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Bioenergy Systems Report

MARCH 1982 : BIOGAS IN DEVELOPING COUNTRIES

BIOENERGY SYSTEMS AND TECHNOLOGY PROJECT

The U. S. Agency for International Development established an Office of Energy in 1979 to stimulate and support the development of promising approaches to energy problems common to most developing countries. The Office provides technical and professional leadership in AID energy programs and technical support to field missions and regional bureaus. The bioenergy activities of the Office are conducted through the Bioenergy Systems and Technology (BST) Project. Project staff include Paul Weatherly, the AID project manager, and a full-time four man team contracted from the U. S. Department of Agriculture. These four are Gus Wahlgren, team leader, and Pieter Hoekstra from the Forest Service, and George Beinhart and Kjell Christopherson from the Agricultural Research Service. All correspondence concerning BST Project activities should be addressed to:

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The BST Project helps USAID field missions and host country energy officials to identify and plan bioenergy projects. In response to a request from a USAID mission, a member of the project staff may be sent to conduct an initial reconnaissance or make a prefeasibility study. Where appropriate, the project may contract for a detailed, site-specific feasibility study to be prepared by a consulting firm.

Staff or contract consultants have assessed biomass resources for energy production in Tunisia, evaluated the potential role of biogas in Ecuador, helped develop renewable energy research institutions in Morocco and Indonesia, evaluated the economics of firewood projects in Niger and Sri Lanka, designed a management program for use of forest resources for energy production in Panama and the Dominican Republic, planned a research program on energy from coffee hulls in Central America, and studied the feasibility of the use of rice husks for power generation at a rice mill in Guyana.

The Project sponsors workshops to provide developing country energy planners the opportunity to see and discuss operational bioenergy systems. In March 1982 twenty energy officials will attend a workshop in Brazil to study the Acesita/Florestal integrated charcoal production system.

The Project has commissioned the writing of a "Bioenergy Conversion Handbook for Developing Countries" which contains basic information on conversion processes. This handbook is backed up by a series of comprehensive reports which provide detailed information on the state-of-the-art of each of the major biomass conversion systems. Copies of these "state-of-the-art reports" can be requested by USAID missions for the use of host country planners or others.

The BST Project is sponsoring the publication of a series of "Bioenergy Systems Reports" beginning with this report. These Reports are designed to contribute to (a) the wider international exchange of experience among persons involved with the use of biomass for energy production in developing countries and (b) an expanded flow of information on bioenergy activities in the U.S. and other developed countries which may be relevant to the use of biomass for energy in developing countries.

The reports in this series are compiled and written by Dean B. Mahin, International Energy Projects, P.O. Box 591, Front Royal, Virginia USA 22630, telephone (703) 636-2126, under a contract with the U.S. Department of Agriculture funded through the Bioenergy Systems and Technology Project of the U.S. Agency for International Development. Copies are distributed primarily through USAID missions in developing countries.

BIOGAS IN DEVELOPING COUNTRIES: AN OVERVIEW

This Bioenergy Systems Report, the first of four Reports to be published in 1982, will focus on the production of biogas by the anaerobic digestion of animal and human wastes and plant residues.

A gas consisting mainly of about 60% methane and 40% carbon dioxide can be produced from such residues by microbial action in the absence of oxygen. This biogas can be used for cooking, heating, lighting, and the operation of gasoline and diesel engines. The residual slurry and sludge are excellent fertilizers. Biogas plants have other important health, environmental, social, and macroeconomic benefits. During the 1970's biogas plants have been built in at least 46 developing countries, although many of these have been only experimental or demonstration units.

In China, biogas plants offered a more hygienic way to continue to use human wastes as fertilizer and a means of producing energy from these wastes and the dung from a greatly expanded swine production. During the 1970's seven million digesters were built to supply biogas to thirty million members of rural communes in China. Five million of these digesters are in Szechuan, an agriculturally productive province on the western edge of China's agricultural zone. Most of the Chinese digesters are family-scale plants. Manures from communal piggeries and state farms are also used in numerous large-scale plants; the gas from these is typically used to provide mechanical or electrical power.

In India, cow dung has traditionally been dried and used for cooking in rural areas. A biogas plant permits the Indian farmer to use the dung for both fuel and fertilizer. Biogas research and development has been under way in India for several decades, and 87,000 plants had been built by 1981. All but a few of these have been individually-owned, family scale plants using cow dung. However, the Indian government is now giving greater priority to the development of community-scale plants designed to spread the benefits of biogas.

Nearly 30,000 family-scale digesters have been built in Korea, although the government's biogas program now stresses larger-scale plants. Taiwan has over 9,000 digesters, including 1,000 plastic bag types. There are about 750 plants in Nepal. Extensive biogas research and demonstration projects have been carried out in the Philippines, Indonesia, and Thailand. In the Philippines, Maya Farms produces over 3,000 m^3 of biogas daily from the manure of more than 25,000 pigs. There is also substantial biogas activity in Pakistan, Bangladesh, and Sri Lanka.

Eighteen African countries have one or more institutions engaged in biogas experiments or demonstrations. In the Near East, biogas projects are being conducted in Egypt, Israel, and Turkey. In the Western Hemisphere, biogas activities are being carried out in Brazil, Guatemala, Costa Rica, El Salvador, Honduras, Nicaraugua, Panama, Jamaica, Ecuador, Colombia, Bolivia, Peru, and Chile.

At present the U.S. Agency for International Development is supporting biogas projects, usually within broader renewable energy programs, in Panama, Honduras, Guatemala, Ecuador, Egypt, Morocco, Tanzania, Mali, Rwanda, Lesotho, Cape Verde, Nepal, Indonesia and Thailand. U.S. Peace Corps volunteers are participating in biogas projects in the Philippines, Ecuador, and Botswana.

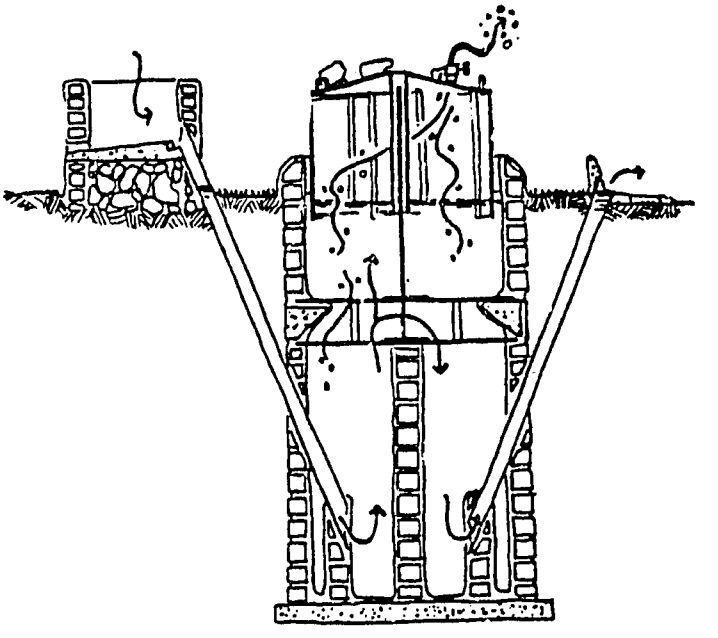
ABOUT THIS REPORT

This Report has been compiled primarily from research and project reports received from organizations in developing countries. Highlights of research and project results have been provided as feasible. However, the editor and sponsoring agencies can accept no responsibility for the accuracy of specific technical data. Readers are referred to the original sources for more detailed information. (See "Referral Service", p. 22)

PART ONE: DIGESTER DESIGNS AND OPERATIONS

1. "Indian" Digesters

The Conventional Models in India



The great majority of the biogas plants built in India have been similar to the basic design shown in the adjacent drawing. The digester consists of a deep circular pit or well built of brick, mortar, and plaster. The input slurry is mixed in a small masonry tank on the surface and is fed through a pipe to a point near the bottom of the digester. The larger $6m^3$ models (shown here) are divided into two chambers by a brick wall; the slurry flows up over the wall and down to the outlet pipe near the bottom of the second chamber. Smaller $3m^3$ models have no dividing wall and the slurry rises to an outlet pipe near the top of the digester.

The gasholder is made of steel and resembles a bell or drum. In early Indian models it was suspended on counter-weighted pulleys hanging from several poles around the digester, but these led to tilting and the loss of gas pressure. Most Indian plants now have two central guide pipes. The inner pipe is connected to a steel frame imbedded in the wall of the digester. The outer pipe is part of the structure of the gasholder, which is free to rise or fall depending on the producton and use of gas.

There are two main advantages to this type of digester, hereafter referred to as the "Indian" digester: (a) The weight of the steel gasholder provides a constant level of gas pressure, which is usually equivalent to about a 10 cm column of water. (b) Because it normally used only cow or pig manure diluted to less than 10% total solids, sludge formation is slow and frequent cleaning is not necessary.

However, there are a number of disadvantages to the Indian design: (a) The steel gasholder is expensive. In India in 1980 a $3\,m^3$ brick masonry digestor with steel gasholder cost Rs. 3400 (US$400), while on equal-sized "Chinese" plant cost only Rs. 2264 (US$266). (b) There have been serious corrosion problems with the steel gasholders. (c) The uninsulated steel gasholder is a good heat conducter and is thus not well suited for use in cold weather. (d) The plant has very little capacity for digesting fibrous plant materials. Each of these problems will be explored in a subsequent section of this Report.

Shallower and Wider Digesters

Conventional Indian digesters have been narrow and deep. The $3\,m^3$ plants are 5 m deep and 1.6 m wide, while the $6\,m^3$ plants are 4.4 m deep and 2.2 m wide. The narrowness apparently resulted from an effort to minimize the cost of the steel gasholder; the depth was due to retention times of 50 to 55 days which are considerably longer than in most other designs.

During the past year or two several factors have resulted in a decision by the primary Indian biogas agency, the Khadi and Village Industries Commission (KVIC), to move to shallower and wider digesters. The Indian Institute of Science (IIS) conducted studies of the optimization of dimensions of biogas plants and tested several plants with shallower and wider dimensions. IIS concluded that the total cost of these new plants was 25 to 40% less than the conventional models and that their performance was slightly better than

that of the standard plants of comparable size. A committee established by the Department of Science and Technology to evaluate designs of biogas plants concluded that the retention times being used in India were longer than necessary. If the retention times were to be reduced, digesters could be smaller (i.e., shallower) and considerably cheaper.

By the fall of 1981 field tests had convinced KVIC that the retention times could be reduced to 30 days in southern India and to 40 days in northern areas. Plans for shallower and wider (and less expensive) digesters are now being prepared. (Details of the specifications of these new biogas plants will be provided in a subsequent Bioenergy Systems Report.)

"Water Jacket" Designs

Recently KVIC recommended the wider use of "water jacket" plants as a means of reducing corrosion in steel gasholders. In the standard Indian models the gasholder floats directly in the cow dung slurry. In the "water" jacket design, the upper part of the digester wall is surrounded by an additional wall and the two walls are sealed together at the bottom. The gasholder floats in water poured in the circular cavity between the two walls.

These models have several advantages: (a) A steel gasholder floating in water is less prone to corrosion than one floating directly in the slurry, especially if the slurry contains human wastes. Thinner steel can be used, and the saving in steel costs offsets the somewhat higher construction costs due to the additional outer wall. (b) Since the slurry has no direct contact with the air outside the digester, heat loss in cold weather is reduced. (c) Excessive dilution of the slurry by rainwater seepage during the rainy season is eliminated. (d) The completely sealed plant is more sanitary and odor free than the conventional Indian plants. One disadvantage of the water jacket design is that it eliminates the use of rotations of the gasholder to break scum on the digester surface; however, it is possible to attach stirring rods which extend down into the slurry.

New Materials and Designs for Gasholders

Cost and corrosion problems with steel gasholders have led to experiments with other materials for gasholders in India and elsewhere.

Plastic gasholders have been used in Korea, India and Brazil. The standard Korean family digester of the middle 1970's has a gasholder of rigid polyvinylchloride (PVC), but these did not prove entirely satisfactory due to deterioration in sunlight and rising costs of PVC. High-density plastic gasholders are now manufactured by Heliplastics of Bombay in cooperation with KVIC. They are described as corrosion and leak proof, light weight, transportable over long distances, and easy to handle without cracking or breaking. A water chamber on the top of the gasholder provides additional weight and gas pressure; it can also be used as a solar heater for slurry water.

The cost of manufacturing these gasholders is about the same as the steel gasholders. KVIC hopes that the higher total costs can be reduced by manufacturing the gasholders in a number of decentralized locations. Gas production of plants with the new high-density polyethylene gasholders was about the same as conventional plants at two of KVIC's regional centers but was from 17 to 38% lower at three other centers.

Ferrocement gasholders have been developed by the Structural Engineering Research Center at Roorkee, India. The side or wall unit is cast on a wooden mold lined with galvanized metal. Mortar is applied over three layers of galvanized wire; a steel ring adds strength to the bottom edge. The domed roof is cast separately on a masonry or wooden mold.

Advantages of ferrocement gasholders cited by the Roorkee Center including lower cost of manufacture than steel gasholders of equal capacity, relative ease of fabrication using a combination of skilled and unskilled labor, low thermal conductivity and hence a fairly uniform rate of gas production in all seasons, high resistance to corrosion, minimal need for maintenance, high impact

strength, and ability to withstand rigours of transport and handling.

In comparative tests with other gasholders at the KVIC regional center at Gandhigram, a plant with a ferrocement digester and gasholder and a water jacket design has the highest average gas production per unit of volume of digester. Despite some leakage and transport problems with these gasholders, KVIC is considering a plan to manufacture small ferrocement gasholders at 200 locations in India.

Thin concrete gasholders for "Indian" plants are being tested at the Guangzhou Institute for Energy Conversion in China. A clay form is covered with paper, over which a thin layer of concrete is formed. After curing for ten days it is easily lifted off the form; the interior is well plastered using the thin plaster coating techniques developed for sealing the inside of the Chinese digestors.

Shallower steel gasholders are used on many of the "Indian" plants in other countries. Although the standard gasholder is a meter or more high in India, in other countries the bell is often no higher than 50 cm. These shallow bells do not hold a great deal of gas; more gas is stored in the upper part of the digester chamber as in the Chinese models. With the aid of rocks piled on the top in some cases, the bell serves primarily as a pressure regulator. If the gas pressure becomes too high, the bottom edge of the bell is pushed up to the surface of the slurry or water seal, the seal is broken, and some gas escapes.

Horizontal and Rectangular Models

Many of the "Indian" biogas plants built in other countries have square or rectangular digester pits and frequently also square floating gasholders. In most of these the longer horizontal dimension was equal to or greater than the vertical dimension. Such horizontal digesters are more appropriate in countries where the water table is very high. During the construction of one digester in Papua New Guinea daily pumping out of the pit was necessary until it could be sealed. If the pit is to be shallower, it is also possible to use conventional building materials (including concrete blocks and concrete poured into rectangular forms) which are not useable for circular models.

The Central American Institute for Industrial and Technical Research (ICAITI) has designed a 20 m^3 horizontal digester with concrete block walls and floor and a top of reinforced concrete. It has a small square gasholder on one side, but most of the top is covered with soil for greater insulation. In Egypt, the National Research Center has built a prototype 7.5 m^3 horizontal digester with an Indian-style gasholder; the remainder of the surface area is divided between a solar pond for heating slurry and a pit for composting crop residues before they are used in the digester.

Other Modifications of the "Indian" Design

A unique center pipe gas outlet is used on most "Indian" digesters in Nepal to replace the hose usually connected to the top of the gasholder. Holes in the gasholder's slide pipe allow the gas to pass through to the open top of the guide pipe which is also used as the gas outlet pipe; it extends down through the bottom of the digester and is connected underground with the main gas line. This modification is applicable only to the relatively tall gasholders in south Asia; a guide pipe is usually not necessary for the shallower gasholders used in many other countries.

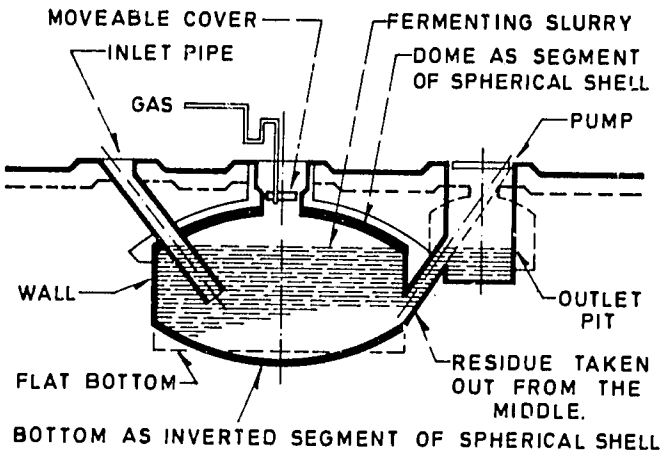
In Nepal, where the water table is also high in some areas, the Gobar Gas Company has designed a vertical Indian digester which is shallower than the conventional models; digester capacity is maintained by sloping the bottom third of the digester outward so that the bottom is 45% wider than the top.

In Kenya, circular galvanized iron cattle-watering tanks are used as gasholders. Cross bars, welded across the top of the tanks, support a vertical slide pipe. Several sizes of watering tanks are used as gasholders in circular stone digesters of approximately two, three, and four meters diameter; the depth is equal to the diameter in each case.

2. "Chinese" Digesters

Water Pressure Digesters in China

Most of the digesters built in China are circular units with domed roofs which resemble the model shown in the adjacent sketch. They are built mainly from locally available masonry materials. The digester floor and walls may be made of lime and clay, lime and cement, concrete, concrete blocks, cast concrete, brick, slate, or cobblestone. The domed roofs are usually of brickwork or cast concrete, but other materials have been used.



There are also a number of variations in the width and shape of the digesters. Several ingenious construction techniques have been developed. A "liquid mortar" plant is built by accurately excavating the pit, drilling holes into the side to provide additional grip, and then applying mortar directly to the sides of the pit; the method requires firm soil and a high degree of construction skill. A "ball" digester can be built in a shallow round hole; the top half of the ball is completed above the ground. A deeper hole is then dug alongside, filled with water, and the ball is floated into its permanent position. The "cast in place" technique begins with a ring trench into which concrete is poured to form the walls. Next the interior is excavated just deeply enough to make room for forms for a cast concrete dome. After it is cast, the remainder of the soil is removed and the floor is poured.

Virtually all of the family scale digesters built in China operate on a common "water pressure" principle. The digester slurry occupies most but not all of the main chamber. As biogas is produced pressure builds up under the roof and slurry is pushed out of the digester and into the vertical outlet chamber. When gas is used, slurry flows back into the main chamber.

This "Chinese" type of digester has several basic advantages: (a) Because it requires no steel and is built with local materials, it is from 10 to 30% less expensive than the "Indian" digester depending on the relative costs of cement and steel. (b) Since the digester is completely underground, it is less affected by cold weather than the "Indian" digester. (c) It can accomodate feedstock mixtures which include a rather high percentage of fibrous plant material.

Most of the disadvantages of the "Chinese" digesters are related to problems of gas pressure and leakage: (a) Since the gas must be retained within a masonry structure, several coats of plaster are required to seal the digester. (b) Even so, many of the digesters in China have been shut down due to leakage problems. (c) Gas pressure can be very high but constantly varies depending upon the amount of gas produced and used. (d) If gas pressure becomes excessive, some gas is lost by venting through a pressure-relief valve. (e) A part of the gas is produced in the outlet chamber and thus inevitably lost.

The most important disadvantage, however, is that gas production is very low. Rates may reach 0.5 m^3 per m^3 of digester per day in summer but drop in winter to 0.07 in south China and around 0.04 in the north. A Chinese biogas expert gave 0.15 vol/vol/day as the annual average in 1980; however, a United Nations report in 1981 indicated that the Chinese hope to raise the average gas production from 0.1 m^3/m^3/day to 0.15 or 0.20. In comparison, the average daily production of a conventional Indian digester in 18 month field tests in India was 0.46 vol/vol/day.

The leakage problems and low gas production of the "water pressure" digesters

have led the Chinese biogas agencies to consider using Indian-style floating gasholders on their digesters. The Chengdu Institute of Biology reported 33 to 41% higher gas production with a "segregated" biogas plant with a separate gas storage tank. As indicated earlier, the Guangzhou Institute is experimenting with thin concrete gasholders, and other research institutes are reported to be working on low-cost materials for floating gasholders.

"Chinese" Digesters in Other Countries

India has more "Chinese" digesters than any other country except China itself. The Gobar Gas Research Station at Ajitmal, Uttar Pradesh, began a search for a alternative to the conventional Indian digester in 1976. Fourteen designs of drumless plants were evaluated for ease and cost of construction and the "Janata" model was adopted for widespread use in the state of Uttar Pradesh.

The Janata plant is essentially a Chinese water-pressure digester; it has a domed masonry roof like most Chinese models, but no manhole. Access to the digester tank is only through the relatively wide inlet and outlet openings. It is much shallower and wider than the conventional Indian plants. In recent tests the average gas production for a Janata plant was 0.318 m^3 per m^3 of digester per day; the Janata plants are more productive than the water-pressure digesters in China but only about two-thirds as productive as the conventional Indian plants. Development and Consulting Services of Butwal, Nepal, has built "Chinese" digesters by beginning with a concrete dome which is cast over a mud mold in a shallow pit. After the dome is dry, the digester pit is dug out under the dome; two coats of plaster are applied to the floor and walls. Eleven of these digesters are reported to be working satisfactorily in Nepal.

The Asian Institute of Technology in Bangkok has developed a small and very simple version of the "Chinese" digester. The 1.3 m wide concrete main tank has a covered top but no bottom; it can be cast in a single piece with the narrower water pressure tank which sits on top. A pipe runs from the water pressure tank down into the slurry; plastic or bamboo pipes replace the usual masonry inlet and outlet chambers. Although it is a simplified version of the Chinese digester, it is designed for use with dilute manure slurries like an "Indian" digester. An average of 0.5 m^3 of gas per m^3 of digester volume was produced with the prototype model using a mixture of 65% pig manure and 35% chicken manure. Stirring is provided by a plastic rope with rings or loops attached which is passed through the inlet pipe, across the bottom of the digester, and out through the outlet pipe.

3. Plastic Bag Digesters and Gasholders

The third basic type of biogas plant found in developing countries consists of a flexible bag made of plastic or synthetic rubber; the bag is usually both digester and gasholder, although separate plastic and metal gasholders have been used with these digesters.

The most widely used bag digesters are apparently those made by Union Industrial Research Laboratories (UIRL) in Hsinchu, Taiwan. In 1974 UIRL invented a new material called Red Mud Plastic (RMP) which is a mixture of red mud waste from aluminum production, new or used PVC, waste engine oil, and other ingredients. RMP is made in both soft sheets and hard pipe. UIRL claims that biogas digesters made of RMP have the following advantages: (a) Metal oxides in the material give it three times or more the resistance to ultraviolet light of ordinary PVC products. The first RMP digester, installed some years ago, is reported to be still in good condition. (b) RMP is resistant to dilute acid, strong alkali, and hydrogen sulfide. (c) Because the red mud and waste engine oil are worthless, the cost of RMP is among the lowest of all plastic materials. A firm planning two 100 m^3 digesters in Barbados concluded that a concrete digester with equal capacity would cost three times as much as the RMP units. The RMP digesters are available in various sizes from 15 m^3 to 400 m^3. The sausage-shaped units are installed in a horizontal pit shaped to the

contour of the lower half of the bag; the upper third or half, which is above ground, serves as a gasholder unless a separate gasholder has been provided. Gas pressure can be increased with a wooden platform riding on top of the digester and loaded with rocks; the University of Hawaii added pressure by lashing old tires on top of the bag.

Sanamatic Tanks Manufacturing Corporation, which was founded by an Australian, offers a large digester-gasholder made of butyl rubber. The bag is placed on a sand base and is supported by a steel cage with panels of rigid foam insulation. Macroenergetica S.A. of Brazil makes a digester and separate gasholder of reinforced PVC. The digester bag is supported by galvanized steel reinforcing bars. The gasholder resembles a large pillow held up by stakes; a water bag on top increases gas pressure. An English firm, Lockstoke Developments, makes relatively flat rubber digester-gasholders in 2.2 m^3 and 13.5 m^3 sizes.

These bag digesters have been primarily designed for the continuous digestion of manure slurries with a low percentage of total solids. However, Lockstoke Developments also sells a hand-cranked vegetation shredder which can be used to add some plant material to manures or night soil. UIRL gas production estimates include 2.0 m^3 per m^3 of digester at 30-35° C. and a 20-day retention time. The Office of Rural Development in Korea compared gas production from pig manure in a 3 m^3 PVC bag digester with that from chicken manure in a 5.8 m^3 concrete digester with a PVC gasholder. Average production was 43% higher in the smaller bag digester; the increase was attributed to the considerably higher temperatures in the bag digester, especially in summer months.

Plastic bags are widely used in China as gasholders. They are sometimes used to capture the excess pressure which can build up in the Chinese digesters. Bags of gas may be taken to the fields in trucks or carts and used to operate irrigation pumps. At the biogas power station in Foshan, gas from 28 digesters is collected in two large PVC bags with a total volume of 240 m^3. The bags are kept in a smooth-walled room to avoid physical damage and degradation due to sunlight.

Perhaps the most unusual plastic gasholders are reported by the biogas newsletter in Nepal: "In Tibet one sees cars and busses with what looks like an elongated balloon on the roof, containing several cubic meters of gas, enough for two or four hours of running, depending on the size of the bag and the horsepower of the vehicle." The Livestock Research Institute in Taiwan found that a 2000 cc car would go 9 to 10 km on each m^3 of purified methane in a similar rooftop bag.

4. Temperature-Raising Devices

Most of the extra equipment added to the standard components of digesters has been designed to raise or maintain temperatures inside the digesters. Optimum temperatures for the mesophilic group of methane-producing bacteria are between 30 and 40° C. These bacteria are very sensitive to temperature changes, and gas production drops rapidly when the digester temperature drops close to or below 20° C. A number of temperature raising devices and techniques have been used:

Insulation: Since it is mostly underground, the Chinese digester is better insulated than the Indian type. Further insulation can be provided by piling manure, straw, leaves, crop residues, or other materials on the covered inlet and outlet chambers. A Guatemalan organization, ICADA, found that the exothermic heat from composting manure and straw, piled around a digester, raised interior temperatures 8 to 10° C above the ambient temperatures even in the coldest season in the Guatemalan highlands. The Indian Institute of Science in Bangalore, Mysore State, showed that the gasholder was the major source of heat losses from the conventional Indian plant. Since the gasholder must be free to rise as gas pressure increases, the Indian plant is difficult to insulate. Some of the heat loss is eliminated with a "water jacket" which is placed to prevent any contact between the

slurry and the outside atmosphere. The Indian Agricultural Research Institute found that a wooden frame around the gasholder covered with plastic sheeting kept digester temperatures 5 to 8° above the ambient temperature and improved gas production. In Korea the Office of Rural Development tried insulating "Indian" digesters with rice hulls or straw and with vinyl sheeting, but neither technique raised the temperatures to optimum levels during Korea's severe winters.

Passive solar heating: In Guatemala ICADA built a simple solar greenhouse over an underground digester; this passive solar technique raised digester temperatures about 10° C. and permitted an ample gas production at an altitude of about 1700 meters. A subsequent ICADA experiment with a greenhouse over an above-ground uninsulated metal barrel digester was much less successful due to the rapid drop in digester temperatures during the cold mountain nights. A digester built with the help of U.S. Peace Corps volunteers at an even higher elevation (2750 m) in Ecuador used a greenhouse cover and a solar water heater to keep temperatures at an acceptable level.

Solar-heated slurry water: In cold weather, the temperature of the digester is lowered by the daily addition of slurry at ambient temperatures. Solar energy has been used in various ways to heat water for slurry mixing. In China the solar water heater often consists of a black-painted basin with a glass cover. The Indian Institute of Science built a "solar pond" on the top of a steel gasholder; it reduced heat losses from the gasholder and the solar heated water was used for slurry mixing. The National Research Center in Egypt is experimenting with a prototype plant with a similar solar pond. The new high-density plastic gasholders in India contain a water chamber which can be used as a solar water heater. Solar panels are used at a biogas-fueled cheese plant in Nepal to heat slurry water as well as for space heating in the structure which houses the biogas plant. A 100 cubic meter village-scale plant in Korea used a 3.3 square meter solar panel to heat slurry water.

Direct digester heating with solar energy: At a community-scale plant in Kubadthal, India, water heated in a solar pond on the top of a 140 m^3 digester is circulated through coils in the digester by a biogas powered pump. Most other such systems use water heated with flat-plate solar collectors. U.S. Peace Corps volunteers designed a "thermosiphon" system to circulate solar-heated water through a digester at Quilango, Ecuador; hot water from solar collectors on a hillside below the digester flowed naturally upward to coils inside the digester. The thermosiphon principle has also been used in the solar heating systems in a large ferrocement digester built by ICADA in Guatemala and in the cheese plant in Nepal. A Belgian rural development organization, AIDR, is experimenting with the solar heating of several digesters in the cool highlands of Rwanda. UIRL in Taiwan has designed a solar heating system to be used with a 300 m^3 RMP bag digester, and the Taiwan Livestock Institute is experimenting with digestion at thermophilic temperatures (50 to 60° C) using solar heat supplemented with heat from biogas combustion.

Digester heating with biogas: Korea's Office of Rural Development used about 32% of the biogas produced by a 137 m^3 plant for digester heating, but only 16% of the gas was needed to heat a 100 m^3 plant when the slurry was mixed with water heated by a solar collector. Waste heat from biogas-fueled engines has also been used for digester heating. A state dairy farm in Szechuan province in China uses waste heat from two large digesters. Waste heat from a biogas-fueled automobile engine heats a 60 m^3 digester in Rwanda.

Additives: Biogas experts in India, Pakistan, and Nepal recommend the addition of animal urine to stimulate gas production from cow dung plants in colder months; a biogas manual in Nepal recommends replacing one-third of the slurry water with urine but warns that higher percentages of urine produce ammonia concentrations which inhibit or kill methane-producing bacteria. The addition of poultry droppings, dried straw powder, composted dried grasses, algae, and molasses has been

recommended in one or more countries. AIDR, which built a digester at a slaughterhouse in Belgium, found that enzymes in the cow's stomach stimulate biogas production; these additives were subsequently used to increase gas production from a mixture of millet stalks and manure in Upper Volta. The Guangzhou Institute of Energy Conversion in China has begun a six-year research program on additives to stimulate anaerobic digestion.

5. Scum-breaking Equipment

The other major area for innovation in digester equipment has been the development of new means of breaking up the layer of scum which tends to form on the surface of the slurry. In India, rods or flanges are installed on the inside of gasholders which float directly in the slurry; the scum is broken by rotating the gasholder once or twice a day. Longer rods, extending down into the slurry, can be used even if the gasholder floats in a water jacket. Several other devices have been developed for scum-breaking in "Indian" digesters. In Taiwan, a piece of plastic pipe hangs vertically from the inside of the top of the gasholder; two crossed pieces of pipe are attached to it just below the slurry surface. A plastic rope is attached to the crossed pipes and passed out through the outlet pipe; pulling and releasing the rope agitates the surface of the digester. A variation on this device was developed in Sri Lanka. A wheel-like structure floats on the slurry surface; it is attached to a plastic rope which passes through a pully or ring at the bottom of the digester and then out through the outlet pipe. Pulling the rope draws the floating wheel under the surface of the slurry and breaks the scum.

The daily ebb and flow of the slurry within the "Chinese" digester provides some agitation. As the gas pressure builds up, a part of the slurry is forced up into the outlet chamber; when the gas is used, the slurry flows back into the digester. When more agitation is needed, the Chinese normally use a piston-shaped device; a wooden disc is attached to a long bamboo pole and braced with wires. It is used to feed the digester with plant materials which will not readily drop through the inlet. When the device is inserted into the digester through the inlet, a back and forth movement will cause a rapid turning over of the digester contents. However, this technique is used sparingly to avoid disturbing pathogens and parasite eggs accumulated at the bottom of the digester. Mechanical stirring devices have been added to "Chinese" digesters in several other countries. A pipe usually extends through the domed roof of the digester, with a crank on the top and stirring flanges on the portion extending into the slurry.

6. Digester Size & Retention Times

Loading rates are more or less fixed by the availability of feedstocks. A larger digester provides a longer retention time (RT). Longer RT's are desirable when priority is given to (a) deriving the maximum amount of gas from a limited quantity of feedstock, (b) maximizing gas production during winter months, and/or (c) destroying pathogens in the effluent. Each of these objectives is important in China, and the 8 to 10 m^3 family digesters are considerably larger than those in India and elsewhere.

Digester size and retention times can be reduced when the above goals are less important than (a) reducing the cost of digesters and (b) obtaining the maximum gas production per volume of digester. The latter goals have had the highest priority in India, where a fundamental decision has been reached to move to smaller digesters and shorter retention times.

Information on loading rates and retention times in China is limited; dung, night soil, and plant materials are added to digesters as available without precise measurement. There is considerable evidence that Chinese biogas experts are examining every option for improving the performance of digesters in China, but it is not clear whether the possibility of smaller digesters and shorter retention times is being considered. Meanwhile, important experience with shorter RT's is being developed in several other countries.

PART TWO: FEEDSTOCKS FOR BIOGAS PRODUCTION

1. Animal and Human Residues

Cow Manure

Cattle dung is used in most of India's digestors and in a considerable number of units in other developing countries. Most of these digesters are family-sized, "Indian" models producing gas primarily for household cooking.

Larger biogas plants have been built on dairy farms and cattle stations in several countries. At a state dairy farm in Szechuan province in China manure from 125 cows produces 200 m^3 of gas per day in six digesters; the gas is used for cooking and electrical power generation. Biogas from 50 cows at the Alabang dairy plant in the Philippines is used in a refrigerator and stove in the milk processing facility. The Delhi Dairy Corporation in India is reportedly operating a 420 m^3 digester. The Bharatiya Agro-Industries Foundation uses the manure from 600 cows to make 340 m^3/day of biogas at a cattle breeding station near Poona, India; the gas is used for cooking, lighting, water pumping, and generating electricity. Research institutions in Costa Rica and Indonesia are testing digesters on dairy farms. Large units are being built or planned at a cattle feedlot and slaughterhouse in the Ivory Coast and at a borehole well in Botswana.

Cow dung is rarely mixed with other manures or plant materials. While lower Carbon/Nitrogen ratios are usually given in developed countries for cow manure, research institutions in China and India have indicated C/N ratios for cow dung of 24 or 25; the dung is thus not far below the optimum level for biogas production which is considered to be around 30. Night soil is added to about one-fourth of the cow dung digesters in India and appears to increase gas production: this may be due to increased microbiological activity rather than to an improved C/N ratio. Laboratory tests have indicated that the addition of most crop residues to cow dung decreases gas production, apparently because the C/N ratio is raised beyond the optimum level.

Pig Manure

Swine residues are used in most of China's seven million digesters and in the numerous biogas plants in Korea, Taiwan, and the Philippines.

Since pigs eat less forage than cows, pig manure has a higher percentage of nitrogen (3 to 4%), a lower C/N ratio (13 to 15), and a lower percentage of nondigestible lignin than cow manure. In laboratory tests in China, India, and New Zealand and commercial operations in the Philippines, biogas production per unit of weight was nearly twice as high for pig manure as for cow manure.

Because of its low C/N ratio, pig manure is suitable for digestion in combination with crop residues which have a higher C/N ratio. However, it is frequently mixed with other feedstocks only in China. Pig raising by individual families is encouraged by the Chinese government and the goal of two pigs per rural family has been achieved in many areas. On the typical small family plot the pig pen, latrine, and digester are adjacent; night soil and pig manure are flushed directly into the digester. Partially composted crop wastes, straw, grass, and weeds are also added. The most common mixture is 60% pig manure, 20% night soil, and 20% plant material, plus water. The appropriate technology organization in Guatemala (CEMAT) also uses night soil with pig manure in "Chinese" digesters. In Korea, the Office of Rural Development obtained a very high level of gas production (1.67 m^3 per m^3 of digester volume per day) in a 1.37 m^3 digester with a mixture of 63% pig manure, 25% cow manure, and 12% chicken manure. An equal mixture of pig manure and cow manure has been used at the Alabang plant in the Philippines.

However, in most East Asian countries other than China pig manure is normally used in "Indian" or bag digesters in dilute slurries without mixing with other feedstocks. Manure-water ratios range from 1:5 to 1:4 at several plants in Korea and the

Philippines, 1:3.5 in the Red Mud Plastic digesters in Taiwan, and 1:3 or 1:1 in many digesters in Korea, the Philippines, and Indonesia. Research on manure-water ratios at Maya Farms indicated that a 1:1 ratio yielded the most gas per volume of digester but less gas per unit of manure than more dilute slurries.

Pig manure is used in digesters in several Western Hemisphere developing countries. ICAITI has tested a 5 m^3 horizontal digester at a swine research station in Costa Rica; the gas is used to warm the piglets. A development agency in Chile tested a large prototype horizontal digester with pig manure and helped a farmer build a 100 m^3 unit on a large pig farm. The Costa Rican Institute of Technology will use two 50 m^3 nylon-lined PVC digesters with a separate 50 m^3 plastic gasholder at a 300-pig farm. In Barbados a firm is planning a two-stage plant using two 100 m^3 plastic bag digesters on a 500-pig farm; the gas will be used to cook swill for the pigs.

Experiments with mixtures of pig manure and plant materials have been conducted in only a few countries except China. Maya Farms tried mixtures of pig manure and rice straw and subsequently designed a batch digester for the use of this mixture on integrated livestock farms producing both livestock and rice. In the South Pacific, biogas pioneer George Chan concluded that gas production from pig manure could be increased by the addition of leaves and grass to boost the C/N ratio.

Poultry Manure

Droppings from chickens and other poultry are used as digester feedstocks in several countries. Four digesters are being built from large concrete culverts at the chicken-raising community of San Jose, Batangas, in the Philippines; the gas will be used for water heating and for brooders or heaters. Gujurat Agro Industries in Ahmedabad, India, operates an 8 m^3 digester using droppings from 1200 chickens; the chicken house is warmed with the biogas by burning it in gas lamps surrounded by wire. Gas from a small digester will also be used to warm a chicken house in Zimbabwe. Several large digesters are being built by the Belgian rural development organization, AIDR, in poultry-raising communities in Burundi. Experiments with gas production from poultry manure are being conducted with the Pakistan Council of Scientific and Industrial Research in Lahore and the Central Luzon University in the Philippines.

Poultry droppings have a high nitrogen content (4 to 6%) and thus a C/N ratio of about 15 which is well below the optimum level. Moreover, the high nitrogen content can lead to ammonia concentrations which will kill the methane-forming bacteria. This can be avoided by diluting the manure with water or by balancing the C/N ratio by mixing the manure with shredded straw, bagasse, or other high carbon materials.

However, experience with mixing poultry manure with other feedstocks appears to be rather limited. The operator of a large chicken farm in Barbados plans a biogas plant using a mixture of droppings from 75,000 birds and bagasse. In laboratory tests of various manures and mixtures by the Office of Rural Development in Korea, the highest gas yield was obtained with an equal mixture of pig and chicken manure. No mixture with any other feedstock provided as high a gas production as unmixed chicken manure.

Gas production from poultry manure has varied widely, apparently because of variations in C/N ratios and the problem of ammonia buildup. Two Indian institutions reported gas production per unit of dry weight 30 to 40% lower for poultry manure than for cow dung. Some results have been about the same as for cow dung. However, tests in Korea, New Zealand, and the U.S. have yielded gas production figures for poultry manure which were 50 to 100% higher than for cow dung.

Other Manures

Manures from other animals have been tested by several research institutions but are apparently not widely used in biogas plants. One Indian research institution gave horse manure a higher gas production

rating than cow dung, while another Indian institution reported lower production from horse manure. The two research centers agreed that camel dung produced only 60 to 70% of the gas derived from cow dung. The only available studies indicated that sheep manure produces about the same amount of gas as cow dung, buffalo dung makes slightly more, bullock dung makes slightly less, and goat dung produces only about 65% of the gas from cow dung.

Night Soil

In developed countries, night soil may have 5 to 6% nitrogen and a C/N ratio which is well below the optimum for gas production. However, there are indications that, because of the lower protein levels in human diets in many developing countries, the nitrogen levels in night soil may be lower and thus the C/N ratios may be closer to the optimum levels.

Human excreta are used with pig manure and plant materials in most of the family-size digesters in China. The high nitrogen levels of both pig manure and night soil are balanced by the addition of plant materials with a high carbon content. The most frequently used formula is 20% plant material, 20% human waste, and 60% animal dung, plus water. The addition of some plant material also helps gas production in digesters operated primarily with night soil. The biogas manual in Nepal indicates that adding 500 grams of wheat straw per person per day to a night soil digester will result in a dramatic increase in gas production. Gas yields were boosted in a night soil digester at a hospital in Papua New Guinea when finely ground grasses or straw were added, although it was found that more frequent desludging was required. The Office of Rural Development in Korea found that an equal mixture of night soil and weeds produced 46% more biogas than unmixed night soil. Low gas production from unmixed night soil convinced Philippine officials that animal and possibly plant wastes should be added.

In China, where untreated human wastes have traditionally been spread on the fields as fertilizer, there does not seem to be much resistance to cooking with gas made from human wastes. However, many people in India and other countries are reluctant to use such gas. The Indian biogas agency, KVIC, estimated in 1980 that about 20,000 family digesters, or about 30% of the total in India, were connected to latrines. A new community-scale biogas plant operated by KVIC in Dhaniv uses cow manure only in a first-phase digester, so that villagers who object to the use of gas made from human wastes can get pure "gobar gas." The slurry from this digester flows to a second digester where it is combined with human wastes from eight public latrines. Maya Farms in the Philippines has developed a three-phase digestion system which uses night soil from worker dormitories.

There are also large plants using night soil alone in China, India, and Nepal. The world's largest biogas power plant, at Foshan in China, generates 90 kw of electricity with biogas made from night soil (see page 19). The National Environmental Engineering Research Institute in Nagpur, India, built three digesters with a total capacity of 47 m^3 to use night soil at a nearby prison: the plant produces 25 to 35 m^3 of gas daily or about 0.5 to 0.7 volumes per volume of digester, a higher level than that from cow dung plants in India. Smaller night soil plants have been built in India at a leprosy home, a womens college, and a bus station. A circular building in Kathmandu contains a ring of public toilets with a digester in the middle. Lockstoke Developments Ltd. of England is marketing its bag digesters for use as combined biogas plants and village sewage disposal units in Africa; two bags connected in series are recommended for the rapid digestion of human wastes in hot arid areas.

Two special operating problems have been encountered in digesters using night soil. KVIC in India reports that the night soil may be difficult to keep in suspension, with some parts settling to the bottom and fatty substances floating on the digester surface. Reports from India and Nepal indicate that the corrosion problem with steel gasholders is especially severe when night soil is used, apparently due to the higher level of hydrogen sulfide in the slurry.

2. Plant Materials

Limiting Factors

At present crop residues and other plant materials are widely used in family-scale digesters only in China, although such materials have been tested by research institutions in a number of other countries and used in a few other digesters. The use of these materials has been limited by several factors:

1. Digester designs: The use of fibrous crop wastes in "Indian" digesters, which are in the most common models everywhere but in China, is prevented by the narrow (3 to 5 cm) diameters of the inlet pipes. These digesters have been designed for use with liquid slurries with a low percentage of solids. In contrast, the Chinese digesters have been designed to accept fibrous materials through the rather wide opening between the inlet tank and the main digester chamber.

2. Clogging problems: Many experiments with the digestion of plant materals have run into severe clogging problems. Most crop residues consist of plant stalks and stems which have considerable structural rigidity. Clogging problems seem particularly severe with plant materials which have a high percentage of lignin, which is almost totally non-biodegradable. A high mineral and ash content may contribute to these problems in some plant residues. Digestion of these materials is accelerated if they are shattered, chopped, or ground before digestion. The Punjab Agricultural University in India fed a digester with relatively large (8 cm) pieces of rice straw and wheat straw; semi-solid lumps of undigested material remained floating on he digester surface. The Institute of Electrical Research in Mexico found that adding crop residues in ground form to cow manure produced more gas and a higher methane content than when the same residues were only chopped.

3. Carbon/Nitrogen ratios. The process of anaerobic digestion requires that the feedstock contain carbon and nitrogen in a ratio which is rather close to 30:1. Most grains are harvested when the stalks and stems are relatively dry and have a very high C/N ratio. In general, crop residues are used more effectively when they are mixed with green plant materials or certain animal residues which have a high nitrogen content. However, some green plant materials have too low a C/N ratio for optimum digestion unless they are mixed with residues with a higher carbon content.

4. Acidity problems: In the initial phases of anaerobic digestion, acid-forming bacteria break down the carbohydrates into volatile fatty acids. These are then converted to methane by methane-forming bacteria. Because of the high percentage of soluble carbohydrates in many crop residues, volatile acids may be produced more rapidly than the methane-forming bacteria can convert them to methane. The excessive acidity inhibits or kills the methane bacteria, the digester goes "sour", and gas production ceases. In China, where lime is usually available, crop residues are composted with lime for ten days before digestion or lime is added to the digester tank to maintain a pH level of between 7 and 8. At the Invernay Agricultural Research Institute in New Zealand, plant materials to be digested were first stored for a time as silage; the breakdown of the carbohydrates began in the silo and the acids were neutralized before the material was added to the digester. If the acidity is controlled, such pretreatment or composting can accelerate the digestion process.

Straws

Wheat straw contains over 20% lignin and a very low percentage of nitrogen (0.3 to 0.5%); its carbon-nitrogen ratio (130 to 150) is far beyond the optimum level. Despite these handicaps, there have been some reports of success with the digestion of unmixed wheat straw. A Chinese publication reported that one-third more gas had been produced from wheat straw than from cow manure in laboratory tests. By careful control of acidity levels, the Invermay Institute in New Zealand produced twice as much biogas per kilogram from wheat straw as from cow manure.

In experiments at both Cornell University in the U.S. and the Indian Agricultural Research Institute (IARI), the addition of substantial quantities of wheat straw to cow manure reduced gas production by 30 to 50%. ICADA in Guatemala also obtained rather low initial gas production from a mixture of wheat straw and cow dung. As previously indicated, cow dung in developing countries is already close to the optimum C/N ratio; adding the wheat straw raises the carbon content of the mix to an excessive level. However, small quantities of wheat straw may improve the C/N ratio and gas production of cow dung. The Appropriate Technology Development Organization in Pakistan recommends the addition of 1 kg of powdered wheat straw to 50 kg of cow dung to increase gas production in winter months.

Wheat straw is better suited for mixing in larger quantities with other feedstocks which contain a higher percentage of nitrogen. The Cheng Hsiang research station in China reported that the gas production from wheat straw doubled when 20% night soil was added. Combinations of wheat straw with pig manure and with poultry manure should also produce favorable C/N ratios, but specific studies of these mixtures do not seem to be available.

Experiments with the digestion of unmixed rice straw in continuous digesters in India, the Philippines, and California have proved unsuccessful due to clogging of the digesters. These problems may be related to the slagging problems encountered in the thermal gasification of rice residues due to the high percentage of minerals including silicon.

Rice straw has slightly more nitrogen and a somewhat more favorable C/N ratio (50 to 70) than wheat straw. The Chengdu Institute of Biology in China has reported that in several tests mixtures of rice straw and pig manure (which has up to 3 to 4% nitrogen) have produced large quantities of gas rather rapidly. When 20% night soil was added to rice straw at the Cheng Hsiang station, gas production increased by 60%.

In contrast, gas production was depressed when rice straw was mixed with cow dung, which already has a near-optimum C/N ratio. The Maharashtra Association for the Cultivation of Science in India added 25% rice straw to cow dung, and gas production was reduced by abut 25%. However, ORD in Korea obtained 21% more gas when a rice straw extract was added to cow dung. The addition of 20% rice bran (which presumably has a lower C/N ratio) to cow dung by the Maharashtra group resulted in an increase in gas yield.

Both oat straw and rye straw contain nearly 20% lignin but apparently have lower C/N ratios than wheat straw. No studies of these straws have been noted.

Barley straw has less than 10% lignin; when 20% barley straw was combined with 80% cow manure at the University of California, gas production was slightly higher than from manure alone.

Corn Stalks

The residues of corn or maize have less than 10% lignin and C/N ratios between 50 and 60. No experiments with the digestion of unmixed corn residues have been noted. The Institute of Electrical Research in Mexico found that the addition of corn stover to cow manure increased gas production. The National Research Center in Egypt reported that adding maize to a mixture of cow dung and sewage increased gas yields until maize reached 70% of the mixture.

Grasses

Most grasses have low C/N ratios (from 10 to 27) and lower percentages of lignin (from 4 to 6%) than most other plant and animal residues. Both the Invernay Institute in New Zealand and the Cheng Hsiang station in China have reported gas production from grasses which was 50 to 75% higher than from cow dung. A Chinese publication lists a gas production figure for fresh grasses (630 m^3 per ton) which is double that for cow manure.

The Institute of Gas Technology in Chicago reported that unmixed coastal Bermuda grass, which has only 1.96%

nitrogen and a C/N ratio of 24, produced 0.313 volumes of gas per volume of digester per day; however, gas production increased to 0.587 vol/vol/day when a nitrogen compound was added. After experiments with the digestion of elephant grass in Uganda, Makerere University concluded that its successful use depends on plant age, the degree of laceration, and the treatment of the grass before digestion.

Grasses are mixed with pig manure and night soil in many family digesters in China. One of the recommended formulas in China calls for 60% marsh grass, 20% human wastes, and 20% animal waste, plus water, although smaller percentages of grass would normally be used. The Belgian rural development organization, AIDR, uses a mixture of 75% millet stalks and 25% cow dung at a rural hospital in Upper Volta; gas production averaging 0.50 vol/vol/day was achieved with the help of enzymes from the cow's stomach.

Water Hyacinths

Research institutions in a dozen countries have experimented with the digestion of water hyacinths, the fast growing aquatic weed which clogs the waterways of many countries. The plants are being used in several digesters in the Sudanese village of Tawilla on the While Nile, under a joint Sudanese-German hyacinth control program. Gas production averaged 0.6 to 0.72 vol/vol/day from a bag digester with 60 kg/day of hyacinths and a 40 day retention time. Using retention times as short as six days, the IGT in Chicago obtained up to 1.0 vol/vol/day of gas from hyacinths grown in sewage-fed lagoons in Mississippi. The lack of cost-effective harvesting techniques remains the principal barrier to the widespread use of water hyacinths for biogas production and perhaps electric power generation.

Two Indian research agencies obtained modest increases in gas production when 20 to 25% water hyacinths were added to cow dung. Later the biogas research station in Uttar Pradesh concluded that a mixture of 60% hyacinths and 40% dung gave the best overall results.

In Indonesia USAID is funding a three year program on biogas production from water hyacinths. Prototype ferrocement digesters are being tested at Padjadjaran University in Bandung, West Java. A village demonstration is planned and the economic, social, and technical feasibility of wider use of these plants will be studied.

Bagasse

The residues from sugar production have a very high C/N ratio (around 150) and are widely used as a boiler fuel. A few institutions have used bagasse in digesters along with animal manures. The Maharastra Association in India obtained 40% more gas when bagasse was substituted for 30% of the dung in an Indian digester. The National Sugar Institute in Kanpur, India, has used a 2:1 mixture of bagasse and cow dung in a very large digester; gas production averaged 300 m^3 per ton. A sugar cane research center in the Dominican Republic is also studying the digestion of a mixture of bagasse and cow manure. In Barbados the operator of a large poultry farm plans to make biogas from a mixture of bagasse and poultry manure. Brazilian institutions including the University of Paraiba have studied bagasse as a digester feedstock.

Coffee Pulp

About 40% of the original weight of the coffee berry remains as pulp after processing. The pulp has a rather high C/N ratio (about 70) and a substantial initial sugar content. In digestion tests of the pulp with relatively high loading rates and short retention times, ICAITI in Guatemala found that acidity levels built up quickly due to the rapid conversion of sugars to volatile acids. Gas production reached 1.07 vol/vol/day with 60-day retention times. There are indications that the juice from pressed pulp may be a more suitable feed stock for biogass production than the raw pulp.

Cotton Stalks

The National Research Center in Egypt reported that mixing shredded cotton stalks with cow dung in laboratory digesters had an

adverse effect on gas yield. When the same mixture was tried in a "Chinese" digester, scum formation was excessive and the unit became inoperable. The high ash content in cotton stalks (17%) led to severe clogging problems in tests of the thermal gasification of the stalks at the University of California; the undigestible minerals may also inhibit biogasification of these residues.

Marine Plants

The Institute of Gas Technology in Chicago obtained 0.51 to 0.85 vol/vol/day of gas from giant kelp (Macrocystis pyrifera). The University of Hawaii found two seaweed species were suitable for methane generation without nitrogen supplements; gas yields were four times as high for Ulva as for Eucheuma. Salinity is apparently not a problem. In Hawaii, twice as much gas was obtained from unwashed seaweeds as from those washed with fresh water. The University of the South Pacific in Fiji obtained biogas from two seaweed species (Sargasam sp. and Gracilaria sp.) with both fresh water and sea water with 35 parts per thousand salinity.

Fruit and Vegetable Residues

Makerere University in Uganda found that a 2:1 mixture of plantain peels and cow dung gave a good gas yield. The National Institute of Science & Technology in the Philippines has studied the digestion of banana peels. The German Agency for Technical Cooperation and ICAITI in Guatemala are studying the possibility of making biogas from banana stems and stalks, possibly mixed with cattle or pig manure. Lab tests on the digestion of potatoes, cassava, and other tubers have been conducted by the Tropical Products Institute in London.

Urban Solid Wastes

When urban solid wastes are buried in landfills, anaerobic digestion of the biodegradable portion of the wastes takes place underground. The biogas can be tapped by collecting wells drilled into the landfill. Biogas is being recovered at several landfills in the U.S. and Brazil.

PART THREE: BENEFITS OF BIOGAS PLANTS

I. The Uses of Biogas

Cooking

In developing countries more biogas is used for cooking than for any other purpose. Most of this gas is produced in family-sized digesters and used in individual households. However, biogas is also used in a number of communal canteens in China and cafeterias in other countries.

Unlike gas made through the thermo-chemical conversion of coal or biomass, biogas contains no poisonous carbon monoxide. It is odorless and burns with a clean bluish, and sootless flame. However, proper combustion requires the pre-mixing of biogas with air in a suitable burner. Burners intended for use with coal gas or LP gas are designed to operate at a much higher pressure than is produced by biogas plants. In the early years of the Indian biogas program, inefficient burners were made of tins which had held cigarettes or shoe polish; these consumed a great deal of gas, the cooking was slow, and the gas supply was often exhausted before the meal was ready. The Indian biogas agency, KVIC, designed a cast iron burner with a gunmetal injector which premixes the air and gas. It operates at about 60% efficiency and costs $12 to 15.

The Chinese developed burners made of fired clay; these cost less than $2 but their efficiency is below 40%. The Chinese also use a ceramic biogas stove; a sunken recess for a cooking pot holds the heat around the sides of the pot. A major goal of the Chinese biogas research program, outlined to a UN conference in 1981, was increasing the heat efficiency of biogas burners, stoves, and lamps from 40% to 60%. Indian biogas organizations are also giving a high priority to developing lower cost but efficient burners, especially procelain units.

Lighting

Illumination can be provided by burning the gas in a gas lamp or by using it to generate electricity. Lamps made for use

with coal gas are not suitable for biogas because of the lower gas pressure and the difficulty of handling fragile gas mantles in rural areas. In India KVIC has developed biogas lamps using ordinary silk mantles similar to those used on "Petromax" lanterns. They provide approximately 100 candlepower illumination and consume about 0.07 m^3 (or about 70 liters) of gas per hour per mantle. The Chinese have developed a biogas lamp using the lower half of a mantle from a kerosene pressure lamp.

Biogas is burned for lighting mainly in individual households. Community lighting has been included in at least one of the new community-scale biogas systems in India. Biogas from night soil and cow dung is used to light twelve lamps for community lighting at a refugee camp in Nepal.

Heating

Biogas can be used to heat air and water, although such applications seem relatively rare in developing countries. The biogas research group in Uttar Pradesh in India designed a room heater for use with biogas. The gas is burned as it comes out of 12 holes in a 30 cm piece of iron pipe; wire mesh surrounding the pipe becomes red hot and radiates heat into the room. In several developing countries biogas is used to heat incubators and structures housing chicks and piglets. Water heated with biogas is used for dairy operations on several large farms. A propane bath water heater was modified to operate on biogas in Taiwan.

Refrigeration

Refrigerators designed to operate on propane or kerosene can also use biogas. A 12 ft^3 kerosene refrigerator ran for eight months on biogas in Nepal using a specially designed bunsen-type burner; gas consumption was approximately 100 liters per hour. An agricultural cooperative in Gujurat, India, established a community cold storage plant with biogas-fueled refrigerators. Researchers at the National Taiwan University built a three-ton (9,000 kcal per hour) cold storage unit which consumes 7 m^3 of biogas per hour; the gas production needed for the cold storage unit requires the wastes of 600 hogs in the summer and 800 in the winter. Biogas made mainly from millet stalks provides refrigeration for vaccines and medicines in a small rural hospital in Upper Volta. A USAID-supported energy research program in Rwanda included testing of biogas-fueled refrigerators.

Mechanical Power

Both gasoline (petrol) and diesel engines can be converted to run mainly on biogas. It is extensively used in engines and engine-generators in China, and such engines are becoming more numerous in other developing countries. Mechanical power for water-pumping, fodder-crushing, grain threshing, flour-milling, and similar purposes is provided by biogas-fueled engines on between 600 and 700 Chinese farms.

A petrol engine can be modified to run on biogas by drilling a 1/4" (7mm) hole in the carburetor near the choke; the tube is inserted which is connected to the gas supply via a control valve. The engine is started on petrol and then switched to biogas.

A diesel engine is most easily converted to a dual-fueled engine which will run on a mixture of about 10 to 20% diesel oil and 80 to 90% biogas. The gas is fed in between the air intake and the engine; after the engine is started on diesel oil, the gas valve is opened very gradually and the engine's governor automatically reduces the intake of diesel oil. The Rural Industries Innovation Center in Botswana replaced 82% of the diesel oil with biogas on a 5 HP Kirloskar engine and 87% of the oil on a 6 HP Lister engine.

Indian companies now manufacture diesel engines designed to run on biogas, including low speed (600 RPM) and high speed (1500 RPM) models. These engines use 453 liters (or 0.45 m^3) of gas per horse-power per hour. In Nepal 14 m^3 of biogas, produced daily from the dung of 24 buffaloes on one farm, is sufficient to run a 5 HP Kirloskar dual-fueled engine for eight hours; it pumps 50 liters of water per minute

up a seven meter head from stream to irrigation channel. The Livestock Research Institute in Taiwan pumped up to 16 m^3 of water for each m^3 of biogas used in a gasoline engine.

Petrol and diesel engines do not develop their full rated horsepower when used with biogas, which is only about 60% methane. Engine performance can be improved through various techniques for the removal of cabon dioxide. Water scrubbing is easiest but requires large quantities of water. The gas can be bubbled through calcium hydroxide (lime water) which is relatively inexpensive, but large quantities of precipitate are formed. Sodium hydroxide is more convenient but more expensive. Recently researchers at the Indian Agricultural Research Institute and the National Cheng Kung University in Taiwan have successfully tested biogas scrubbing with monoethanolamine (MEA) which is widely used for CO_2 removal in industry.

Most of the technical literature states that, in order to prolong engine life, hydrogen sulfide (H_2S) should be removed from the biogas before use in the engine. The most common technique is to run the gas through iron oxide, which is usually mixed with an inert material such as wood chips. The Institute of Electrical Research in Mexico filtered 800 m^3 of biogas with 10 kg of iron filings; the filings were ready to reuse after exposure to air for four days. In the ICAITI digester design in Central America, a plastic tube filled with iron filings and wood chips is inserted into the gas line following a moisture trap. The University of the Philippines in Quezon City and the National Research Center in Egypt are studying the use of various bacteria for biogas desulfurization. There is not total agreement, however, on the need to remove H_2S from gas used in engines. Biogas pioneer L. John Fry ran a 13 HP diesel continuously for six years in South Africa on unscrubbed biogas and felt that the engine had not been harmed. Many of the reports on the use of biogas in engines make no reference to H_2S removal. (Note: information is requested from readers on biogas use in engines and H_2S and CO_2 scrubbing).

Electrical Power Generation

Biogas-fueled engines run electrical generators at 200 to 300 of the larger biogas plants in China and a few larger plants in other developing countries. Most of the generators in China seem to be in the 6 to 12 KW range, although one visitor reported a 70 KW unit on a large farm. Some of the engine-generator sets draw biogas from a series of inter-connected digesters, while others obtain gas from a single large plant.

The world's largest biogas power plant uses night soil as the feedstock at Foshan in China's Guangdong province. About 170 tons a day of night soil is fed to 28 inter-connected 47 m^3 digesters. The plant has a total digester volume of 1316 m^3 and produces 720 m^3 of biogas daily which is stored in two flexible plastic gasholders. Gas production is thus about 0.54 m^3 per m^3 of digester capacity. The methane content is rather high (71 to 72%). The gas is used in two diesel engine-generator sets to produce about 90 KW of electricity.

Two of the biogas-fueled engines at Maya Farms in the Philippines produce electricity in a 12.5 KW generator and a 60 KVA unit; the power is used in a meat processing plant, dormitories, and canteen. A diesel engine running on biogas was used to generate power on the Hutchison farm in Kenya in the late 1950's, and some of the 140 biogas plants subsequently built in that country were used for on-farm power generation. The Rural Energy Center built by the UN Environment Program in a village in Sri Lanka includes a 89.5 m^3 digester designed to supply gas to 37.5 and 12.5 KVA engine-generators. At a community biogas plant built with UNICEF funds in Uttar Pradesh some of the gas is used to generate electric power for lighting homes and streets, although the use of biogas for power generation in India is relatively rare. Gas from a 60 m^3 digester in Rwanda will be used in a 12 KVA generator to provide for the electrification of an adjacent village. In Dhanusha, Nepal, gas from a 14 m^3 digester will fuel a 3 KW generator on an integrated farm; the power will be used in a fruit processing plant by day, for household

light in the evening, and in a water pump as needed.

When biogas is used to generate electricity, conversion efficiencies are usually lower than 25%. Estimates of the gas needed for electric power generation have ranged from 0.55 to 1.1 m^3 per kilowatt hour.

2. The Uses of Slurry and Sludge

Fertilizer

The value of both digested slurry and sludge from the bottom of the digester as fertilizer has been clearly established by experiments in many countries. A Philippine research institution reported that vegetables and pasture grass irrigated with slurry grew taller, greener, and more vigorously. In Colombia tomatoes fertilized with digester slurry grew much more rapidly than those growing in a mixture of soil and manure. The Kibbutz Industries Associaton in Israel reported a 15 to 20% higher corn production with slurry than with undigested manure. One Indian wrote of a 50% increase in rice producton due to slurry use.

Virtually all of the nutrients in the original feedstocks are retained in the slurry and sludge. A part of the organic nitrogen is converted to ammonia nigrogen, which is readily available for plant use. The Indian Agricultural Research Institute found that about 15% of the nitrogen in digested cow dung was in the ammonia form, the National Research Center in Egypt reported that up to 25% of the nitrogen in manure may be converted to ammonia nitrogen. This conversion is a mixed blessing. Ammonia nitrogen will volatilize if the slurry is stored in an open tank or lagoon. If the slurry is spread on the land and allowed to dry without mixing into the soil by cultivation or rainfall, virtually all of the ammonia nitrogen will be lost to the atmoshpere.

These nitrogen losses can be avoided by incorporating the slurry and sludge promptly into the soil. In India KVIC states that the most profitable use of the digested slurry is to mix it immediately with irrigation water. The NRC in Egypt found that only 2% of the nitrogen was lost when the digested slurry was absorbed into silt, although the resulting product had a lower percentage of organic matter and nutrients than the unmixed slurry. In India, where most digesters cannot use plant materials directly, the digested slurry is often used for the rapid composting of crop residues and plant materials.

Under some circumstances the soil conditioning benefits of the dried slurry may be more important than the addition of the maximum quantity of nitrogen. Wet or dry, the digested slurry still contains 70 to 80% of the organic matter of the original feedstock; this humus improves the aeration and water-holding capacity of the soil and may keep the plants alive during a drought. During the wet season, soil conditioning may be more desirable than adding slurry, which is mostly water, to soils which are already waterlogged. In tests conducted by IARI in India, average yields of rice fertilized with dried slurry were 21% higher than those of rice grown with wet slurry. A biogas manual published in Nepal states that dried slurry is preferable to liquid slurry for use as a fertilizer.

Sludge from the bottom of the digester is also an excellent fertilizer. In India, where fibrous materials are avoided, sludge accumulates slowly. While a few owners remove sludge regularly, most plants are rarely cleaned. Only six of 174 plant owners surveyed by the Indian Institute of Management had ever cleaned their plants. Due to the narrow inlet and outlet pipes, sludge can be removed from the "Indian" plants only by removing the gasholder. Because of the extensive use of plant materials in China, more frequent sludge removal is necessary. In areas which produce both rice and wheat the sludge may be removed twice a year -- once in the spring to fertilize the rice sprouts and again in the fall when winter wheat is planted. In most other areas the digesters are completely cleaned once a year. A biogas publication from Szechuan recommends the use of liquid ammonia, lime, or other chemicals to disinfect the sludge before it is used.

In the circular Chinese digesters, some sludge can be removed diagonally through the outlet chambers; full cleaning requires entering the chamber through the manhole on the top of the digester. However, the flat-top, rectangular digesters built in Szechuan and the "Janata" version of the Chinese digesters in India have no manholes, and sludge can be removed only through the outlet chamber. The Janata model has a step half-way down in the outlet chamber which a worker can stand on while removing sludge.

Several of the newer rectangular digesters provide vertical access to the bottom of the digster through the outlet chamber. The Szechuan fixed-top digester has a removable drop board which fits into a slot between the main chamber and the outlet chamber and blocks the lower part of the passageway. This board permits the removal of most of the slurry for use as fertilizer during the spring or fall planting without disturbing the sludge which contains pathogens and parasite eggs. The board is removed when sludge removal is necessary. Alternatively, the digester may have an "applied excreta tank" connected to the outlet chamber by a small opening above the sludge level; the slurry is removed from this tank without disturbing the sludge which extends into the bottom of the outlet chamber. The Chinese rely heavily on these physical separation techniques to avoid the premature use of sludge containing only partially digested human wastes.

Livestock Feeding

Digester effluent has been used as a supplementary feed for livestock in several countries. Maya Farms initially tried adding dried sludge from digested pig manure to the feed for 300 pigs and found that it could be used for up to 15% of the feed mix. When drying the sludge became difficult and expensive in the rainy season, wet solid sludge was tried; the pigs ate it voraciously and Maya Farms now uses only wet sludge as a feed supplement. The Kibbutz Industries Association in Israel, which operates digesters successfully with solids concentrations of 15 to 18%, has used this concentrated slurry for 15 to 20% of the feed for sheep, cows, and calves; the animals gained weight normally. In the U.S., Biogas of Colorado, Inc, reported that their feeding trials with digester slurry indicated that it was possible to produce a valuable and low cost cattle feed from feedlot wastes.

Several institutions in the Philippines have experimented with the use of digester effluent to grow high-protein algae, which is then used to replace soybean meal as a high-protein supplement in livestock feed. The Tarlac Swine Breeding Station used effluent from a large digester to grow chorella algae in a very shallow pond; the algae contained 38 to 40% protein. Studies of the value of chorella as a feed supplement for cattle were conducted at the Alabang Stock Farm. Maya Farms tried growing chorella with digester slurry and using the algae for pig feed. However, the cost of harvesting, drying, and grinding the chorella proved to be greater than the cost of the soybean meal it replaced.

Fish Feeding

Maya Farms found that tilapia fish grew fat when released in their chorella tank; now algae are grown in fish ponds fertilized with digester slurry, and the fish eat the algae. The Kibbutz Industries Association in Israel used high-solids slurry directly as a food supplement for fish breeding and saved 50% of the cost of commercial feed. There was no loss in the rate of growth of the fish and, due to the low biological oxygen demand (BOD) of the slurry, the oxygen levels in the fish ponds with slurry were slightly higher than in the control ponds.

3. Other Benefits of Biogas Plants

Organizations promoting the production and use of biogas in developing countries have cited many benefits derived from building biogas plants, in addition to the various uses of the biogas, slurry, and sludge.

Health benefits are especially important where digesters receive human wastes which were formerly left in the open or spread on the fields as fertilizer. Biogas plants

motivate rural people to build and use latrines. Odors, flies, and mosquitoes are eliminated. Digestion greatly reduces the number of pathogens and parasite eggs in animal and human wastes. Smoke is banished from the villager's house, the cleanliness of the household is enhanced, and eye and lung diseases caused by smoke are eliminated. The pollution of rural water supplies is greatly reduced. Since digested slurry has a much lower biological oxygen demand (BOD) than untreated wastes, the digestion of the wastes helps maintain oxygen levels in ponds and streams and thus supports a larger fish population.

Social benefits relate mainly to saving labor. Biogas plants usually require less labor to operate than would have been needed to obtain the same amount of energy from traditional sources. The plants often eliminate the need to walk long distances in search of fuelwood. They eliminate many disagreeable tasks connected with the handling of human wastes and dung, including the forming of cow dung into patties by Indian women for drying and burning as fuel. Biogas can be used to mechanize some agricultural tasks (water pumping, grain grinding, threshing, etc) which would otherwise require much labor. The time saved in these various ways can be used for other economically or socially useful activities.

Macroeconomic benefits of biogas programs can be significant in terms of national economic and development goals. Biogas can be used to replace kerosene, propane, gasoline, and diesel oil. In oil-importing countries, biogas production reduces the imports of these fuels. In oil-producing countries, it can free petroleum products for export. The construction of biogas plants creates employment and income where they are most needed, i.e., in rural areas. By providing new sources of heat, light, mechanical energy, and electricity, biogas plants can contribute significantly to economic development and the improvement of the quality of life in rural areas.

There is little doubt or controversy about most of these health, environmental, social, and macroeconomic benefits, although they do not apply in equal degree in every country and situation. However, there is much less agreement on the economic benefits of a family-scale biogas plants for the individual owner. The World Bank noted recently that "Although there has been no dearth of studies on the economics of biogas, no consensus has emerged. Cost-benefit analysis of the comparatively well-documented Indian experience has yielded various concusions, reflecting widely different assumptions made about the cost of dung, the quantity and value of the labor required to operate the digester, and the value of the gas and sludge as fuel and fertilizer." Moreover, these cost-benefit studies tend to underrate the health, environmental, social, and macroeconomic benefits of biogas plants. These are benefits to the community as a whole which are not easily factored into the calculations of the "cost effectiveness" of a given individual investment.

REFERRAL SERVICE

Space limitations in this report have precluded the inclusion of names and addresses of individuals conducting biogas research projects and the full addresses of biogas agencies and research institutions. However, the name and full address of the key person responsible for any study or project mentioned in this report will be provided on request to the Office of Energy (see p. 1). Alternatively, a letter requesting information on a specific study or project will be forwarded directly to the appropriate person, with a confirming notice to the sender.

Illustrations: The "Indian" digester on p. 3 is from "Biogas Plants" by the German Appropriate Technology Exchange. The "Chinese" digester on p. 6 is from the Nepal Biogas Newsletter.

PLANNING LARGER-SCALE BIOGAS PLANTS

Most of the published material on biogas deals mainly with family-scale plants. However, some general principles have emerged which should be considered by those contemplating the construction of a sizeable plant to serve the energy needs of a large farm, community, institution, agency or firm.

Organizational auspices: Larger-scale plants should be planned, built, and operated by organizations which have a moderate to high level of technical and management capability. At this stage of biogas development, every larger plant is experimental in some degree. Later, when designs and operating modes have been perfected, these organizational requirements may be less crucial.

Access to comparable experience: Those planning larger-scale plants should seek full information on the experience of other organizations with somewhat comparable plants and feedstocks. In many cases this information will be available only from other countries. Present channels for international sharing of experience with larger biogas plants are rather limited. (See "Referral Service, p. 22). Nonetheless, it may be very important to obtain information about similar projects in other countries and evaluate it carefully in light of local conditions.

Availability and ownership of feedstocks: Most larger plants have been built in locations where the feedstocks to be used were already available and were owned by the organization which owned and operated the biogas plant. If feedstocks must be collected from other locations and/or purchased from or contributed by individual farmers, critical problems of collection, delivery, pricing, and total costs may arise.

Scale of plant: The size of a plant should be carefully considered in relation to the availability of feedstocks, the relative priority of high gas production and completely digested effluent, and the planned uses of the biogas. Bigger plants are not necessarily better plants. In some cases feedstock limitations have led to low loading rates which automatically result in longer retention times and lower gas production rates per unit volume of digester. However, too high loading rates will reduce the gas production per volume of feedstock and limit the environmental and health benefits derived from more fully digested effluent.

Construction materials and techniques: The choice of materials and construction techniques for a larger plant will depend on the design of the digester and the availability and cost of materials, skilled labor, and necessary equipment. There are few well-established guidelines for the design or construction of larger plants, so decisions should be made with care. With "Chinese" or related designs in which the gas is trapped within masonry structures, a high priority should be given to techniques for preventing gas leakage.

Uses of biogas: A plant will be considered successful only if it supplies a sufficient quantity of gas for the prime purpose or purposes for which it was built. The planned use should be consistent with the size of the plant, planned loading rates and retention times, and conservatively estimated gas production rates including expected seasonal variations. Great or total dependence on full-scale gas production should be avoided; the plan for the project should provide other sources of energy (i.e., use of wood for cooking or use of more diesel oil in a dual-fueled engine) for periods when gas production is reduced or suspended for any reason.

Ownership of biogas and fertilizer: The biogas, slurry, and sludge produced by most large plants have been used within the same organizational entity which owns the biogas plant. Difficult social and economic problems may arise when biogas, electricity generated with biogas, or fertilizer must be priced and sold to other organizations or to individuals.

A REQUEST FOR INFORMATION

Three additional Bioenergy Systems Reports will be published in 1982. The second Report, to be distributed in June, will focus on the thermochemical conversion of biomass including direct combustion, thermal gasification, and pyrolysis. The third Report, due in September, will review projects and potentials for the production of alcohol fuels in developing countries. A "Biogas Update" section will review information on biogas projects received after the deadline for this Report. The fourth Report, to be published in December, will review social, cultural, institutional, economic, environmental, and educational aspects of bioenergy development.

Organizations considering or planning bioenergy projects are urged to send papers or reports on these projects to Bioenergy Systems Reports, P.O. Box 591, Front Royal, Virginia (USA) 22630. The Editor takes this opportunity to thank all those who have provided information for this initial Report.

A BIOGAS LIBRARY

Methane Generation from Human, Animal, and Agricultural Wastes, 1977, 129 pp. Board on Science and Technology for International Development, National Academy of Sciences, 2101 Constitution Ave., Washington, D.C. (USA) 20418 (A USAID-funded review of the technology of anaerobic digestion as utilized in developing countries.)

State-of-the-Art Review: Methane Fermentation of Biomass, 1980, 290 pp., Olympic Associates Company, Seattle. (A comprehensive review of the current state of development of biogas technology, prepared for AID: copies may be requested through USAID missions.)

Fuel Gas from Cowdung, by B. R. Saubolle, S. J., and Andreas Bachmann, 1980, 76 pp. Box 113, Kathmandu, Nepal. (The best manual on the operation of "Indian" plants plus construction plans for several "Chinese" models.)

A Chinese Biogas Manual, 1979, 135 pp. Available from VITA, 3706 Rhode Island Ave., Mt. Rainer, Md. USA 20712, $9.95, plus 10% for postage and handling within the U.S. or 40% for foreign surface mail or 60% for air mail. (Translation of a Chinese manual on the construction and use of biogas plants).

Guidebook on Biogas Development, 1981, United Nations document S&T/ BSOMP/96, Sales No. R 80.II.F./10. $11.00. (A handbook on the construction and operation of small-scale plants, based on a UN seminar in Bangkok and a UN study tour in China).

Biogas Plants: Building Instructions, 1980, 64 pages. German Appropriate Technology Exchange, Fostfach 5180, D-6236 Eschborn 1, West Germany. (Detailed instructions with blueprints for construction in "Indian" and "Chinese plants).

Compost, Fertilizer, and Biogas Production in the People's Republic of China, 1978, 93 pp. International Development Research Center, Box 8500, Ottawa, Canada KIG 3H9. (Translations of Chinese articles on the construction and use of a flat-top digester and on excreta treatment in biogas plants).

Biogas Technology in the Third World, 1978, 129 pp. IDRC, Canada. (A multi-disciplinary review of technical options, social and economic aspects, and the status of biogas systems in Asian countries.)

Biomass Energy Projects, 1981, 183 pp, Bergamon Press, Elmsford, New York USA 10523, $27.50. (Accounts by key participants of the planning and management of biogas programs in the Philippines and Fiji).

International Bio-Energy Directory, 1981, 1201 pp, Bio-Energy Council, 1625 Eye Street NW, Washington, D.C. 20006, $90.00 (The most comprehensive directory of bioenergy projects around the world).