project activities should be addressed to:

S&T/Office of Energy
Room 509, SA-18, AID
Washington, DC 20523
Telephone: (703) 235-8902

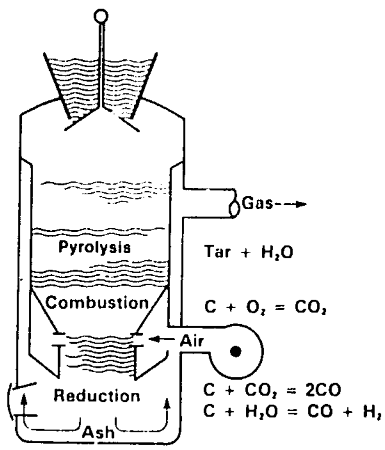
AN APPEAL TO READERS

The next Report, due in mid-summer, will review the use of biomass fuels for the generation of electric power. A fall Report will provide digests of research on selected bioenergy topics. Research and power agencies are urged to send reports on their bioenergy activities to the Editor at the address on page 1.

PART ONE: FARM ENERGY FROM THE THERMAL GASIFICATION OF BIOMASS

1. Gasification Overview

Producer gas, a mixture of energy-rich and inert gases, is generated by the partial combustion of wood or other biomass with limited air intake. Nearly all of the gasifiers producing gas for use in engines are down-draft units similar to that shown below:



The air enters through nozzles or tuyeres at the side of the unit just above the point where the diameter of the internal chamber is narrowed by a throat or choke plate. The gases travel down through the hottest zone of the gasifier and exit through the grate at the bottom. Since the air and gases move downward with the fuel, this type of gasifier is also known as a "co-current" unit.

Biomass fuels for down-draft gasifiers should have (a) no more than about 20% moisture, (b) no more than about 5% ash content, to avoid ash-fouling and slagging problems, and (c) particle sizing which permits the flow of air through the fuel and avoids compaction or bridging. The most common fuels are wood chips or charcoal chunks without too many fine particles.

The energy content in the producer gas varies from about 100 to 200 Btu per cubic foot or about 2.9 to 7.8 MJ/m^3. The energy is provided by carbon monoxide (17 to 27%), hydrogen (7 to 18%), methane (2 to 5%), and various tars and hydrocarbons. About half the gas is nitrogen and the rest is mainly carbon dioxide; neither of these adds energy.

Most of the tars and oils produced in the pyrolysis zone near the top of the gasifier are converted to gases as they pass through the high temperature zone at the throat of the gasifier. The gas from down-draft gasifiers is much cleaner than that produced by updraft units in which air enters at the bottom and gas exits at the top. Nonetheless, further cleaning of the gas is essential if it is to be used in an engine.

The effectiveness of the gas cleaning equipment is even more important than the design of the gasifier. Most cleaning and cooling systems include (a) a cyclone separator which traps larger particulates through centrifugal actions (b) either a wet scrubber which removes tars by bubbling the gas through oil or water or a dry scrubber with a condensing coil to cool the gas and condense out the tars, and (c) a filter made of fiberglass, plastic foam, or biomass materials such as rice hulls.

Producer gas has been used in stationary engines and vehicles since early in this century. About one million vehicles ran on producer gas in Sweden, Germany, and France during World War II. Spark-ignition (gasoline) engines can be operated on 100% producer gas after minor modifications of the air and fuel intake equipment and of the ignition timing. Due to the lower energy content of the producer gas compared to gasoline, the power output will usually be only about 60% of that with gasoline.

A compression-ignition diesel engine needs some diesel fuel for ignition, but 80 to 90% of the diesel fuel can be replaced with producer gas. Due to the higher compression ratios of diesel engines, the power loss from dual-fuel operation normally does not exceed about 20%.

2. Gasifiers for Water Pumping

a. Philippines

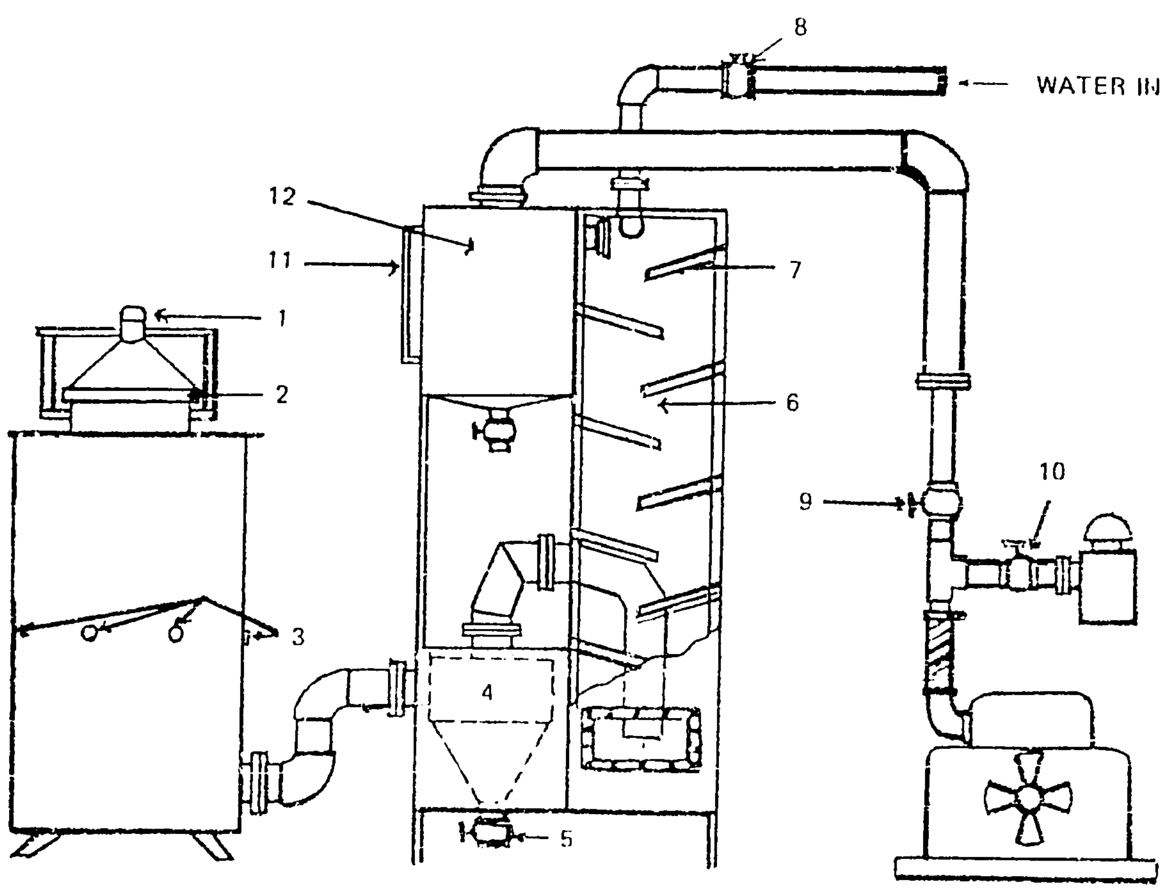
A major program to use thermal gasifiers to provide most of the energy for irrigation pumping is being carried out by the Farm Systems Development Corporation (FSDC), an agency of the Philippine government.

FSDC, which was established in 1975 to accelerate rural development, has organized associations of small farmers called Integrated Service Associations (ISA's) and assists them to buy and operate diesel irrigation pumps. By 1981 FSDC had installed small irrigation systems for about 1,000 ISA's in the Philippines. The typical association includes about 55 farm families; they cultivate 125 hectares, of which 70 are irrigated. However, use of these irrigation systems has been severely restricted by the rapid increases in the price of diesel fuel.

Thermal gasifiers were used on some cars in the Philippines during World War II.

Several Philippine research and other agencies began experiments in the late 1970's with gasifiers to provide fuel for irrigation pumps, generators, and other machinery. In February 1981 the President of the Philippines directed FSDC to launch a major program for the widespread utilization of gasifiers to provide fuel for irrigation and other agricultural equipment. A manufacturing subsidiary, the Gasifier and Equipment Manufacturing Corporation (GEMCOR), was established by FSDC to fabricate gasifiers.

By November 30, 1982, gasifiers had been installed with irrigation pumps in 108 Integrated Service Association areas. The typical gasifier system is a stationary application similar to that shown below. The gasifier is about 2 feet (0.6 m) in diameter and about 5'5" (1.6 m) high. It consumes about 20 kg of charcoal per day. Such a unit usually provides fuel for a 50 HP engine which pumps 3,000 gallons (11,355 liters) of water per minute. The gas fuel replaces about 80% of the diesel fuel normally needed by the engine.



LEGEND:

1. Cap cover
2. Charging Port
3. Air Holes
4. Cyclone Separator
5. Drain Valve
6. Scrubber
7. Wooden Baffles
8. Water Supply Valve
9. Gas Intake Valve
10. Air Intake Valve
11. Sight Glass
12. Wet Filter

According to FSDC figures, the use of a gasifier with a 60 HP irrigation pump reduces annual operating cost from about 57,000 pesos to 43,000 peros, a saving of 14,000 pesos. This gasifier system costs about 18,000 pesos, so the payback period for the system is only 1.28 years.

Gasifier production is expanding rapidly and FSDC plans to provide 2,000 ISAs with gasifiers for irrigation during the next five years. Smaller portable gasifier systems are also being developed including a "wheel-barrow" model which can be moved from field to field as needed. Gasifiers built by GEMCOR are also being used to operate threshers, rice mills, dryers, boats, and vehicles and to generate electric power.

FSDC is also conducting a program to greatly expand the production of charcoal for use in gasifiers and in industry. Farmers associations are planting fast-growing Leucaena (ipil-ipil) trees in upland areas; after four years the trees will be harvested for charcoal production.

b. South Africa

Irrigation is a major priority within the large program which is being launched by the government of South Africa to promote the use of gasifiers in industry and agriculture. The national target is to have 10,000 gasifiers in operation in 1985.

The program, conducted by the National Timber Research Institute (NTRI) of the Council for Scientific and Industrial Research, emphasizes the use of wood fuels from plantations, bush encroachments, and wood processing industries. However, consideration is also being given to the use of corn cobs and various nut shells which appear to be very promising fuels. Studies are also under way on economical methods of hogging and chipping wood fuels, on the use of wood residues with high moisture contents, and on the use of pelletized agricultural residues.

Due to the poor performance of many of the woodgas systems installed in South Africa prior to 1982 (including 45 units in 1980/81), NTRI has tested engine/generator sets from 15 kW to 80 kW and burners with outputs up to 320 kW of heat. The Institute is cooperating with several South African manufacturers who are ready to market gasifier systems which meet NTRI guidelines and standards. NTRI is commissioning eight demonstration systems in 1983, including at least three demontrations of agricultural uses of gasifiers. On-farm gasifiers will provide power for irrigation pumping and heat for domestic hot water and crop drying. Some gasifier-powered engines will provide direct mechanical power for water pumps; others will generate electrical power which will be used to operate electrical pumps and for other purposes.

The South African program also includes several types of industrial uses of gasifiers including mechanical power for sawmills and wood processing plants, electrical power for factories, and heat for drying kilns.

c. India

India has seven million irrigation pumps; three million are powered by 5 to 10 HP diesel engines. Diesel oil shortages and restrictions on electricity supplies have disrupted pumped irrigation in many areas. Six Indian research organizations and firms have conducted studies on the use of producer gas in small engines for irrigation and other purposes.

Jyoti Solar Energy Institute of Vallabh Vidyanagar is conducting a research program funded by the Ford Foundation for the development of a 5 kW gasifier-engine system. Foundation and Institute officials stated recently that gasifier-powered irrigation pumping could generate a "Second Green Revolution" in India. Most of the drought-prone areas receive sufficient rain to meet crop requirements, but it falls rapidly during the monsoon and can be captured only in low-lying areas. Gasifier-powered pumps could lift this water up to farms and forests, greatly increase yields, and benefit the poorest people in India. Since experience with organizing Indian farms to share irrigation water has not been very encouraging, gasifier-powered engines might operate small generators which would energize a network of tubewells owned by individual farmers.

The Indian Institute of Technology in New Delhi has built four small updraft gasifiers and is experimenting with the use of gas from these units in two-stroke spark-ignition engines and in compression-ignition engines.

Experiments by Kirloskar Oil Engines Ltd. of Pune with the use of producer gas in the small diesel engines it manufactures indicated that diesels work best with gas made from charcoal or other very dry fuel. High fuel moisture produces a high hydrogen traction (15 to 20%) which is desirable for spark-ignition engines, but causes misfiring and detonation in dual-fueled diesel engines. Other studies on the use of producer gas in small engines have been conducted by the Punjab Agricultural University in Ludhiana, Tamilnadu Agricultural University in Coimbatore, and the Central Institute of Agricultural Engineering in Bhopal.

3. Gasifiers for Grain Milling

a. Philippines

Gasifier-powered engines are being used for the threshing, milling, and drying of rice in the Philippines.

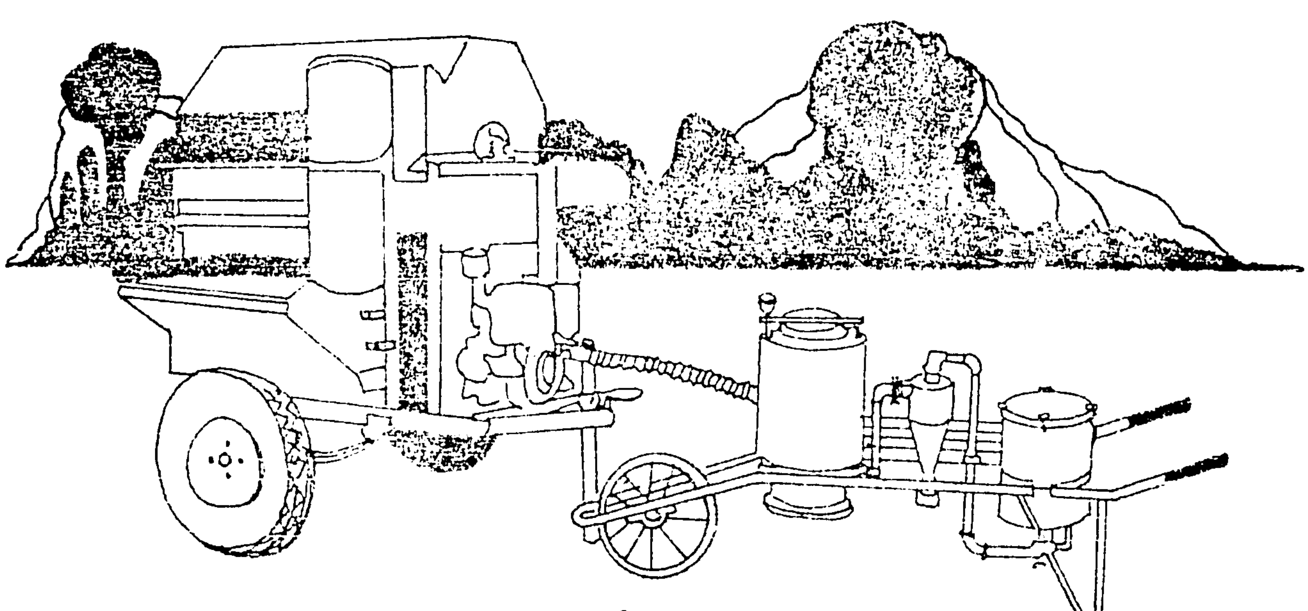
The portable "wheel barrow" unit developed by GEMCOR is used to fuel a portable rice thresher with a 16 HP gasoline engine, as shown below.

The thresher operates on 100% producer gas from the charcoal-fueled gasifier. Annual operating costs are reduced dramatically from 24,400 pesos per year to about 8,800 pesos, a saving of 15,600. Since the gasifier system only costs about 8,000 pesos, the payback period is only slightly more than six months.

A stationary gasifier system similar to that shown on page 3 is used to operate 80 to 150 HP engines in some ricemills in the Philippines. The mechanical power is transmitted from the engine to the rice milling machinery by a belt pulley drive system.

A gasifier system for a smaller 24 HP ricemill costs 20,800 pesos. Annual operating costs are reduced by about 8,300 pesos, so the payback period for these units is about two and a half years.

A federation of 37 rural cooperative organizations in the Philippines is using a gasifier-powered generator to provide electric power for rice drying. The gasifier uses a sack of charcoal per hour and saves 50% of the diesel fuel normally needed by



the 130 HP engine. Power from the 75 kW generator is used in a 47 HP multi-pass dryer, four 3 HP dryers, and a small water pump, as well as for lighting.

b. Tanzania

Twente University of Technology in the Netherlands has been conducting an experimental program on the use of gasifiers to power village mills for grinding corn (maize) in Tanzania. A .66 m diameter down-draft (co-current) gasifier was operated with corn cobs at a test site in Arusha and at Mareu, a 540-family village. The gasifier provided fuel for a two-cylinder engine operating a mill which is capable of grinding about 1100 kg of corn per day. This research unit ran for 1600 hours at Arusha and Mareu.

Subsequently a simplified gasifier was designed and improved gas-cleaning equipment was added. Tests have been conducted with this prototype village gasifier; however, supply and logistical problems have prevented the expansion of the gasifier test program.

3. Gasifiers for Fisheries (Philippines)

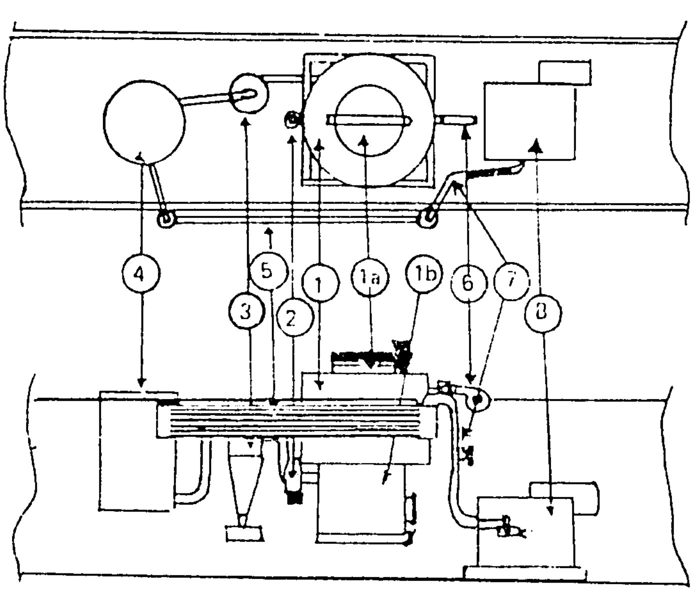
The territory of the Philippines includes about 7,000 islands. About 117,000 fishing boats operate in the waters between these islands. The typical fisherman's "banca" is a slender 30' (9.1 m) boat stabilized with outriggers. About 35% of the bancas are motorized, typically with a 16 HP gasoline engine. However, increased fuel costs have greatly restricted the operation of these motorized fishermen.

Philippine agencies concluded that small gasifiers might provide the solution to the fuel problem for Philippine fishermen. A compact system has been developed which fits into the stern of the banca. The layout is indicated in the diagram in the next column. Most units are fueled with wood chips, although charcoal can also be used. The gasifier is 387 mm in diameter and 775 mm high. The fuel is added through the charging port (1A) and the gas is generated in the hearth assembly (1B). The gas is cleaned in a condensate collector (2), a cyclone separator (3), a primary filter (4), and a cooler/heat exchanger (5) on the side of the boat. The flow of gas is maintained by a small blower (6); gas intake by the engine is regulated by a gas valve (7) in the line to the engine (8).

A gasifier unit for a banca costs about 5,000 pesos but generates savings in annual operating costs of about 5,820 pesos. The system thus will pay for itself in less than a year (10.3 months).

By the end of 1982 gasifier systems were in operation on ten bancas and 171 units had been delivered for installation on bancas. Present plans call for 400 more gasifiers on bancas by the end of 1983 and a total of 2,000 gasifiers in operation in the fishing fleet within the next five years.

The Farm Systems Development Corporation is also pioneering the use of gasifiers as power sources for small ice plants providing ice to fishermen. A charcoal-fed gasifier would provide gas fuel for a 90 HP automobile engine which would drive the plant's compressor, condensor, and agitator and a small generator for lighting. The plant would produce about two tons of block ice per day, which would meet the fish-icing needs of about 100 fishermen.



PART TWO: FARM ENERGY FROM THE ANAEROBIC DIGESTION OF AGRICULTURAL RESIDUES

1. Biogas Overview

A gas fuel generally known as biogas is being generated in many countries around the world through the action of microbes on animal and human wastes; plant residues are also used in a few countries. The biogas is formed by a process known as anaerobic digestion which takes place in a closed vessel in the absence of oxygyn. One group of microbes breaks down the feedstock into volatile fatty acids; a second group of bacteria converts the acids into methane and carbon dioxide.

About 60% of the biogas is methane (CH_4), which provides the principal energy content in natural gas. Biogas is an excellent fuel for cooking, lighting, and space heating and for the operation of both spark-ignition (gasoline) and compression-ignition (diesel) engines.

About six million biogas digesters have been built on farms in China, although many of these are not currently operating due to structural defects. India has about 80,000 farm digesters. Hundreds of digesters have been built in Korea, Taiwan, Pakistan, and Nepal. Several other countries have sizeable programs to promote the construction and use of digesters on farms. There are biogas plants in about 50 other countries, although many of these are experimental units operated by research institutions.

The most common feedstocks are animal manures. Cow manure is generally used in family biogas plants in India, other South Asian countries, and a few other developing countries. Most of the 40 to 50 biogas systems in the U.S. have been built on dairy farms or beef cattle feedlots. Pig manure is the most widely used feedstock for biogas production in China, other East Asian countries, and the majority of other developing countries. Only a few systems use poultry manure or other animal manures. Human wastes are added in most of the Chinese digesters, some of the digesters in India, and a few units in other countries.

Crop residues and other plant materials are extensively used along with animal and human wastes for biogas production only in China, where the digesters have been designed to accomodate these fibrous materials. The family digesters in India and most of the large digesters built in the U.S. and elsewhere have been designed for liquid slurries and cannot handle plant materials. The use of some crop residues is inhibited by the high carbon/nitrogen ratio in the feedstock. However, batch digesters suitable for use with a variety of feedstocks have been used in several countries and a number of research institutions are experimenting with the use of crop residues and food processing wastes in biogas digesters.

The great majority of the biogas plants built in developing countries are 6 to 10 m^3 units designed to produce cooking gas for individual families. These digesters do not produce enough gas to operate an engine and thus do not provide energy for agricultural production or processing. However, considerable experience is accumulating around the world with the design and operation of larger-scale digesters and with the use of biogas from these plants to provide mechanical and electrical power and heat energy for the agricultural sector.

The design of a system to produce mechanical or electrical power from biogas involves a number of prerequisites, variables, and options which do not apply to family-scale digesters. Daily gas production rates depend on the size of the digester, the daily loading rate, and the temperature of the digester. Daily gas consumption rates depend on the size of the engine and the hours of operation. Biogas-fueled engines are usually feasible only at sites where a substantial number of animals are confined in a limited area.

The most common sites are dairy farms, beef cattle feedlots, and large pig farms, although biogas plants have also been built at large poultry farms.

2. Types of Large-scale Digestors

a. Chinese "Water Pressure" Digestors

China has more large digesters than any other country. Most of the larger communal digesters used to make biogas for the operation of engines are simply larger versions of the "water pressure" digesters built for individual families in China. The gas accumulates under the domed or flat roof of the underground digester which is built of brick, stone and/or other masonry materials. As gas pressure builds up, some of the slurry is pushed out of the main chamber into the outlet chamber shown at right in the sketch below. When gas is used, this slurry flows back into the main chamber.

Severe problems persist in China with gas leakage and liquid seepage from these digesters; a Chinese official stated recently that about one out of three of the Chinese digesters is not functioning properly. In addition to the gas loss from leakage, the gas which is generated from slurry in the outlet chamber escapes through the top of that chamber and is lost to the atmosphere. For these and other reasons, the volume of usable gas produced by the Chinese digesters is very low. Additional information on the use of these digesters in the production of mechanical and electric power in China will be found on pages 16, 17, 18, and 22.

b. Indian-style Digesters

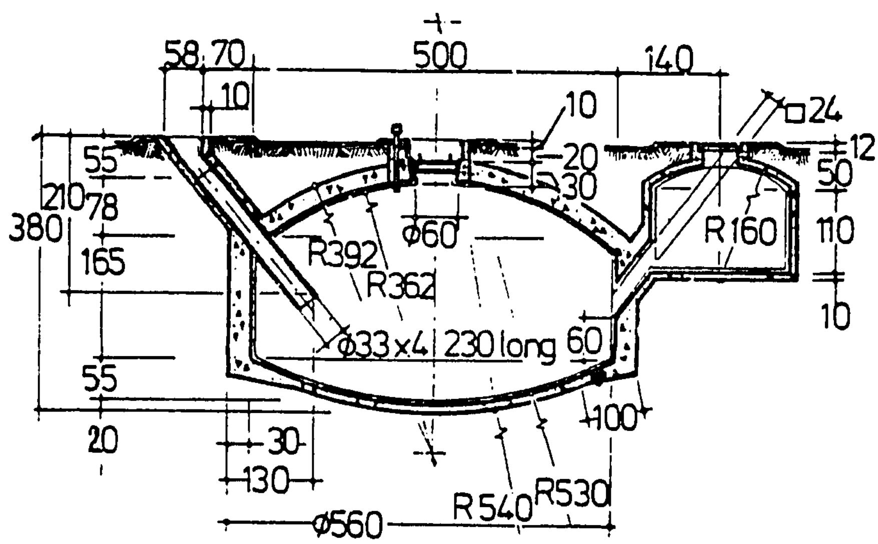
Larger versions of the vertical digesters with floating steel gasholders which are widely used for family biogas production in India have been rare. However, a 75 m^3 Indian-style digester is producing biogas for water pumping in Botswana (See page 22.)

c. Fixed-top Digesters

In many of the larger systems the gas is generated in a non-expandable digester and stored in a separate gasholder. Several types of materials have been used:

Steel Tanks: Some of the very large biogas systems in the U.S. and a few smaller units use aboveground steel tanks for digesters. Due to corrosion problems arising from the hydrogen sulphide in the biogas, steel tanks must have an interior coating of porcelain, enamel, or epoxy. A system built by Biogas of Colorado, Inc. at the Leefer beef cattle farm in Carlinville, Illinois, includes a 150,000 gallon (567 m^3) bolted steel plate digester lined with porcelain. At Otter Run Farm, a 100-head dairy farm near Bedford, Virginia, a biogas system used a 21,000 gallon (79 m^3) steel tank coated with less expensive epoxy.

Concrete Silos: Several systems in the U.S. use components which are commercially available for the construction



of farm silos. A 140 m^3 digester was built at the University of Missouri's swine research center in 1976 from prefabricated concrete silo staves; the interlocking edges were sealed with butyl rubber and tightened with steel tension bands. The digester has a concrete base and fixed concrete roof.

Rectangular Masonry Digesters: The digesters in this group have walls, floors, and fixed roofs made of concrete or other masonry materials. The Central American Institute for Industrial Research and Technology (ICAITI) in Guatemala prepared a detailed manual in Spanish for the construction of a 20 m^3 rectangular digester. The unit has a floor and roof of reinforced concrete and walls of concrete blocks reinforced with steel rods. The floor slopes toward one end to facilitate sludge removal through a rectangular opening. The Latin American Energy Organization (OLADE) has published detailed plans for a horizontal digester developed in Mexico which is built with low-cost ferrocement construction. The National Research Center of Egypt has recently completed a long rectangular digester with a capacity of 50 m^3 (see page 15). Maya farms in the Philippines has 32 rows of horizontal concrete digesters.

Several types of separate gas storage units have been used with these fixed-top digesters:

Plastic Storage Bags: In China inflatable plastic bags are frequently used to accumulate sufficient gas to operate an engine. (See page 19.) At the University of Missouri gas is stored in a 1300 ft^3 (36 m^3) bag; a similar bag is used for temporary gas storage at the Leefer farm in Illinois. Inflatable storage bags should not be confused with plastic bags which serve as both digester and gasholder, or with the flexible-top digesters described in the next section.

Floating Steel Gasholders: Small steel gasholders have been used with some smaller rectangular digesters, and larger floating gasholders are used for gas storage in some systems.

High-pressure Storage Tanks: In a few of the larger systems the gas flows to a compressor and is then stored in a high-pressure steel tank. When sufficient gas is accumulated in the plastic temporary storage bag at the Leefer farm in Illinois, a compressor is automatically triggered; the gas is stored in a 30,000 gallon (113 m^3) tank at a pressure of 250 pounds per square inch (psi). The new system at the University of Nebraska stores gas in a 1,000 gallon (3.75 m^3) propane tank, also at 250 psi. Similar cylinders are used for pressurized storage of biogas at Otter Run Farms in Virginia.

d. Flexible-top Digesters

Many of the new biogas systems in the U.S. and elsewhere consist of an open-top or pit which is covered by an inflatible gasholder made of plastic or other flexible material.

In cold climate areas in the U.S., the digester and gasholder are placed inside a structure built from wood, metal or concrete to protect the gasholder from ice and snow and reduce heat loss. Such protective structures are not necessary in the warmer climate of California, although it was necessary to build a board fence around one gasholder to protect it from strong coastal winds.

One of the largest flexible-top digester systems is at Mason-Dixon Farms, a 1,000-head dairy farm near Gettysburg, Pennsylvania. Slurry flows first into a 185,000 gallon (700 m^3) digester and then through a 165,000 (624 m^3) digester. Both units are covered by inflatable hypalon plastic gasholders. When fully inflated, each gasholder rises about 10' (3 m) above the digester and holds about 15,000 ft^3 (425 m^3) of gas. The system was designed by Sheaffer and Roland, Inc. of Chicago.

A large flexible-top digester at Foster Farms, a 600-head dairy farm near Middlebury, Vermont, has a liquid capacity of 24,320 ft^3 (688 m^3) and produces 28,000 ft^3 (792 m^3) of gas per day. This system was built by Hadley and Bennett, Inc., of Henniker, New Hampshire.

A 180,000 gallon (681 m^3) digester with a hypalon plastic cover produces more than 1,000 m^3 of gas per day at the 600-head Baum dairy farm near Jackson, Michigan; several similar systems have been built by the Energy Cycle Company of Lincoln, Nebraska.

New biogas systems at North Dakota State University and the University of Nebraska use plastic gasholders which inflate above the slurry within an enclosed concrete structure.

In most of the flexible-top systems the digester is a concrete tank resembling a swimming pool. However, several California digesters have only earth walls and floors. These are lined with plastic and the entire unit is covered with a flexible plastic gasholder. One of these systems, funded in part by the California Energy Commission, is shown in the sketch below.

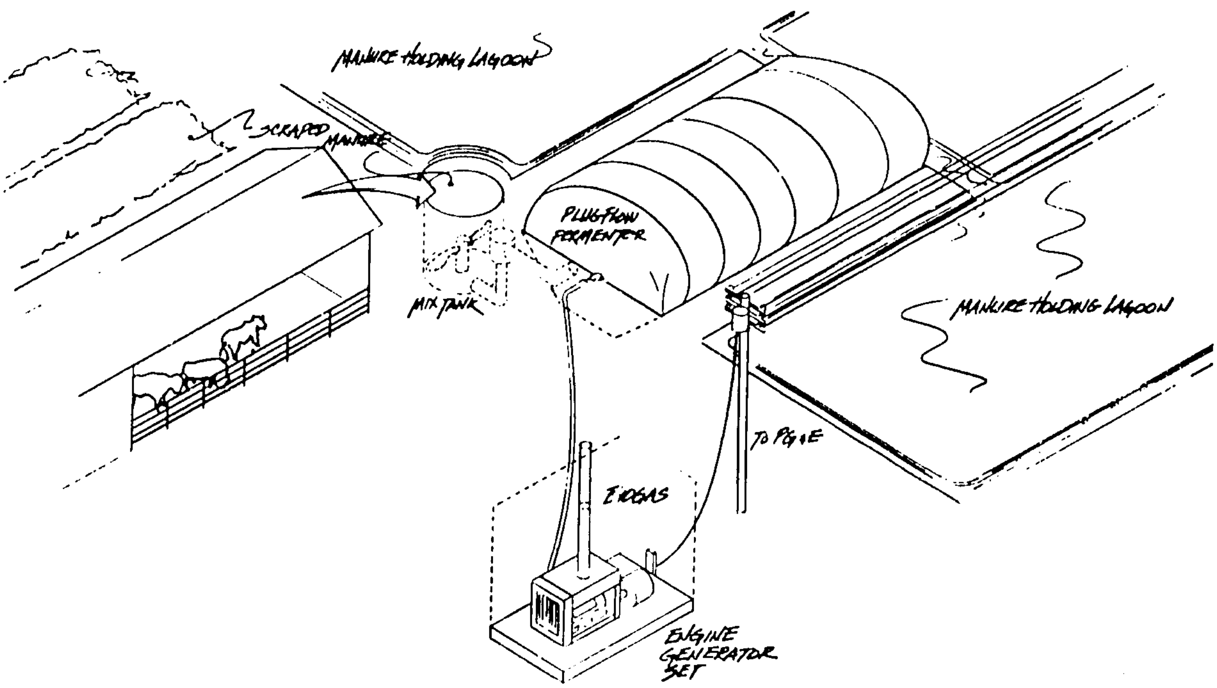
An earthen digester with a flexible rubber gasholder has been built by a German organization at a cattle fattening center and slaughterhouse in the Ivory Coast; a detailed report on this project is presented on page 20.

e. Plastic Bag Digesters

If properly supported, a large bag of plastic or butyl rubber can be used as both digester and gasholder. Systems developed by firms in Australia and Brazil use above ground steel structures to support the bag.

The most widely used plastic bag digesters are made in Taiwan of a unique "Red Mud" plastic which includes wastes from aluminum production, PVC, old engine oil, and other ingredients. The metal oxides in the material give it much more resistance to ultraviolet light than other plastics and the use of waste materials reduces the cost. The sausage-shaped unit is installed in a horizontal pit shaped to the contours of the lower half of the bag; the upper half, which is above ground, serves as a gasholder unless a separate gasholder has been provided.

Gas pressure from these units can be increased with a wooden platform riding on top of the digester which is loaded with rocks. The University of Hawaii added pressure to an RMP system by lashing old tires on top of the bag.



3. Loading Rates & Retention Times

The great majority of the digesters in use today are continuous-flow units. In the operation of such digesters several factors - daily loading rates, digester volume, retention time, digester temperature, and gas production rates - are highly interrelated. With a given digester, increasing the loading rate decreases the retention time. If the loading rate is fixed by the limited supply of feedstock (as is the case in most situations in developing countries), increasing the loading rate decreases the retention time. If the loading rate is fixed by the limited supply of feedstock (as is the case in most situations in developing countries), increasing the size of the digester increased the retention time.

If the primary goal of the designer of a biogas plant is to obtain the maximum amount of biogas from a limited supply of feedstock, he should choose a larger digester which provides a longer retention time. If the primary goal is to maximize the daily production of gas per cubic meter of digester volume (in order to reduce the cost of digesters and thus the cost of the gas), he should choose a smaller digester and a shorter retention time.

Most loading rates and retention times in developing countries have been based on the need to obtain the maximum energy from each kilogram of manure and other feedstock. Until recently loading rates in India were calculated to provide a retention time of 45 to 55 days depending on the climatic zone. Retention times in China were similar, although less precisely calculated. During the past two years, however, various studies in India indicated that the retention time for the typical family digesters was longer than necessary and could be shortened by building shallower digesters. These conclusions were reflected in new digester designs developed by early 1982. There are also some indications that Chinese research is also pointing toward shorter retention times under some circumstances.

The optimum retention time for a given digester is greatly influenced by the internal temperature of the digester. As the digester temperature increases toward 35°C, gas production rates increase and the optimum retention time decreases. The effect of temperature of gas production has been demonstrated by research in many countries. In a comparative study at Cornell University gas production from cow manure at 22°C was only .268 liters per liter of digester volume per day with a retention time of 12 days and increased to only .368 liters/liter/day when the retention time was extended to 30 days. In contrast, gas production in 12 days at 35°C was 1.318 liters/liter/day or five times the production at the lower temperature during a comparable period.

Despite these striking differences in gas productivity, the heating of family biogas digesters in developing countries has seemed prohibitively complicated and expensive. In the two countries with the largest biogas programs - China and India - the main emphasis has been on reducing the cost of construction and the complexity of operation of the family-scale units. Aside from a few experiments with the solar heating of digesters or water for slurry mixing, there has been very little interest in techniques for heating family-scale digesters. This lack of interest in digester heating has carried over to most of the larger-scale biogas projects in developing countries.

Most of the biogas systems in the U.S. have been built in zones with cold winters; the great majority of these systems include equipment for heating the influent materal and/or the contents of the digester. As a result, there is a sharp contrast between the typical retention times and gas production rates in biogas systems in the U.S. and the typical performance of the unheated digesters in developing countries. In developing countries the average retention time is well beyond 30 days and gas production rates are usually below .5 m^3 per m^3 of digester per day. In contrast, the typical retention times in the U.S. are between 10 and 15 days and gas production is usually well above 1.0 m^3 per m^3 of digester per day.

4. Digester Heating Techniques

In several systems in the U.S. a heat exchanger transfers heat from the digested slurry leaving the digester (effluent) to the new slurry which is entering the digester (influent). In the North Dakota State University system the effluent flows from the digester through a steel tank in the center of the influent storage tank, warming the influent before passing on out to the effluent storage unit. The biogas system built in 1977 at the dairy plant of a penal institution near Monroe, Washington, uses pipes to carry the influent through a small tank which contains effluent on its way out of the digester. A similar regenerative heat exchanger is used in the very large biogas system at the Kaplan Industries meat packing plant at Bartow, Florida.

In most of the U.S. and European systems, the contents of the digester are heated by passing hot water through a heat exchanger inside the digester. About 40% of the systems in the U.S. burn some of the biogas produced by the system to heat the water. The Pennsylvania State University system is heated with biogas burned in a standard gas-fired boiler. The Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia used a 68 liter gas water heater in its piggery waste pilot plant. At the University of Missouri the biogas is used in a burner specially designed for biogas and operating at a pressure of 4" (10.2 cm) water column. Several systems use propane or butane for digester heating during the start-up phase and switch to biogas when the system is in full operation.

Up to one third of the biogas produced by the system may be needed for digester heating, although the net gas production is still much higher than from unheated digesters. One way to maximize net production is to use waste heat from a biogas-fueled engine for digester heating. In larger systems the water ususally circulates through the radiator and through the exhaust silencer, capturing heat from both the radiator and the exhaust, before passing through the heat exchanger within the digester. Smaller (5 to 10 HP) generator sets are ususally air-cooled, and waste heat can only be obtained from the exhaust. One disadvantage of digester heating with waste heat from any engine is that the engine may not be in use at night when ambient temperatures are lowest. The system at the University of Missouri includes an insulated water tank to store hot water for use for digester heating at night.

Larger biogas-fueled engines usually produce more heat than is needed for digester heating and the designers of biogas systems have found a number of ways of using this surplus heat. Waste heat from two large generating sets is used to heat a farmhouse and farm buildings at Mason-Dixon Farms in Pennsylvania. Engine heat will be used at North Dakota State University and the University of Nebraska to heat offices and laboratories adjacent to the biogas plants. Several systems use "Totem" cogeneration units built by Fiat of Italy which produce both 15 kW of electricity and heat energy in the form of water at 85 to 90°C. Eleven of the Totem units are used in a large facility at Perugia, Italy, which produces biogas from the manure from 8,600 pigs and 45,000 hens; the hot water is used to heat two 1,000 m^3 digesters and the farm buildings. In the warm climate of Puerto Rico, where digester heating is not a major problem, heat from an engine/generator set will be used to dry the solid part of the digester effluent for use as an animal feed supplement.

Biogas will be used for digester heating in a 50 m^3 digester recently completed in a poultry-raising community in Egypt. Details on this project will be found on p. 15.

The Institute of Agricultural Sciences of Korea's Office of Rural Development demonstrated the substantial increase in gas production per unit of volume of the digester which can be achieved through digester heating. The initial demonstration was in a 137 m^3 unit consisting of an underground closed reinforced concrete tank and a separate 110 m^3 gas storage unit with floating steel gasholder. The digester was heated by burning some of the biogas in a water boiler and circulating the hot water with a 0.2 kW pump through a hollow vertical steel cylinder in the center of the digester. Heat transfer was aided by recirculating some of the biogas through the digester with a "bubble gun" mixer. The average gas production was 229 m^3 per day or 1.67 m^3 per m^3 of digester. About 32% of the gas was used for digester heating but the net energy production (156 m^3) was still several times that of unheated digesters of comparable size.

Subsequently the Institute built a 100 m^3 digester with a similar heating system but added 3.3 m^3 of solar panels to heat the water for slurry mixing. The use of solar energy reduced the consumption of biogas for digester heating to only 16% of the average gross production of 185.1 m^3 per day or 1.85 m^3/m^3/day.

The feasibility of using flat- plate solar collectors to heat biogas digesters has been demonstrated in a number of experiments in developing countries. By locating the collectors well below the digester, the solar heated water rises naturally to the heat exchanger in the digester through the operation of the "thermosiphon" principle; no pumps are needed.

At a biogas-fueled cheese plant in Nepal sponsored by the Swiss Association for Technical Assistance, solar collectors were used to heat barrels of water surrounding the three digesters; solar panels also heated water for slurry mixing and the ambient air inside the digester building. The solar system kept digester temperatures at near optimum levels. However, the gas boiler did not provide sufficient energy for cheese making at the plant's 1,800 m elevation. Due to this and other problems, the plant is now closed.

3. Heat From Biogas For Agricultural Production and Processing

The calorific value of biogas ranges from 4700 to 6,000 kcal/m^3 or 20 to 24 MJ/m^3, depending mainly on the percentage of methane in the biogas. The energy content of a cubic meter of biogas is about the same as in a kilogram of firewood, .7 kg of charcoal, half a liter of kerosene, or .4 kg of butane.

Most of the biogas produced in China, India, and other developing countries is burned as a domestic cooking fuel or in lamps. However, biogas is burned in burners and boilers in several countries to provide heat energy for agricultural production and processing.

a. Philippines

The most extensive use of biogas for process heat in an agro-industrial complex in a developing country is at Maya Farms, a large livestock production and meat packing operation of Liberty Flour Mills, Inc. near Manila. The installation has a present livestock population of 43,000 pigs, 10,000 ducks, 100 head of cattle, and 180 goats. Manure is digested in an industrial-scale biogas complex which includes 48 batch process digesters and 32 rows of horizontal continuous process digesters.

Total biogas production is currently 130,000 ft^3 (3,681 m^3) per day. Some of the biogas is used to heat scalding tanks in the slaughterhouse, cooking vats in the canning plant, and retorts in the rendering plant as well as in burners in drying rooms, canteens, and dormitories. Biogas burners are fabricated from galvanized iron pipes perforated with one or two rows of holes 1/8" to 3/16" (.31 to .48 cm) in diameter and 1/2" to 3/4" (1.3 to 1.9 cm) apart. The use of the remaining biogas in engines for water pumping, electric power generation and other purposes at Maya Farms will be described in subsequent sections.

Biogas provides part of the energy for the operation of a dairy at the Bureau of Animal Industry's Alabang dairy plant near Manila. Manure from 50 milk cows is fed daily to two 14.5 m^3 digesters; gas production averages 21.5 m^3 per day. The gas has been used in several types of dairy equipment as well as an electric generator. A 5-burner gas range uses 5.1 m^3 of biogas in four hours; another stove needs 2.55 m^3 for six hours. A gas refrigerator uses 1.7 m^3 during a 24-hour period.

A Ministry of Energy pamphlet in the Philippines indicates that stoves and refrigerators designed for use with liquified petroleum gas (LPG) can be modified for use with biogas by enlarging the opening in the brass nozzle from 1/16" (.15 cm) to 1/8" (.32 cm).

b. Egypt

Biogas from chicken manure will soon be used to heat a chicken house in the poultry-raising community of Shubra Kass in Egypt. The area has 600 poultry farms, each capable of raising about 5,000 birds in each 60 to 70 day cycle. Two to three 12 kg bottles of butane gas are used each day on each farm to heat the poultry houses. However, the butagas bottles are in short supply and cost more than double the official price. Heating is essential to keep the chicks alive in winter months. Disposal of 25 to 30 m^3 of poultry droppings per cycle is also a problem for the farmers.

Using funds provided by Volunteers in Technical Assistance (VITA) under a program sponsored by the U.S. Agency for International Development, the National Research Center of Egypt has recently completed a 50 m^3 horizontal concrete and brick digester at Shubra Kass. The gas will be used to heat a poultry house with two stories, each with 250 m^2 of space. Because of the need to maximize biogas production during the winter, this will be one of the few biogas plants in developing countries in which the digester is heated. Since the temperature will be maintained at the optimum level of about 35° C, biogas production is expected to be about 50 m^3 per day. The production rate per volume of digester (1.0 to 1.2 m^3/m^3/day) is about four times that from unheated digesters built by the NRC in Egypt. While 10 to 15 m^3/day of the gas will be used for digester heating, the remaining 35 to 40 m^3/day greatly exceeds the production which could have been expected from an unheated digester.

c. United States

The large system at the Leefer beef cattle farm in Carlinville, Illinois, was designed to provide steam for an on-farm alcohol fuel plant which is not yet in operation; meanwhile, the gas is used to heat the farmhouse and farm building and for crop drying as well as for digester heating.

Manure from 20 to 40 hogs, converted to biogas in a 1900 ft^3 (53 m^3) digester at the Jerry Stockwell farm in Palmer, Tennessee, is burned to heat a broiler house. Since manure produced by the chickens is mixed with bedding materials, the residues from the broiler house are not used in the digester.

Biogas is burned as a boiler fuel at the Kaplan Industries meat-packing complex at Bartow, Florida. Manure from up to 10,000 head of cattle is digested at thermophilic temperaturues (55 to 65°C) in two 320,000 gallon (1211 m^3) insulated steel tanks. About 100,000 $ft^3$3 (2832 m^3) of gas is produced daily. It is used in (a) a system boiler providing hot water for digester heating, (b) a 500 HP dual-fuel industrial boiler, modified to burn biogas, which produces steam for the meat packing plant, and (c) a 660 HP engine connected to an electric generator.

The California Energy Commission is supporting two projects in which biogas will be used as boiler fuel. Waste from fruit juice production at the Knudsen and Sons plant in Chico, California, will be digested in an inexpensive plastic digester. The system has been designed to produce about 2,000 ft^3 (57 m^3) of gas per day; the gas will be co-fired with natural gas in one of the boilers that provides process steam for the plant.

Manure from 1,500 beef cattle at the Fat City Feedlot in Gonzales, California, will be used to produce about 30,000 ft^3 (850 m^3) of biogas daily. The gas will be blended with natural gas and used in a boiler to produce steam for a steam flaker; the unit is used to improve the digestibility of corn and other feedstocks fed to the cattle.

Biogas from 180 cows at the State Dairy Farm at Monroe, Washington, is used to fuel a boiler in the farm's creamery.

4. The Use of Biogas in Engines

Biogas is an excellent fuel for both spark-ignition (gasoline) and compression-ignition (diesel) engines. The minimum additions to either type of engine are a simple device to admit the gas between the air filter and the carburetor and a valve to control the flow of gas.

Both types of engines must be started with liquid fuel. The gasoline engine can then be switched to operate on 100% biogas. Indian research agencies found that small gasoline engines used from 10 to 20 ft^3 (0.28 to 0.56 m^3) of biogas HP per hour. Volkswagen research in Germany indicates that the energy content of an optimum (stoichiometric) mixture of biogas and air is about 3.21 MJ/m^3 or about 85% of that of the optimum mixture of gasoline and air. This difference in energy content is reflected in engine output. An Indian biogas manual shows power losses ranging from 10 to 19% due to the use of biogas in 1 to 10 HP gasoline engines. Those two-cycle engines in which lubricating oil is mixed with the gasoline cannot be operated with biogas.

There are two ways to use biogas in a diesel engine. One is to convert it to a spark-ignition engine by adding a spark plug and magneto, but this is only possible on some engines. The more common method is to operate it as a dual-fuel engine. After the engine is started on diesel oil, the gas valve is gradually opened and the engine's governor automatically reduces the intake of diesel oil. The engine will operate on a mixture of 10 to 20% diesel oil and 80 to 90% biogas.

Nearly two thousand engines are operated with biogas to produce mechanical and electrical power on farms in China. All but a few of these are apparently small diesel engines. A recent symposium on biomass conversion in Chengdu, China, sponsored by the Chinese and U.S. Academies of Science, provided updated information on the Chinese experience with these biogas-fueld engines. Highlights of the Chinese reports at Chengdu are presented in the following paragraphs.

Research in China indicated that the percentage of diesel fuel displaced by biogas depends on the design of the engine. Biogas works best in direct injection diesel engines with a single combustion chamber; more diesel oil is needed when biogas is used in indirect injection engines in which the fuel is injected into a pre-combustion chamber. Engines with larger cylinder bores obtain better fuel savings than those with smaller bores. Diesel fuel displacement was 90% in laboratory tests in China of two types of engines and only 70 to 80% for a third type. In practical applications, the Chinese are satisfied with diesel fuel savings between 80 and 90%. If there is not sufficient diesel oil for ignition, the fuel injector nozzles can be clogged or even burned out.

The average biogas consumption rates in diesel engines in both China and India are between 0.4 and 0.5 m^3 per HP per hour. Thermal efficiency of diesel engines operating with biogas is only about 22 to 25%, which is lower than with diesel fuel which ranges from 30 to 36%. Efforts to increase the thermal efficiency of biogas-fueled engines and decrease biogas consumption have a high priority in Chinese reasearch.

Chinese research and experience indicates that the removal of the carbon dioxide from the biogas is unnecessary and even counter-productive. Studies at the Sichuan Institute of Agricultural Machinery showed that the carbon dioxide lowers the flame speed of the biogas and retards detonation when the engine is operated at a high temperature and pressure. Unscrubbed biogas demonstrated better anti-detonation qualities than pure methane.

Some designers of biogas systems believe that it is necessary to remove hydrogen sulphide (H_2S) from the biogas, ususally by passing it through iron oxide, before using the gas in engines. However, Chinese engineers are convinced that H_2S scrubbing is not necessary. None of the biogas in 64 Chinese digesters contained more than .5 gram of H_2S per m^3. A University of Nebraska report suggests that engine corrosion problems arise when H_2S levels reach 1.5 g/m^3.

After 100 hours of operation, the percentage of H_2S in the lubricating oil of biogas-fueled test engine in China has increased only from 0.1 to 0.15%. The Chinese engineers cite these results and the lack of serious durability problems with engines which have operated up to 400 hours with biogas to support their conclusion that biogas can be used safely without H_2S scrubbing. Some of the large biogas plants in the U.S. and elsewhere contain devices for hydrogen sulphide removal, but reports on many other plants contain no reference to any type of gas scrubbing.

There have been some reports of corrosion of metal parts of a biogas system due to hydrogen sulphide escaping into the air around the equipment. The University of Missouri reported corrosion of controls near a biogas burner. In Germany, Volkswagen found that electrical connections and switches were corroded by the H_2S in the air around a biogas-fueled engine. However, theses problems can be resolved by using alternative materials or by coatings and coverings.

5. Electricity Generation With Biogas On Farms

After domestic cooking, the most common use of biogas is for the generation of electric power. Although there is some energy loss in converting mechanical power produced by a biogas-fueled engine to electrical power, this loss may be offset by the greater flexibility in the use of the energy. The electricity produced by small generating sets in China and elsewhere is typically used for several purposes including lighting, water pumping, and the operation of small machines for agricultural processing. At a given season or time of day the power output can be used for the highest priority purpose. Moreover, it may be more feasible to transmit the energy for short distances through electrical wires than to transport the biomass fuel or the biogas.

Both Chinese and Indian reports have pointed to the advantages of using biogas for electric lighting over burning the gas in lamps. In China .75 m^3 of biogas produces about 1 kWhr of electricity which will operate 25 40-Watt bulbs for an hour; if the same amount of biogas is burned in lamps, it would provide fuel for only seven lamps for an hour.

a. China

Recently the director of China's leading biogas research institution stated that there are now about 1100 biogas-fueled electrical generating sets in China. The number of these units has tripled since early 1980 when the same official indicated that there were 376 of these generating sets. Total power output from these biogas-fueled generators is about 9,000 kW. Most of the units are small systems producing from 3 to 10 kW. Generators rated at 3 kW, 5.5 kW, and 7.5 kW and designed to match available small diesel engines are being mass-produced in China.

Due to the very low gas production per unit of digester volume of the Chinese-type digesters (typically 0.15 volume/volume/ day), the operation of an engine to generate mechanical or electrical power requires either a rather large digester or an interconnected series of digesters. Most of the digesters producing gas for power generation are simply larger models of the "water pressure" digesters built for individual families in China. The standard $6m^3$ circular family digester has an internal diameter of 2.2m. A communal 50 m^3 digester has a 4.6m diameter, while a 100 m^3 digester is 5.9 m wide. Rectangular models are more popular in some areas especially where water tables are high.

The Chinese calculate the digester volume needed to operate an engine by a formula which considers hours per day of operation, gas consumption per HP per hour, HP of engine, gas production per m^3 of total digester volume, and ratio between liquid volume and total volume. One calculation with this formula indicated that a total digester volume of 250 m^3 would be necessary to produce enough gas to operate a 10.8 HP engine/generator for 6 hours a day. A digester volume of 250 m^3 is equivalent to the total volume of 25 of the largest family-sized digesters. Extensive research efforts are being made in China to improve the efficiency of digesters, engines, and generators. Meanwhile, rather small engines and generators are being used to match the rather limited biogas production even from rather large digesters.

At the model "New Energy Village" of the Xinbu Brigade in Guangdong Province, biogas from seven larger digesters with a total volume of 218 m^3 is used to operate a 12 kW generator five hours a day. Since 86 of the production team's 90 families have family digesters which are used to make gas for cooking, the communal digesters are fed manure from the communal piggery, night soil imported from other villages, wastes from the team's banana and silkwork production, the bulbs of water hyacinths harvested in nearby streams, and napier grass which has been masticated and regurgitated by the pigs. About 1.5 kWhr of electricity is produced from each cubic meter of biogas. This power covers about 40% of the production team's power needs for communal lighting and the operation of a pulverizer. However, it is expected that 90% of these needs will be provided by power from biogas when the sytem has been fully perfected. During cold weather some of the biogas is used in heaters to keep the silkworms warm; waste heat from the engine/generator helps heat the drying shed for silkworm cocoons.

The digester volume available for communal biogas production is considerably smaller at most other Chinese villages with manure-to-electricity systems. At the village of Su Zhuang, two hours from Bejing, wastes from a communal piggery and cattle farm are digested in a 100 m^3 digester. Biogas from a 64 m^3 digester provides power for irrigation pumping, lighting, warming the silkworm house, and grinding pig fodder at a commune in Guangdong Province.

At the latter village the biogas is stored in two 18 m^3 plastic storage balloons which are kept inside a smooth-walled building to avoid abrasion when they inflate and deflate. These balloons, made of .24 to .28 mm thick plastic, are widely used for gas storage in China when the gas is to be used in engines. The balloon provides no gas pressure, but the engine sucks the gas into its cylinders. At present the life of the balloons is about two years. Two 120 m^3 balloons store gas from night soil at the large biogas power plant at Fo Shan in Guangdong Province. One advantage of the use of the inflatable balloons is that they reduce the gas pressure within the digester, limit the amount of slurry flowing into the outlet chamber, and reduce the loss to the atmosphere of the gas generated within that chamber.

b. Taiwan

About 1,000 Red Mud Plastic (RMP) digesters have been installed on farms in Taiwan; some of these produce enough gas to operate engines and generators. The RMP units come in seven sizes, from 15 m^3 to 400 m^3. The manufacturer, Union Industrial Research Laboratories of Hsinchu, Taiwan, indicates that gas from a 300 m^3 digester would generate 640 kW of electricity. The Taiwan Livestock Research Institute reported that .9 m^3 of biogas is needed to produce 1 kWhr of electricity, in contrast to the .75 m^3 per kWhr reported in mainland China.

c. Philippines

Power from five biogas-fueled generators now meets all of the power needs of the large meat processing and canning plants at Maya Farms. One 37.5 Kva generator and three 60 Kva generators are driven by gasoline engines operating on 100% biogas. A 188 Kva generator is powered by a turbo-charged natural gas engine which has been adapted to operate on biogas. Due perhaps to the use of larger engines and generators, the gas consumption rates at Maya Farms are the lowest cited in this report. Only .42 m^3/HP/hr is used by the average engine; .63 m^3 is needed to produce 1 kWhr of electricity.

d. India

Although India has more biogas plants than any other country except China, all but a few of the 80,000 digesters in India are family-sized units which do not produce enough gas to operate an engine. The gas is used primarily for domestic cooking and lighting. However, engines are operated with biogas from a few community-size biogas plants and larger digesters in agro-industrial complexes.

Part of the 80 m^3/day biogas production from two community digesters at Fatehsingh-ka-Purwa is used in two engines. A 6 HP diesel generator set provides power for two 40-Watt bulbs in 23 homes plus 18 40-Watt tubelights in streets and other homes. A 7 HP engine is used for water pumping and agricultrual processing. At a 600-head cattle breeding station at Urli Kanchan, the Bharatiya Agro-Industries Foundation uses some of the 340 m^3 of biogas produced daily to generate electric power.

e. Pakistan

A biomass energy reconnaissance in Pakistan conducted by staff of the AID Bioenergy Systems and Technology Project resulted in a recommendation for a pilot biogas congeneration system at a government-administered cattle breeding station in the Punjab. The sytem would use about 20 tons per day of wastes from about 400 cattle to produce around 13,500 ft^3 (382 m^3) of biogas per day. The gas would be used in a 25 kW engine/generator set. The initial project would provide opportunities for performance monitoring, evaluation, demonstration, and training. Although about 1,000 family-sized digesters and several 75 m^3 community digesters have been built in Pakistan, there is not yet substantial experience with the generation of electric power from biogas.

f. Ivory Coast

Manure from 320 cows is being used to generate about 12 kW of electricity at a cattle fattening center and slaughterhouse in Fessedougou, Ivory Coast. The biogas system is one of the largest to be built in Africa. It was funded by the German Agency for Technical Cooperation and built by OEKOTOP, an association for appropriate technologies in developing countries based in Berlin. Information for this report on the project was provided by OEKOTOP and the project manager in the Ivory Coast, Reinhard Henning.

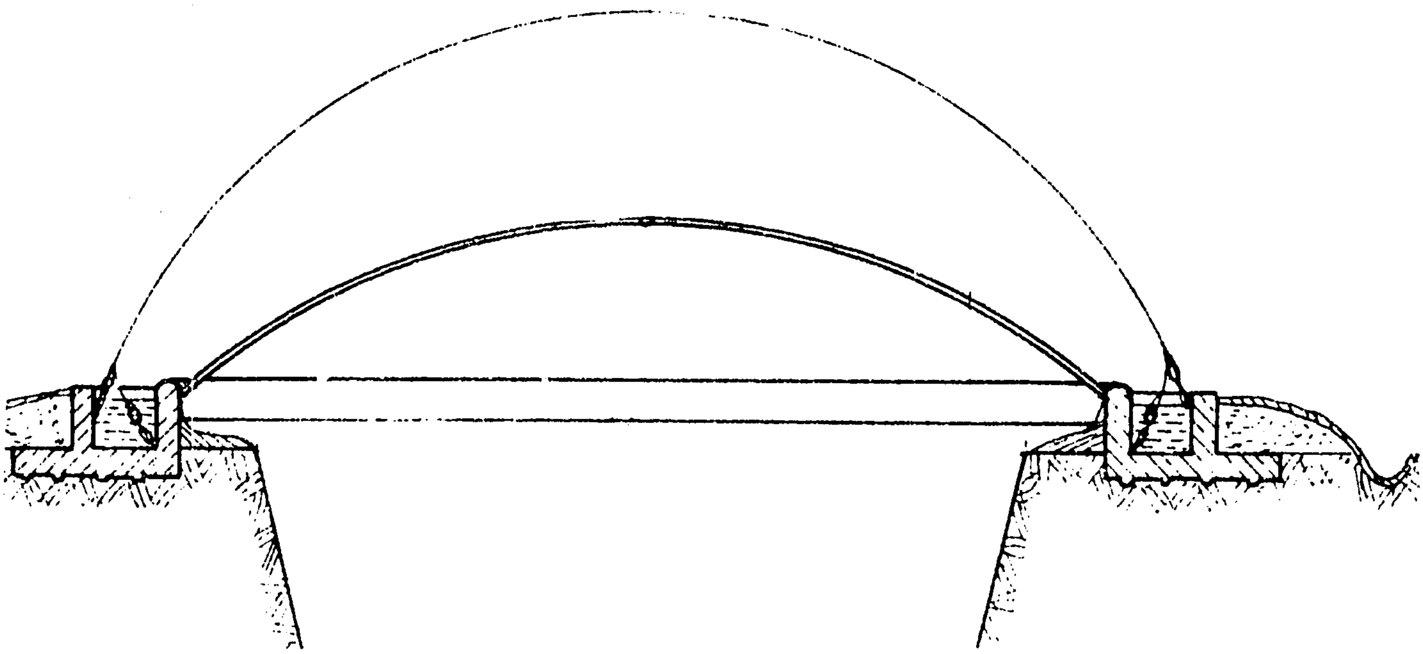
The cattle fattening center has 3,000 steers in 18 feedlots. The initial biogas unit uses manure from about 320 steers in two concrete feedlots. The lots are flushed every morning; the sludge is pushed with hand scrapers into slotted concrete drainage channels. The sludge flows through a grill with 3 cm spaces between the bars; straw and fodder wastes are removed by hand and composted. The remaining sludge flows on to a 11 m^3 mixing basin, where water is added to make a slurry containing 6 to 8% solids.

The digester consists of a large rectangular pit which was dug with a tractor equipped with a frontend loader. The pit is about 5 m wide, 3.8 m deep, and about 20 m long; it was dug in laterite, a decayed rock found in tropical areas. In this firm soil seepage is not a major problem, and it was not necessary to line the walls and bottom of the pit.

The pit is covered with a flexible rubber inflatable gasholder; it is sealed over the pit by attaching the edges of the canopy to the bottom of a .4 m x .4 m concrete channel which completely surrounds the pit. Water is added to form a water seal (See sketch on next page.)

The rubber canopy is elevated over the pit by a circular framework of iron tubes to prevent it from being filled with rain water during periods when it is not fully inflated. Drainage channels dug around the digester disperse the rain water as it runs from the canopy. The iron framework keeps the canopy about 1.1 meter above the manure at the center of the pit; the canopy raises about another meter when fully inflated. The canopy holds about 120 m^3 of biogas or about one day's production.

As fresh slurry is added at one end of the digester each morning, an equal quantity



of digested slurry flows through the 150 mm diameter outlet pipe and into a 400 m^3 collecting basin, from which it is spread on the fields as fertilizer.

Fresh slurry is added at a rate which provides a retention time of about 40 days. Temperature in the digester pit remains stable at about 26°C. Daily biogas production is about 120 m^3 or about 0.3 m^3 per m^3 of digester volume; this rate is about twice that of typical "Chinese" digesters and somewhat below that of the "Indian" digesters.

All of the gas produced by the sytem is used in an internal combustion engine for the generation of electricity. A 3-cylinder diesel engine was converted to a spark-ignition engine by adding spark plugs and reducing piston pressure. During the first 250 hours of operation the engine/generator ran for an average of 11.5 hours per day and produced an average of 12 kW. Gas consumption averaged 9.8 m^3/hour but increased to 14.6 m^3/hr when the system operated at full power (16 to 18 kW).

Eight to ten additional units may be built to supply the total energy requirements of the feedlots and slaughterhouse which currently use about 258,000 liters of diesel oil per year. Congeneration units may be installed in order to use waste engine heat for water heating, for absorption refrigerators or coolers, for the production of alcohol from molasses, and/or for the sterilization of slaughterhouse wastes.

g. United States

Electric power is produced from biogas at about 30 farms and feedlots in the U.S. One type of system produces electricity only for use on the farm itself. The majority of these are on dairy farms and are generating from 10 to 25 kW; most of the power is used for milking machines, other dairy equipment, and refrigeration. These and other livestock farms also need power for feed processing, water pumping, manure scraping, flushing systems, ventilation, space heating, and other purposes. Systems of this type have been built by schools of agriculture of six universities and others under grants from the U.S. Department of Energy and Agriculture, as well as by several private farmers.

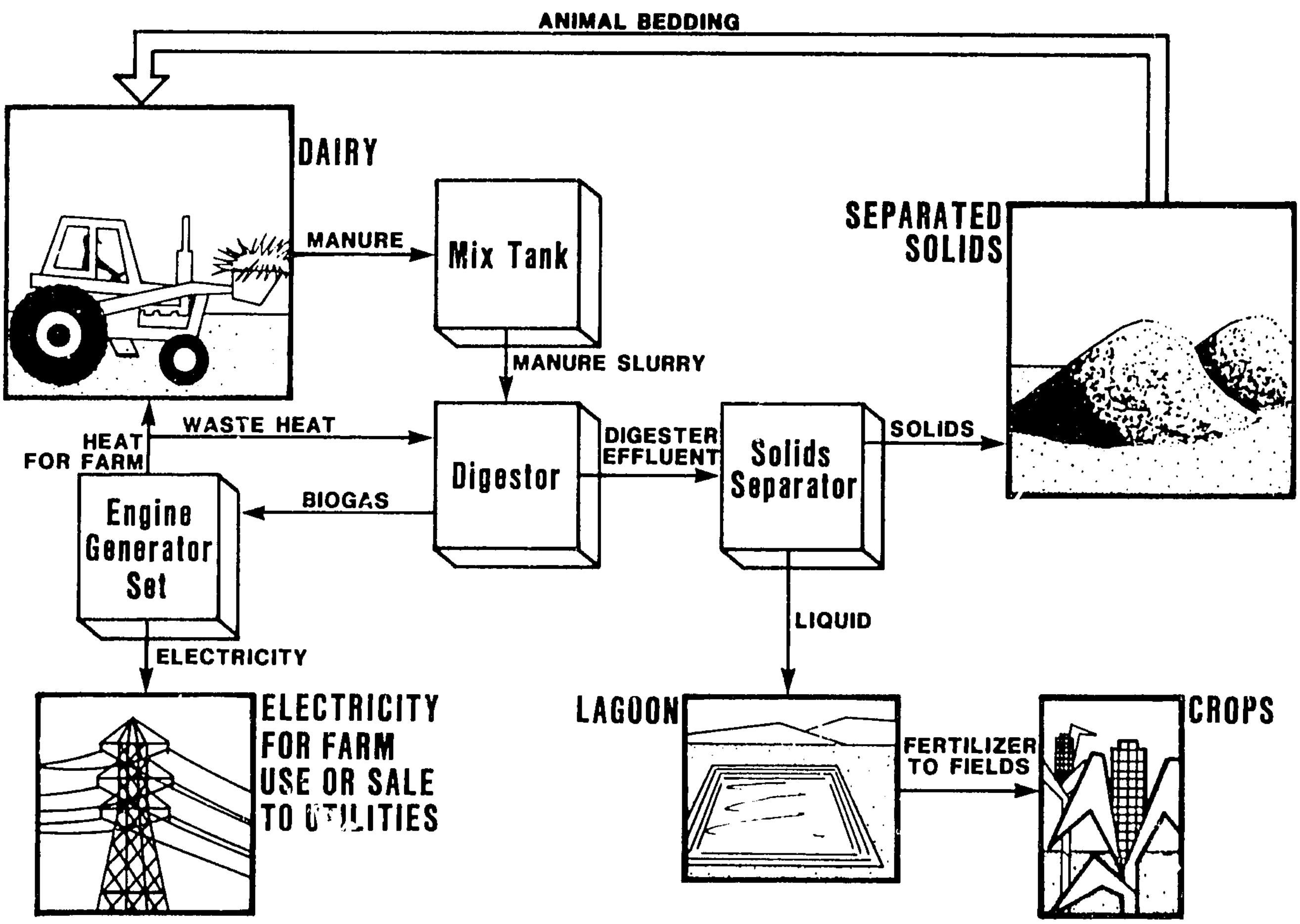
All of the power produced by two 150 kW biogas-fueled generating sets at Mason-Dixon Farms in Pennsylvania is used on the 1,000-head dairy farm, although some power may be sold to the local power company in 1983.

A second group of manure-to-power systems on larger farms and feedlots produce power in excess of farm needs and sell the surplus power to the area electric power company. Recent U.S. legislation requires power companies to buy power from anyone who can produce it, paying rates equal to the generating costs avoided through the purchase. Most of the companies pay the highest rates during periods of peak demand for power. Some of the biogas systems accumulate gas during off-peak periods and generate power only during peak demand periods.

At the Warren Fales poultry and beef cattle farm near Melbourne, Arkansas,. biogas from the droppings of 50,000 layer hens is used to make electricity for the farm and for sale to the Arkansas Power and Light Company. The system includes a 90,000 gallon ($340m^3$) digester built by the Energy Cycle Company, of Lincoln, Nebraska. It consists of a 18' x 19' concrete trough with a "v" shaped bottom that is 12.5' deep in the middle; the digester is covered with a hypalon plastic bag which stores eight hours of gas production. A 65 Kw engine-generator set, designed for use with natural gas, is operated for 10 to 11 hours per day.

Due to the large biogas production from a 180,000 gallon (681 m^3) digester, another 65 kW engine-generator is running 24 hours per day at the Baum farm in Michigan. A 90 kW generating set will soon be added to the system and the Baums hope to produce 1800 kWhr per day valued at about $120 per day. The total system will cost about $220,000; however, the annual return will be about $75,000 and the payback period will be about three years not counting interest or taxes.

Whey from a nearby cheese plant is added to manure from 570 cows in the 240,000 gallon (910 m^3) digester at R-M Farms in Stamford, New York. The gas operates a 300 HP diesel engine connected



to a 90 kW engine. Once the system is in full operation, the farm manager hopes to sell $70,000 worth of electricity to the local electric power company annually and save $30,000 a year in fertilizer.

The California Energy Commission assisted Marindale Dairy of Novato, California to install a system which produces 645 m^3 of biogas per day. The gas is used in a 5.4 liter gas engine which drives a 40 kW induction generator producing 680 kWhr daily. Sunny Valley Foundation is using a 25 kW induction generator with a 60,000 gallon dairy digester in a manure-to-power demonstration at New Milford, Connecticut.

A unique covered lagoon biogas system is producing electricity at Royal Farms in Tulare, California. An anaerobic lagoon was installed to treat the wastes from the farm's 8,000 pigs and piglets in 1975. The California Energy Commission recently funded a 1,170 m^2 hypalon plastic cover, supported by floats and ropes, over a part of the lagoon. Gas accumulates under the cover and is drawn off through a perforated pipe connected to a 1/2 HP suction blower. A generator set provided by Perennial Energy Inc. of Dora, Missouri, includes a 13.4 liter gas engine and a 75 kW induction generator. Daily gas production has ranged from 770 m^3 in winter to 1,150 m^3 in summer; electricity production ranges from 1,080 to 1,560 kWhr per day.

Foster Farms, a 600-head dairy farm near Middlebury, Vermont, operates a 353 HP Catepillar engine/generator with biogas from a 688 m^3 digester. The system produces 125 kW.

Some of the biogas from the 2832 m^3 daily production at the Kaplan Industries facility at Bartow, Forida, is used in a 660 HP Catepillar engine connected to a generator rated at 440 HP; maximum power output to date has been 200 kW.

A Vermont firm is planning a central digester system which will use manure from 6,000 cows collected by trucks in an area with many dairy farms. Vermont Bioelectric will operate two 350 kW generators 24 hours per day.

6. Water Pumping with Biogas

a. China

In 1973 the Leuping People's Commune of Da Yang Contry used biogas from an 80 m^3 digester in a 3 HP gasoline engine to pump water for irrigation. The larger harvest due to increased irrigation demonstrated the potential contribution of biogas to increased agricultural production in China. Today water pumping is among the priority uses for the mechanical power produced by 800 biogas-fueled engines on farms in China and for the electric power produced by the prevously-described 1100 generating sets on farms. On some farms large plastic balloons are inflated with gas and carried to the fields in trucks or carts for use in small irrigation pumps.

b. Taiwan

Some biogas produced on farms in Taiwan is used for water pumping. Each m^3 of gas fueled the pumping of up to 16 m^3 of water in a pumping set at the Taiwan Livestock Research Institute.

c. Botswana

The Rural Industries Innovation Centre and a group of rural families have built a biogas system to pump water from a borehole at Diphawana near Kanye. Cattle dung is collected from family cattle lots and from around the watering point. A 75 m^3 Indian-type digester with a floating steel gasholder produces 22 m^3 per day. The gas is used in a 8.1 kW 2-cylinder Lister engine which pumps 27,000 liters/day from a ground water level about 18 m below the surface. About 20 m^3/day of biogas replaces 80 to 85% of the diesel fuel and saves 1500 liters of fuel per year. The pump provides water for 1,000 cattle, 300 smaller stock, and 30 rural families.

A rural water supply will be provided by another biogas system planned by RIIC in Botswana's central district. A system at the Botswana Agricultural college will provide energy for water pumping as well as lighting and cooking.

d. Philippines

Maya Farms uses biogas to operate three deepwell pumps with a total capacity of 550 gallons (2082 liters) per minute, as well as five smaller slurry pumps.

e. Nepal

Biogas from buffalo manure powers a small irrigation pump in a rice-producing farm in Parwanipur, Nepal. About 350 kg of dung from 24 buffaloes is carried by wheel barrow each day to the Indian-type biogas plant shown in the sketch bleow. The dung is mixed with an equal amount of water using a mixing device developed in Nepal. As the fresh slurry is added, the effluent flows out of the outlet pipe into the irrigation flume and is carried to the fields.

The digester produces about 14 m^3 of biogas per day. The gas flows through an underground pipe to a 5 HP Kirloskar engine. The daily gas production, supplemented with about a liter of diesel fuel, runs the engine for about eight hours per day. The engine drives a Kirloskar water pump with a 75 mm inlet which lifts the water up a 7 m head from the river to the irrigation flume.

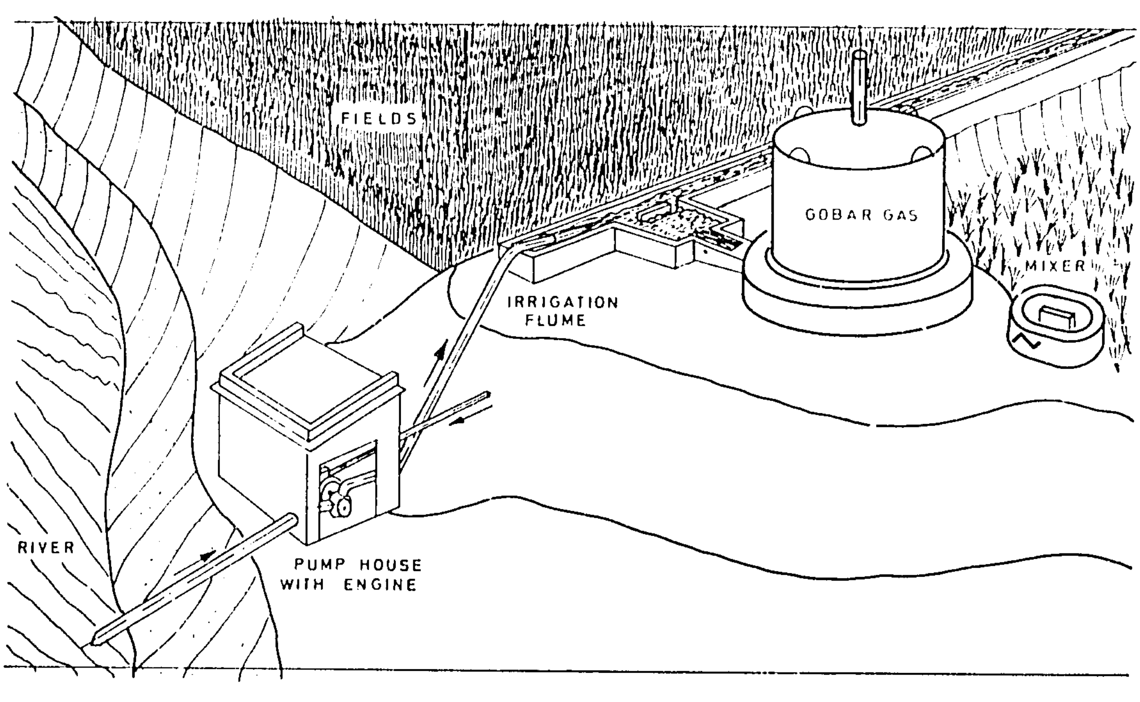
7. The Uses of Effluent Material

a. Fertilizer

Most evidence indicates that the digested slurry is a better fertilizer than raw manure.

It is virtually odor free and does not attract flies. Almost all of the mineral nutrients in the raw manure are retained in the digested slurry. Moreover, 15 to 25% of the nitrogen is converted to ammonia nitrogen which is readily available for plant use. If the slurry is stored in an open tank or lagoon, the ammonia nitrogen will volatilize and be lost to the atmosphere. However, this can be avoided by storing the slurry in covered tanks or by mixing it immediately with irrigation water.

The National Research Center in Egypt has conducted comparitive tests on the use of digester slurry, raw manure, and commercial NPK fertilizer for wheat production. Yields from the application of 20 tons of digester slurry per feddan (8.4 tons/ha) were about the same as from normal applications of NPK fertilizer. Only



5 tons per feddan of digester slurry gave almost the same yield as 20 tons/feddan of raw manure.

In several large biogas operations in the U.S. the liquid and solid fractions of the digester slurry are separated. Kaplan Industries in Florida is packing the solid portion of its digester effluent and selling it as household horticultural fertilizer. Vermont Bioelectric plans to market the solid portion of the effluent from its large manure-to-power plant for domestic fertilizer and potting soil.

b. Livestock Feed Supplement

Experiments with the use of solids from digester effluent as a supplement to the feed for cattle and other livestock have been conducted by several organizations in the U.S. and other countries. Researchers in the U.S. Department of Agriculture's Meat Animal Research Center at Clay Center, Nebraska, found that the protien content of solids from digested cattle manure was 24.5%, although the protien level depends on the diet fed to the animals. The Nebraska research also indicated some limitations on the feeding of the solids due to the rather high ash content (24.3%), as much of which was relatively indigestible silica.

Most of the cattle fed up to 9% digester solids by Biogas of Colorado Inc. gained weight as well as cattle fed normal rations, and there were no significant differences in the condition of the carcasses after slaughtering. Proposals for large biogas plants at cattle feedlots in California and Colorado include the sale of the solid fraction of the effluent as livestock feedstuff.

The effluent can also be used in feeding without full dewatering. The Kibbutz Industries Association in Israel, which is able to operate digesters at high solids concentrations (15 to 18%), has used this concentrated slurry for 15 to 20% of the feed for sheep, cows, and calves. Maya Farms in the Philippines has used wet digester sludge for up to 15% of the feed for pigs.

c. Fish Feeding

Digester effluent can be used to feed fish directly or to feed algae or plankton eaten by the fish.

Digester slurry has been used on pig farms in the Philippines and Taiwan to grow chorella algae, which is fed to fish and also to livestock. Maya Farms fertilizes its large fish ponds with slurry to increase the chorella algae eaten by tilapia fish. Effluent from two 14 m^3 digesters at the Alabang Stock Farm in the Philippines was used to produce chorella in a 52 m^3 pond; feeding trials indicated that dried chorella could also replace up to 50% of the feed for cattle without adverse effect on the livestock.

At the Xinbu Brigade's New Energy Village in China, effluent from biogas digesters is added to the fish ponds to nourish plankton, which are eaten by carp. Comparitive studies showed that ponds receiving digested wastes had a higher percentage of dissolved oxygen, fewer diseased fish, and from 9 to 27 higher carp species production (depending on the carp species) than ponds fed undigested pig manure.

The Kibbutz Industries Association in Israel used digester slurry directly as a supplementary fish food, saving about half the commercial food.

d. Livestock Bedding

After dewatering, the solid fraction of the digester effluent makes a good bedding material for livestock. These solids provide one third of the bedding for 1,000 cows at Mason-Dixon Farms in Pennsylvania. Two and a half tons of bedding material is extracted from the effluent daily at the Baum farm in Michigan. The 580-head Grant Amen Dairy Farm in California expects to save $4,500 per year in bedding costs by using digester solids. North Dakota State University plans to remove 35% of the solids from the manure before digestion, in order to use the solids for bedding.