Biogas Digest

Volume I

Biogas Basics

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Imprint

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Concept and contents:

Werner Kossmann, Uta Pnitz

Information and Advisory Service on Appropriate Technology (ISAT)
GATE in Deutsche Gesellschaft fr Technische Zusammenarbeit (GTZ), GmbH
(German Agency for Technical Cooperation)
Post Box 5180
D-65726 Eschborn
Federal Republic of Germany
Telephone: +49 6196/79-0
Fax: +49 6196/797352
E-

E-mail: gate-isat@gtz.de

Stefan Habermehl

Household Energy Appropriate Technologies (HEAT) GmbH
Limburger Strae 29
D-61479 Glashtten
Federal Republic of Germany
Telephone: +49 6174 964077
Fax: +49 6174 61209
E-mail: heatinternational@t-online.de

Thomas Hoerz, Pedro Krmer, B. Klingler, C. Kellner, Thomas Wittur, F. v. Klopotek, A. Krieg, H. Euler

Naturgerechte Technologien, Bau- und Wirtschaftsberatung (TBW) GmbH
Baumweg 10
60316 Frankfurt
Tel.: 069 943507-0
Fax: 069 943507-11
E-mail: tbw@pop-frankfurt.com

Design:

Utz Dornberger
Stckelstr. 20
04347 Leipzig
Tel.: 0341 2334980

E-mail: utz@imb-jena.de

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Biogas Basics

What is biogas.

Biogas originates from bacteria in the process of bio-degradation of organic material under anaerobic (without air) conditions. The natural generation of biogas is an important part of the biogeochemical carbon cycle. Methanogens (methane producing bacteria) are the last link in a chain of micro-organisms which degrade organic material and return the decomposition products to the environment. In this process biogas is generated, a source of renewable energy.

Biogas and the global carbon cycle

Each year some 590-880 million tons of methane are released worldwide into the atmosphere through microbial activity. About 90% of the emitted methane derives from biogenic sources, i.e. from the decomposition of biomass. The remainder is of fossil origin (e.g. petrochemical processes). In the northern hemisphere, the present tropospheric methane concentration amounts to about 1.65 ppm.

Biology of methanogenesis

Knowledge of the fundamental processes involved in methane fermentation is necessary for planning, building and operating biogas plants. Anaerobic fermentation involves the activities of three different bacterial communities. The process of biogas-production depends on various parameters. For example, changes in ambient temperature can have a negative effect on bacterial activity.

Substrate and material balance of biogas production

In principle, all organic materials can ferment or be digested. However, only homogenous and liquid substrates can be considered for simple biogas plants: faeces and urine from cattle, pigs and possibly from poultry and the wastewater from toilets. When the plant is filled, the excrement has to be diluted with about the same quantity of liquid, if possible, the urine should be used. Waste and wastewater from food-processing industries are only suitable for simple plants if they are homogenous and in liquid form. The maximum of gas-production from a given amount of raw material depends on the type of substrate.

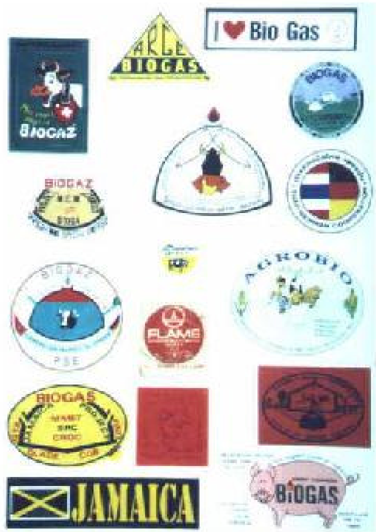
Composition and properties of biogas

Biogas is a mixture of gases that is composed chiefly of:

- methane (CH_4): 40-70 vol.%
- carbon dioxide (CO_2): 30-60 vol.%
- other gases: 1-5 vol.%
  - including
    - hydrogen (H_2): 0-1 vol.%
    - hydrogen sulfide (H_2S): 0-3 vol.%

Like those of any pure gas, the characteristic **properties of biogas are pressure and** temperature-dependent. They are also affected by the moisture content. The factors of main interest are:

- change in volume as a function of temperature and pressure,
- change in calorific value as a function of temperature, pressure and water-vapor content, and
- change in



Biogas is used as an ecologically friendly and

change in water vapor content as a function of temperature and pressure.

and future oriented technology in many countries Photo: Krieg

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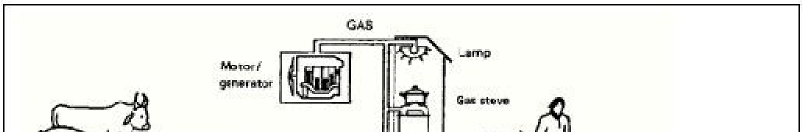
The calorific value of biogas is about 6 kWh/m^3- this corresponds to about half a litre of diesel oil. The net calorific value depends on the efficiency of the burners or appliances. Methane is the valuable component under the aspect of using biogas as a fuel.

Utilization

The history of biogas utilization shows independent developments in various developing and industrialized countries. The European biogas-history and that of Germany in particular, as well as developments in Asian countries form the background of German efforts and programmes to promote biogas technology worldwide.

Normally, the biogas produced by a digester can be used as it is, just in the same way as any other combustible gas. But it is possible that a further treatment or conditioning is necessary, for example, to reduce the hydrogen-sulfide content in the gas. When biogas is mixed with air at a ratio of 1:20, a highly explosive gas forms. Leaking gas pipes in enclosed spaces constitute, therefore, a hazard. However, there have been no reports of dangerous explosions caused by biogas so far.

A first overview of the physical appearance of different types of biogas plants describes the three main types of simple biogas plants, namely balloon plants, fixed-dome plants and floating-drum plants.



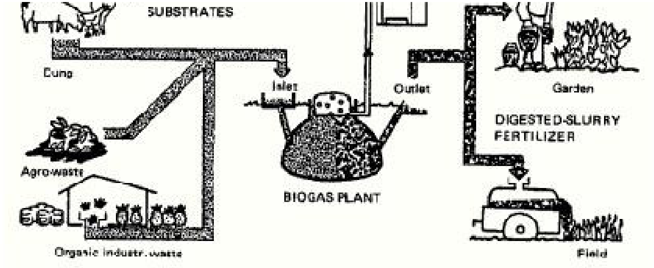


Figure 1: A typical biogas system configuration
Source: OEKOTOP

The Benefits of Biogas Technology

Well-functioning biogas systems can yield a whole range of benefits for their users, the society and the environment in general:

- production of energy (heat, light, electricity) ;
- transformation of organic waste into high quality fertilizer;
- improvement of hygienic conditions through reduction of pathogens, worm eggs and flies;
- reduction of workload, mainly for women, in firewood collection and cooking.
- environmental advantages through protection of soil, water, air and woody vegetation;
- micro-economical benefits through energy and fertilizer substitution, additional income sources and increasing yields of animal husbandry and agriculture;
- macro-economical benefits through decentralized energy generation, import substitution and environmental protection

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Thus, biogas technology can substancially contribute to conservation and development, if the concrete conditions are favorable. However, the required high investment capital and other limitations of biogas technology should be thoroughly considered.

The Costs of Biogas Technology

An obvious obstacle to the large-scale introduction of biogas technology is the fact that the poorer strata of rural populations often cannot afford the investment cost for a biogas plant. This is despite the fact that biogas systems have proven economically viable investments in many cases.

Efforts have to be made to reduce construction cost but also to develop credit and other financing systems. A larger numbers of biogas operators ensures that, apart from the private user, the society as a whole can benefit from biogas. Financial support from the government can be seen as an investment to reduce future costs, incurred through the importation of petrol products and inorganic fertilizers, through increasing costs for health and hygiene and through natural resource degradation.

Fuel and Fertilizer

In developing countries, there is a direct link between the problem of fertilization and progressive deforestation due to high demand for firewood. In many rural areas, most of the inhabitants are dependant on dung and organic residue as fuel for cooking and heating. Such is the case, for example, in the treeless regions of India (Ganges plains, central highlands), Nepal and other countries of Asia, as well as in the Andes Mountains of South America and wide expanses of the African Continent. According to data published by the FAO, some 78 million tons of cow dung and 39 million tons of phytogenic waste were burned in India alone in 1970. That amounts to approximately

35% of India's total non-commercial and conventional energy consumption.

The burning of dung and plant residue is a considerable waste of plant nutrients. Farmers in developing countries are in dire need of fertilizer for maintaining cropland productivity. Nonetheless, many small farmers continue to burn potentially valuable fertilizers, even though they cannot afford to buy chemical fertilizers. At the same time, the amount of technically available nitrogen, pottasium and phosphorous in the form of organic materials is around eight times as high as the quantity of chemical fertilizers actually consumed in developing countries. Especially for small farmers, biogas technology is a suitable tool for making maximum use of scarce resources: After extraction of the energy content of dung and other organic waste material, the resulting sludge is still a good fertilizer, supporting general soil quality as well as higher crop yields.

Public and Political Awareness

Popularization of biogas technology has to go hand in hand with the actual construction of plants in the field. Without the public awareness of biogas technology, its benefits and pitfalls, there will be no sufficient basis to disseminate biogas technology at grassroots level. At the same time, awareness within the government is essential. Since impacts and aspects of biogas technology concern so many different governmental institutions (e.g. agriculture, environment, energy, economics), it is necessary to identify and include all responsible government departments in the dissemination and awareness-raising process.

History of Biogas Technology

Europe/Germany

1770 The Italian Volta collected marsh gas and investigated its burning behavior.

1821 Avogadro identified methane (CH_4).

1875 Propoff states that biogas is produced under anaerobic conditions.

1884 Pasteur researched on biogas from animal residues. He proposed the utilization of horse litter to produce biogas for street-lighting.

1906 First anaerobic wastewater-treatment plant in Germany.

1913 First anaerobic digester with heating facility.

1920 First German sewage plant to feed the collected biogas into the public gas supply system.

1940 Addition of organic residues (fat) to increase sewage gas production.

1947 Research demonstrates that the dung of one cow can give a hundred times more gas than the feces of one urban inhabitant.

Establishment of the first working group on biogas in Germany.

1950 Installation of the first larger agricultural biogas plant.

1950s Nearly 50 biogas plants are built, fed by litter mixed with water and dung. Low oil prices and technical problems lead to the shutdown of all but two plants.

1974 After the first energy crisis, increased promotion of research on and implementation of agricultural biogas technology by the EC and federal departments

departments.

1985 75 biogas plants are listed (built or planned). Biogas slurry is increasingly used as liquid manure.

1990 Progress due to guaranteed prices for biogas-generated electricity. Progress in optimizing the mixture of substrates, the use of biogas for different purposes and technology details.

1992 Foundation of the German biogas association Fachverband Biogas

1997 More than 400 agricultural biogas plants exist in Germany.

China and India

The history of biogas exploration and utilization in China covers a period of more than 50 years. First biogas plants were build in the 1940s by prosperous families. Since the 1970s biogas research and technology were developed at a high speed and biogas technology was promoted vigorously by the Chinese government. In rural areas, more than 5 million small biogas digesters have been constructed and,currently, over 20 million persons use biogas currently as a fuel.

In India, the development of simple biogas plants for rural households started in the 1950s. A massive increase in the number of biogas plants took place in the 1970s through strong government backing. Meanwhile, more than one million biogas plants exist in India.

The historical experiences in Germany, China and India demonstrate clearly, how biogas development responds to favorable frame conditions. In Germany, biogas dissemination gained momentum through the need for alternative energy sources in a war-torn economy and during an energy crisis or later by the change of electricity pricing. In India and China it was a strong government program that furthered the mass dissemination of biogas technology.

German promotion of biogas technology in the south

In the late 1970s, triggered by Schuhmachers Small is Beautiful, appropriate, simple technologies entered the arena of development work in the South. Not but then high-tech, Not innovative, affordable, simple and traditional technologies, it was believed, were the

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remedy for the development- and technology-gap between industrialized and developing countries. Following its launching in 1980, GTZ-GATE chose biogas technology as a focal point of its activities. This resulted in a cross-sectoral scheme that has been accompanying and supporting the development and dissemination of biogas technology in Latin America, Asia and Africa.

Industrialized countries neither had sufficient experience nor appropriate technologies to build on in developing countries. Rather, this experience was identified in India and China and transmitted by a South-North-South transfer. The term appropriate technology seemed justified by the fact that this technology was adapted to the respective local conditions during a learning-with-developing-countries process.

A number of biogas dissemination programs involving German Technical Cooperation (GTZ) were launched in Bolivia, Colombia, Nicaragua, the Caribbean (see Belize and Jamaica), Tanzania, Kenya, Burundi, Morocco and Thailand. Initially, biogas and anaerobic technology focused on small scale farmers. At a later stage, larger farms as well as waste treatment issues increasingly became the focus of biogas technology.

These activities have resulted in a number of positive spin-off effects in the partner countries, in Germany, Europe and international development cooperation. Like in other fields of appropriate technology (AT) promotion, environmental protection, energy provision and the support to private enterprise development are increasingly seen as inseparable elements of sustainable (technology) development.

Outlook

Today, the highest degree of market maturity can be found in the area of municipal sludge treatment, industrial wastewater purification and treatment of agricultural wastes. The use of the technology in municipal wastewater treatment is currently the technology in municipal wastewater treatment is currently experiencing an upswing in Asia (India in particular) and Latin America. Anaerobic treatment of municipal organic waste is experiencing a boom in Northern Europe. Agricultural biogas plants in developing countries are usually promoted on a large scale in connection with energy and environmental issues, and are installed particularly where water pollution through liquid manure from agriculture is most severe.

The increasing emission of greenhouse gases, increasing water consumption and water pollution, declining soil fertility, unsatisfactory waste management and the growing rate of deforestation must be seen as parts of the unsustainable resource use systems that prevail worldwide. Biogas technology is one of the important hardware components in a chain of measures to counteract the above problems. GATE/ISAT is committed to play a lead role in networking and information exchange to ensure that the potential of biogas technology is recognized and made optimal use of.

Microbiology

The three steps of biogas production

Biogas microbes consist of a large group of complex and differently acting microbe species, notable the methane-producing bacteria. The whole biogas-process can be devided into three steps: hydrolysis, acidification, and methane formation (Figure 2). Three types of bacteria are involved (Figure 3).

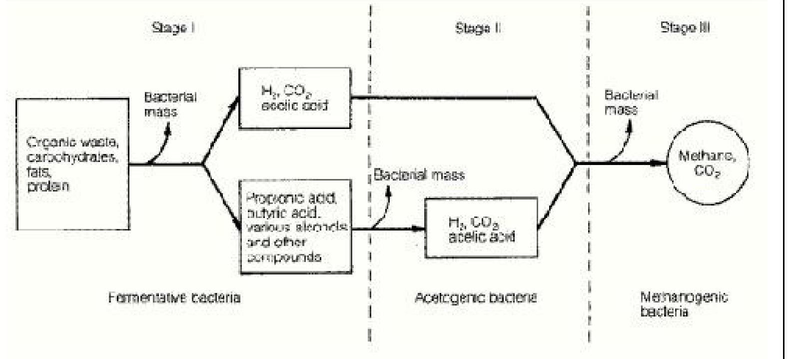

Figure 2: The three-stage anaerobic fermentation of biomass

from: Production and Utilization of Biogas in Rural Areas of Industrialized an d Developing Countries, Schriftenreihe der gtz, No. 97, p. 54; after: Mrkl, H.: Mikrobielle Methangewinnung; in: Fortschritte der

Methangewinnung, in: Fortschritte der Verfahrenstechnik, Vol. 18, p. 509, Dsseldorf, FRG

Hydrolysis

In the first step (hydrolisis), the organic matter is enzymolyzed externally by extracellular enzymes (cellulase, amylase, protease and lipase) of microorganisms. Bacteria decompose the long chains of the complex carbohydrates, proteins and lipids into shorter parts. For example, polysaccharides are converted into monosaccharides. Proteins are split into peptides and amino acids.

Acidification

Acid-producing bacteria, involved in the second step, convert the intermediates of fermenting bacteria into acetic acid (CH_3COOH), hydrogen (H_2) and carbon dioxide (CO_2). These bacteria are facultatively anaerobic and can grow under acid conditions. To produce acetic acid, they need oxygen and carbon. For this, they use the oxygen solved in the solution or bounded-oxygen. Hereby, the acid-producing bacteria create an anaerobic condition which is essential for the methane producing microorganisms. Moreover, they reduce the compounds with a low molecular weight into alcohols, organic acids, amino acids, carbon dioxide, hydrogen sulphide and traces of methane. From a chemical standpoint, this process is partially endergonic (i.e. only possible with energy input), since bacteria alone are not capable of sustaining that type of reaction.

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Methane formation

Methane-producing bacteria, involved in the third step, decompose compounds with a low molecular weight. For example, they utilize hydrogen, carbon dioxide and acetic acid to form methane and carbon dioxide. Under natural conditions, methane producing microorganisms occur to the extent that anaerobic conditions are provided, e.g. under water (for exemple in marine sediments), in ruminant stomaches and in marshes. They are obligatory anaerobic and very sensitive to environmental changes. In contrast to the acidogenic and acetogenic bacteria, the methanogenic bacteria belong to the archaebacter genus, i.e. to a group of bacteria with a very heterogeneous morphology and a number of common biochemical and molecular-biological properties that distinguish them from all other bacterial general. The main difference lies in the

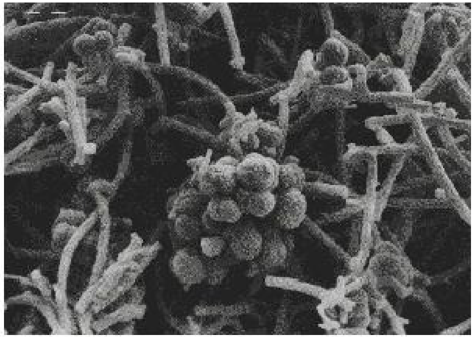

Figure 3: Various types of methanogenic bacteria. The spherically shaped bacteria are of the *methanosarcina genus; the long, tubular ones are methanothrix bacteria, and the short, curved rods* are bacteria that catabolize furfural and sulfates. The total length of the broken bar at top left, which serves as a size reference, corresponds to 1 micron.
Source: Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries,

difference lies in the makeup of the cell walls.

Schriftenreihe der gtz, No. 97, p. 55

Symbiosis of bacteria

Methane- and acid-producing bacteria act in a symbiotical way. On the one hand, acid-producing bacteria create an atmosphere with ideal parameters for methane-producing bacteria (anaerobic conditions, compounds with a low molecular weight). On the other hand, methane-producing microorganisms use the intermediates of the acid-producing bacteria. Without consuming them, toxic conditions for the acid-producing microorganisms would develop.

In practical fermentation processes the metabolic actions of various bacteria all act in concert. No single bacteria is able to produce fermentation products alone.

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Parameters and process optimisation

The metabolic activity involved in microbiological methanation is dependent on the following factors:

- Substrate temperature
- Available nutrients
- Retention time (flow-through time)
- pH level
- Nitrogen inhibition and C/N ratio
- Substrat solid content and agitation
- Inhibitory factors

Each of the various types of bacteria responsible for the three stages of the methanogenesis is affected differently by the above parameters. Since interactive effects between the various determining factors exist, no precise quantitative data on gas production as a function of the above factors are available. Thus, discussion of the various factors is limited to their qualitative effects on the process of fermentation.

Substrate temperature

Temperature range of anaerobic fermentation

Anaerobic fermentation is in principle possible between 3C and approximately 70C. Differentiation is generally made between three temperature ranges:

The psychrophilic temperature range lies below 20C,

the mesophilic temperature range between 20C and 40C and

the thermophilic temperature range above 40C.

Minimal average temperature

The rate of bacteriological methane production increases with temperature. Since, however, the amount of free ammonia also increases with temperature, the bio-digestive performance could be inhibited or even reduced as a result. In general, unheated biogas plants perform satisfactory only where mean annual temperatures are around 20C or above or where the average daily temperature is at least 18C. Within the range of 20-28C mean temperature, gas production increases over-proportionally. If the temperature of the bio-mass is below 15C, gas production will be so low that the biogas plant is no longer economically feasible.

Changes in temperature

The process of bio-methanation is very sensitive to changes in temperature. The degree of sensitivity, in turn, is dependent on the temperature range. Brief fluctuations not exceeding the following limits may be regarded as still un-inhibitory with respect to the process of fermentation:

psychrophilic range: 2C/h

mesophilic range: 1C/h

thermophilic range: 0,5C/h

The temperature fluctuations between day and night are no great problem for plants built underground, since the temperature of the earth below a depth of one meter is practically constant.

Available nutrient

In order to grow, bacteria need more than just a supply of organic substances as a source of carbon and energy. They also require certain mineral nutrients. In addition to

carbon and energy. They also require certain mineral nutrients. In addition to
carbon, oxygen and hydrogen, the generation of bio-mass requires an adequate supply of nitrogen, sulfur,

phosphorous, potassium, calcium, magnesium and a number of trace elements such as iron, manganese, molybdenum, zinc, cobalt, selenium, tungsten, nickel etc. "Normal" substrates such as agricultural residues or municipal sewage usually contain adequate amounts of the mentioned elements. Higher concentration of any individual substance usually has an inhibitory effect, so that analyses are recommended on a case-to-case basis to determine which amount of which nutrients, if any, still needs to be added.

Retention time

Batch-type and continuous plants

The retention time can only be accurately defined in batch-type facilities. For continuous systems, the mean retention time is approximated by dividing the digester volume by the daily influent rate. Depending on the vessel geometry, the means of mixing, etc., the effective retention time may vary widely for the individual substrate constituents. Selection of a suitable retention time thus depends not only on the process temperature, but also on the type of substrate used.

Cost efficiency

Optimizing the process parameters retention time - process temperature - substrate quality - *volumetric load determine, among others, the cost efficiency of the biological processes. But* as each m^3 digester volume has its price, heating equipment can be costly and high quality substrates may have alternative uses, the cost-benefit optimum in biogas production is almost always below the biological optimum.

Substrate

For liquid manure undergoing fermentation in the mesophilic

For liquid manure undergoing fermentation in the mesophilic temperature range, the following approximate values apply:

- liquid cow manure: 20-30 days
- liquid pig manure: 15-25 days
- liquid chicken manure: 20-40 days
- animal manure mixed with plant material: 50-80 days

If the retention time is too short, the bacteria in the digester are "washed out" faster than they can reproduce, so that the fermentation practically comes to a standstill. This problem rarely occurs in agricultural biogas systems.

pH value

The methane-producing bacteria live best under neutral to slightly alkaline conditions. Once the process of fermentation has stabilized under anaerobic conditions, the pH will normally take on a value of between 7 and 8.5. Due to the buffer effect of carbon dioxide-bicarbonate (CO_2- HCO_3^-) and ammonia-ammonium (NH_3- NH_4^+), the pH level is rarely taken as a measure of substrate acids and/or potential biogas yield. A digester containing a high volatile-acid concentration requires a somewhat higher-than-normal pH value. If the pH value drops below 6.2, the medium will have a toxic effect on the methanogenic bacteria.

Nitrogen inhibition and C/N ratio

Nitrogen inhibition

All substrates contain nitrogen. Tabelle 1 lists the nitrogen content of various organic substances and the C/N ratio. For higher pH values, even a relatively low nitrogen concentration may inhibit the process of fermentation. Noticeable inhibition occurs at a nitrogen concentration of roughly 1700 mg ammonium-nitrogen (NH_4-N) per liter substrate. Nonetheless, given enough time, the methanogens are capable of adapting to NH_4-N concentrations in the range of 5000-7000 mg/l substrate, the main prerequisite being that the ammonia $_3$) $_3$-

level (NH	does not exceed 200 - 300 mg NH	N per liter substrate. The rate of	12

ammonia dissociation in water depends on the process temperature and ph value of the substrate slurry.

Table 1: Nitrogen-content and C/N-ratio data for a selection of substrates, compiled from various sources

Source	Biodegradable material	N in [%]	C/N
Maramba, Felix: Biogas and Waste Recycling - The Phillipine Experience; Metro Manila, Phillipines, 1978, p. 43	A. Animal Dung		
	1. Hog	2.8	13.7
	2. Carabao	1.6	23.1
	3. Cow	1.8	19.9
	4. Chicken	3.7	9.65
	5. Duck	0.8	27.4
	6. Pugo	5.0	6.74
	Household Wastes		
	1. Nightsoil	7.1	6.72
	2. Kitchen waste	1.9	28.60
	C. Crop Residues (air-dry)		
	1. Corn stalks	1.2	56.6
	2. Rice straw	0.7	51.0
	3. Corn cobs	1.0	49.9
	4. Peanut hulls	1.7	31.0
	5. Cogon	1 07	-
	6. Bagasse	0.40	-
	D. Others		
	1. Kangkong	4.3	7.8
	2. Water lily	2.9	11.4
	3. Grass trimmings	2.5	15.7
Barnett, A. et al.: Biogas Technology in the Third	Night soil	6	6-10

in the Third World; 1978, p. 51 Ottawa, Canada,	Cow manure	1.7	18
	Chicken manure	6.3	7.3
	Horse manure	2.3	25
	Hay, grass	4	12
	Hay, alfalfa	2.8	17
	Seaweed	1.9	79
	Oat straw	1.1	48
	Wheat straw	0.5	150
	Bagasse	0.3	150
	Sawdust	0.1	200-500
Kaltwasser, Bernd: Biogas; Wiesbaden, FRG, 1980, pp. 35-36	Night soil	6.0	5.9-10
	Cow manure	1.7	16.6-25
	Pig manure	3.8	6.2-12.5
	Chicken droppings	6.3	5-7.1
	Horse manure	2.3	25
	Sheep manure	3.8	33
	Hay	4.0	12.5-25
	Lucernes	2.8	16.6
	Algae	1.9	100
	Oat straw	1.1	50
	Wheat straw	0.5	100-125
	Cane trash (bagasse)	0.3	140
	Sawdust	0.1	200-500
	Cabbage	3.6	12.5
	Tomatoes	3.3	12.5
	Mustard (runch)	1.5	25
	Potato peels	1.5	25
	Rice straw	0.6	67
	Corn straw	0.8	50
	Fallen leaves	1.0	50
	Soybean stalks	1.3	33
	Peanut shoots	0.6	20

Source: Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries, Schriftenreihe der gtz, No. 97, pp. 71-72

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C/N ratio

Microorganisms need both nitrogen and carbon for assimilation into their cell structures. Various experiments have shown that the metabolic activity of methanogenic bacteria can be optimized at a C/N ratio of approximately 8-20, whereby the optimum point varies from case to case, depending on the nature of the substrate.

Substrate solids content and agitation

Substrate solids content

The mobility of the methanogens within the substrate is gradually impaired by an increasing solids content, and the biogas yield may suffer as a result. However, reports of relatively high biogas yields from landfill material with a high solids content may be found in recent literature. No generally valid guidelines can be offered with regard to specific biogas production for any particular solids percentage.

Agitation

Many substrates and various modes of fermentation require some sort of substrate agitation or mixing in order to maintain process stability within the digester. The most important objectives of agitation are:

removal of the metabolites produced by the methanogens (gas)

mixing of fresh substrate and bacterial population (inoculation)

preclusion of scum formation and sedimentation

avoidance of pronounced temperature gradients within the digester

provision of a uniform

- provision of a uniform bacterial population density
- prevention of the formation of dead spaces that would reduce the effective digester volume.

In selecting or designing a suitable means of agitation, the following points should be considered:

1. The process involves a symbiotic relationship between various strains of bacteria, i.e. the metabolite from one species can serve as nutrient for the next species, etc. Whenever the bacterial community is disrupted, the process of fermentation will remain more or less unproductive until an equivalent new community is formed. Consequently, excessive or too frequent mixing is usually detrimental to the process. Slow stirring is better than rapid agitation.
2. A thin layer of scum must not necessarily have an adverse effect on the process. For systems in which the digester is completely filled with substrate, so that any scum always remains sufficiently wet, there is little or no danger that the extraction of gas could be impeded by the scum.
3. Some types of biogas systems can function well without any mechanical agitation at all. Such systems are usually operated either on substrates with such a high solid content, that no stratification occurs, or on substrates consisting primarily of solute substances.

Since the results of agitation and mixing are highly dependent on the substrate in use, it is not possible to achieve a sufficiently uniform comparative evaluation of various mixing systems and/or intensity levels. Thus, each such system can only be designed on the basis of empirical data.

Inhibitory factors

The presence of heavy metals, antibiotics (Bacitracin, Flavomycin, Lasalocid, Monensin, Spiramycin, etc.) and detergents used in livestock husbandry can have an inhibitory effect on the process of bio-methanation. The following table (Tabelle 2) lists the limit concentrations (mg/l) for various inhibitors.

Substance	[mg/l]
Copper:	10-250
Calcium:	8000
Sodium:	8000
Magnesium:	3000
Nickel:	100-1000
Zinc:	350-1000
Chromium:	200-2000
Sulfide (as Sulfur):	200
Cyanide:	2

Table 2: Limiting concentrations for various inhibitors of biomethanation

The Physical Appearance of Different Types of Biogas Plants

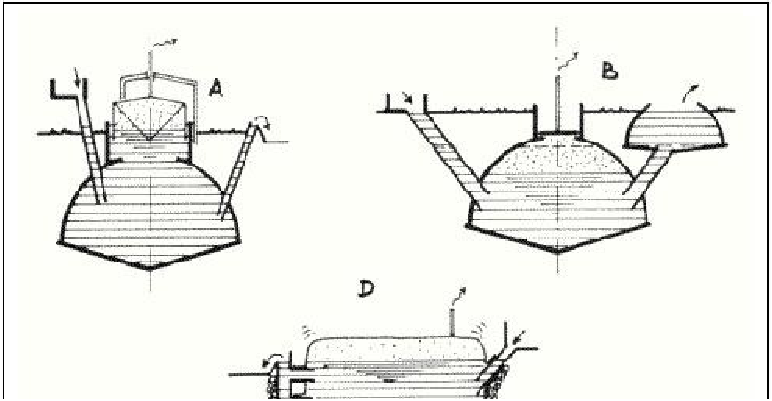
The three main types of simple biogas plants are shown in Figure 4:

balloon plants

fixed-dome plants

floating-drum plants

More information about the different types of biogas plants is provided under digester types.



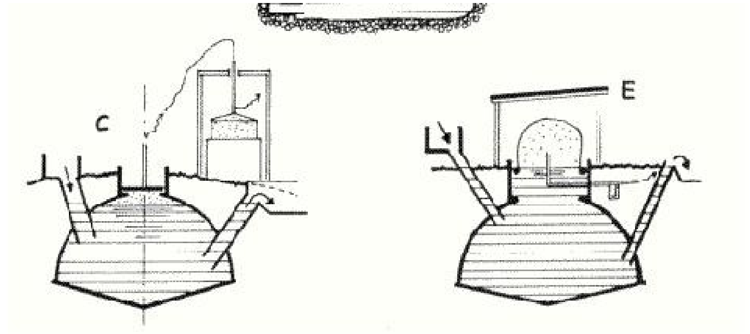


Figure 4: Simple biogas plants. Floating-drum plant (A), fixed-dome plant (B), fixed-dome plant with separate gas holder (C), balloon plant (D), channel-type digester with plastic sheeting and sunshade (E).
Source: Biogas Plants, L. Sasse, GATE, 1988, p. 14

Balloon plants

The balloon plant consists of a digester bag (e.g. PVC) in the upper part of which the gas is stored. The inlet and outlet are attached directly to the plastic skin of the balloon. The gas pressure is achieved through the elasticity of the balloon and by added weights placed on the balloon.

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Advantages are low cost, ease of transportation, low construction sophistication, high digester temperatures, uncomplicated cleaning, emptying and maintenance.

Disadvantages can be the relatively short life span, high susceptibility to damage, little creation of local employment and, therefore, limited self-help potential.

A variation of the balloon plant is the channel-type digester, which is usually covered with plastic sheeting and a sunshade (Figure 4E). Balloon plants can be recommended wherever the balloon skin is not likely to be damaged and where the temperature is even and high.

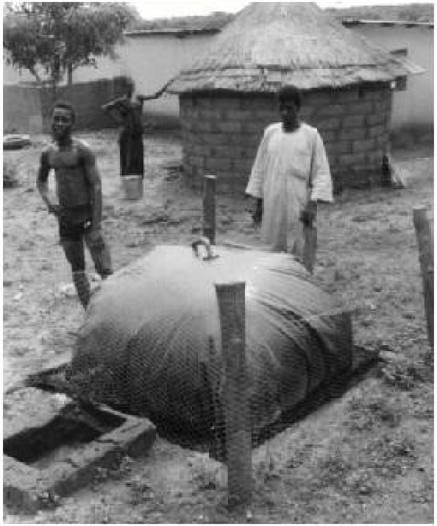

Figure 5: Small "foil-plant" (Ivory Coast)

Photo: Henning

Fixed-dome plants

The fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank.

Advantages are the relatively low construction costs, the absence of moving parts and rusting steel parts. If well constructed, fixed dome plants have a long life span. The underground construction saves space and protects the digester from temperature changes. The construction provides opportunities for skilled local employment.

Disadvantages are mainly the frequent problems with the gas-tightness of the brickwork gas holder (a small crack in the upper brickwork can cause heavy losses of biogas). Fixed-dome plants are, therefore, recommended only where construction can be supervised by experienced biogas technicians. The gas pressure fluctuates substantially depending on the volume of the stored gas. Even though the underground construction buffers temperature extremes, digester temperatures are generally low.

Floating-drum plants

Floating-drum plants consist of an underground digester and a moving gas-holder. The gas-holder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame. If the drum floats in a water jacket, it cannot get stuck, even in substrate with high solid content.

Advantages are the simple, easily understood operation - the volume of stored gas is directly visible. The gas pressure is constant, determined by the weight of the gas holder. The construction is relatively easy, construction mistakes do not lead to major problems in operation and gas yield.

Disadvantages are high material costs of the steel drum, the susceptibility of steel parts to corrosion. Because of this, floating drum plants have a shorter life span than fixed-dome plants and regular maintenance costs for the painting of the drum.

To contrast these simple biogas plants, Figure 6 gives an impression about dimensions of industrial plants which are, for example, built in Europe.

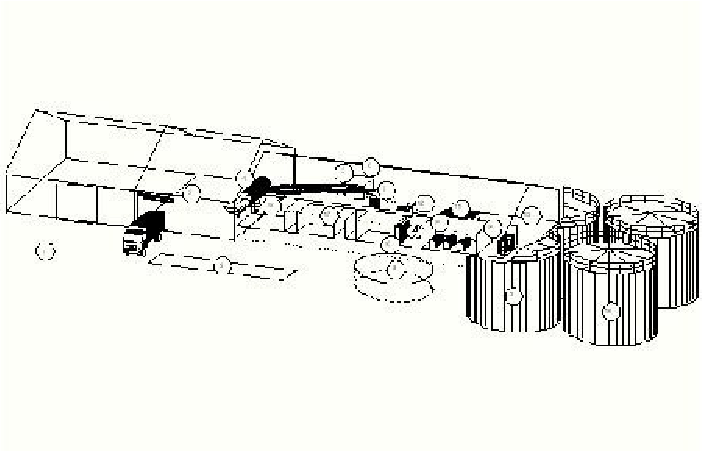

Figure 6: Industrial biogas plant with utilization of domestic organic wastes
Source: TBW

Biogas Appliances

Biogas is a lean gas that can, in principle, be used like other fuel gas for household and industrial purposes, especially for:

- Gas cookers/stoves
- Biogas lamps
- Radiant heaters
- Incubators
- Refrigerators
- Engines

Gas cookers/stoves

Biogas cookers and stoves must meet various **basic requirements:**

- simple and easy operation
- versatility, e.g. for pots of various size, for cooking and broiling
- easy to clean
- acceptable cost and easy repair
- good burning properties, i.e. stable flame, high

high efficiency

attractive appearance

Figure 7: I nstitutional burner in a community kitchen
Photo: Krmer (TBW)

Two-flame burners

A cooker is more than just a burner. It must satisfy certain aesthetic and utility requirements, which can vary widely from region to region. Thus, there is no such thing as an all-round biogas burner. Most households prefer two-flame burners. The burners should be set initially and then fixed. Efficiency will then remain at a high practical level. Single-flame burners and lightweight cook-stoves tend to be regarded as stop-gap solutions until more suitable alternatives can be afforded.

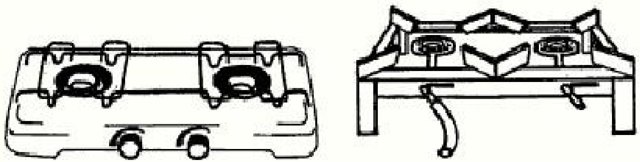

Figure 8: Lightweight and stable 2-flame biogas burners
Source: OEKOTOP

Biogas cookers require purposeful installation with adequate protection from the wind. Before any cooker is used, the burner must be carefully adjusted, i.e.:

for a compact, bluish flame

the pot should be cupped by the outer cone of the flame without being touched by the inner

inner
cone

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- the flame should be self-stabilizing, i.e. flameless zones must re-ignite automatically within 2 to 3 seconds

Test measurements should be performed to optimize the burner setting and minimize consumption.

Figure 9: Biogas stove in China
Photo: Grosch (gtz/GATE)

Gas demand

The gas demand can be defined on the basis of energy consumed previously. For example, 1 kg firewood then corresponds to 200 l biogas, 1 kg dried cow dung corresponds to 100 l biogas and 1 kg charcoal corresponds to 500 l biogas.

The gas demand can also be defined using the daily cooking times. The gas consumption per person and meal lies between 150 and 300 liter biogas. For one liter water to be cooked 30-40 l biogas, for 1/2 kg rice 120-140 l and for 1/2 kg legumes 160-190 l are required.

Biogas lamps

Efficiency of biogas lamps

In villages without electricity, lighting is a basic need as well as a status symbol. However, biogas lamps are not very energy-efficient. This means that they also get very hot. The bright light of a biogas lamp is the result of incandescence, i.e. the intense heat-induced luminosity of special metals, so-called "rare earth" like thorium, cerium, lanthanum, etc. at temperatures of 1000-2000C. If they hang directly below the roof, they cause a fire hazard. The mantles do not last long. It is important that the gas and air in a biogas lamp are thoroughly mixed before they reach the gas mantle, and that the air space around the mantle is adequately warm.

Figure 10: Biogas lamp in Thailand
Photo: Kossmann (gtz/GATE)

Light output

The light output (luminous flux) is measured in lumen (lm). At 400-500 lm, the maximum light-flux values that can be achieved with biogas lamps are comparable to those of a normal 25-75 W light bulb. Their luminous efficiency ranges from 1.2 to 2 lm/W. By comparison, the overall efficiency of a light bulb comes to 3-5 lm/W, and that of a fluorescent lamp ranges form 10 to 15 lm/W. One lamp consumes about 120-150 liter biogas per day.

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Optimal tuning

The performance of a biogas lamp is dependent on optimal tuning of the incandescent body (gas mantle) and the shape of the flame at the nozzle, i.e. the incandescent body must be surrounded by the inner (=hottest) core of the flame at the minimum gas consumption rate. If the incandescent body is too large, it will show dark spots; if the flame is too large, gas consumption will be too high for the light-flux yield. The lampshade reflects the light downward, and the glass prevents the loss of heat.

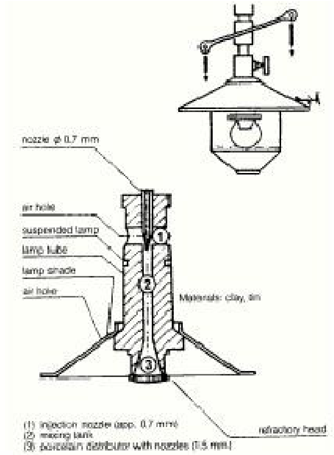

Figure 11: Schematic structure of a biogas lamp
Photo: Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries, Schriftenreihe der gtz No. 97, p. 186

Shortcomings of commercial-type biogas lamps

Practical experience shows that commercial-type gas lamps are not optimally designed for the specific conditions of biogas combustion (fluctuating or low pressure, varying gas composition). The most frequently observed shortcomings are:

- excessively large nozzle diameters
- excessively large gas mantles
- no possibility of changing the injector
- poor or lacking means of combustion-air control

Such drawbacks result in unnecessarily high gas consumption and poor

Such drawbacks result in unnecessarily high gas consumption and poor lighting. While the extension officer has practically no influence on how a given lamp is designed, he can at least give due consideration to the mentioned aspects when it comes to selecting a particular model.

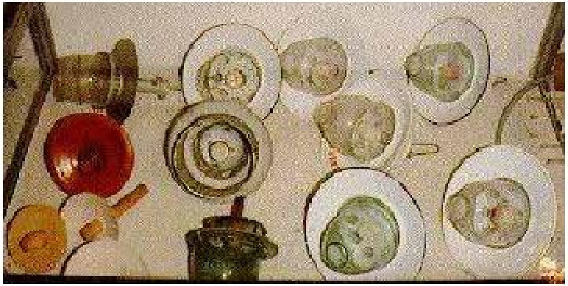

Figure 12: Different types of Biogas lamps at an agricultural exhibition in Beijing/China
Photo: Grosch (gtz/GATE)

Adjusting a biogas lamp

Biogas lamps are controlled by adjusting the supply of gas and primary air. The aim is to make the gas mantle burn with uniform brightness and a steady, sputtering murmur (sound of burning, flowing biogas). To check the criteria, place the glass on the lamp and wait 2-5 minutes, until the lamp has reached its normal operating temperature. Most lamps operate at a gas pressure of 5-15 cm WC (water column). If the pressure is any lower, the mantle will not glow, and if the

Figure 13: Biogas lamp in

(fixed-dome plants) pressure is too high the mantle may tear.

Burundi
Photo: gtz/GATE

Adjusting a biogas lamp requires two consecutive steps:

1. pre-control of the supply of biogas and primary air without the mantle, initially resulting in an elongated flame with a long inner core
2. fine adjustment with the incandescent body in place, resulting in a brightly glowing incandescent body, coupled with slight further adjustment of the air supply (usually more).

The adjustment is at its best when the dark portions of the incandescent body have just disappeared. A lux-meter can be used for objective control of the lamp adjustment.

Radiant heaters

Infrared heaters are used in agriculture for achieving the temperatures required for raising young stock, e.g. piglets and chicken in a limited amount of space. The nursery temperature for piglets begins at 30-35C for the first week and than gradually drops off to an ambient temperature of 18-23C in the 4th/5th week. As a rule, temperature control consists of raising or lowering the heater. Good ventilation is important in the stable / nursery in order to avoid excessive concentrations of CO or CO_2. Consequently, the animals must be kept under regular supervision, and the temperature must be checked at regular intervals. Heaters for pig or chicken rearing require some 200-300 l/h as a rule of thumb.

Thermal radiation of heaters

Radiant heaters develop their infrared thermal radiation via a ceramic body that is heated to 600-800C (red-hot) by the biogas flame. The heating capacity of the radiant heater is defined by multiplying the gas flow by its net calorific value, since 95% of the biogas' energy content is converted to heat. Small-heater outputs range from 1.5 to 10 kW thermal power.

Gas pressure

Figure 14: Biogas radiant heater for raising piglets in Thailand
Photo: Kossmann (gtz/GATE)

Commercial-type heaters are designed for operating on butane, propane and natural gas at a supply pressure of between 30 and 80 mbar. Since the primary air supply is factory-set, converting a heater for biogas use normally consists of replacing the injector; experience shows that biogas heaters rarely work satisfactorily because the biogas has a low net calorific value and the gas supply pressure is below 20 mbar. The ceramic panel, therefore, is not adequately heated, i.e. the flame does not reach the entire surface, and the heater is very susceptible to draft.

Safety pilot and air filter

Biogas-fueled radiant heaters should always be equipped with a safety pilot, which turns off the gas supply if the temperatures goes low i.e. the biogas does not burn any longer. An air filter is required for sustained operation in dusty barns.

Incubators

Incubators are supposed to imitate and maintain optimal hatching temperatures for eggs. They are used to increase brooding efficiency.

Warm-water-heated planar-type incubators

Indirectly warm-water-heated planar-type incubators in which a burner heats water in a heating element for circulation through the incubating chamber are suitable for operating on biogas. The temperature is controlled by ether-cell-regulated vents.

Refrigerators

Absorption-type refrigerating machines operating on ammonia and water and equipped for automatic thermo-siphon circulation can be fuelled with biogas.

Burner

Since biogas is only the refrigerators external source of heat, just the burner itself has to be modified. Whenever a refrigerator is converted for operating on biogas, care must be taken to ensure that all safety features (safety pilot) function properly. Remote ignition via a piezoelectric element substantially increases the ease of operation.

Gas demand

For 100 liters refrigeration volume, about 2000 l of biogas per day, depending on outside temperatures, must be assumed. A larger household refrigerator consumes about 3000 l per day.

Biogas-fueled engines

Gas demand

If the output of a biogas system is to be used for fueling engines, the plant must produce at least 10 m^3 biogas per day. For example, to generate 1 kWh electricity with a generator, about 1 m^3 biogas is required. Small-scale systems are therefore unsuitable as energy suppliers for engines.

Types of engines

The following types of engines are, in principle, well-suited for

The following types of engines are, in principle, well-suited for operating on biogas:

Four-stroke diesel engines

Four-stroke spark-ignition engines

Converting diesel engines

Converting spark-ignition engines

Four-stroke diesel engines:

A diesel engine draws air and compresses it at a ratio of 17:1 under a pressure of approximately 30-40 bar and a temperature of about 700C. The injected fuel charge ignites itself. Power output is controlled by varying the injected amount of fuel, i.e. the air intake remains constant (so-called mixture control).

Four-stroke spark-ignition engines:

A spark-ignition engine (gasoline engine) draws a mixture of fuel (gasoline or gas) and the required amount of combustion air. The charge is ignited by a spark plug at a comparably low compression ratio of between 8:1 and 12:1. Power control is effected by varying the mixture intake via a throttle (so-called charge control).

Four-stroke diesel and spark-ignition engines are available in standard versions with power ratings ranging from 1 kW to more than 100 kW. Less suitable for biogas fueling are:

- loop-scavenging 2-stroke engines in which lubrication is achieved by adding oil to the liquid fuel, and
- large, slow-running (less than 1000 r.p.m) engines that are not built in large series, since they are accordingly expensive and require complicated control equipment.

Biogas engines are generally suitable for powering vehicles like tractors and light-duty trucks (pickups, vans). The fuel is contained in 200-bar steel cylinders (e.g. welding-gas cylinders). The technical, safety and energetic cost of gas compression, storage and filling is substantial enough to hinder large-scale application.

Converting diesel engines:

Diesel engines are designed for continuous operation (10000 or more operating hours). Basically, they are well-suited for conversion to biogas utilization according to either of two methods:

In the dual fuel approach the diesel engine remains extensively unmodified, except for the addition of a gas/air mixing chamber on the air-intake manifold (the air filter can be used as a mixing chamber). The injected diesel fuel still ignites itself, while the amount injected is automatically reduced by the speed governor, depending on how much biogas is injected into the mixing chamber. The biogas supply is controlled by hand. The maximum biogas intake must be kept below the point at which the engine begins to stutter. If that happens, the governor gets too much biogas and has turned down the diesel intake to an extent that ignition is no longer steady. Normally, 15-20% diesel is sufficient. As much as 80% of the diesel fuel can thus be replaced by biogas. Any lower share of biogas can also be used, since the governor automatically compensates with more diesel.

As a rule, dual-fuel diesels perform just as well as comparable engines operating on pure diesel. As in normal diesel operation, the speed is controlled by an accelerator lever, and load control is normally effected by hand, i.e. by adjusting the biogas valve (keeping in mind the maximum acceptable biogas intake level). In case of frequent power changes at steady speed, the biogas intake should be somewhat reduced to let the governor decrease the diesel intake without transgressing the minimum diesel intake. Thus, the speed is kept constant, even in case of power fluctuations. Important: No diesel engine should be subjected to air-side control.

While special T-pieces or mixing chambers with a volume of 50 to 100% of the engine cylinder volume can serve as the diesel / biogas mixing chamber, a proper mixing chamber offers the advantage of more offers the advantage of more thorough mixing

To sum up, conversion according to the dual-fuel method is:

a quick & easy do-it-yourself technique;

able to accommodate an unsteady supply of biogas;

well-suited for steady operation, since a single manual adjustment will suffice and

requires a minimum share of diesel to ensure ignition

Conversion to Spark Ignition (Otto cycle) involves the following permanent modifications at the engine:

removing the fuel-injection pump and nozzle

adding an ignition distributor and an ignition coil with power supply (battery or dynamo)

installing spark plugs in place of the injection nozzles

adding a gas mixing valve or carburetor

adding a throttle control device

reducing the compression ratio (ratio of the maximum to the minimum volume of the space enclosed by the piston) to E=11-12

observing the fact that, as a rule, engines with a pre-combustion or swirl chamber are not suitable for such conversion.

Converting a diesel engine to a biogas-fueled spark-ignition engine is expensive and complicated so that only pre-converted engines of that type should be procured.

Converting spark-ignition engines:

Converting a spark-ignition engine for biogas fueling requires replacement of the gasoline carburettor with a mixing valve (pressure-controlled venturi type or with throttle). The spark-ignition principle is retained, but should be advanced as necessary to account for slower combustion (approx. 5-10 crankshaft angle) and to avoid overheating of the exhaust valve while precluding loss of energy due to still-combustible exhaust gases.

The engine speed should be limited to 3000 rpm for the same reason. As in the case of diesel-engine conversion, a simple mixing chamber should normally suffice for continuous operation at a steady speed. In addition, however, the mixing chamber should be equipped with a hand-operated air-side control valve for use in adjusting the air/fuel ratio (optimal "actual air volume/stoichiometric air volume" = 1.1).

Converting a spark-ignition engine results in a loss of performance amounting to as much as 30%. While partial compensation can be achieved by raising the compression ratio to E=11-12, such a measure also increases the mechanical and thermal load on the engine. Spark-ignition engines that are not explicitly marketed as suitable for running on gas or unleaded gasoline may suffer added wear & tear due to the absence of lead lubrication.

The speed control of converted spark-ignition engines is effected by way of a hand-operated throttle. Automatic speed control for different load conditions requires the addition of an electronic control device for the throttle.

The conversion of spark-ignition engines is evaluated as follows:

Gasoline engines are readily available in the form of vehicle motors, but their useful life amounts to a mere 3000-4000 operating hours.

The conversion effort essentially consists of adding a (well-turned) gas mixer.

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Organic Fertilizer from Biogas Plants

Organic substances in fertilizers

While there are suitable inorganic substitutes for the nutrients nitrogen, potassium and phosphorous from organic fertilizer, there is no artificial substitute for other substances such as protein, cellulose, lignin, etc.. They all contribute to increasing a soils permeability and hygroscopicity while preventing erosion and improving agricultural conditions in general. Organic substances also constitute the basis for the development of the microorganisms responsible for converting soil nutrients into a form that can be readily incorporated by plants.

Nutrients and soil organisms

Due to the decomposition and breakdown of parts of its organic content, digested sludge provides fast-acting nutrients that easily enter into the soil solution, thus becoming immediately available to the plants. They simultaneously serve as primary nutrients for the development of soil organisms, e.g. the replenishment of microorganisms lost through exposure to air in the course of spreading the sludge over the fields. They also nourish actinomycetes (ray fungi) that act as organic digesting specialists in the digested sludge. (Preconditions: adequate aeration and moderate moisture).

Reduction of soil erosion

The humic matter and humic acids present in the sludge contribute to a more rapid humification, which in turn helps reduce the rate of erosion (due to rain and dry scatter) while increasing the nutrient supply, hygroscopicity, etc. The humic content is especially important in low-humus tropical soils. The relatively high proportion of stable organic building blocks such as lignin and certain cellulose compounds contributes to an unusually high formation rate of stable humus (particularly in the presence of argillaceous matter). The amount of stable humus formed with digested sludge amounts to twice the amount that can be achieved with decayed dung. It has also been shown that earthworm activity is stimulated more by fertilizing with sludge than with barnyard dung.

Digested sludge decelerated the irreversible bonding of soil nutrients with the aid of its ion-exchanger contents in combination with the formation of organomineral compounds. At the same time, the buffering capacity of the soil increases, and temperature fluctuations are better compensated.

Reduction of nitrogen washout

The elevated ammonium content of digested sludge helps reduce the rate of nitrogen washout as compared to fertilizers containing substantial amounts of more water-soluable nitrates and nitrites (dung, compost). Soil nitrogen in nitrate or nitrite form is also subject to higher denification losses than is ammonium, which first requires nitrification in order to assume a denitrificable form. It takes longer for ammonium to seep into deeper soil strata, in part because it is more easily adsorbed by argillaceous bonds. However, some of the ammonium becomes fixed in a non-interchangeable form in the intermediate layers of clay minerals. All aspects considered, it is a proven fact, that ammonium constitutes the more valuable form of nitrogen for plant nutrition. Certainly, the N-efficiency of digested sludge may be regarded as comparable to that of chemical fertilizers.

In addition to supplying nutrients, sludge also improves soil quality by providing organic mass. The porosity, pore-size distribution and stability of soil aggregates are becoming increasingly important as standards of evaluation in soil-quality analyses.

Effects on crops

Crop yields are generally aknowledged to be higher following fertilization with digested sludge. Most vegetable crops such as potatos, radishes, carrots, cabbage, onions, garlic, etc., and many types of fruit (oranges, apples, guaves, mangos, etc.), sugar cane, rice and jute appear to react favorably to jute appear to react favorably to sludge fertilization.

In contrast, crops such as wheat, oilseed, cotton and baccra react less favorably. Sludge is a good fertilizer for pastures and meadows. The available data vary widely, because the fertilizing effect is not only plant-specific, but also dependent on the climate and type of soil. Information is still extensively lacking on the degree of reciprocity between soil fertility, type of soil and the effect of fertilizers (particularly N-fertilizers) in arid and semi-arid climates. Thus, no definitive information can be offered to date. Nor, for the same reason, is it possible to offer an economic comparison of the cost of chemical fertilizers vs. biogas sludge. The only undisputed fact that can be stated is that biogas sludge is better from an ecological point of view.

Figure 15: Fertilisation with slurry: Transportation of slurry by a modified wheelbarrow and buckets
Photo: Kellner (TBW)

The Contribution of Biogas Technology to Conservation and Development

Conservation

The conversion of waste material into fertilizer and biogas helps protect the environment in five principal ways:

- The generated biogas can replace traditional energy sources like firewood and animal dung, thus contributing to combat deforestation and soil depletion.
- Biogas can contribute to replace fossil fuels, thus reducing the emission of greenhouse gases and other harmful emissions.
- By tapping biogas in a biogas plant and using it as a source of energy, harmful effects of methane on the biosphere are reduced.
- By keeping waste material and dung in a confined space, surface and groundwater contamination as well as toxic effects on human populations can be minimized.
- By conversion of waste material and dung into a more convenient and high-value fertilizer (biogas slurry), organic matter is more readily available for agricultural purposes, thus protecting soils from depletion and erosion.

Development

Farmers, industrial estates, municipalities and governments have diverging concepts of development. They can use biogas technology in different ways to contribute to their own development objectives.

Farmers may want to substitute inputs such as fertilizers, household and engine fuels by biogas slurry and the biogas itself. A biogas system can relieve farmers from work that they have formerly spent on dung disposal or dung application on their fields. By using biogas for cooking, lighting and heating, life quality for the whole family can improve. Improved stables, if they are part of the biogas system, can increase the output of animal husbandry. Improved farmyard manure may raise the yields of plant production.

Industrial estates can, by processing their waste in a biogas plant, fulfill legal obligations of waste disposal. They can, at the same time, generate energy for production processes, lighting or heating.

Municipalities can use biogas technology to solve problems in public waste disposal and waste water treatment. The energy output of biogas digestion is usually not a priority, but may respond to public energy demands such as street lighting, water pumping and cooking in hospitals or schools.

National Governments have macro-economic interests that may render biogas technology an interesting option in overall development plans. On a national scale, a substantial number of working biogas systems will help reduce deforestation, increase agricultural production, raise employment, and substitute imports of fossil fuels and fertilizers. If macro-economic benefits are obvious and quantifiable, a government may even consider to subsidize biogas systems to bridge a micro-economic profitability gap.

Craftsmen, engineers and maintenance workers have long been overlooked as a target group for biogas promotion. Not only does biogas technology open market niches for masons, plumbers, civil engineers and agronomists, they are often the most effective promoters of biogas technology.

Under which conditions can biogas technology contribute to development and conservation.

Mature technology: A positive contribution of biogas technology can only materialize, if the technology works. The development of biogas technology has passed the experimental stage. Trials with uncertain outcome can only be accepted if the costs of failure are not to be paid by the end-users. Whatever the chosen design of the biogas plant may be, those in charge for its dissemination bear the responsibility to deliver a reliable, durable and user-friendly product.

Appropriate Design: Only appropriate designs will perform satisfactory and will have a favorable cost-benefit ratio. Existing basic designs of biogas systems have to be adapted to the following framework conditions:

- climatic and soil conditions;
- the quality of substrate to be digested;
- the quantities of substrate;
- the prioritization of expected benefits;
- the capital available;
- the availability of skills for operation, maintenance and repair.

Official Policy Support: The policies of governments and donor organizations cannot turn immature technologies and inappropriate designs into success stories, nor can they create an artificial demand for alternative energy or improved fertilizer. But where a national need for energy alternatives exists and the increasing burden of water pollution, deforestation and soil depletion is felt, governments can asupport biogas dissemination by a legal framework against unsustainable use of natural resources and in favor of green technologies.

Donor organizations can provide take-off funding and initial technical assistance where biogas technology is hitherto unknown.

The Critical Mass of Biogas Systems: For small and medium scale farmers, the investment in a biogas system is a considerable risk. Besides the confidence in the technology itself, they need reassurance from neighbors and colleagues. Farmers believe what they see. The more working biogas systems are around, the more they will be willing to invest. In addition, professional (commercial) advice, maintenance and repair will only evolve, if a sufficient number - the critical mass - of biogas systems are established in the area.

Limitations of Biogas Technology

Currently, there is no doubt anymore that biogas systems all over the world are functioning under a variety of climatic conditions. They respond successfully to needs of poor rural populations, urban communities and industrial estates. However, a widespread acceptance and dissemination of biogas technology has not yet materialized in many countries. One main reason, often mentioned, is the required high investment capital. But often the reasons for failure were the unrealistically high expectations of potential users. Biogas technology cannot solve every problem of a farm, a village or a big animal production unit. If disappointment is to be avoided, the limitations of biogas technology should be clearly spelt out. If from the below listed guiding questions one or more cannot be answered with YES, the success of biogas technology is questionable or even unlikely.

Is there a real problem that biogas technology can address.

e.g. Is there a problem with the affordability and availability of energy.

Is the substrate to be bio-degraded an environmental hazard.

Is the lack of high-quality fertilizer a serious problem in the farming system.

Can a permanent supply of bio-degradable material be guaranteed at low cost.

e.g. Are animals kept in a stable, connected to the biogas plant.

Would filling the biogas plant reduce the workload of the farmer.

If necessary, is transport capacity for the substrate guaranteed permanently.

Will the biogas plant be connected reliably to the sewage system.

Can the financing of biogas systems realistically be solved.

e.g. Do potential users have access to credit.

Can a substantial subsidy be expected from private or public sources.

How realistic is the optimism of the biogas plant owner-to-be.

For unheated biogas plants: does the climate allow bio-digestion for most of the year.

Under arid conditions: Is the availability of water secured and affordable.

Is the use of human feces as substrate and fertilizer culturally acceptable.

Is the use of biogas, generated from human waste, acceptable for cooking.

Are there allies among government and institutional decision makers with a certain degree of awareness of environmental problems.

Is in the region a sufficient number of skillful craftsmen available who can be upgraded to be biogas technicians.

e.g. Is good quality masonry work known in the region.

Is plumbing a trade that is practiced in the region.

Does the number of potential biogas users in the region justify a biogas project or the establishment of private biogas business.

Biogas technology is not a universally accepted technology such as the transistor radio. A biogas plant has to fit into existing farming-, production- or waste disposal systems. Attempts to make the system fit to the biogas plant will result in expensive and frustrating failures.

Biogas technology has many competitors. Energy can be produced by fuelwood plantations (with other positive side-effects), by solar systems, micro-hydro-power and other renewable

energy technologies. Producing high quality fertilizer can be done in other, cheaper ways such as composting which are even closer to traditional techniques.

What makes biogas an attractive option is the fact that this technology can provide solutions to a variety of problems simultaneously. That is, if this variety of problems exists.

Biogas - Framework Conditions

The implementation of biogas projects and programs, even on a small-scale level, must take into account the underlying socio-cultural, political, economic and ecological conditions. As an appropriate technology, mainly for rural areas, the realization of economically viable and sociologically and ecologically beneficial biogas projects heavily relies on social and political acceptance. Benefits of biogas as well as major obstacles depend on the specific and complex relationships between social organization, economic premises, environmental problems and political intentions.

Social aspects in the planning process

Participation of the local population is a key issue in the project planning phase. People should be involved as early as possible. The basic facts about biogas technology should be made clear beforehand, so that possible problems of biogas technology are transparent to the actors involved. Obstacles can arise from religious and/or social taboos in the following respects:

- prohibitions in the use of gas primarily for the preparation of food
- prohibitions in the use of the slurry
- social prohibition of work involved in running a biogas unit, either due to the separation of classes, sexes, age groups or due to ethnic or religious affiliation.

In order to deal with these obstacles in a way that considers local conditions as well as requirements of the project, the assistance and attitude of ruling or generally recognized institutions is of major importance. Class structure and barriers have to be taken into account for as well. General features of the societys class structure and comparison with neighboring areas and/or similar projects can serve for a preliminary analysis. The concrete conditions in the project area have to be investigated based on this "general model" focusing on the social position of the target group. For the delegation and organization of tasks during the project, the existing social regulations on the division of labour represent a framework, that is often difficult to determine. Women are often kept out of decision-making processes even though they are usually the primarily affected group regarding household energy issues. Their participation can, for instance, be encouraged by integration into authoritative bodies or by forming special female committees.

Social and political aspects in the dissemination process

For the dissemination of biogas technology certain social and cultural convictions and norms can act as impediments:

- Ethical barriers
- Sociocultural taboos
- Denfense mechanisms, (specifically aginst the use of human excrements as fertilizer)
- Lack of regularity in the attendance and maintenance of biogas systems
- Fertilization

The implementation of biogas programmes is also linked to a number of political and administrative factors that have to be considered.

Specific regional developments

Specific developments in the region can, positively or negatively, impact a biogas dissemination program. They can occur, for example, as the result of:

- Regional (energy) development: a dam is built in a region and the population is resettled. In many aspects the resettlement villages would be ideally suited for community biogas plants. The villages are to be newly constructed and can be designed accordingly. Moreover, social mobility is increased by resettlement. On the other hand the dam is being erected to produce

electricity. Biogas will have to
compete with (possibly cheap) electric energy.

- Emergencies: a village has had to be resettled because of a natural disaster. Similar planning advantages apply as in the first example. Care must be taken here to ensure that biogas is not misunderstood as an "emergency measure" but as a development initiative arising out of an emergency situation.
- Changes in infrastructure: an all weather road is to be constructed to link a previously remote area to the urban center. This will change the prices for building materials, for charcoal and labor. The cost-efficiency of biogas plants may increase as a result.
- Conservation policies: the area in question will soon be part of a large national park. The collection of firewood will be largely restricted, the road infrastructure improved and access to development funds made easier.
- Other technology innovations in the area which have led to disruptions within the social structure, or which have evoked the fear of disruptions. The result can be a negative attitude towards technological innovation.

National energy & fertilizer supply strategies

Chemical fertilizer

For developing countries, the production of biogas and bio-fertilizer holds the promise of substituting increasing amounts of imported fossil fuels and mineral fertilizers. On an economic scale, the importance of digested sludge as a supplementary source of fertilizer is gradually gaining recognition. As populations continue to grow, there is a corresponding increase in the demand for food, fertilizers and energy. Consequently, for example in India, both the production and consumption of chemical fertilizers have been steadily expanding over the past decades.

According to a recent estimate by Indian experts, the national

According to a recent estimate by Indian experts, the national consumption of mineral fertilizers could be reduced by 30-35% through the use of digested biogas sludge as fertilizer.

Fertilizer policies, energy policies

For biogas programs, it is crucial,

- to be familiar with official government policies on fertilizers and fuel;
- to be familiar with the realities of implementation of these policies;
- to have a clear understanding of the possibilities and processes of policy change. This includes an intimate knowledge of persons and institutions involved in possible policy changes.

If national policies have a strong self-reliance character, involving high import taxation on mineral fertilizers and fossil fuel, biogas technology will have an easy start. If world market integration is high on the agenda of national planning, biogas technology will face stiff competition from imported fuels and fertilizers.

According to available economic data, it may be assumed that (at least in remote, sparsely settled areas) biogas programs are usually less costly than comparable energy & fertilizer supply strategies based on fossil resources, like electrification and the production or importation of chemical fertilizers. The latter strategies involve not only high transmission and transportation costs, but are also largely dependent on imports.

In any comparison between biogas technology and traditional approaches to the provision of energy and fertilizer, due consideration should be given to the fact that the continuation or expansion of the latter would surely magnify the ecological damage that has already been done and accelerate the depletion of natural resources.

Environmental aspects

Biogas technology is feasible in principle in most climatic zones under all climatic conditions, where temperature or precipitation are not too low.

Using biogas technology is, besides direct thermal or photovoltaic use and hydropower, a form of using solar energy, mediated through the processes of photosynthesis (for build-up of organic material) and anaerobic decomposition. As such it is a renewable energy source. In many regions of the world, the consumption of firewood exceeds natural regrowth. This leads to deforestation and degradation of forests and woodlands with adverse effects on climate, water budget, soil fertility and natural products supply. Biogas is one of the solutions to this problem, because it substitutes firewood as a fuel and helps sustaining favourable soil conditions. It is also an important contribution to the mitigation of the global greenhouse effect.

The potential contribution of biogas technology to combat deforestation, soil erosion, water pollution and climate change is undisputed. But how much support biogas dissemination will receive from government institutions will depend largely on the role of environmental considerations in government decision making.

The success of biogas technology also depends on the influence of potential allies in the environmental NGO scene. Biogas programs can, if environmental policies are favorable, be perceived as "status projects" for environmental authorities.

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Socio-Cultural Aspects of Biogas Projects

Participation

The basic principle of any planning should be to involve those concerned in the planning process as early as possible. This principle applies even more if the pre-feasibility studies have revealed a considerable amount of problems. In any case it is better to discuss these quite openly with those concerned and seek mutual solutions rather than to rely on the method "it will all work out in the end".

The point in time when participation is started is decisive. It is too early to expect full participation before the technology has reached a certain technical maturity and the conditions for its dissemination are fully explored. It is, on the other hand, just as wrong to confront people with final solutions. In this case there is the risk of obtaining verbal agreement without effective consequence. The ideal time for introducing concept and technology is during the last phase of the investigation, when preliminary results can be shown to those concerned as a basis for discussion. These discussions serve as a first test of the preliminary results. Furthermore, the structures of leadership and decision making can be observed clearly in such situations.

That does not mean that each of the proposals by the community should be accepted blindly. The fact that biogas technology requires a specific technical and economical organization should be stressed. A breakdown of planning would be preferable to unfeasible compromises. In view of this it is often advisable to invite the local technician to take part in these negotiations. His technically based arguments tend to be well accepted in situations of disagreement.

Religious and social taboos

Taboos, as a rule, are always of an overall social character. Violation of taboos is sanctioned (penalized), the extent and form of penalty being determined socially. Sanctions can vary from a direct punishment to social disrespect. In many cases an immediate punishment (corporal punishment, exile from the village etc.) is no longer possible nowadays as state legislation claims a monopoly for punishment. This does not simplify the problem but makes it even more difficult. Instead of an official, foreseeable punishment, social exclusion occurs now in many cases and can be just as serious for those concerned but becomes practically inaccessible for a project or for authorities. As social punishment is forbidden the sanctions are not spoken about, especially when they target a program desired and aided by the state. An exclusion of participants by the community with all its negative consequences is not declared as such by the community and therefore rarely directly accessible.

On the other hand, from these sanctions arises the opportunity to overcome resentments. In general, sanctions are governed by a ruling instance or authority who watches over these taboos and proclaims the punishment when they are violated. But this authority also determines possible exceptions. A general misconception is that taboos basically cannot be broken. No society is inflexible to the extent that regulations do not allow for changes and modifications. In any case, exceptions have to be agreed upon by a recognized instance.

Authorities

Authorities can be:

- for religious taboos: priests or members with a religious function, for instance the elders of the community.
- for social taboos: social leaders, e.g. the elders, traditionally or modern politically leading groups or personalities etc. Often older women play a more important role than the outside observer would see.
- or general: especially recognized members (key persons), either in the sense of traditional structures of leadership or people of certain professions like teachers or local

bank
managers. 35

Disregard of taboos

For the acceptance of exceptions a person or group of persons has a greater effect the more the taboo and the system behind it is generally recognized. If the system and its leaders have been accepted they become the only instance to be consulted concerning exceptions. Any opposition to this group will result in resistance even if individuals within the group are prepared to disregard the regulations.

It should not be assumed that any recognized leader can disregard taboos or suspend them and remain unpunished. These people are also part of the system and have to observe the rules of the system. It is quite right to start lobbying for technical innovations with recognized leaders, but is also necessary, if they can be won, to leave them with the initiative and allow them to decide on the procedure of technology introduction.

Just as the general extensive survey provides the basis for the problem analysis and the starting point of a project, it is essential to recognize that local application cannot be structured according to a general method but has to be integrated in the local context. To mention one example, priests are generally seen as religious leaders but this does not mean that their influence is equal in all localities. Cooperation with priests for local programs should depend on the quality of their local status.

Social classes and class barriers

In their general features, social classes are the binding structure in each society and an important phenomenon which has to be reckoned with and included early enough in planning. It must be taken into account that class structures and class barriers exist in locally specific variations which have a considerable influence on implementation. Typical deviations are:

a) For hierarchical societies:

- the absence of certain hierarchical groups in a village
- the shifting of the hierarchy on account of certain (changing) conditions
- a restructuring of the hierarchy for certain projects

b) For more egalitarian societies:

- the abolition of egalitarian principles by specific village personalities
- the abolition of egalitarian principles by specialization

As these deviations cannot be foreseen, it is wise to compare the results of similar or comparable projects for the preliminary analysis. An essential preliminary analysis offers the following possibilities:

- the development of a general class model including test criteria to check its local application
- the potential for the allocation of individual functions
- the potential for the allocation of certain jobs

Development of a general model

If such a quite rudimentary model is enriched by additional material from other measures in neighboring areas, a series of check questions can be derived and applied in the target area or group. This preliminary model serves as a reference instrument for the main survey and also as a control for results gained. The latter is very important since over-optimistic statements can be made by target groups which are interested in project measures. This applies to the whole project as well as to the allocation of special functions to individual groups. The model is in no case a substitute for a local survey. Local deviations, possibly on account of personality, can be so great that they do not principally change the model but can very much affect the degree of functioning in an initial implementation.

Definition of position of the target group

Equally important to the development of question and control structures is

Equally important to the development of question and control structures is the definition of

position of the target group in relation to neighboring groups. The extensive observation of

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the whole society can provide a series of criteria for the initial analysis. Special importance is attached to this method in the following situations:

a) The proposed group or institution is not or only minimally self-sufficient in its biogas measures. It requires deliveries (material or service) from other groups, either a neighboring village or another enterprise.

Such matters become relevant whenever certain regulations exist within the extensive class system but do not appear within the local system. In such cases an investigation has to take place, for example, whether neighboring groups who would have to deliver substrate, would accept this.

This investigation is of great importance when within the target group a violation of the class system is accepted. It is frequently found out afterwards that this violation is not given because the essential suppliers do not accept their counterparts; now and again it can be seen that certain groups within the target group only give their approval because they are sure that the conditions negotiated would not be accepted by the partner groups.

b) The implementation takes place within the context of a more extensive program, possibly a pilot program. In this case it is not sufficient to obtain the acceptance only within the temporary target group but an investigation into whether this model is acceptable for later target groups has to be carried out.

Although it is in principle practicable to keep the model variable for later adaptation to other target groups, it should not be overlooked that the interest of later target groups will be affected by the pilot model. Violations against social norms which are acceptable for the initial target group could be rejected in neighboring communities and lead to a general rejection of the biogas project. Consequently pilot models should avoid far-reaching violations even if these are locally possible.

Social regulations for the division of labor

Reasons for regulations on the division of labor

Social regulations for the division of labor can arise for the following reasons:

- Privileges of certain groups in taking over specific jobs or being released from less desirable work. These privileges can stem from belonging to a social or ethnic group, age group or sex.
- Social and traditional allocation of specific work for specific groups. The division of labor among the sexes belongs here.
- Regulations on the division of labor caused by political or economic dependency which means e.g. the necessity for the village rich to carry out certain tasks in order to secure labor during agricultural seasons etc.

The regulations on the division of labor always prove to be an especially persistent phenomenon; leading groupings frequently refuse to carry out socially or religiously banned jobs (handling feces, heavy manual work etc.) as they are non-rank conform and force socially or economically dependent groups to take over these tasks. This applies especially to the division of labor between sexes.

Difficulties in researching social regulations

To investigate in social regulations is difficult as their existence is often not admitted to strangers, however strong their influence on the later course of the measures may be. It is not an exception when, for example, in an interview a man agrees to take over a certain task - but means in saying this that his wife or a person dependent on him will carry out the task. For the interviewee this is no lie; for him it is a matter of course that he means, by agreeing, that he will allocate the task. In individual interviews this leads to wrong that he will allocate the task. In individual interviews this leads to wrong interpretations which could have a considerable influence on the implementation model. Leaders in many societies assume that their statement will be valued as correct. Who would think that they carry out such jobs themselves. On the other hand, the purpose of the interview is accurately guessed and the answer given accordingly. The implementer would like an as even distribution of work as possible; he could consider the regulations of labor division to be bad. And so, the answer is given accordingly, so that noone has to be ashamed. Unfortunately this changes nothing as far as the later reality is concerned. Especially in the case of traditionally underprivileged groups, often including women, it has to be expected that the leaders as well as the laborers find it very difficult to give correct statements on the division of tasks.

Conclusions

It can be concluded that:

- On the one hand an extensive preliminary investigation which can often refer to literature is essential. If there are general strong tendencies towards division of labor within a target region, statements concerning the even delegation of jobs within the target group have to be treated with caution.
- The local interviewing of the target group does not initially refer to the future project, but to comparable, existent job routines. If there is a strict division of labor here, no promises of an egalitarian division of work within the proposed biogas project should be made.

Gender considerations

Women are kept out of many decision-making processes as far as they exceed the family, are connected with the allocation of finances or are concerned with technical measures. On the other hand, women may be the main interested parties concerning biogas for cooking. Once a plant is constructed, they are the most affected by the malfunctioning of a plant.

Forms of participation

Which form of participation is appropriate for women cannot be decided from outside. It is of little use to the women if they are forced into a decision-making body without being truly accepted by other members. Their impact could be even less than by influencing of the husband. When there are problems with the plant, it is the women who can be a stabilizing element. As they are more affected by malfunctioning of the plant, they are more interested than men in, for example, a well functioning repair service.

Different models should be considered according to the standing of women in society:

- the careful integration of women into decision making bodies
- women committees for the regulation of consumer problems whilst matters of finance are left to the men
- specialized committees with a mixed central body

Special female committees

The impact of a female committee should not be underestimated. Even if it has no direct influence on decisions it embodies a greater confidence of the women and so indirectly influences decisions. This sort of special committee can also be an initial step towards full participation in the future.

It is necessary to take not only the women but also the men into consideration when discussing gender specific questions. A participation model which is not effective for these will also not help the women.

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Social Problems Affecting the Propagation of Biogas Technology

Ethical barriers

Many religions have very strict laws with regard to cleanliness, especially in connection with human and, to a lesser extent, animal excrement. The suppression or bypassing of such laws is always a mistake. Every new case of illness would invariably be ascribed to the transgression of religious laws. It would be of little importance how much such an illness may actually have to do with the production of biogas.

Implementation strategies should be based on cooperation with appropriate domestic institutions that are looked upon as benign and "clean". The positions and attitudes of such institutions must always be clarified in advance, since it is not their general posture that is of decisive importance, but rather their attitudes with respect to the transgression of religious doctrine. For example: the socio-cultural expectation is that illness will result from the handling of human or animal excrement. Since, however, hospitals are generally accepted as the absolute "experts" in matters of health (or lack of it), it could have a beneficial model effect on the popularization of biogas technology to see that their local hospital or dispensary is operating a biogas system.

On the other hand, hospitals are also regarded as secular institutions; one accepts their services as a necessary evil without affording them a social rank. Seen in that light, religious taboos cannot be overcome by way of the hospitals example. At best, the reaction would amount to: "They can get away with it. They have special defense powers. But we dont!".

Socio-cultural taboos

Many socio-cultural taboos, though rooted in ancient religious beliefs, Many socio-cultural taboos, though rooted in ancient religious beliefs, have gradually become altered by way of missionary activities and the extenuation of religious interests to "generally applicable" taboos, which are frequently more difficult to handle than "pure" religious taboos, since no priest or minister is able to exert any influence. The only way to overcome taboos is by way of example. Highly respected members of the community, approved educational institutions, etc. may be able to make inroads in a model function. Here, too, a preliminary study of the envisioned mediator is imperative. The question of individual acceptance must be clarified in advance. It is by no means a foregone conclusion that someone who is considered highly acceptable in a certain field or function, e.g. politics, will enjoy the same high standing in a different context, e.g. hygiene.

Of equal importance is the effective investigation of existing interrelations between, and relative influence of, the various taboos. For example, the socio-cultural cross-linkage between social behavior and illness must be expected to appear illogical to a Western implementer. Such associations must be heeded if the strategy being applied is to meet with success in generating acceptance for biogas and in instigating a (partial) breach of taboos. Often enough, the breakthrough may be easier to achieve indirectly (by way of the cross-links) than directly. In the Pacific region, for example, human feces were traditionally "disposed of" by pigs. This was a matter of general practice and no one considered it repulsive. The potential solution: a "three-in-one" system in which the human excrement "pass through" the pigs, so to speak, by being routed underneath the pigpen on their way to the digester. No one "sees" what actually takes place, or more precisely, what does not take place.

Defense mechanisms against the use of human excrements as fertilizer

In practical terms, this subject could be viewed as a subgroup of the socio-cultural taboos, the main distinction being that the use of night-soil for the production of biogas is regarded as acceptable, but the use of the digested sludge as fertilizer is not. This stance is particularly well-entrenched in regions where the use of fertilizers is relatively new, and mineral fertilizers have been introduced as a "clean" product, i.e. in regions where shifting cultivation is traditional.

It is unusual in such regions to find that the arguments against the use of manure have been generated, or at least amplified, by hygiene propaganda. In the Pacific Basin, for example, a region in which few epidemics have been known so far, but were belatedly infused by way of acculturation. A potential solution would be to conduct demonstrations in cooperation with institutions known for - and viewed as credible because of - their close involvement with matters of hygiene.

Figure 16: Toilet (under construction), directly connected to the plant
Photo: Kellner (TBW)

Irregular attendance and maintenance of biogas systems

This is a frequent problem in the tropics, where the climate dictates no particular sequence of agricultural activities. Applied to biogas systems, the connection between a process breakdown and irregular charging is not immediately recognizable, because there is a substantial time lag between the owners forgetting to feed substrate into the system and the eventual, resultant decrease in gas production. Similarly, once the biogas system has stopped producing, it will take up to about 10 days of regular charging to get the gas production back to normal levels. Once again, the connection is blurred. The only possible solution would be to provide long-term intensive training aimed at instilling an appreciation for the need to ensure that the system is charged on a regular basis.

Fertilization

This problem stands in close relation to the ethical barriers, socio-cultural taboos, defense mechanisms and the lack of regularity in the attandance of biogas systems. Insufficient, untimely or otherwise improper fertilizing may be the result of a lack of familiarization with regard to the work involved, the type of fertilizer being used or the necessity of methodical regularity. To the extent that neither ethical barriers nor socio-cultural taboos are involved, the only workable approach is to provide intensive training for the owner-operators.

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Political and Administrative Frame Conditions for Biogas Programmes

Political will and public opinion

The development of biogas technology depends on the political will of donor and recipient governments. It is the task of the governmental and administrative authorities to provide access to the technology and to secure and organize the requisite material, financial and legal basis. According to their political will to promote biogas, governments can play a more or less supportive role in biogas research, information dissemination and regulations for funding, subsidies or tax waving. The formation of a political will does not evolve in a vacuum. Political will and public opinion develop in interrelation. Successful practical examples, encouraging research findings, the use of media to spread information, all these are tools to influence both political will and public opinion.

Biogas programs should attempt to lobby for biogas at various entry points of the government system simultaneously. Creating a favorable climate for biogas dissemination depends almost always on a whole range of decision makers. For example:

The Ministry of Finance will decide on subsidies and tax wavers for biogas users.

The Ministry of Energy can propose laws regarding the feeding of biogas-produced electricity into the grid. It can also propose financial and other assistance.

The Ministry of Agriculture and Livestock can include biogas in the training curriculum of extension officers and agricultural colleges.

The Ministry of Education can include biogas in the curricula of high schools and promote the construction of promote the construction of bio-latrines for schools.

The Ministry of Health can include biogas in the curricula of public health workers and encourage the building of bio-latrines for hospitals.

Simultaneously to political lobbying, PR work is important to influence public opinion:

Radio Programs are an effective means in rural areas to familiarize the population with basics of biogas technology.

Articles in Print Media usually reach members of the middle class, among whom are the most promising potential users: middle to large farmers.

Pilot Biogas Systems must be located strategically to be easily accessible. The more these pilot plants have a real life character, i.e. be an operational part of a farm, the more convincing they will be for other farmers.

Visits in Agricultural Schools and Colleges does not reach the decision makers of today, but lays the ground for biogas acceptance in the future.

Figure 17: Sign of the National Biogas Department/National Energy Board in Ghana
Photo: Kellner (TBW)

Program goals

Since the actual installation of a biogas plant is ultimately the decision of the individual investor, it is important that the program goals and the organizational environment is conducive to affirmative individual decisions. The prerequisites for this must be established at all planning stages by and for all sectors concerned. A biogas program which is part of a larger development program must harmonize with the other departments of the parent program. The introduction of biogas as an alternative source of energy affects various sectors, each of which functions within its own specific structural setting. These, of course, vary from one country to another. As a rule, the responsibilities within a biogas program should be distributed along the lines of existing contacts with the corresponding target groups. If, for example, certain farmers are considered the target group of an information campaign, it would be appropriate to have the ministry of agriculture be involved in the biogas program.

Administration

No new administrative bodies should be established for performing the above tasks. Instead, it is advisable to set up biogas promotion units or biogas contact persons within the existing departments and agencies. Within the framework of a well-established development program, particular importance should be attached to self-help groups, voluntary agencies and/or private foundations.

The authorities efforts in favor of biogas promotion will be more effective, if sufficient detailed information is placed in the hands of the self-help groups. The concerned administrative bodies must disseminate the requisite information and provide inexperienced groups with a satisfactory explanation of how to best exploit the promotional options available to them. Practical assistance should be offered wherever possible. Active self-help

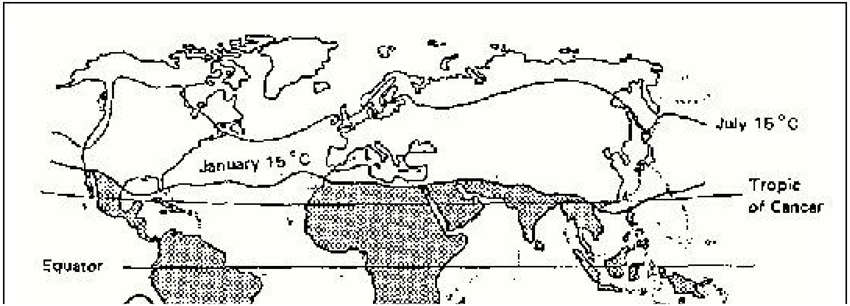
Practical assistance should be offered wherever possible. Active self-help groups will then become ideal multipliers.

Environmental Frame Conditions of Biogas Technology

Climatic conditions for biogas dissemination

Temperatures

Biogas technology is feasible in principle under almost all climatic conditions. As a rule, however, it can be stated that costs increase for biogas production with sinking temperatures. Either a heating system has to be installed, or a larger digester has to be built to increase the retention time. Unheated and un-insulated plants do not work satisfactory when the mean temperature is below 15 C. Heating systems and insulation can provide optimal digestion temperatures even in cold climates and during winter, but the investment costs and the gas consumption for heating may render the biogas system not viable economically.



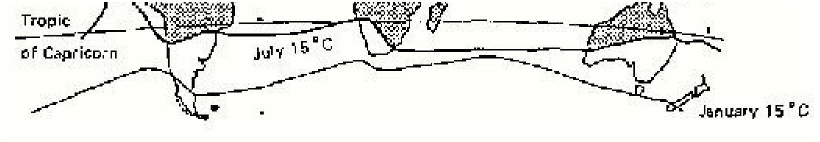


Figure 18: Global 15 °C isotherms for January and July, indicating the biogas-conducive temperature zone
Source: OEKOTOP

Not only the mean temperature is important, also temperature changes affect the performance of a biogas plant adversely. This refers to day/night changes and seasonal variations. For household plants in rural areas, the planner should ensure that the gas production is sufficient even during the most unfavorable season of the year. Within limits, low temperatures can be compensated with a longer retention time, i.e. a larger digester. Changes of temperature during the course of the day are rarely a problem as most simple biogas digesters are built underground.

Precipitation

The amount of seasonal and annual rainfall has mainly an indirect impact on anaerobic fermentation:

- Low rainfall or seasonal water scarcity may lead to insufficient mixture of the substrate with water. The negative flow characteristics of substrate can hamper digestion.
- Low precipitation generally leads to less intensive systems of animal husbandry. Less dung is available in central locations.
- High precipitation can lead to high groundwater levels, causing problems in construction and operation of biogas plants.

Suitability of climatic zones

Tropical Rain Forest: annual rainfall above 1.500 mm, mean temperatures between 24 and 28C with little seasonal variation. Climatically very suitable for biogas production. Often animal husbandry is hampered by diseases like trypanosomiasis, leading to the virtual absence of substrate.

Tropical Highlands: rainfall between 1.000 and 2.000 mm, mean temperatures between 18 and 25C (according to elevation). Climatically suitable, often agricultural systems highly suitable for biogas production (mixed farming, zero-grazing).

Wet Savanna: rainfall between 800 and 1.500 mm, moderate seasonal changes in temperature. Mixed farming with night stables and day grazing favor biogas dissemination.

Dry Savanna: Seasonal water scarcity, seasonal changes in temperatures. Pastoral systems of animal husbandry, therefore little availability of dung. Use of biogas possible near permanent water sources or on irrigated, integrated farms.

Thornbush Steppe and Desert: Permanent scarcity of water. Considerable seasonal variations in temperature. Extremely mobile forms of animal keeping (nomadism). Unsuitable for biogas dissemination.

Firewood consumption and soil erosion

A unique feature of biogas technology is that it simultaneously reduces the need for firewood and improves soil fertilization, thus substantially reducing the threat of soil erosion. Firewood consumption in rural households is one of the major factors contributing to deforestation in developing countries. Most firewood is not acquired by actually cutting down trees, but rather by cutting off individual branches, so that the tree need not necessarily suffers permanent damage. Nonetheless, large amounts of firewood are also obtained by way of illegal felling.

In years past, the consumption of firewood has steadily increased and will continue to do so as the population expands - unless adequate alternative sources of energy are developed. In many developing countries such as India, the gathering of firewood is, strictly speaking, a form of wasteful exploitation. Rapid deforestation due to increasing wood consumption contributes heavily to the acceleration of soil erosion. This goes hand in hand with overgrazing which can cause irreparable damage to soils. In the future, investments aimed at soil preservation must be afforded a much higher priority than in the past. It will be particularly necessary to enforce extensive reforestation.

Soil protection and reforestation

The widespread production and utilization of biogas is expected to make a substantial contribution to soil protection and amelioration. First, biogas could increasingly replace firewood as a source of energy. Second, biogas systems yield more and better fertilizer. As a result, more fodder becomes available for domestic animals. This, in turn, can lessen the danger of soil erosion attributable to overgrazing. According to the ICAR paper (report issued by the Indian Council of Agricultural Research, New Delhi), a single biogas system with a volume of 100 cft (2,8 m^3) can save as much as 0.3 acres (0,12 ha) woodland each year.

Taking India as an example, and assuming a biogas production rate of 0.36 m^3/day per livestock unit, some 300 million head of cattle would be required to produce enough biogas to cover the present consumption of firewood. This figure is somewhat in excess of the present cattle stock. If, however, only the amount of firewood normally obtained by way of deforestation (25.2 million trees per year) were to be replaced by biogas, the dung requirement could be satisfied by 55 million cattle. Firewood consumption could be reduced to such an extent that - at least under the prevailing conditions - a gradual regeneration of India's forests would be possible.

According to empirical data gathered in India, the consumption of firewood in rural households equipped with a biogas system is much lower than before, but has not been fully eradicated. This is chiefly attributable to a number of technical and operational short-comings. At present, many biogas systems are too small to handle the available supply of substrate;

- many biogas units are operated inefficiently;
- many of the existing biogas systems are not used due to minor mistakes;
- biogas users tend to increase energy consumption to the point of wastage, then requiring additional energy in the form of firewood.

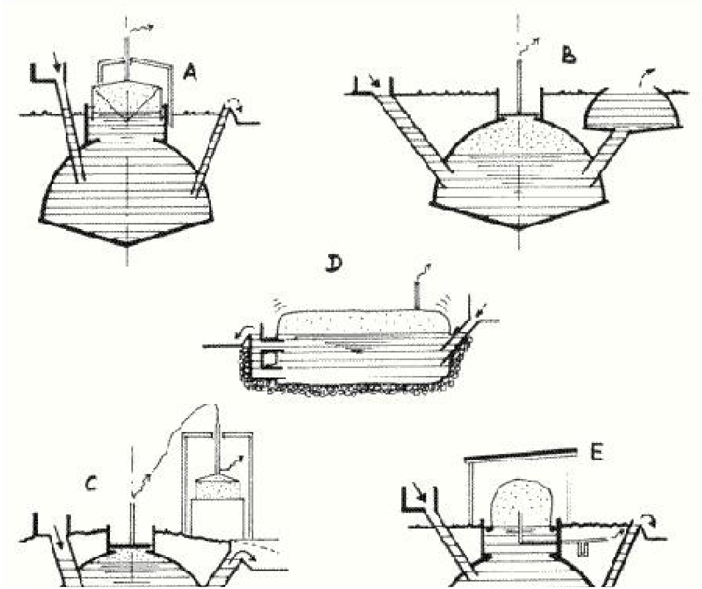
A more serious problem, however, is the fact that a household biogas system program can only reach the small percentage of farmers who have the investment capital required. The majority of rural households will continue to use firewood, dried cow dung and harvest residues as fuel.

Reduction of the greenhouse effect

Last but not least, biogas technology takes part in the global struggle against the greenhouse effect. It reduces the release of CO_2 from burning fossil fuels in two ways. First, biogas is a direct substitute for gas or coal for cooking, heating, electricity generation and lighting. Additionally, the reduction in the consumption of artificial fertilizer avoids carbon dioxide emissions that would otherwise come from the fertilizer producing industries. By helping to counter deforestation and degradation caused by overusing ecosystems as sources of firewood and by melioration of soil conditions biogas technology reduces CO_2 releases from these processes and sustains the capability of forests and woodlands to act as a carbon sink.

Methane, the main component of biogas is itself a greenhouse gas with a much higher "greenhouse potential" than CO_2. Converting methane to carbon dioxide through combustion is another contribution of biogas technology to the mitigation of global warming. However, this holds true only for the case, that the material used for biogas generation would otherwise undergo anaerobic decomposition releasing methane to the atmosphere. Methane leaking from biogas plants without being burned contributes to the greenhouse

from biogas plants without being burned contributes to the greenhouse
effect! Of course, burning biogas also releases CO_2. But this, similar to the sustainable use of firewood, does only return carbon dioxide which has been assimilated from the atmosphere by growing plants maybe one year before. There is no net intake of carbon dioxide in the atmosphere from biogas burning as it is the case when burning fossil fuels.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Biogas Digest

Volume II

Biogas - Application and Product Development

isat

Information and Advisory Service
on Appropriate Technology

gtz

Imprint

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Concept and contents:

Werner Kossmann, Uta Pnitz

Information and Advisory Service on Appropriate Technology (ISAT)
GATE in Deutsche Gesellschaft fr Technische Zusammenarbeit (GTZ), GmbH
(German Agency for Technical Cooperation)
Post Box 5180
D-65726 Eschborn
Federal Republic of Germany
Telephone: +49 6196/79-0
Fax: +49 6196/797352
E-

E-mail: gate isat@gtz.de

Stefan Habermehl

Household Energy Appropriate Technologies (HEAT) GmbH
Limburger Strae 29
D-61479 Glashtten
Federal Republic of Germany
Telephone: +49 6174 964077
Fax: +49 6174 61209
E-mail: heatinternational@t-online.de

Thomas Hoerz, Pedro Krmer, B. Klingler, C. Kellner, Thomas Wittur, F. v. Klopotek, A. Krieg, H. Euler

Naturgerechte Technologien, Bau- und Wirtschaftsberatung (TBW) GmbH
Baumweg 10
60316 Frankfurt
Tel.: 069 943507-0
Fax: 069 943507-11
E-mail: tbw@pop-frankfurt.com

Design:

Utz Dornberger
Stckelstr. 20
04347 Leipzig
Tel.: 0341 2334980
E

E-
mail:
utz@imb
-
jena.de 1

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Biogas - Application and Product Development

Planning a biogas plant

Before building a biogas plant, there are different circumstances which should be considered. For instance, the natural and agricultural conditions in the specific countries are as important as the social or the economic aspects. To consider the most important factors, we provide a checklist for the planning procedure, a planning guide and a checklist for construction of a biogas plant.

Failure or unsatisfactory performance of biogas units occur mostly due to planning mistakes. The consequences of such mistakes may be immediately evident or may only become apparent after several years. Thorough and careful planning is, therefore, of utmost importance to eliminate mistakes before they reach irreversible stages.

As a biogas unit is an expensive investment, it should not be erected as a temporary set-up. Therefore, determining siting criteria for the stable and the biogas plant are the important initial steps of planning.

A general problem for the planning engineer is the interference of the customer during planning. As much as the wishes and expectations of customers have to be taken into consideration, the most important task of the planner is to lay the foundation for a well functioning biogas unit. As in most cases the customer has no experience with biogas technology, the planner has to explain all the reasons for each planning step. Planners should have the courage to withdraw from the planning process, if the wishes of the customer will lead to a white elephant on the farm.

Moreover, all extension-service advice concerning agricultural biogas plants must begin with an estimation of the quantitative and qualitative energy requirements of the an estimation of the quantitative and qualitative energy requirements of the interested party.

Then, the biogas-generating potential must be calculated on the basis of the given biomass production and compared to the energy demand. Both the energy demand and the gas-generating potential, however, are variables that cannot be accurately determined in the planning phase. Sizing the plant (digester, gasholder, etc.) is the next step in the planning process.

In the case of a family-size biogas plant intended primarily as a source of energy, implementation should only be recommended, if the plant can be expected to cover the calculated energy demand.

Information about the economic evaluation of a biogas plant can be found in the section on Costs and Benefits.

Design

Throughout the world, a countless number of designs of biogas plants have been developed under specific climatic and socio-economic conditions. Chosing a design is essentially part of the planning process. It is, however, important to familiarize with basic design considerations before the actual planning process begins. This refers to the planning of a single biogas unit as well as to the planning of biogas-programs with a regional scope.

Physical conditions

The performance of a biogas plant is dependent on the local conditions in terms of climate, soil conditions, the substrate for digestion and building material availability. The design must respond to these conditions. In areas with generally low temperatures, insulation and heating devices may be important. If bedrock occurs frequently, the design must avoid deep excavation work. The amount and type of substrate to be digested have a bearing on size and design of the digester and the inlet and outlet construction. The choice of design will also be based on the building materials which are available reliably and at reasonable cost.

Skills and labor

High sophistication levels of biogas technology require high levels of skills, from the planner

as well as from the constructor and user. With a high training input, skill gaps can be bridged, but the number of skilled technicians will get smaller the more intensive the training has to be. In addition, training costs compete with actual construction costs for scarce (project) resources. Higher technical sophistication also requires more expensive supervision and, possibly, higher maintenance costs. To which extent prefabricated designs are suitable depends largely on the cost of labor and transport.

Standardization

For larger biogas programs, especially when aiming at a self-supporting dissemination process, standards in dimensions, quality and pricing are essential. Standard procedures, standard drawings and forms and standardized contracts between the constructor, the planner, the provider of material and the customer avoid mistakes and misunderstandings and save time. There is, however a trade-off between the benefits of standardization and the necessity of individual, appropriate solutions.

Types of plants

There are various types of plants. Concerning the feed method, three different forms can be distinguished:

- Batch plants
- Continuous plants
- Semi-batch plants

Batch plants are filled and then emptied completely after a fixed retention time. Each design and each fermentation material is suitable for batch filling, but batch plants require high labor input. As a major disadvantage, their gas-output is not steady.

Continuous plants are fed and emptied continuously. They empty automatically through the

overflow whenever new material is filled in. Therefore, the substrate must be fluid and homogeneous. Continuous plants are suitable for rural households as the necessary work fits well into the daily routine. Gas production is constant, and higher than in batch plants. Today, nearly all biogas plants are operating on a continuous mode.

If straw and dung are to be digested together, a biogas plant can be operated on a semi-**batch basis. The slowly digested straw-type material is fed in about twice a year as a batch** load. The dung is added and removed regularly.

Concerning the construction, two main types of simple biogas plants can be distinguished:

- fixed-dome plants
- floating-drum plants

But also other types of plants play a role, especially in past developments. In developing countries, the selection of appropriate design is determined largely by the prevailing design in the region. Typical design criteria are space, existing structures, cost minimization and substrate availability. The designs of biogas plants in industrialized countries reflect a different set of conditions.

Parts of a biogas plant

The feed material is mixed with water in the influent collecting tank. The fermentation slurry flows through the inlet into the digester. The bacteria from the fermentation slurry are intended to produce biogas in the digester. For this purpose, they need time. Time to multiply and to spread throughout the slurry. The digester must be designed in a way that only fully digested slurry can leave it. The bacteria are distributed in the slurry by stirring (with a stick or stirring facilities). The fully digested slurry leaves the digester through the outlet into the slurry storage.

The biogas is collected and stored until the time of consumption in the gasholder. The gas pipe carries the biogas to the place where it is consumed by gas appliances. Condensation collecting in the gas pipe is removed by a water trap.

Depending on the available building material and type of plant under construction, different variants of the individual components are possible. The following (optional) components of a

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biogas plant can also play an important role and are described seperatly: Heating systems, pumps, weak ring.

Construction details

The section on construction of biogas plants provides more information on:

- Agitation
- Heating
- Piping systems
- Plasters and Coats
- Pumps
- Slurry equipement
- Underground water

Starting the plant

Initial filling

The initial filling of a new biogas plant should, if possible, consist of either digested slurry from another plant or cattle dung. The age and quantity of the inoculant (starter sludge) have a decisive effect on the course of fermentation. It is advisable to start collecting cattle dung during the construction phase in order to have enough by the time the plant is finished. When the plant is being filled for the first time, the substrate can be diluted with more water than usual to allow a complete filling of the digester.

Type

Type of substrate

Depending on the type of substrate in use, the plant may need from several days to several weeks to achieve a stable digesting process. Cattle dung can usually be expected to yield good gas production within one or two days. The breaking-in period is characterized by:

- low quality biogas containing more than 60% CO_2
- very odorous biogas
- sinking pH and
- erratic gas production

Stabilization of the process

The digesting process will stabilize more quickly if the slurry is agitated frequently and intensively. Only if the process shows extreme resistance to stabilization should lime or more cattle dung be added in order to balance the pH value. No additional biomass should be put into the biogas plant during the remainder of the starting phase. Once the process has stabilized, the large volume of unfermented biomass will result in a high rate of gas production. Regular loading can commence after gas production has dropped off to the expected level.

Gas quality

As soon as the biogas becomes reliably combustible, it can be used for the intended purposes. Less-than-optimum performance of the appliances due to inferior gas quality should be regarded as acceptable at first. However, the first two gasholder fillings should be vented unused for reasons of safety, since residual oxygen poses an explosion hazard.

Managing input- and output-material

Substrate input

For a simple, small-scale biogas system, only a minimum amount of time and effort must be spent on procuring the feedstock and preparing it for fermentation. The technical equipment

is relatively inexpensive. Theoretically any organic material can be digested. Substrate pre-

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processing and conveying depends on the type of material to be used. One of the most important problems in substrate management to be considered is the problem of scum.

Effluent sludge

The sludge resulting from the digestion process represents a very valuable material for fertilization. The following aspects of sludge treatment and use are considered here:

- Sludge storage
- Composition of sludge
- Fertilizing effect of effluent sludge
- Sludge application and slurry-use equipment

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Biogas - Digester types

In this chapter, the most important types of biogas plants are described:

- Fixed-dome plants
- Floating-drum plants
- Balloon plants
- Horizontal plants
- Earth-pit plants
- Ferrocement plants

Of these, the two most familiar types in developing countries are the fixed-dome plants and the floating-drum plants. Typical designs in industrialized countries and appropriate design selection criteria have also been considered.

Fixed-dome plants

The costs of a fixed-dome biogas plant are relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected. The plant is constructed underground, protecting it from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes.

The construction of fixed dome plants is labor-intensive, thus creating local employment. Fixed-dome plants are not easy to build. They should only be built where construction can be supervised by experienced biogas technicians. Otherwise plants may not be gas-tight (porosity and cracks).

The basic elements of a fixed dome plant (here the Nicarao Design) are shown in the figure below.

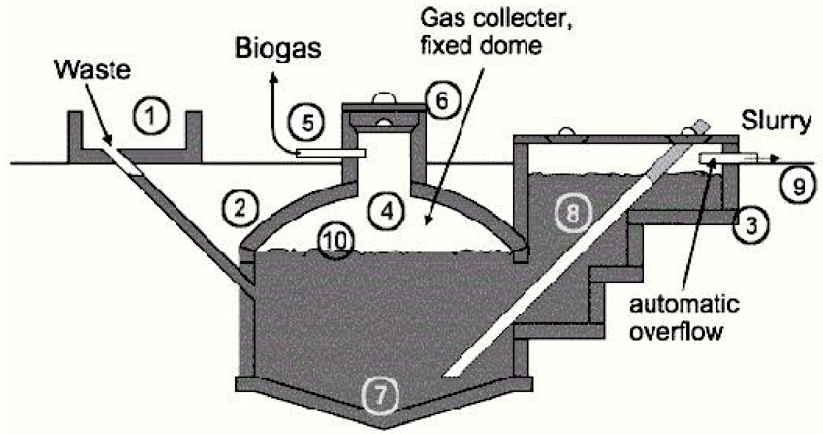

Figure 1: Fixed dome plant Nicarao design: 1. Mixing tank with inlet pipe and sand trap. 2. Digester. 3. Compensation and removal tank. 4. Gasholder. 5. Gaspipe. 6. Entry hatch, with gastight seal. 7. Accumulation of thick sludge. 8. Outlet pipe. 9. Reference level. 10. Supernatant scum, broken up by var ying level.
Source: TBW

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Function

A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gas-holder and a displacement pit, also named compensation tank. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gas-holder, the gas pressure is low.

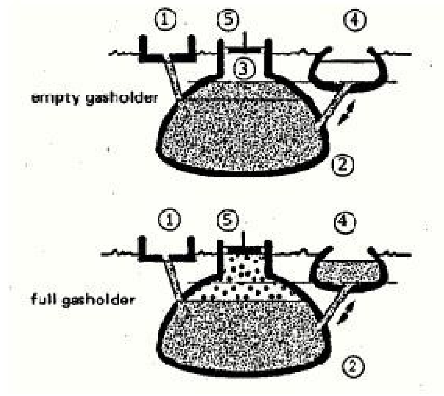

Figure 2: Basic function of a fixed-dome biogas plant, 1 Mixing pit, 2 Digester, 3 Gasholder, 4 Displacement pit, 5 Gas pipe
Source: OEKOTOP

Digester

The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferro-cement exist. Main parameters for the choice of material are:

- Technical suitability (stability, gas- and liquid tightness);
- cost-effectiveness;
- availability in the region and transport costs;
- availability of local skills for working

with the particular building material.

Fixed dome plants produce just as much gas as floating-drum plants, if they are gas-tight. However, utilization of the gas is less effective as the gas pressure fluctuates substantially. Burners and other simple appliances cannot be set in an optimal way. If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gas-holder is necessary.

Gas-Holder

Figure 3: Fixed-dome plant in Tunesia. The final layers of the masonry structure are being fixed.
Photo: gtz/GATE

The top part of a fixed-dome plant (the gas space) must be gas-tight. Concrete, masonry and cement rendering are not gas-tight. The gas space must therefore be painted with a gas-tight layer (e.g. Water-proofer, Latex or synthetic paints). A possibility to reduce the risk of cracking of the gas-holder consists in the construction of a weak-ring in the masonry of the digester. This "ring" is a flexible joint between the lower (water-proof) and the upper (gas-proof) part of the hemispherical structure. It prevents cracks that develop due to the hydrostatic pressure in the lower parts to move into the upper parts of the gas-holder.

Types of fixed-dome plants

Chinese fixed-dome plant is the archetype of all fixed dome plants. Several million have been constructed in China. The digester consists of a cylinder with round bottom and top.

Janata model was the first fixed-dome design in India, as a response to the Chinese fixed dome plant. It is not constructed anymore. The mode of construction lead to cracks in the gasholder - very few of these cracks in the gasholder - very few of these plant had been gas-tight.

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Deenbandhu, the successor of the Janata plant in India, with improved design, was more crack-proof and consumed less building material than the Janata plant. with a hemisphere digester

CAMARTEC model has a simplified structure of a hemispherical dome shell based on a rigid foundation ring only and a calculated joint of fraction, the so-called weak / strong ring. It was developed in the late 80s in Tanzania.

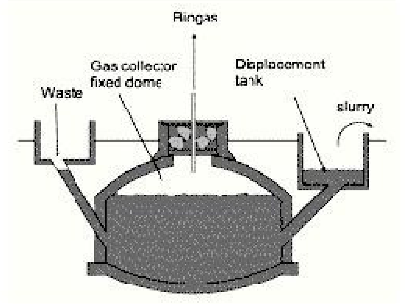
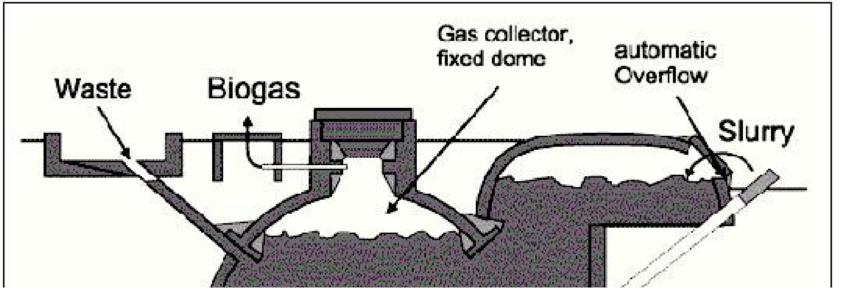


Figure 4: Chinese fixed dome plant
Source: TBW



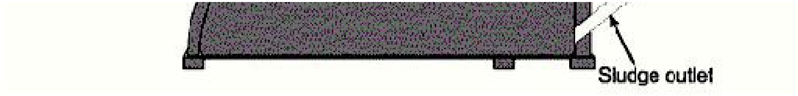


Figure 5: Fixed dome plant CAMARTEC design
Source: TBW

Climate and size

Fixed-dome plants must be covered with earth up to the top of the gas-filled space to counteract the internal pressure (up to 0,15 bar). The earth cover insulation and the option for internal heating makes them suitable for colder climates. Due to economic parameters, the recommended minimum size of a fixed-dome plant is 5 m^3. Digester volumes up to 200 m^3 are known and possible.

> ***Advantages: Low initial costs and long useful life-span; no moving or rusting parts*** involved; basic design is compact, saves space and is well insulated; construction creates local employment.
>
> ***Disadvantages: Masonry gas-holders require special sealants and high technical skills*** for gas-tight construction; gas leaks occur quite frequently; fluctuating gas pressure complicates gas utilization; amount of gas produced is not immediately visible, plant operation not readily understandable; fixed dome plants need exact planning of levels; excavation can be difficult and expensive in bedrock.

Fixed dome plants can be recommended only where construction can be supervised by experienced biogas technicians.

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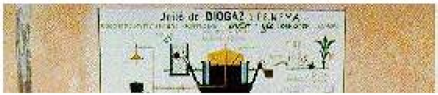
Figure 6: Installation of a Shanghai fixed-dome system near Shanghai, PR China
Photo: L. Sasse

Floating-drum plants

The drum



In the past, floating-drum plants were mainly built in India. A floating-drum plant consists of a cylindrical or dome-

Figure 7: Floating-drum plant in Mauretania
Photo: gtz/GATE

shaped digester and a moving, floating gas-holder, or drum. The gas-holder floats either directly in the fermenting slurry or in a separate water jacket. The drum in which the biogas collects has an internal and/or external guide frame that provides stability and keeps the drum upright. If biogas is produced, the drum moves up, if gas is consumed, the gas-holder sinks back.

Size

Floating-drum plants are used chiefly for digesting animal and human feces on a continuous-feed mode of operation, i.e. with daily input. They are used most frequently by small- to middle-sized farms (digester size: 5-15m ^{3}) or in institutions and larger agro-industrial estates (digester size: 20-100m ^{3}).

> ***Advantages: Floating-drum plants are easy to understand and operate. They provide*** gas at a constant pressure, and the stored gas-volume is immediately recognizable by the position of the drum. Gas-tightness is no problem, provided the gasholder is de-rusted and painted regularly.
>
> ***Disadvantages: The steel drum is relatively expensive and maintenance-intensive.*** Removing rust and painting has to be carried out regularly. The life-time of the drum is short (up to 15 years; in tropical coastal regions about five years). If fibrous substrates are used, the gas-holder shows a tendency to get "stuck" in the resultant floating scum.

Water-jacket floating-drum plants

Water-jacket plants are universally applicable and easy to maintain. The drum cannot get stuck in a scum layer, even if the substrate has a high solids content. Water-jacket plants are characterized by a long useful life and a more aesthetic appearance (no dirty gas-holder). Due to their superior sealing of the substrate (hygiene!), they are recommended for use in the fermentation of night soil. The extra cost of the masonry water jacket is relatively modest.

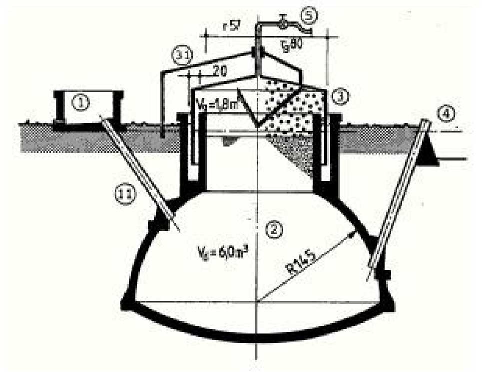


Figure 8: Water-jacket plant with external guide frame. 1 Mixing pit, 11 Fill pipe, 2 Digester, 3 Gasholder, 31 Guide frame, 4 Slurr y store, 5 Gas pipe
Source: Sasse, 1984

Material of digester and drum

The digester is usually made of brick, concrete or quarry-stone masonry with plaster. The gas drum normally consists of 2.5 mm steel sheets for the sides and 2 mm sheets for the top.
It has welded-in braces which break up surface scum when the drum rotates. The drum must be protected against corrosion. Suitable coating products are oil paints, synthetic paints and bitumen paints. Correct priming is important. There must be at least two preliminary coats and one topcoat. Coatings of used oil are cheap. They must be renewed monthly. Plastic

sheeting stuck to bitumen sealant has not given good results. In coastal regions, repainting is necessary at least once a year, and in dry uplands at least every other year. Gas production will be higher if the drum is painted black or red rather than blue or white, because the digester temperature is increased by solar radiation. Gas drums made of 2 cm wire-mesh-reinforced concrete or fiber-cement must receive a gas-tight internal coating. The gas drum should have a slightly sloping roof, otherwise rainwater will be trapped on it, leading to rust damage. An excessively steep-pitched roof is unnecessarily expensive and the gas in the tip cannot be used because when the drum is resting on the bottom, the gas is no longer under pressure.

Floating-drums made of glass-fiber reinforced plastic and high-density polyethylene have been used successfully, but the construction costs are higher compared to using steel. Floating-drums made of wire-mesh-reinforced concrete are liable to hairline cracking and are intrinsically porous. They require a gas-tight, elastic internal coating. PVC drums are unsuitable because they are not resistant to UV.

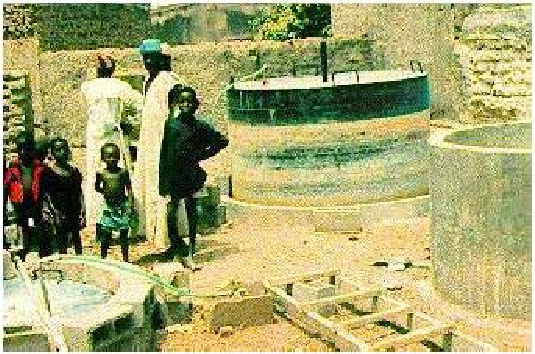


Figure 9: Floating-drum plant in Burkina Faso
Photo: gtz/GATE

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Guide frame

The side wall of the gas drum should be just as high as the wall above the support ledge. The floating-drum must not touch the outer walls. It must not tilt, otherwise the coating will be damaged or it will get stuck. For this reason, a floating-drum always requires a guide. This guide frame must be designed in a way that allows the gas drum to be removed for repair. The drum can only be removed if air can flow into it, either by opening the gas outlet or by emptying the water jacket.

The floating gas drum can be replaced by a balloon above the digester. This reduces construction costs but in practice problems always arise with the attachment of the balloon to the digester and with the high susceptibility to physical damage.

Types of floating-drum plants

There are different types of floating-drum plants (see drawings under Construction):

- KVIC model with a cylindrical digester, the oldest and most widespread floating drum biogas plant from India.
- Pragati model with a hemisphere digester
- Ganesh model made of angular steel and plastic foil
- floating-drum plant made of pre-fabricated reinforced concrete compound units
- floating-drum plant made of fibre-glass reinforced polyester
- BORDA model: The BORDA-plant combines the static advantages of hemispherical digester with the process-stability of the floating-drum and the longer life span of a water jacket plant.

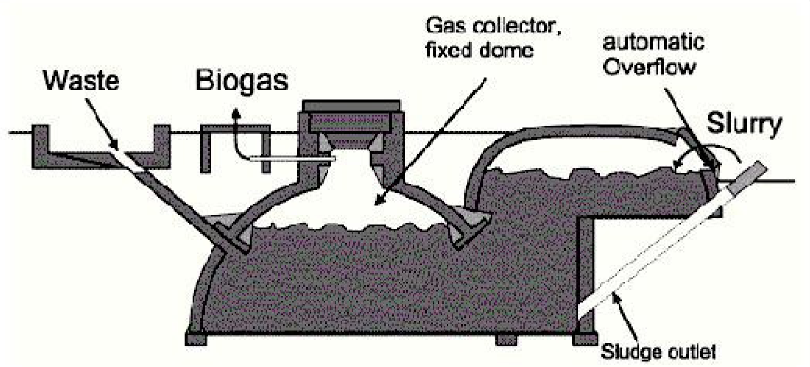

Figure 10: Fixed dome plant CAMARTEC design
Source: TBW

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Biogas Plant Types and Design

Digester types in industrialized countries

To give an overview, we have chosen three fictitious designs as they could be found in, for example, Europe. The designs are selected in a way that all the typical elements of modern biogas technology appear at least once. All designs are above-ground, which is common in Europe. Underground structures, however, do exist.

Figure 11: Control glasses for an industrial digester for solid organic waste, TBW, Germany

Mixing pit varies in size and shape according to the nature of substrate. It is equipped with propellers for mixing and/or chopping the substrate and often with a pump to transport the substrate into the digester. At times, the substrate is also pre-heated in the mixing pit in order to avoid a temperature shock inside the digester.

Fermenter or digester is insulated and made of concrete or steel. To optimize the flow of substrate, large digesters have a longish channel form. Large digesters are almost always agitated by slow rotating paddles or rotors or by injected biogas. Co-fermenters have two or more separated fermenters. The gas can be collected inside the digester, then usually with a flexible cover. The digester can also be filled completely and the gas stored in a separate gas-holder.

Gas-holder is usually of flexible material, therefore to be protected against weather. It can be placed either directly above the substrate, then it acts like a balloon plant, or in a separate gas-bag.

slurry store for storage of slurry during winter. The store can be open (like conventional open liquid manure storage) or closed and connected to the gas-holder to capture remaining gas production. Normally, the store is not heated and only agitated before the slurry is spread on the field.

Gas use element is in Europe in 95% of the cases a thermo-power unit which produces electricity for the farm, the grid and heat for the house, greenhouses and other uses. The thermo-power unit has the advantage, that the required energy can be produced in any mixture of gas and fossil energy. It can, therefore, react to periods of low gas production and high energy requirements or vice versa.

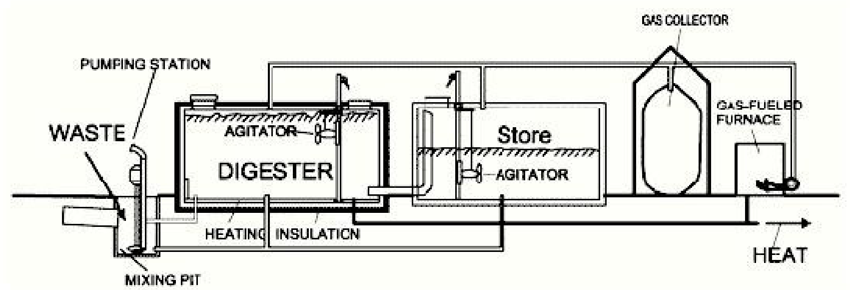


Figure 12: Concrete digester with two chambers (one heated, one unheated for storage)
Source: TBW

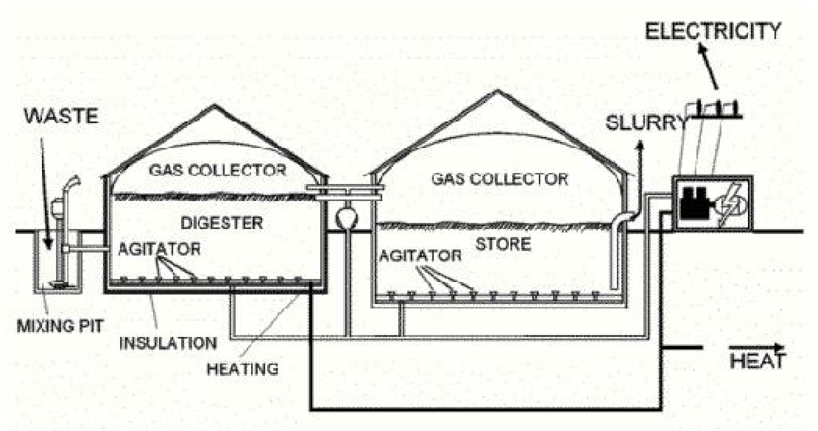
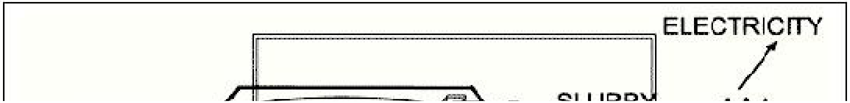


Figure 13: Concrete digester with integrated plastic gas-holder
Photo: TBW



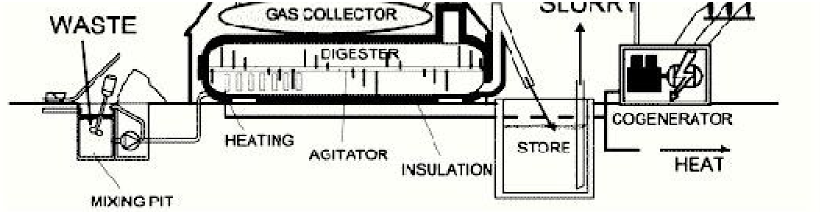


Figure 14: Steelvessel fermenter with seperate ballon gas-holder
Photo: TBW

Selection of appropriate design

In developing countries, the design selection is determined largely be the prevailing design in the region, which, in turn takes the climatic, economic and substrate specific conditions into consideration. Large plants are designed on a case-to-case basis.

Typical design criteria are:

Space: determines mainly the decision if the fermenter is above-ground or underground, if it is to be constructed as an upright cylinder or as a horizontal plant.

Existing structures may be used like a liquid manure tank, an empty hall or a steel container. To reduce costs, the planner may need to adjust the design to theses existing structures.

Minimizing costs can be an important design parameter, especially when the monetary benefits are expected to be low. In this case a flexible cover of the digester is usually the cheapest solution. Minimizing costs is often opposed to maximizing gas yield.

Available substrate determines not only the size and shape of mixing pit but the digester volume (retention time!), the heating and agitation devices. Agitation through gas injection is

only feasible with homogenous substrate and a dry matter content below 5%. Mechanical agitation becomes problematic above 10% dry matter.

Ballon plants

A balloon plant consists of a heat-sealed plastic or rubber bag (balloon), combining digester and gas-holder. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon. Gas pressure can be increased by placing weights on the balloon. If the gas pressure exceeds a limit that the balloon can withstand, it may damage the skin. Therefore, safety valves are required. If higher gas pressures are needed, a gas pump is required. Since the material has to be weather- and UV resistant, specially stabilized, reinforced plastic or synthetic caoutchouc is given preference. Other materials which have been used successfully include RMP (red mud plastic), Trevira and butyl. The useful life-span does usually not exceed 2-5 years.

> ***Advantages: Standardized prefabrication at low cost; shallow installation suitable for*** use in areas with a high groundwater table; high digester temperatures in warm climates; uncomplicated cleaning, emptying and maintenance; difficult substrates like water hyacinths can be used.

> ***Disadvantages: Low gas pressure may require gas pumps; scum cannot be removed*** during operation; the plastic balloon has a relatively short useful life-span and is susceptible to mechanical damage and usually not available locally. In addition, local craftsmen are rarely in a position to repair a damaged balloon.

Balloon biogas plants are recommended, if local repair is or can be made possible and the cost advantage is substantial.

Horizontal plants

Horizontal biogas plants are usually chosen when shallow installation is called for (groundwater, rock). They are made of masonry or concrete.

Advantages: Shallow construction despite large slurry space.

Disadvantages: Problems with gas-space leakage, difficult elimination of scum.

Earth-pit plants

Masonry digesters are not necessary in stable soil (e.g. laterite). It is sufficient to line the pit with a thin layer of cement (wire-mesh fixed to the pit wall and plastered) in order to prevent seepage. The edge of the pit is reinforced with a ring of masonry that also serves as anchorage for the gas-holder. The gas-holder can be made of metal or plastic sheeting. If plastic sheeting is used, it must be attached to a quadratic wooden frame that extends down into the slurry and is anchored in place to counter its buoyancy. The requisite gas pressure is achieved by placing weights on the gas-holder. An overflow point in the peripheral wall serves as the slurry outlet.

Advantages: Low cost of installation (as little as 20% of a floating-drum plant); high potential for self help approaches.

Disadvantages: Short useful life; serviceable only in suitable, impermeable types of soil.

Earth-pit plants can only be recommended for installation in impermeable soil located above the groundwater table. Their construction is particularly inexpensive in connection with plastic sheet gas-holders.

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Ferrocement plants

The ferro-cement type of construction can be applied either as a self-supporting shell or an earth-pit lining. The vessel is usually cylindrical. Very small plants (Volume under 6 m^3) can be prefabricated. As in the case of a fixed-dome plant, the ferrocement gasholder requires special sealing measures (proven reliability with cemented-on aluminium foil).

> ***Advantages: Low cost of construction, especially in comparison with potentially high*** cost of masonry for alternative plants; mass production possible; low material input.
>
> ***Disadvantages: Substantial consumption of essentially good-quality cement;*** workmanship must meet high quality standards; uses substantial amounts of expensive wire mesh; construction technique not yet adequately time-tested; special sealing measures for the gas-holder are necessary.

Ferro-cement biogas plants are only recommended in cases where special ferro-cement know-how is available.

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Parts of Biogas Plants

Influent collecting tank

Size and homogenization

Fresh substrate is usually gathered in an influent collecting tank prior to being fed into the digester. Depending on the type of system, the tank should hold one to two days substrate. An influent collecting tank can also be used to homogenize the various substrates and to set up the required consistency, e.g. by adding water to dilute the mixture of vegetable solids (straw, grass, etc.), or by adding more solids in order to increase the bio-mass. The fibrous material is raked off the surface, if necessary, and any stones or sand settling at the bottom are cleaned out after the slurry is admitted to the digester. The desired degree of homogenization and solids content can be achieved with the aid of an agitator, pump or chopper. A rock or wooden plug can be used to close off the inlet pipe during the mixing process.

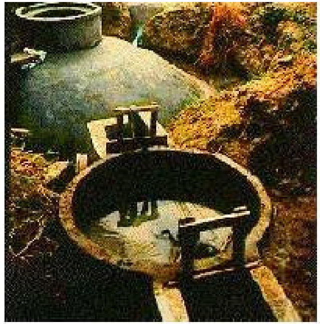

Figure 15: Installation of a fixed-dome plant in Thailand: The influent collecting tank is in front of the photo, the digester and the outlet are located behind it.
Photo: Kossmann (gtz/GATE

Location

A sunny location can help to warm the contents before they are fed into the digester in order to avoid thermal shock due to the cold mixing water. In the case of a biogas plant that is directly connected to the stable, it is advisable to install the mixing pit deep enough to allow installation of a floating gutter leading directly into the pit. Care must also be taken to ensure that the low position of the mixing pit does not result in premature digestion. For reasons of hygiene, toilets should have a direct connection to the inlet pipe.

Inlet and outlet

Size and material

The inlet (feed) and outlet (discharge) pipes lead straight into the digester at a steep angle. For liquid substrate, the pipe diameter should be 10-15 cm, while fibrous substrate requires a diameter of 20-30 cm. The inlet and the outlet pipe mostly consist of plastic or concrete.

Position of inlet and outlet

Both the inlet and the outlet pipe must be freely accessible and straight, so that a rod can be pushed through to eliminate obstructions and agitate the digester contents. The pipes should penetrate the digester wall at a point below the lowest slurry level (i.e. not through the gas storage). The points of penetration should be sealed and reinforced with mortar.

The inlet pipe ends higher in the digester than the outlet pipe in order to promote more uniform flow of the substrate. In a fixed-dome plant, the inlet pipe defines the bottom line of the gas-holder, acting like a security valve to release over-pressure. In a floating-drum plant, the end of the outlet pipe determines the digesters (constant) slurry level.

Inlet and outlet pipe must be placed in connection with brick-laying. It is not advisable to break holes into the spherical shell afterwards, this would weaken the masonry structure.

Digester

Requirements

No matter which design is chosen, the digester (fermentation tank) must meet the following requirements:

Water/gastightness - watertightness in order to prevent seepage and the resultant threat to soil and groundwater quality; gastightness in order to ensure proper containment of the entire biogas yield and to prevent air entering into the digester (which could result in the formation of an explosive mixture).

Insulation - if and to which extent depends on the required process temperature, the local climate and the financial means; heat loss should be minimized if outside temperatures are low, warming up of the digester should be facilitated when outside temperatures are high

- Minimum surface area - keeps cost of construction to a minimum and reduces heat losses through the vessel walls. A spherical structure has the best ratio of volume and surface area. For practical construction, a hemispherical construction with a conical floor is close to the optimum.
- Structural stability - sufficient to withstand all static and dynamic loads, durable and resistant to corrosion.

Internal and external forces

Two relevant forces act on the digester. The external active earth pressure causes compressive forces within the masonry. The internal hydrostatic and gas pressures causes tensile stress in the masonry. Thus, the external pressure applied by the surrounding earth must be greater at all points than the internal forces. Round and spherical shapes are able to accept the highest forces and distribute them uniformly. Edges and corners lead to peak tensile stresses which can result in cracking.

Shapes of digesters

From the standpoint of fluid dynamics and structural strength, an egg-shaped vessel is about the best possible solution. This type of construction, however, is comparatively expensive, so that its use is usually restricted to large-scale sewage treatment plants. The Chinese fixed-dome designs are of similar shape, but less expensive. The hemispherical CAMARTEC design is optimized in structural strength, but does not make optimal use of the excavation required.

Simplified versions of such digester designs include cylinders with conical covers and bottoms. They are much easier to build and are sometimes available on the market as prefabricated units. Their disadvantage lies in their less favorable surface-volume ratio. The cylinder should have a height equal to its diameter. Prone cylinders have become quite popular on farms, since they are frequently the more favorable solution for small-scale bio-methanation. Cuboid digesters are often employed in batch-fed systems used primarily for fermenting solid material, so that fluid dynamics are of little interest.

Building material of digester

Digesters can be made from any of the following materials:

Steel vessels

Steel vessels are inherently gas-tight, have good tensile strength, and are relatively easy to construct (by welding). In many cases, a discarded steel vessel of appropriate shape and size can be salvaged for use as a biogas digester. Susceptibility to corrosion both outside (atmospheric humidity) and inside (aggressive media) can be a severe problem. As a rule, some type of anticorrosive coating must be applied and checked at regular intervals. Steel vessels are only cost-effective, if second-hand vessels (e.g. train or truck tankers) can be used.

Figure 16: Construction of the digester neck with steel reinforcement
Photo: Krmer (TBW)

Concrete vessels

Concrete vessels have gained widespread acceptance in recent years. The requisite gas-tightness necessitates careful construction and the use of gas-tight coatings, linings and/or seal strips in order to prevent gas leakage. Most common are stress cracks at the joints of the top and the sides. The prime advantage of concrete vessels are their practically unlimited useful life and their relatively inexpensive construction. This is especially true for large digesters in industrialized countries.

Masonry

Masonry is the most frequent construction method for small scale digesters. Only well-burnt clay bricks, high quality, pre-cast concrete blocks or stone blocks should be used in the construction of digesters. Cement-plastered/rendered masonry is a suitable - and inexpensive - approach for building an underground biogas digester, whereby a dome-like shape is recommended. For domes larger than 20 m^3 digester volume, steel reinforcement is advisable. Masons who are to build masonry digesters have to undergo specific training and, initially, require close supervision.

Figure 17: Construction of the dome for a 30 m^3 digester in Cuba

Photo: Krmer (TBW)

Plastics

Plastics have been in widespread use in the field of biogas engineering for a long time. Basic differentiation is made between flexible materials (sheeting) and rigid materials (PE, GRP, etc.). Diverse types of plastic sheeting can be used for constructing the entire digesting chamber (balloon gas holders) or as a vessel cover in the form of a gas-tight "bonnet".

Sheeting made of caoutchouc (india rubber), PVC, and PE of various thickness and description have been tried out in numerous systems. The durability of plastic materials exposed to aggressive slurry, mechanical stress and UV radiation, as well as their gas permeability, vary from material to material and on the production processes employed in their manufacture. Glass-fibre reinforced plastic (GRP) digesters have proven quite suitable, as long as the in-service static stresses are accounted for in the manufacturing process. GRP vessels display good gas-tightness and corrosion resistance. They are easy to repair and have a long useful life span. The use of sandwich material (GRP - foam insulation - GRP) minimizes the on-site insulating work and reduces the cost of transportation and erection.

Wood

A further suitable material for use in the construction of biogas systems is wood. It is often used for building liquid-manure hoppers and spreaders. Wooden digesters require a vapor-proof membrane to protect the insulation. Closed vessels of any appreciable size are very hard to render gas-tight without the aid of plastic sheeting. Consequently, such digesters are very rare.

Gasholders

Basically, there are different designs of construction for gasholders used

Basically, there are different designs of construction for gasholders used in simple biogas plants:

- floating-drum gasholders
- fixe-domes gasholders
- plastic gasholders
- separate gasholders

Floating-drum gasholders

Most floating-drum gas-holders are made of 2-4 mm thick sheet steel, with the sides made of thicker material than the top in order to compensate for the higher degree of corrosive attack. Structural stability is provided by L-bar bracing that also serves to break up surface scum when the drum is rotated. A guide frame stabilizes the gas drum and prevents it from tilting and rubbing against the masonry. The two equally suitable and most frequently used types are:

- an internal rod & pipe guide with a fixed (concrete-embedded) cross pole (an advantageous configuration in connection with an internal gas outlet);
- external guide frame supported on three wooden or steel legs.

For either design, substantial force can be necessary to rotate the drum, especially if it is stuck in a heavy layer of floating scum. Any gas-holder with a volume exceeding 5 m^3 should be equipped with a double guide (internal and external).

All grades of steel normally used for gas-holders are susceptible to moisture-induced rusting both in- and outside. Consequently, a long service life requires proper surface protection, including:

- thorough de-rusting and de-soiling
- primer coat of minimum 2 layers
- 2 or 3 cover coats of plastic or bituminous paint.

The cover coats should be reapplied annually. A well-kept metal gas-holder can be expected to last between 3 and 5 years in humid, salty air or 8-12 years to last between 3 and 5 years in humid, salty air or 8-12 years in a dry climate.

Materials regarded as suitable alternatives to standard grades of steel are galvanized sheet metal, plastics (glass-fiber reinforced plastic (GRP), plastic sheeting) and ferro-cement with a gas-tight lining. The gas-holders of water-jacket plants have a longer average service life, particularly when a film of used oil is poured on the water seal to provide impregnation.

Fixed-dome gasholders

A fixed-dome gas-holder can be either the upper part of a hemispherical digester (CAMARTEC design) or a conical top of a cylindrical digester (e.g. Chinese fixed-dome plant). In a fixed-dome plant the gas collecting in the upper part of the dome displaces a corresponding volume of digested slurry. The following aspects must be considered with regard to design and operation:

An overflow into and out of the compensation tank must be provided to avoid over-filling of the plant.

The gas outlet must be located about 10 cm higher than the overflow level to avoid plugging up of the gas pipe.

A gas pressure of 1 m WC or more can develop inside the gas space. Consequently, the plant must be covered sufficiently with soil to provide an adequate counter-pressure.

Special care must be taken to properly close the man hole, which may require to weigh down the lid with 100 kg or more. The safest method is to secure the lid with clamps.

The following structural measures are recommended to avoid cracks in the gas-holder:

The foot of the dome (gas-holder) should be stabilized by letting the foundation slab project out enough to allow for an outer ring of mortar.

A rated break/pivot ring should be provided at a point located between 1/2 and 2/3 of the minimum slurry level. This in order to limit the occurrence or propagation of cracks in the vicinity of the dome foot and to displace forces through its stiffening/articulating effect such that tensile forces are reduced around the gas space. Alternatively, the lowest point of the gas-holder should be reinforced by a steel ring or the whole gas-holder be reinforced with chicken mesh wire.

Normally, masonry, mortar and concrete are not gas-tight, with or without mortar additives. Gas-tightness can only be achieved through good, careful workmanship and special coatings. The main precondition is that masonry and plaster are strong and free of cracks. Cracked and sandy rendering must be removed. In most cases, a plant with cracked masonry must be dismantled, because not even the best seal coating can render cracks permanently gas-tight.

Some tried and proven seal coats and plasters:

- multi-layer bitumen, applied cold (hot application poses the danger of injury by burns and smoke-poisoning; solvents cause dangerous/explosive vapors). Two to four thick coats required;
- bitumen with aluminum foil, thin sheets of overlapping aluminum foil applied to the still-sticky bitumen, followed by the next coat of bitumen;
- plastics, e.g. epoxy resin or acrylic paint; very good but expensive;
- paraffin, diluted with 2-5% kerosene, heated up to 100C and applied to the preheated masonry, thus providing an effective (deep) seal. Use kerosene/gas torch to heat masonry.
- multi-layer cement plaster with water-proof elements

In any case, a pressure test must be carried out before the plant is put in service.

Plastic gas-holders

Gas-holders made of plastic sheeting serve as integrated gas-holders, as separate balloon/bag-type gas-holders and as integrated gas-transport/storage

balloon/bag-type gas holders and as integrated gas transport/storage
elements. For plastic

(sheet) gas-holders, the structural details are of less immediate interest than the question of which materials can be used.

Separate gas-holders

Differentiation is made between:

- low-pressure, wet and dry gas-holders (10-50 mbar). Basically, these gas-holders are identical to integrated and/or plastic (sheet) gas-holders. Separate gas-holders cost more and are only worthwhile in case of substantial distances (at least 50-100 m) or to allow repair of a leaky fixed-dome plant. This type of separate gas-holder is also used to buffer extreme differences between gas-production and gas-use patterns.
- medium- or high-pressure gas-holders (8-10 bar / 200 bar)

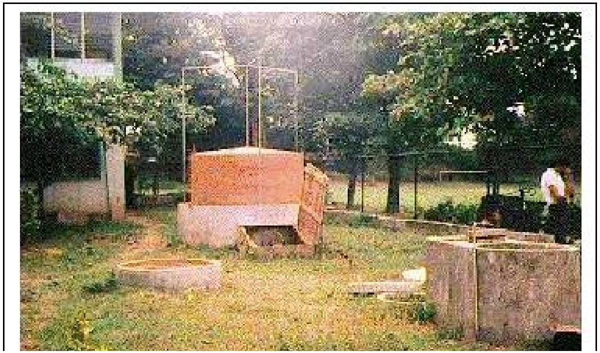

Figure 18: Biogas plant with seperate gasholder in Nicaragua
Photo: gtz/GATE

Neither system can be considered for use in small-scale biogas plants. Even for large-scale plants, they cannot be recommended under the conditions in most developing countries. High-pressure gas storage in steel cylinders (as fuel for vehicles) is presently under discussion. While that approach is possible in theory, it would be complicated and, except in special cases, prohibitively expensive. It would also require the establishment of stringent safety regulations.

Gas pipe, valves and accessories

Biogas piping

At least 60% of all non-functional biogas units are attributable to defect gas piping. Utmost care has to be taken, therefore, for proper installation. For the sake of standardization, it is advisable to select a single size for all pipes, valves and accessories.

The requirements for biogas piping, valves and accessories are essentially the same as for other gas installations. However, biogas is 100% saturated with water vapor and contains hydrogen-sulfide. Consequently, no piping, valves or accessories that contain any amounts of ferrous metals may be used for biogas piping, because they would be destroyed by corrosion within a short time. The gas lines may consist of standard galvanized steel pipes. Also suitable (and inexpensive) is plastic tubing made of rigid PVC or rigid PE. Flexible gas pipes laid in the open must be UV-resistant.

Steel pipes

Galvanized steel water supply pipes are used most frequently, because the entire piping system (gas pipe, valves and accessories) can be made of

Universally applicable

English/U.S. customary system components, i.e. with all dimensions in inches. Pipes with

24

nominal dimensions of 1/2" or 3/4" are adequate for small-to-midsize plants of simple design and pipe lengths of less than 30 m. For larger plants, longer gas pipes or low system pressure, a detailed pressure-loss (pipe-sizing) calculation must be performed.

When installing a gas pipe, special attention must be paid to:

- gas-tight, friction-type joints
- line drainage, i.e. with a water trap at the lowest point of the sloping pipe in **order to empty water accumulation**
- protection against mechanical impact

Stirring facilities

Optimum stirring substantially reduces the retention time. If agitation is excessive, the bacteria have "no time to eat". The ideal is gentle but intensive stirring about every four hours. Of similar importance is the breaking up of a scum layer which has lost contact with the main volume of substrate and is, therefore, not further digested. This top layer can form an impermeable barrier for biogas to move up from the digester to the gas holder.

Figure 19: Stirring device for a european biodigester

As a rule of thumb it can be stated that stirring facilities are more important in larger plants than in small-scale farm plants.

Photo: Krieg

Types of stirring facilities

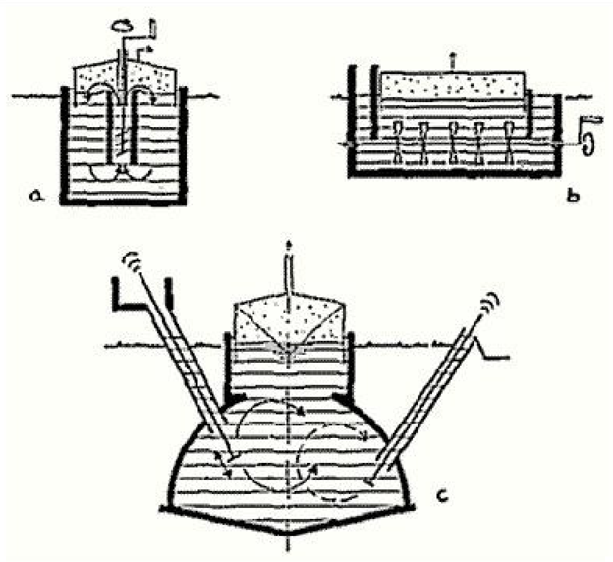

Figure 20: Stirring facilities in the digester
Source: OEKOTOP

a. The impeller stirrer has given good results especially in sewage treatment plants.

b. The horizontal shaft stirs the fermentation channel without mixing up the phases. Both schemes originate from large-scale plant practice.

c. For simple household plants, poking with a ***stick is the simplest and*** safest stirring method.

Optional Parts of Biogas Plants

Heating systems

Normally, because of the rather high involved costs, small-scale biogas plants are built without heating systems. But even for small scale plants, it is of advantage for the bio-methanation process to warm up the influent substrate to its proper process temperature before it is fed into the digester. If possible, cold zones in the digester should be avoided. In the following, a number of different ways to get the required amount of thermal energy into the substrate are described. In principle, one can differentiate between:

- direct heating in the form of steam or hot water, and
- indirect heating via heat exchanger, whereby the heating medium, usually hot water, imparts heat while not mixing with the substrate.

Direct heating

Direct heating with steam has the serious disadvantage of requiring an elaborate steam-generating system (including desalination and ion exchange as water pretreatment) and can also cause local overheating. The high cost is only justifiable for large-scale sewage treatment facilities.

The injection of hot water raises the water content of the slurry and should only be practiced if such dilution is necessary.

Indirect heating

Indirect heating is accomplished with heat exchangers located either inside or outside of the digester, depending on the shape of the vessel, the type of substrate used, and the nature of the operating mode.

4. Floor heating systems have not served well in the past, because the accumulation of sediment gradually hampers the transfer of heat.
5. In-vessel heat exchangers are a good solution from the standpoint of heat transfer as long as they are able to withstand the mechanical stress caused by the mixer, circulating pump, etc. The larger the heat-exchange surface, the more uniformly heat distribution can be effected which is better for the biological process.
6. On-vessel heat exchangers with the heat conductors located in or on the vessel walls are inferior to in-vessel-exchangers as far as heat-transfer efficiency is concerned, since too much heat is lost to the surroundings. On the other hand, practically the entire wall area of the vessel can be used as a heat-transfer surface, and there are no obstructions in the vessel to impede the flow of slurry.
7. Ex-vessel heat exchangers offer the advantage of easy access for cleaning and maintenance.

While in Northern countries, often a substantial amount of the produced biogas is consumed to provide process energy, in countries with higher temperatures and longer sunshine hours, solar-heated water can be a cost-effective solution for heating. Exposing the site of the biogas plant to sunshine, e.g. by avoiding tree shade, is the simplest method of heating.

Pumps

Pumps become necessary parts of a biogas unit, when the amounts of substrate require fast movement and when gravity cannot be used for reasons of topography or substrate characteristics. Pumps transport the substrate from the point of delivery through all the stages of fermentation. Therefore, several pumps and types of pumps may be needed. Pumps are usually found in large scale biogas units.

Types of pump

There are two predominant types of pump for fresh substrate: centrifugal pumps and

positive-displacement pumps (reciprocating pumps). Centrifugal pumps operate on the

principle of a rapidly rotating impeller located in the liquid flow. They provide high delivery rates and are very robust, i.e. the internals are exposed to little mechanical stress. They do, however, require a free-flowing intake arrangement, because they are not self-priming (regenerative).

Data of pumps

Practically all centrifugal pump characteristics are geared to water. They show the delivery rates for various heads, the achievable efficiency levels, and the power requirement for the pump motor. Consequently, such data cannot be directly applied to biogas systems, since the overall performance and efficiency level of a pump for re-circulating slurry may suffer a serious drop-off as compared to its standard "water" rating (roughly 5-10%).

Substrate

Sometimes, namely when the substrate is excessively viscous, a centrifugal pump will no longer do the job, because the condition of the substrate surpasses the pumps physical delivery capacity. In such cases, one must turn to a so-called positive-displacement or reciprocating type of pump in the form of a piston pump, gear pump or eccentric spiral pump, all of which operate on the principle of displacing action to provide positive delivery via one or more enclosed chambers.

Positive displacement pumps

Positive displacement pumps offer multiple advantages. Even for highly viscous substrate, they provide high delivery and high efficiency at a relatively low rate of power consumption. Their characteristics - once again for water - demonstrate how little the delivery rate depends on the delivery head. Consequently, most of the characteristics show the delivery rate as a function

function of pump speed

The main disadvantage as compared to a centrifugal pump is the greater amount of wear and tear on the internal occasioned by the necessity of providing an effective seal between each two adjacent chambers.

Pump delivery lines

Pump delivery lines can be made of steel, PVC (rigid) or PE (rigid or flexible), as well as appropriate flexible pressure tubing made of reinforced plastic or rubber. Solid substrate, e.g. dung, can also be handled via conveyor belt, worm conveyor or sliding-bar system, though none of these could be used for liquid manure. When liquid manure is conducted through an open gutter, small weirs or barrages should be installed at intervals of 20-30 m as a means of breaking up the scum layer.

Each such barrier should cause the scum to fall at least 20-30 cm on the downstream side. All changes of direction should be executed at right angles (90). Depending on the overall length, the cross gutter should be laid some 30-50 cm deeper than the main gutter. Transitions between a rectangular channel and a round pipe must be gradual. An inclination of about 14% yields optimum flow conditions. The channel bottom must be laid level, since any slope in the direction of flow would only cause the liquid manure to run off prematurely. All wall surfaces should be as smooth as possible.

Weak ring

Position of the weak ring

The weak/strong ring improves the gas-tightness of fixed-dome plants. It was first introduced in Tanzania and showed promising results. The weak ring separates the lower part of the hemispherical digester, (filled with digesting substrate), from the upper part (where the gas is stored). Vertical cracks, moving upwards from the bottom of the digester, are diverted in this ring of lean mortar into horizontal cracks. These cracks remain in the slurry area where they are of no harm to the gas-tightness. The strong ring is a reinforcement of the bottom of the gas-holder, it could also be seen as a foundation of the gas-holder. It is an additional device

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to prevent cracks from entering the gas-holder. Weak and strong ring have been successfully combined in the CAMARTEC design.

Figure 21: Construction of the weak/strong ring of a 16 m^3, Tanzania
Photo: Kellner (TBW)

Materials and construction

The weak ring consists of mortar of a mixture of sand, lime and cement (15:3:1). The top of the weak ring restores the horizontal level. It is interrupted only by the inlet pipe passing through. The strong ring rests on the weak ring and is the first layer of the upper part of the hemispherical shell. It consists of a row of header bricks with a concrete package at the outside. In case of soft or uncertain ground soil one may place a ring reinforcement bar in the concrete of the strong ring. The brick of the strong ring should be about three times wider than the brickwork of the upper wall. A detailed description of the weak/strong ring construction can be found in Sasse, Kellner, Kimaro.

Further reading:

Ringkamp, M.; Tentscher, W.; Schiller, H.: Preliminary results on: statical optimization of family-sized fixed-dome digesters. Tilche, A.; Rozzi, A. (ed.): Poster Papers. Fifth International Symposium on Anaerobic Digestion, Bologna 1988, pp. 321-324

Sasse, L.; Kellner, Ch.; Kimaro, A.: Improved Biogas Unit for Developing Countries. Deutsche Gesellschaft fr Technische Zusammenarbeit (GTZ) GmbH, Vieweg & Sohn Verlagsgesellschaft Braunschweig, 1991

Balancing Biogas Production and Energy Demand

Determining the biogas production

The quantity, quality and type of biomass available for use in the biogas plant constitutes the basic factor of biogas generation. The biogas incidence can and should also be calculated according to different methods applied in parallel.

- Measuring the biomass availability
- Determining the biomass supply via pertinent-literature data
- Determining the biomass supply via regional reference data
- Determining biomass supply via user survey

It should be kept in mind that the various methods of calculation can yield quite disparate results that not only require averaging by the planner, but which are also subject to seasonal variation.

The biomass supply should be divided into two categories:

8. quick and easy to procure
9. procurement difficult, involving a substantial amount of extra work

Measuring the biomass availability (quantities of excrement and green substrate)

This is a time-consuming, cumbersome approach, but it is also a necessary means of adapting values from pertinent literature to unknown regions. The method is rather inaccurate if no total-solids measuring is included. Direct measurement can only provide indication of seasonal or fodder-related variance if sufficiently long series of measurements

are
conducted.

Determining the biomass supply via literature data

According to this method, the biomass supply can be determined at once on the basis of the livestock inventory. Data concerning how much manure is produced by different species and per liveweight of the livestock unit are preferable.

Dung yield = liveweight number of animals specific quantity of excrements [kg/d]

Often, specific quantities of excrement are given in % of liveweight per day, in the form of moist mass, total solids content or volatile solids content

Determining the biomass supply via regional reference data

This approach leads to relatively accurate information, as long as other biogas plants are already in operation within the area in question.

Determining biomass availability via user survey

This approach is necessary if green matter is to be included as substrate.

Determining the energy demand

The energy demand of any given farm is equal to the sum of all present and future consumption situations, i.e. cooking, lighting, cooling, power generation etc. The following table helps to collect all data concerning the energy demand.

Table 1: Outline for determining biogas demand		
Energy consumers Data		**Biogas demand [l/d]**
1. Gas for cooking Number of persons Number of meals Present energy consumption Present source of energy Gas demand per person and meal Gas demand per meal Anticipated gas demand Specific consumption rate of burner Number of burners Duration of burner operation Anticipated gas demand **Total anticipated cooking-gas demand**		

demand		
2. Lighting Specific gas consumption per lamp Number of lamps Duration of lamp operation Gas demand		
3. Cooling Specific gas consumption * 24 hours		
4. Engines Specific gas consumption per kWh Engine output Operating time Gas demand		
5. Miscellaneous consumers Gas demand		
Anticipated increase in consumption (%)		
Total biogas demand 1st-priority consumers 2nd-priority consumers 3rd-priority consumers		

consumers

30

The following alternative modes of calculation are useful:

Determining biogas demand on the basis of present energy consumption, e.g. for ascertaining the cooking-energy demand. This involves either measuring or inquiring the present rate of energy consumption in the form of wood, charcoal, kerosene and bottled gas.

Calculating biogas demand via comparable-use data: Such data may consist of

- empirical values from neighboring systems, e.g. biogas consumption per person and day,
- reference data taken from literature, although this approach involves considerable uncertainty, since cooking-energy consumption depends on local cooking and eating habits and can therefore differ substantially from case to case.

Estimating biogas demand by way of appliance consumption data and assumed periods of use: This approach can only work to the extent that the appliances to be used are known in advance, e.g. a biogas lamp with a specific gas consumption of 120 l/h and a planned operating period of 3 h/d, resulting in a gas demand of 360 l/d.

Then, the interested partys energy demand should be tabulated in the form of a requirements list. In that connection, it is important to attach relative priority values to the various consumers, e.g.:

1. priority: applies only when the biogas plant will cover the demand.
2. priority: coverage is desirable, since it would promote plant usage.
3. priority: excess biogas can be put to these uses.

Biogas Planning Guide

This guide to planning is intended to serve agricultural extension officers as a comprehensive tool for arriving at decisions concerning the suitability of locations for family-sized biogas plants. The detailed planning outline has a data column for entering the gathered information and a rating column for noting the results of evaluation.

Evaluation criteria are:

+ Siting condition are favorable

o Siting condition are unfavorable, but

a) compensable by project activities

b) not serious enough to cause ultimate failure

- Siting condition are not satisfactory

Despite its detailed nature, this planning guide is only a framework within which the extension officer should proceed to conduct a careful investigation and give due consideration, however subjectively, to the individual conditions in order to arrive at a locally practical solution. By no means is this planning guide intended to relieve the agricultural extension officer of the responsibility to thoroughly familiarize himself with the on-the-spot situation and to judge the overall value of a given location on the basis of the knowledge thus gained.

Detailed planning guide for biogas plants

0. Initial situation	Data	Rating
Addresses/project characterization Plant acronym: Address of operator/customer: Place/region/country: Indigenous proj. org./executing org.: Extension officer/advisor: **General user data** Household structure and number of persons: Users economic situation: Crops: types, areas, manner of cultivation: Non-agricultural activity: Household/farm income: Cultural and social characteristics of user: **Problems leading to the "biogas approach"** Energy-supply bottlenecks: Workload for prior source of energy: Poor soil structure/yields: Erosion/deforestation: Poor hygiene and other factors: **Objectives of the measure "biogas plant"** User interests: Project		

Other interests:			

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1. Natural / Agricultural conditions	Data	Rating
Natural conditions Mean annual temperature: Seasonal fluctuations: Diurnal variation: Rating:		- o +
Subsoil Type of soil: Groundwater table, potable water catchment area: Rating:		- o +
Water conditions Climatic zone: Annual precipitation: Dry season (months): Distance to source of water: Rating:		- o +
Livestock inventory (useful for biogas production) Animals: kind and quantity: Type of stable: Use of dung: Persons		

Persons responsible for animals: Rating:		- o +
Vegetable waste (useful for biogas production) Types and quantities: Prior use: Rating:		- o +
Fertilization Customary types and quantities of fertilizer/areas fertilized: Organic fertilizer familiar/in use: Rating:		- o +
Potential sites for biogas plant Combined stable/biogas plant possible: Distance between biogas plant and livestock stable: Distance between biogas plant and place of gas consumption: Rating:		- o +
Overall rating 1		- o +
2. Balancing the energy demand with the biogas production	Data	Rating
Prior		

energy supply Uses, source of energy,		

consumption:		
Anticipated biogas demand (kwh/day or l/d)		
for cooking:		
for lighting:		
for cooling:		
for engines:		
Total gas demand		
a) percentage that must be provided by the biogas plant:		
b) desired demand coverage:		
Available biomass (kg/d) and potential gas production (l/d)		
from animal husbandry		
pigs:		
poultry:		
cattle:		

cattle:

Night soil

Vegetable waste (quantities and potential gas yield)

1.

2.

Totals: biomass and potential gas production

a) easy to procure:

b) less easy to procure:

Balancing

Gas production clearly greater than gas demand
-> positive rating (+)

Gas demand larger than gas production
-> negative rating (-); but review of results in order regarding:

a) possible reduction of gas demand by the following measures
->

b) possible increase in biogas production by the following measures
->

If the measures take hold:
-> qualified positive rating

for the plant location (o)		

If the measures do not take hold: -> site rating remains negative (-)		
Overall rating 2		**- o +**
3. Plant Design and Construction	Data	Rating
Selection of plant design Locally customary type of plant: Arguments in favor of floating-drum plant: Arguments in favor of fixe-dome plant: Arguments in favor of other plant(s): Type of plant chosen: **Selection of site** **Availability of building materials** Bricks/blocks/stone: Cement: Metal: Sand: Piping/fittings: Miscellaneous:		

Miscellaneous: **Availability of gas appliances** Cookers: Lamps:		
Overall rating 3		**- o +**
4. Plant operation / maintenance / repair	Data	Rating
Assessment of plant operation Incidental work: Work expenditure in h: Persons responsible: Rating with regard to anticipated implementation:		**- o +**
Plant maintenance Maintenance-intensive components: Maintenance work by user: Maintenance work by external assistance: Rating with regard too anticipated implementation:		**- o +**
Plant repair Components liable to need repair: Repairs that can be made by the user: Repairs requiring external		

assistance:		- o +

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Requisite materials and spare parts: Rating with regard to expected repair services:		
Overall rating 4		**- o +**
5. Economic analysis	Data	Rating
Time-expenditure accounting Time saved with biogas plant Time lost due to biogas plant Rating:		**- o +**
Microeconomic analysis Initial investment: Cost of operation/maintenance/repair: Return on investment: energy, fertilizer, otherwise: Payback time (static): Productiveness (static): Rating:		**- o +**
Quality factors, useful socioeconomic effects and		

and costs Useful effects: hygiene, autonomous energy, better lighting, better working conditions, prestige: Drawbacks: need to handle night soil, negative social impact: Rating:		**- o +**
Overall rating 5		**- o +**
6. Social acceptance and potential for dissemination	Data	Rating
Anticipated acceptance Participation in planning and construction Integration into agricultural setting: Integration into household: Sociocultural acceptance: Rating:		**- o +**
Establishing a dissemination strategy Conditions for and chances of the professional-craftsman approach: Conditions for and chances of the self-help oriented approach:		**- o +** **- o +**
General conditions for dissemination		

Project-executing		- o +

organization and its staffing: orgnaizational structure: interest and prior experience in biogas technology: Regional infrastructure for transportation: communication: material procurement: Craftsman involvement, i.e. which acitivities: minimum qualifications: tools and machines: Training for engineers, craftsman and users: Proprietary capital, subsidy/credit requirement on the part of user: craftsmen: Rating:		
Overall rating 6		- o +
7. Summarization		
Siting conditions	No.	Rating
Natural/agricultural	1	

conditions	1.	- o +
Balancing the energy demand and the biogas production	2.	- o +
Plant design and construction	3.	- o +
Plant operation/maintenance/repa ir	4.	- o +
Economic analysis	5.	- o +
Social acceptance and potential for dissemination 6.		- o +
Overall rating of siting conditions		- o +

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Step-by-Step Planning Checklist for Biogas Plants

The following table 2 gives an overview of all the steps required to build a biogas unit. The order follows a usual time-line. There are steps which can be combined. However, to skip any of them might lead to future problems.

Customer	Contractor
	organizes advertisement, awareness creation
hears about biogas, develops interest, gets in contact with the contractor	
	gives first overview over costs
	writes letter to the customer
writes a request	
	starts file
	makes a side visit, including: discussion and calculations
	makes a quantity survey,
	does object planning
	writes invoice explains warranty performances
	organizes

makes first payment	organizes a contract customer and constructor
(50%)	hands over a list of building material to be delivered by the customer
prepares the material he agreed to deliver	sign
	organizes material delivery, reference line, main construction work, finishing, landscaping, slurry component, piping.
starts to fill the plant second payment (50%)	
	finishes piping installation of gas consumption accessories
discusses handing over	
makes an agreement on co-operation regarding fertiliser utilisation	
	makes a follow up on fertiliser utilisation
	does customer monitoring
	conducts technical and agricultural service visits

Sizing a biogas plant

The size of the biogas plant depends on the quantity, quality and kind of available biomass and on the digesting temperature. The following points should be considered

Sizing the digester

The size of the digester, i.e. the digester volume Vd, is determined on the basis of the chosen retention time RT and the daily substrate input quantity Sd.

$$\mathbf{Vd = Sd\ RT\ [\ m}^3 = m^3/\text{day number of days}\ ]$$

The retention time, in turn, is determined by the chosen/given digesting temperature. For an unheated biogas plant, the temperature prevailing in the digester can be assumed as 1-2 Kelvin above the soil temperature. Seasonal variation must be given due consideration, however, i.e. the digester must be sized for the least favorable season of the year. For a plant of simple design, the retention time should amount to at least 40 days. Practical experience shows that retention times of 60-80 days, or even 100 days or more, are no rarity when there is a shortage of substrate. On the other hand, extra-long retention times can increase the gas yield by as much as 40%.

The substrate input depends on how much water has to be added to the substrate in order to arrive at a solids content of 4-8%.

$$\text{Substrate input (Sd)} = \text{biomass (B)} + \text{water (W)}\ [m^3/d]$$

In most agricultural biogas plants, the mixing ratio for dung (cattle and / or pigs) and water (B:W) amounts to between 1:3 and 2:1.

Calculating the daily gas production G

The amount of biogas generated each day G [m^3gas/d], is calculated on the basis of the *specific gas yield Gy of the substrate and the daily substrate input Sd.*

The calculation can be based on:

10. The volatile solids content VS

    G = VS Gy(solids) [m ^{3}/d = kg m ^{3}/(dkg)]

11. the weight of the moist mass B

    G = B Gy(moist mass) [m ^{3}/d = kg m ^{3}/(dkg)]

12. standard gas-yield values per livestock unit LSU

    G = number of LSU Gy(species) [m ^{3}/d = number m ^{3}/(dnumber)]

The temperature dependency is given by:

Gy(T,RT) = mGy f(T,RT)

where

Gy(T,RT) = gas yield as a function of digester temperature and retention time
mGy = average specific gas yield, e.g. l/kg volatile solids content
f(T,RT) = multiplier for the gas yield as a function of digester temperature T and *retention time RT*

As a rule, it is advisable to calculate according to several different methods, since the available basic data are usually very imprecise, so that a higher degree of sizing certainty can be achieved by comparing and averaging the results.

Establishing the plant parameters

The degree of safe-sizing certainty can be increased by defining a number of plant parameters:

Specific gas production Gp

i.e. the daily gas generation rate per m^3 digester volume Vd, is calculated according to the following equation

Gp = G Vd [(m ^{3}/d) / m^3]

Digester loading Ld

The digester loading Ld is calculated from the daily total solids input TS/d or the daily volatile *solids input VS/d and the digester volume Vd:*

$\mathbf{Ld_T}$= TS/d Vd [kg/(m^3d)]
$\mathbf{Ld_V}$= VS/d Vd [kg/(m^3d)]

Then, a calculated parameter should be checked against data from comparable plants in the region or from pertinent literature.

Sizing the gasholder

The size of the gasholder, i.e. the gasholder volume Vg, depends on the relative rates of gas generation and gas consumption. The gasholder must be designed to:

cover the peak consumption rate gc_{max} (->Vg_1) and

hold the gas produced during the longest zero-consumption period tz_{max} (->Vg_2)

$\mathbf{Vg_1}$= $gc_{max} tc_{max}$= vc_{max}

$\mathbf{Vg_2}$= $G_h tz_{max}$

...

with

gc_{max}= maximum hourly gas consumption [m^3/h]

tc_{max}= time of maximum consumption [h]

vc_{max}= maximum gas consumption [m^3]

G_h= hourly gas production [m^3/h] = G 24 h/d

tz_{max}= maximum zero-consumption time [h]

The larger Vg-value (Vg_1 or Vg_2) determines the size of the gasholder. A safety margin of 10-20% should be added:

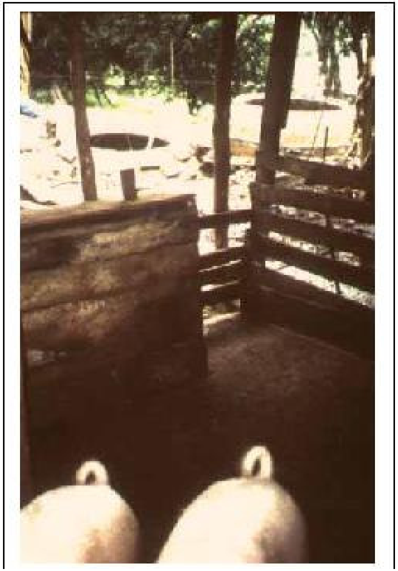
$$\mathbf{Vg = 1.15\ (0.5)\ max(Vg_1, Vg_2)}$$

Practical experience shows that 40-60% of the daily gas production normally has to be stored.

The ratio Vd Vg (digester volume gasholder volume) is a major factor with regard to the basic design of the biogas plant. For a typical agricultural biogas plant, the Vd/Vg-ratio amounts to somewhere between 3:1 and 10:1, with 5:1 - 6:1 occuring most frequently.

Siting of the Biogas Unit

Stable



The stable should be built on an elevated position. This makes it possible to use gravity to collect urine and dung for feeding into the biogas plant. An elevated site on the farm also facilitates the distribution of slurry by gravity onto the farm land.

For security reasons, the stable often is situated near the house.

For easy access the feeding trough should be directed towards the area where fodder is grown.

The milking place has to be at the higher end of the sloping stable floor. The milking should take place under clean conditions, away from the dung alley.

roofed. If it is totally roofed, sun should still enter and ventilation should be assured.

The position of the stable should allow for later extension.

The animals need constant access to clean and fresh water and feeds.

If the present position of the stable is unsuitable as a place for the biogas unit, it is usually better to shift the stable to the optimal position on the farm.

Figure 22: A digester should be as close as possible to the source of dung.

Figure 23: Cowshed, directly connected to the plant: A urine chamber to the right collects the liquid which can be used to wash the dung into the digester.
Photo: Kellner (TBW)

Biogas plant

A golden rule is: the plant belongs to the stable rather than to the kitchen. Preferably, the mixing chamber and inlet are directly connected to a concrete stable floor. A few meters of piping are more economic than the daily transport of dung from the stable to the biogas plant.

The roof of the stable should neither drain on the digester nor on the soil covering the plant. Large amounts of water entering the ground around the plant weaken the soil and cause static instability. Excess rain water may cool down the slurry in the plant and cause the gas production to drop.

The overflow point should guide into farmland owned by the plant user. It has been observed that plants which overflow on public or foreign land can cause social problems. A promise of the owner to remove the slurry daily should not convince the planner.

Water traps in the piping are a constant source of trouble. If the site allows, the plant and its piping should be laid out in a way that a water trap in the piping can be avoided. This is only possible if the pipes are sloping all the way back to the plant.

The piping is a major cost factor. It should not be unnecessarily long. This criterion, however, is given less priority than having the stable close to the inlet and the outlet directed towards the farm land.

A fixed dome plant should not be located in an located in an area required for tractor or heavy machinery movements.

Trees should not be too close to the plant. The roots may destroy the digester or the expansion chamber. In addition older trees may fall and destroy parts of the plant. If the position of the biogas plant is too shady, the soil temperature around the plant will be low in general. This leads to a decrease in gas production.

The area around a biogas plant should not be a playground for children. This is less important for underground fixed dome plants, more important for floating drum plants and essential for balloon plants.

Figure 24: A model of an agricultural digester in Germany with two horizontal steel tanks, a gas storage bag and a co-generation unit in a container.
Photo: Krmer (TBW)

Substrate types and management

Cattle dung and manure

Cattle dung is the most suitable material for biogas plants because of the methane- producing bacteria already contained in the stomach of ruminants. The specific gas production, however, is lower and the proportion of methane is around 65% because of pre-fermentation in the stomach. Its homogenous consistency is favourable for use in continuous plants as long as it is mixed with equal quantities of water.

Fresh cattle dung is usually collected and carried to the system in buckets or baskets. Upon arrival it is hand-mixed with about an equal amount of water before being fed into the digester. Straw and leftover fodder or hay is removed by hand in order to prevent clogging and reduce scum formation. Since most simple cow-sheds have dirt floors, the urine is usually not collected. When it is, it usually runs along the manure gutter and into a pail standing in a recess at the end of the gutter. The pail is emptied into the mixing pit - thereby replacing some of the mixing water - in preparation for charging the digester. Urine can considerably increase the gas production. A cemented stable floor, directly attached to the mixing pit, is the best solution to make optimum use of dung and urine and to save time for charging the digester.

Liquid cattle manure, a mixture of dung and urine, requires no extra water. However, the simple animal housing found on most farms in developing countries normally does not allow the collection of all animal excrement. Hence, most of the urine with its valuable plant nutrients is lost.

Pig dung and manure

When pigs are kept in unpaved areas or pens, only the dung can be collected. It must be diluted with water to the requisite consistency for charging the digester. This could result in considerable amounts of sand being fed into the digester, unless it is allowed to settle in the mixing vessel. Once inside the digester, sand and soil accumulates at the bottom and has to be removed periodically. Some form of mechanical mixer should be used to dilute the dung with water, since the odor nuisance makes manual mixing so repulsive that it is usually neglected. Similar to cow stables, a cemented floor, sloping towards the mixing pit, is a preferable solution.

Compared to cattle, pigs are more frequently kept on concrete floors. The water used for washing out the pens yields liquid manure with a low solids content. Thus, whenever the topography allows, the liquid manure should be allowed to flow by gravity into the digester. Wash-water should be used as sparingly as possible in order to minimize the necessary digester volume. Very frequently, the pig manure is collected in pails, which is advantageous, even though a sand trap should be provided to prevent sand from entering the digester.

Goat dung

For goats kept on unpaved floors, the situation is comparable to that described for pigdung. Since a goat farm is practically the only place where any substantial amount of goat dung can accumulate, and then only if the animals are kept on straw bedding, the available feedstock for a biogas system will usually consist of a mixture of dung and straw bedding. Most such systems are batch-fed versions into which the dung and an appropriate quantity of water are loaded without being pre-mixed. The feed-stock is usually hauled to and from the digester in wheelbarrows or baskets.

Chicken droppings

Chicken droppings can only be used if the chickens roost above a suitable dung collecting area of limited size. Otherwise, the sand or sawdust fraction would be disproportionately high. Chicken droppings can be fed into plants which are primarily filled with cow dung without any problem. There is a latent danger of high ammoniac concentration with pure chicken dung, but despite this there are many well functioning biogas plants combined with egg or meat producing factories. The collected droppings are hard and dry, so that they have to be pulverized and mixed with water before they can be loaded into the digester. Mechanical mixing is advisable. The proportion of methane in biogas from chicken excrement is up to 60%.

Human excrements

In most cultures, handling human excrement is loaded with taboos. Thus, if night soil is to be used in a biogas system, the toilets in question should drain directly into the system so that the night soil is fermented without pretreatment. The amount of water accompanying the night soil should be minimized by ensuring that no water taps or other external sources drain into the toilet bowls, and cleaning/flushing should be limited to rinsing out with about 0.5 - 1 liter water from a bowl. Western-style flush tanks should not be used in connection with small-size biogas plants.

In areas subject to frequent or seasonal water shortages, sand traps are a must, since wiping with stones is often the only means of cleaning after using the toilet.

The problem of scum

If there is heavy gas release from the inlet but not enough gas available for use, a thick scum layer is most likely the reason. Often the gas pressure does not build up because of the continuous gas release through the inlet for weeks. There is a danger of blocking the gas pipe by rising scum because of daily feeding without equivalent discharge. The lid (or man-hole) must be opened or the floating drum removed and scum is to be taken out by hand.

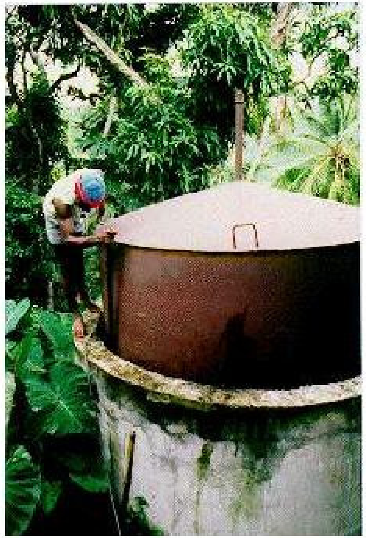


Figure 25: Destruction of the scum in a floating-drum plant in the Carribean
Photo: gtz/GATE

Separation of material

Straw, grass, stalks and even already dried dung tends to float to the surface. Solid and mineral material tends to sink to the bottom and, in the course of time, may block the outlet pipe or reduce the active digester volume. In properly mixed substrate with not too high water contents, there is no such separation because of sufficient friction within the paste-like substance.

Substrate

With pure and fresh cattle dung there is usually no scum problem. Floating layers will become a problem when e.g. undigestible husks are part of the fodder. This is often the case in pig feeds. Before installing a biogas plant at a piggery, the kind of fodder and consequently the kind of dung, must be checked to ensure that it is suitable for a biogas plant. It might be necessary to grind the fodder into fine powder. The user must be aware of the additional costs before deciding on a biogas unit. The problem is even bigger with costs before deciding on a biogas unit. The problem is even bigger with poultry droppings.

The kind of fodder, the sand the chicken pick up, and the feathers falling to the ground make poultry dung a difficult substrate. In case of serious doubt, the building of a biogas plant should be re-assessed.

Scum can be avoided by stirring, but...

> Scum is not brittle but very filthy and tough. Scum can become so solid after only a short time, that it needs heavy equipment to break it. It remains at the surface after being broken up. To destroy it by fermentation, it must be kept wet. Either the scum must be watered from the top or pushed down into the liquid. Both operations demand costly apparatus. For simple biogas plants, stirring is not a viable solution for breaking the scum.

The only solution for simple biogas plants to avoid scum is by selecting suitable feed material and by sufficient mixing of the dung with liquid before entering the plant.

Construction Details of Biogas Plants

This section provides detailed information on materials and devices used in the construction of biogas plants:

Checklist for building a biogas plant

1. Finishing the planning, i.e. site evaluation, determination of energy demand and biomass supply / biogas yield, plant sizing, selection of plant design, how and where to use the biogas, etc., in accordance with the planning guide
2. Stipulate the plants location and elaborate a site plan, including all buildings, gas pipes, gas appliances and fields to be fertilized with digested slurry
3. Draft a technical drawing showing all plant components, i.e. mixing pit, connection to stabling, inlet / outlet, digester, gas-holder, gas pipes, slurry storage

4. Preparation of material / personnel requirements list and procurement of materials **needed for the chosen plant:**

   bricks / stones / blocks for walls and foundation

   sand, gravel

   inlet / outlet pipes

   metal parts (sheet metal, angle irons, etc.)

   gas pipes and fittings

   paint and sealants

   gas appliances

   tools

   mason and helper

   unskilled labor

   workshop for metal (gas-holder) and pipe installation

5. Material / personnel assignment planning, i.e. procedural planning and execution of:

   excavation

   foundation slab

   digester masonry

   gasholder

   rendering and sealing the masonry

   mixing pit - slurry storage pit

   drying out the plant

   installing the gas pipe

   acceptance inspection

6. Regular

3. Regular building supervision	46

Piping Systems

The piping system connects the biogas plant with the gas appliances. It has to be safe, economic and should allow the required gas-flow for the specific gas appliance. Galvanized steel (G.I.) pipes or PVC-pipes are most commonly used for this purpose. Most prominently, the piping system has to be reliably gas-tight during the life-span of the biogas unit. In the past, faulty piping systems were the most frequent reason for gas losses in biogas units.

PVC piping

PVC pipes and fittings have a relatively low price and can be easily installed. They are available in different qualities with adhesive joints or screw couplings (pressure water pipes). PVC pipes are susceptible to UV radiation and can easily be damaged by playing children. Wherever possible, PVC pipes should be placed underground.

Figure 26: Final touches on a piping system with PVC pipes
Photo: Krmer (TBW)

Galvanized steel piping

Galvanized steel pipes are reliable and durable alternatives to PVC pipes. They can be disconnected and reused if necessary. They resist shocks and other mechanical impacts. However, galvanized steel pipes are costly and the installation is labor intensive, therefore they are only suitable for places where PVC is unavailable or should not be used.

Pipe diameters

The necessary pipe diameter depends on the required flow-rate of biogas through the pipe and the distance between biogas digester and gas appliances. Long distances and high flow-rates lead to a decrease of the gas pressure. The longer the distance and the higher the flow rate, the higher the pressure drops due to friction. Bends and fittings increase the pressure losses. G.1. pipes show higher pressure losses than PVC pipes. The table below gives some values for appropriate pipe diameters. Using these pipe diameters for the specified length and flow rate, the pressure losses will not exceed 5 mbar.

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Table 3: Appropriate pipe diameter for different pipe lengths and flow-rate (maximum pressure loss < 5 mbar)

	Galvanized steel pipe			PVC pipe		
Length [m]:	20	60	100	20 60		100
Flow-rate [m^3/h]						
0.1	1/2"	1/2"	1/2"	1/2" 1/2" 1/2"		
0.2	1/2"	1/2"	1/2"	1/2" 1/2" 1/2"		
0.3	1/2"	1/2"	1/2"	1/2" 1/2" 1/2"		
0.4	1/2"	1/2"	1/2"	1/2" 1/2" 1/2"		
0.5	1/2"	1/2"	3/4"	1/2" 1/2" 1/2"		
1.0	3/4"	3/4"	3/4"	1/2" 3/4" 3/4"		
1.5	3/4"	3/4"	1"	1/2" 3/4" 3/4"		
2.0	3/4"	1"	1"	3/4" 3/4" 1"		

The values in this table show that a pipe diameter of 3/4" is suitable for flow rates up to 1.5 m^3/h and distances up to 100 m (PVC pipe). Therefore one could select the diameter of 3/4" as single size for the hole piping system of small biogas plants. Another option is to select the diameter of l" for the main gas pipe and 1/2" for all distribution pipes to the gas appliances.

Lay-out of the piping system

PVC can be used for all underground pipes or pipes that are protected against sun light and out of the reach of children. For all parts of the piping system that are above ground one should install galvanized steel pipes. Therefore it is recommended to use l" G.I. steel pipes for the visible part of the piping system around the biogas digester. For the main pipe one uses l" PVC pipe placed underground. The distribution pipes should be 1/2" G.I. steel pipes or PVC pipes, depending whether they are installed above or under the wall plastering. But even though G.I. pipes are less susceptible to damage, placing them underground should always be the preferred solution.

PVC pipes have to be laid at least 25 cm deep underground. They should be placed in a sand bed and be covered with sand or fine earth. One should carefully back-fill the ditches in order to avoid stones lying directly above the pipe.

When the piping is installed - and before refilling the ditches - it has to be tested for possible gas leakage. This can be done by pumping air into the closed piping system up to a pressure that is 2.5 times the maximum gas pressure of the biogas plant. If pressure loss occurs within few hours, every joint of the piping system has to be checked with soap water. Soap-bubbles indicate any leakage of gas.

Water traps

Due to temperature changes, the moisture-saturated biogas will form inevitably condensation water in the piping system. Ideally, the piping system should be laid out in a way that allows a free flow of condensation water back into the digester. If depressions in the piping system can not be avoided, one or several water traps have to be installed at the lowest point of the depressions. Inclination should not be less than 1%.

Often, water traps cannot be avoided. One has to decide then, if an automatic trap or a manually operated trap is more suitable. Automatic traps have the advantage that emptying - which is easily forgotten - is not necessary. But if they dry up or blow empty, they may cause heavy and extended gas losses. In addition, they are not easily understood. Manual traps are simple and easy to understand, but if they are not emptied regularly, the accumulated condensation water will eventually block the piping system. Both kinds of traps have to be installed in a solid chamber, covered by a lid to prevent an eventual installed in a solid chamber, covered by a lid to prevent an eventual filling up by soil.

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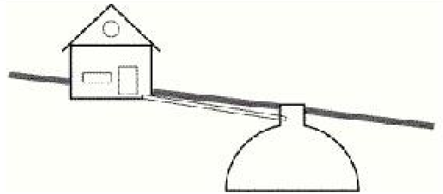


Figure 27: Piping system with straight slope from kitchen to digester. No water trap required as condensation water drains into the digester
Source: TBW

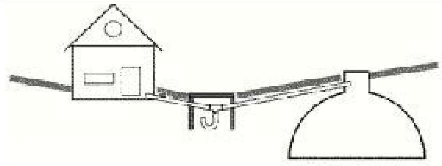
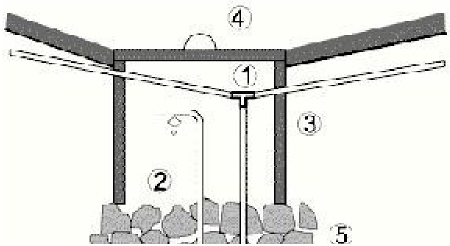
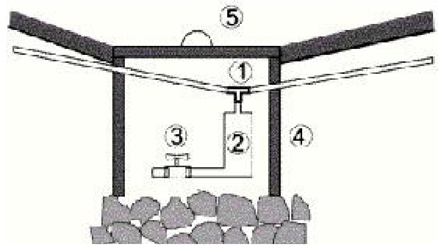


Figure 28: Wherever condensation water cannot drain back into the digester, a water trap becomes necessary
Source: TBW





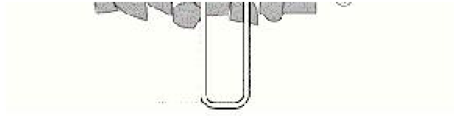


Figure 29: Automatic water trap: (1) T-joint in the piping system, (2) water column, equal to max. gas pressure + 30% security, (3) solid brick or concrete casing, (4) concrete lid, (5) drainage
Source: TBW

Figure 30: Manual water trap: (1) T-joint, (2) buffer storage for condensated water, (3) manual tap, (4) casing, (5) concrete lid, (6) drainage
Source: TBW

Valves

To the extent possible, ball valves or cock valves suitable for gas installations should be used as shutoff and isolating elements. The most reliable valves are chrome-plated ball valves. Gate valves of the type normally used for water pipes are not suitable. Any water valves exceptionally used must first be checked for gas-tightness. They have to be greased regularly. A U-tube pressure gauge is quick and easy to make and can normally be expected to meet the requirements of a biogas plant.

The main gas valve has to be installed close to the biogas digester. Sealed T-joints should be connected before and after the main valve. With these T-joints it is possible to test the digester and the piping system separately for their gas-tightness. Ball valves as shutoff devices should be installed at all gas appliances. With shutoff valves, cleaning and maintenance work can be carried out without closing the main gas valve.

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Pumps for Biogas Plants

Pumps are required to bridge differences in height between the levels of slurry-flow through the biogas unit. They can also be required to mix the substrate or to speed up slow flowing substrates. If substrates have a high solids content and do not flow at all, but cannot be diluted, pumps or transport belts are essential.

Pumps are driven by engines, are exposed to wear and tear and can be damaged. They are costly, consume energy and can disrupt the filling process. For these reasons, pumps should be avoided where possible and methods of dilution and use of the natural gradient be utilized instead.

If pumps cannot be avoided, they can be installed in two ways:

- Dry installation: the pump is connected in line with the pipe. The substrate flows freely up to the pump and is accelerated while passing through the pump.
- Wet installation: the pump is installed with an electric engine inside the substrate. The electric engine is sealed in a watertight container. Alternatively, the pump in the substrate is driven by a shaft, the engine is outside the substrate.

Types of pumps

Rotary pumps

Rotary pumps operate with a rotor which presses the liquid against the outside wall of the rotor chamber. Due to the geometry of the chamber the liquid is pushed into the outlet pipe. Rotary pumps are very common in liquid manure technology. They are simple and robust and used mainly for substrates of less than 8% solids content. The quantity conveyed per

time unit depends largely on the height of lift or the conveying pressure.
The maximum conveying pressure is between 0,8 and 3.5 bar. The quantity that can be conveyed varies from 2 to 6 m^3 per min. at a power input of 3 - 15 kW. Rotary pumps cannot, usually, be used as a sucking device. As a special form of rotary pumps, the chopper pump deserves mentioning. Its rotor is equipped with blades to chop substrates with long fibers like straw and other fodder parts before pumping them up. Both wet and dry installation is possible with rotary pumps.

Positive displacement pumps

Positive displacement pumps are normally used for substrates with higher solids content. They pump and suck at the same time. Their potential quantity conveyed is less dependent on the conveying pressure than with rotary pumps. The direction of pumping / sucking can be changed into the opposite direction by changing the sense of rotation. In biogas units, mainly the eccentric spiral pump and the rotary piston pump (both positive displacement pumps) are used. For better access, a dry installation is the preferred option.

Eccentric spiral pump

This pump has a stainless steel rotor, similar to a cork screw, which turns in an elastic casing. Eccentric spiral pumps can suck from a depth of up to 8.5m and can produce a pressure of up to 24 bar. The are, however, more susceptible to obstructive, alien elements than rotary pumps. Of disadvantage is further the danger of fibrous material wrapping round the spiral.

Rotary piston pump

Rotary piston pumps operate on counter-rotating winged pistons in an oval casing. They can pump and suck as well and achieve pressures of up to 10 bar. The potential quantity conveyed ranges from 0.5 to 4 m^3/min. The allow for larger alien objects and more fibrous material than eccentric spiral pumps.

Table 4: Types of pumps in comparison

	rotary pumps	chopper pumps	eccentric spiral pump	rotary piston pump
solids content	< 8 %	< 8 %	< 15 %	< 15 %
energy input	3 - 15 kW	3 - 15 kW	3 - 22 kW	3 - 20 kW
quantity conveyed	2 - 6 m^3/min	2 - 6 m^3/min	0,3 - 3,5 m^3/min	0,5 - 4 m^3/min
pressure	0,8 - 3,5 bar	0,8 - 3,5 bar	< 25 bar	< 10 bar
structure of substrate	medium long fibers	long fibers	short fibers	medium long fibers
max. size of obstructive elements	approx. 5 cm	depending on choppers	approx. 4 cm	approx. 6 cm
intake	not sucking	not sucking	sucking	sucking
suitability	suitable for large quantities; simple and robust built	suitable for long-fiber substrates which need to be chopped up.	Suitable for high pressures, but susceptible to obstructive bodies	higher pressures than rotary pumps, but higher wear and tear
	cheaper			

price comparison	cheaper than positive displacement pumps	depending on choppers	similar to rotary piston pump	similar to eccentric spiral pump

Heating

To achieve the optimum biogas yield, the anaerobic digestion needs constant environmental conditions, preferably close to the process optimum. The digester temperature is of prime importance. In temperate areas, a heating system and an insulation of the digester is necessary. Hence, the needed temperature for digestion can be reached and a loss of energy by transmission is compensated.

Because of the high costs for material and installation of a heating system, a low-cost biogas plant, as needed in developing countries, can only be build without heating. To boost the biogas yield for those plants, the building of a bigger digester to increase the retention time would be cheaper. A bigger digester reduces the required maintenance, while a heating system, increases maintenance requirements. A bigger digester serves also as a buffer for sediments, pH-variations and gas storage. For example, a fixed dome plant sized 50% bigger, is only 10% more expensive.

Figure 31: Heating system for a biodigester

The mean surrounding temperature and its seasonal variations are very important. Biogas plants without heating system work, therefore, only in warmer regions for the whole year. In regions with extreme temperature variations, for instance in Turkey (hot summer, cold winter), the biogas plant should be built under the stable. Hence the biogas yield would be lower in summer, but constant over the year and at the end higher. Before implementation, at least an approximated average temperature profile and expected extremes over the year should be available for the site.

biodigester (Germany) Construction *Photo: Krieg (TBW)*

A biogas plant with heating system and co-generation can be operated with process energy. Nevertheless the dimensioning of such a heating system is difficult, as the substrate, which has to be heated up, is not homogenous.

A guiding figure for a digester with a hydraulic retention time of 20 days is 270 W/m^3 digester volume. The increasing of the hydraulic retention time makes it possible to reduce the heating power per volume. With a hydraulic retention time of 40 days the digester needs only 150 W/m^3.

Following figures are for heating systems with a heating water temperature difference of 20 K:

hydr. retention time	**40 days**	30 days	20 days
temperature difference	**20 K**	20 K	20 K
heating power	150 kW/m^3	210 kW/m^3	270 kW/m^3

A heating system located in the digester produces a thermal circulation, which is, especially for non-agitated digesters, very important.

An indirect energy transfer by heat exchanger is most common. Exceptions are steam injection, liquefying of solid manure with heated water and the heating by pre-aeration.

Internal and external heating systems

External heating systems have a forced flow on both sides. Due to the turbulent flow patterns of both media, a very good heat transportation can be reached. Therefore, the surface of the heat exchanger can be comparatively small. Nevertheless those systems cannot be recommended for non

recommended for non-
agitated digesters.

The proper dimensioning of an internal heating system seems to be more difficult because of the different currents due to pumping, agitation, thermo-convection and the inflow of bio-mass.

Under-floor heating systems have been very popular, as they have no disturbing parts in the digester itself. Due to sedimentation and the resulting worsening of heat transportation into the digester, under-floor heating is no longer recommended. With the growth of digester volumes and the need of bigger heating systems, it is also more difficult to build under-floor heating big enough to provide the necessary heat.

Heating coils installed at the inner wall of the digester are a rather new practice. Heating coils made out of steel are much more expensive than heating coils out of plastic material (PE). Materials developed during the last years make such a system more stable while not increasing the costs of the heating system.

Another option is to construct two digesters connected in series, the first heated, the second unheated. The first digester can be used as sedimentation tank , in which the substrate is heated up. The second digester is well isolated to reduce loss of heat.

Agitation

The term agitation subsumes different ways of homogenising the substrate or mixing it with water and co-substrate:

- Mixing and homogenizing the substrate in the mixing chamber
- Agitation inside the digester
- Poking through the in- and outlet pipes (small scale plants)

Agitation of the digester contents is important for the trouble-free performance of a biogas-plant. For the following reasons agitation is recommended several times a day:

- to avoid and destroy swimming and sinking layers
- to improve the activity of bacteria through release of biogas and provision of fresh nutrients
- to mix fresh and fermenting substrate in order to inoculate the former
- to arrive at an even distribution of temperature thus providing uniform conditions inside the digester

Even without mixing device, there is a certain agitation through the raising gas, through the movement of substrates with different temperatures and by the inflow of fresh substrate. This agitation, however, is usually insufficient. A well agitated substrate can, leaving other parameters constant, increase its biogas production by 50%.

Agitation, as a general rule, should be performed as much as necessary but as little as *possible. Too frequent mixing with fast rotating, mechanical agitation devices can disturb the* biological processes in the fermenting substrate. In addition, an all-too thorough mixing of the whole digester contents may lead to half-digested substrate leaving the whole digester contents may lead to half-digested substrate leaving the digester prematurely.

Figure 32: Mixing device in an agricultural digester under construction
Photo: Kraemer

Mixing methods

Simple mixing methods have been installed mainly in developing countries:

- tangential inlet and outlet pipes
- separation walls
- forced substrate flow
- vertical hand-operated rotors
- horizontal, hand-operated paddle rotors
- poking through inlet and outlet

Mixing through inherent flow

In fixed dome plants, frequently found in developing countries, a certain mixing of the substrate is provided by the substrate being pushed up in the compensation tank with gas accumulation. When the stored gas is used, the substrate flows back into the digester.

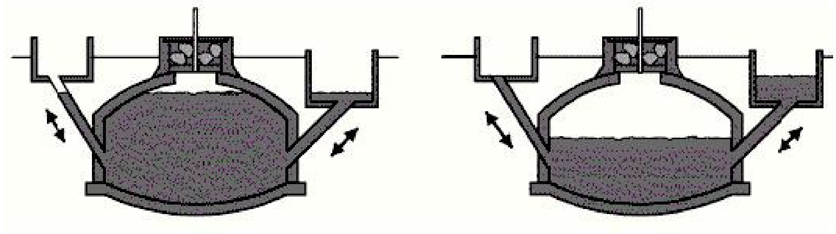


Figure 33: Mixing of substrate through inherent flow in fixed-dome plants
Source: TBW

The company "VSP-Anlagen" further developed and patented this principle:

Through the pressure of the biogas, the substrate is pushed from the main digester into the subsidiary digester, resulting in a difference of levels between the two digesters. By reaching a certain difference in levels, a gas valve opens between main and subsidiary digester which equalizes the height difference. The flow-back of the substrate is guided in a way that destroys sinking and swimming layers.

Mechanical

Mechanical paddle rotor

Mechanical paddle rotors are predominantly used in horizontal steel vessels. A horizontal shaft in hardwood bearings runs through the whole vessel. Attached are paddles or loop-shaped pipes. By turning the shaft the vessel contents are mixed, the swimming layer is broken up and sediments are pushed towards a drainage opening. The loop-shaped pipes can also be used as heat exchangers to warm up the substrate.

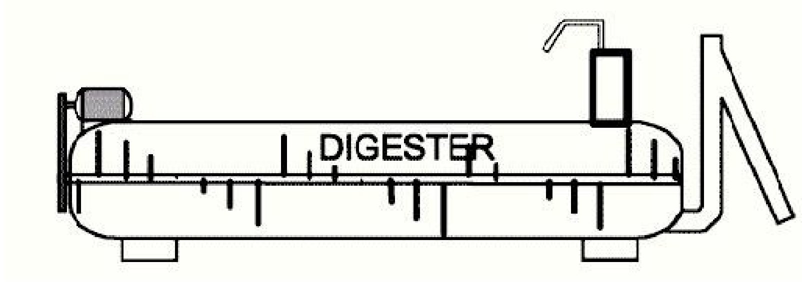


Figure 34: Mechanical paddle rotor
Source: TBW

Submerged motor with rotor stirring

A sealed, submerged electric engine directly drives a rotor. The rotor mixes the substrate by creating a strong current. These stirring devices can usually be adjusted in height and in angle.

Shaft-driven rotors

The mode of operation of a shaft-driven rotor is comparable to that of a submerged engine with rotor, only that the rotor is driven via shaft by an engine or by hand. The shaft should be movable in height and in angle to allow a mixing throughout the digester. The shaft should be long enough to reach both swimming and sinking layers.

The rotor shaft can be inserted in two principle ways:

- Through the digester wall below the slurry level with water-tight sealing
- Through the gas-holder with gas-tight sealing

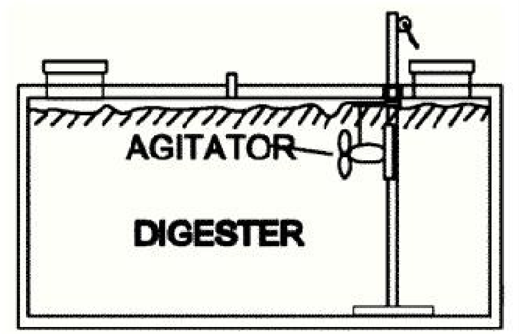
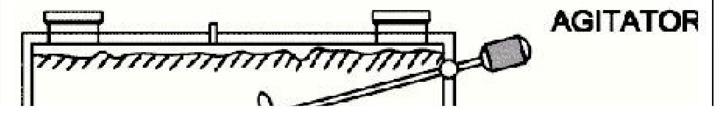


Figure 35: Submerged motor with rotor stirring
Source: TBW



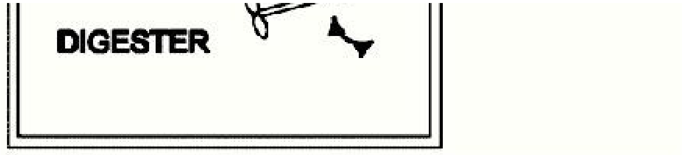


Figure 36: Shaft-driven rotor
Source: TBW

Hydraulic mixing

With a strong pump the whole substrate can be put in motion, provided the intake and outlet of the pump are placed in a way that corresponds with the digester shape. These pumps are often placed in a central position to cater for other tasks.

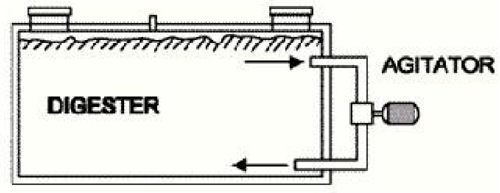


Figure 37: Hydraulic mixing
Source: TBW

Mixing through injection of biogas

A piping system with gas-jets is installed at the bottom of the digester. The raising biogas bubbles provide a gentle mixing of the substrate. The main problem with these systems is slurry entering into the piping system. This can be avoided by fixing pieces of elastic hose-pipe with stainless steel hose coupling to the jets.

Hydraulic mixing by injecting biogas should not be used if the formation of swimming layers is a prevailing problem. Gas bubbles attach themselves to larger fibrous particles and lift them upwards, thus speeding up the formation of a swimming layer. Chopping up the substrate by means of chopper pumps or chopper rotors can only partly solve this problem.

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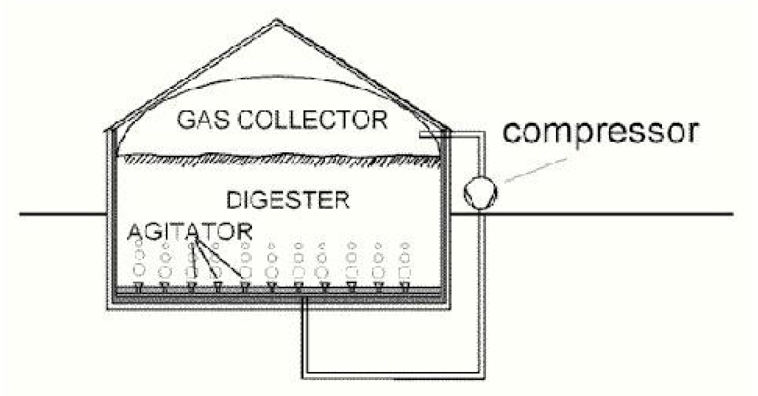


Figure 38: Mixing through injection of biogas
Source: TBW

Slurry-Use Equipment

For the use of biogas slurry, a multitude of tools and technologies have been developed. They differ mainly according to the quantities of digested material. Big differences exist as well between developing and industrialized countries, depending on the technological development and the cost of labor. Slurry use technologies range from hand-application with the help of a bucket to mechanized distribution, supported by GPS (global positioning system) and a computer on board of the liquid manure spreader. The choice of technology essentially depends on the amount of slurry and the area to be fertilized as well as on the financial means and the opportunity cost of labor.

On small farms in developing countries, simple but effective tools are used. They include buckets, scoops, containers with straps, wooden wheelbarrows with lids, barrels on wheels and others. These tools allow a precise application of slurry. The most economic way to apply slurry is by means of gravity, either by a network of small slurry furrows or by mixing slurry in the irrigation system. Both options require a gradient of at least 1% (for irrigation water) and 2% (for slurry distribution), sloping from the biogas plants overflow point to the fields.

Making best and least labor-intensive use of the slurry is an important planning parameter. Especially where gravity distribution is feasible, the positioning of the biogas plant and the expansion chamber and the level of the expansion chamber overflow are of high importance. In rather flat areas, it should be considered to raise both the stable and the biogas-plant in order to allow a slurry distribution by gravity.

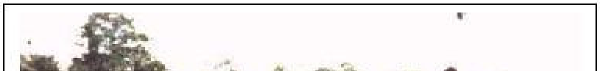


Figure 39: Device for slurry distribution by tractor.
Photo: Krmer (TBW)

In industrialized countries and for large plants in developing countries two methods of mechanized distribution systems have evolved:

Distribution via piping systems

The slurry is pumped directly from the slurry storage tank onto the field and is distributed there. If the pump is rather small and the pressure and transported amounts are low, the distribution can be done by hand. With increasing pressure and transported amounts, the distribution system is attached to a tractor. The tractor does not have to be very powerful as there is no need to pull a heavy tanker. The main advantage of this method is the low ground pressure and the ability to enter into fields of steep slope, of fragile soil structure and during bad weather.

The biogas slurry, if it is not too viscous, can be applied with a liquid manure rainer. The disadvantages are the costly pump and the expensive piping system. Therefore, this method is only economic for fields close to the slurry storage container.

Distribution via tanker

The tanker is filled at the slurry storage and pulled to the field for distribution. Below are the principal distribution systems ex-tanker:

With reflection plate

The slurry is squirted through a nozzle against a reflection plate which, by its special form, diverts and broadens the squirt. An improvement of the simple reflection-plate-distribution is a swiveling plate which leads to a more even distribution.

Direct application through sliding hoses

The slurry is pumped into a distribution system which feeds a number of hoses which move closely to the ground. The slurry is applied directly on the soil surface, therefore reducing nutrient losses. Distances between the hoses can be adjusted to suit different plant cultures.

Hoses with drill coulters

The soil is opened with two disks (drill coulters) in a v-shape. The slurry is applied with sliding hoses into the v-furrows, which are closed behind the hose. This application method could be labeled sub-surface application. It is the most advanced in terms of avoiding nutrient losses. Similar to the hose application, distances between application rows are adjustable. Alternatively to the hose application, the slurry can be positioned by a metal injector.

The application methods close to the soil surface, in contrast to the broadcasting methods, have the advantage of a higher degree of exactness and less nutrient losses to the atmosphere. Fertilization can be better adjusted to plant needs. In contrast to broadcast-spraying, direct application is possible even at later stages of plant growth without damaging the leaves. Disadvantages are the rather sophisticated machinery necessary and the high costs involved. Direct application methods are, therefore, mostly used as inter-farm operation.

Separation of slurry and drying of the moist sludge

In industrialized countries, the slurry is usually separated by means of separators and sieves. The water is re-fed into the digestion process or distributed as liquid manure while the moist sludge is dried or composted. As a simple technology for separation, slow sand-filters can be used.

The moist sludge can be heaped on drying beds, filled in flat pits or simply placed on paved surfaces near the biogas plant for drying. Depending on climatic conditions, large drying areas may be necessary. Drying times and nutrient losses can be reduced by mixing dry substances with the moist sludge. A disadvantage of all drying methods, again depending on the climate, is the high loss of nutrients. In particular heavy rains can wash out the soluble nutrients. Losses of nitrogen, for example, can amount to 50% of the overall nitrogen and up to 90% of the mineral nitrogen. Drying of the moist sludge can only be recommended where long distances and difficult terrain hampers transport to the fields or if composting is difficult for lack of manpower and lack of dry biomass.

Composting of slurry

Dry plant material is heaped in rows and the liquid slurry is poured over the rows. Ideally, plant material and slurry are mixed. The mixing ration depends on the dry matter content of plant material and slurry. The main advantage is the low nutrient loss. Compost, containing plant nutrients in a mainly biologically fixed form, is a fertilizer with long-term effects. Its value for improving soil structure is an additional positive effect of importance.

Plasters and Coats for Digester and Gas-Holder

In industrialized countries, most of the new digesters are built of gas-tight concrete or steel. Additives are mixed into the concrete to render it gas-tight. If existing concrete vessels are used, their gas-tightness has to be checked. Often, they have not been built from gas-tight concrete or cracks have formed over time which allow the gas to escape.

It is important to check the digester and piping system for gas-tightness prior to putting the biogas unit in service. If leakage is detected only during operation, the digester has to be emptied, cleaned and plastered again. Rectifying a leakage before the initial filling is a lot cheaper.

In developing countries, digesters are usually masonry structures. The plastering has to be watertight up to the lowest slurry level and gas-tight from the lowest gas level upwards (gas-holder). The plaster has to resist moisture and temperatures up to 60C reliably. The plaster must be resistant to organic acid, ammonia and hydrogen sulfide. The undercoat must be absolutely clean and dry.

Figure 40: Inside plaster of the gastight section of a fixed dome digester
Photo: Kellner (TBW)

Cement plaster with

Cement plaster with special additives

Good results in water- and gas-tightness have been achieved by adding 'water-proofer' to the cement plaster. For gas-tightness, double the amount of water-proofer is required as compared to the amount necessary for water-tightness. The time between the applications of the layers of plaster should not exceed one day, as the plaster becomes water-tight after one day and the new plaster cannot adhere to the old plaster. The following 'recipe' from Tanzania guarantees gas-tightness, provided the masonry structure has no cracks:

1. layer: cement-water brushing;
2. layer: 1 cm cement : sand plaster 1 : 2.5;
3. layer: cement-water brushing;
4. layer: cement : lime : sand plaster 1 : 0.25 : 2.5;
5. layer: cement-water brushing with water-proofer;
6. layer: cement : lime : sand plaster with water proofer and fine, sieved sand 1 : 0.25 : 2.5;
7. layer: cement screed (cement-water paste) with water-proofer.

The seven courses of plaster should be applied within 24 hours.

A disadvantage of cement plaster is their inability to bridge small cracks in the masonry structure as, for example, bituminous coats can do.

Bitumen (several layers)

Bitumen coats can be applied easily and remain elastic over long periods of time. Problems arise in the application as the solvents are inflammable (danger of explosion inside the digester) and a health hazard. Bitumen coats cannot be applied on wet surfaces. The drying of masonry structures requires several weeks, unless some heating device (e.g. a charcoal stove) is placed inside the digester for two to three days. Furthermore, the bituminous coat can be damaged by the up-and-down movement of the slurry.

Bitumen coat with aluminum foil

On the first still sticky bitumen coat, aluminum foil is mounted with generous overlaps. A second layer of bitumen is applied on the aluminum foil. Gas-tightness is usually higher compared to the several layers of bitumen without foil.

Water-thinnable dispersion paint

These paints are free from fire- or health hazards. Most of them, however are not gas-tight and not resistant to moisture. Only those dispersion paints should be used which are explicitly recommended for underwater use and which form a gas-tight film.

Single- and dual component synthetic resin paints

Synthetic resin paints form elastic, gas-tight coats which can resist rather high physical load. They are comparably expensive, their use seems only justified if the coating has to resist mechanical stress. This is usually the case with fixed dome plants. Measurements have given evidence that the masonry structure of a fixed dome stretches, though minimally, after filling and under gas pressure.

Paraffin

Paraffin, diluted with new engine oil, is warmed up to 100 -150C and applied on the plaster which has been heated up with a flame-thrower. The paraffin enters into the plaster and effects a 'deep-sealing'. If paraffin is not available, simple candles can be melted and diluted with engine oil.

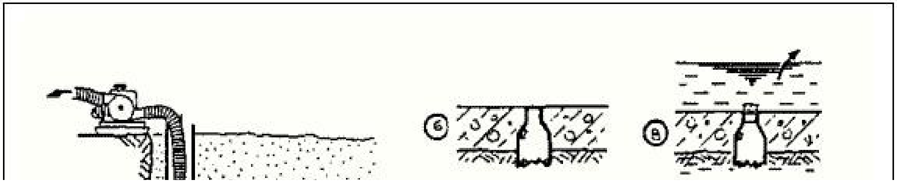
Underground Water

Underground water features in all three steps of biogas implementation:

- During planning, the site selection and design of the digester can eliminate most of the problems caused by groundwater and threats to groundwater.
- During construction, groundwater can be a nuisance, effecting additional costs. But it is during construction, that serious leakage can be avoided.
- During operation, little can be done but to monitor the quality of water and to avoid surface spilling.

By positioning the biogas plant and the well, a great deal of drinking water safety can be achieved. First, the distance should be at least 30 m, second, the biogas plant should be downstream of surface- and groundwater flows and third, the well should be above the biogas unit to avoid contamination through surface spilling.

During construction, ground water must be drained. An empty biogas digester can develop such buoyancy, if surrounded by water, that the whole shell is lifted. The figure below illustrates some simple techniques how to deal with ground water during construction of small biogas plants.



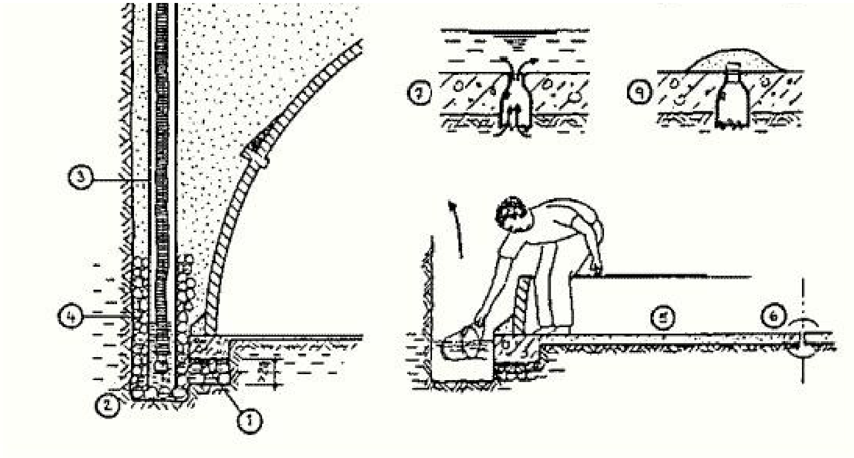


Figure 41: Dealing with ground water during construction: The foundation rests on a stone packing (1) to drain the water into the pump-sink (2). A layer of gravel prevents blockage of the drain. A vertical pipe (3) allows pumping even when back-filling has be done. The lower part of the pipe is surrounded by a stone packing (4). If the ground water is only slightly higher than the digester bottom or if no pump is available, the construction must be flooded. The floor must be of solid concrete (5). Water must be kept away until the outer wall has reached above the ground water table and has been plastered from the outside. Several bottles without bottoms are placed into the concrete (6). When scooping of water has stopped, ground water passes through the bottle and floods the floor (7). After completing the masonry work and covering the dome with soil, the bottle is closed and water might be taken off the digester bottom (8). The cap of the bottle is covered with cement mortar (9). In case of high ground water table a conical or bowl-shaped solid concrete slab is required.

Source: Sasse, Kellner, Kimaro: Improved Biogas Units for Developing Countries, GATE 1991

During the operation of the biogas plant further attention has to be paid to keeping the groundwater clean. Seeping biogas digesters and unprotected slurry storage can pollute water sources chemically (nitrate poisoning can be fatal for infants) and biologically (mainly with toilet biogas plants). Reasons may be wrong configuration of security devices like the pressure relief valves or because of leakage in lower parts of the digester. Smaller cracks, however, close up in the course of time through particles in the slurry.

Trace metals applied to natural systems do not pose a threat to groundwater quality because trace metals are usually removed from the percolating water by adsorption or chemical precipitation within the first few meters of soil, even in rapid infiltration systems with high hydraulic-loading rates.

Bacterial removal from effluents passing through fine soils is quite complete. It may be less complete in the coarse, sandy soil used for rapid infiltration systems. Fractured rock or limestone cavities may provide a passage for bacteria that can travel several hundred meters from the point of application. This danger can be avoided by proper geological investigations during site selection.

Operation and Use

The day-to day operation of a biogas unit requires a high level of discipline and routine to maintain a high gas production and to ensure a long life-span of the biogas unit. Many problems in the performance of biogas plants occur due to user mistakes or operational neglect. Often, these problems can be reduced,

- by less complicated designs that are adapted to the substrate, the climatic conditions and the technical competence of the user,
- by high-quality and user-friendly appliances,
- by design and lay-out of the biogas for convenient work routine,
- by proper training and easy access to advice on operation problems.

During design selection, planning, construction, handing over and follow-up, the biogas extension program should emphasize further on a reduction of the users workload for operating the biogas unit and using the gas and the slurry. In particular during work peaks for farm work, it is important that the biogas unit relieves the user from work rather than adding to the workload. As a general rule, the farming family should have less work with a biogas *unit than without it, while enjoying the additional benefits in terms of a clean fuel and high* quality fertilizer.

Daily operation

Feeding of the digester

In larger biogas units, the dung, urine and other substrate usually enter the plant by pipes, channels, belts or pumps. The available substrate has to enter the digester as soon as it is available to avoid pre-digestion outside the digester. The functioning of the feeding mechanisms has to be checked daily. Separators for unsuitable material have to be checked and emptied. The amounts of substrate fed into the digester may be recorded to monitor the performance of the biogas plant.

Smaller plants in developing countries are fed by hand. The substrates, often dung and urine, should be thoroughly mixed, plant residues should be chopped, if necessary. Obstructive materials like stones and sand should be removed from the mixing chamber. Simple tools like a rubber squegee, a dipper, forks to fish out fibrous material, proper buckets and shovels greatly facilitate this work. Filling work is further made easier by smooth concrete stable-floors and a minimized distance between the stable and the plant.

Agitation

In industrialized countries and for large plants in developing countries, engine driven stirring devices are the norm. Usually, but not always, they are operated automatically. The user, however, should check the operation of the stirring device daily.

Small size biogas plants have manual stirring devices that have to be turned by hand as recommended. If there is no stirring device, poking with sticks through the inlet and outlet is recommended. The stick should be strong, long enough but not too heavy. It should have a plate fixed at the end (small enough to fit in the inlet-/outlet pipes) to produce a movement of the slurry. Regular poking also ensures that the inlet/outlet pipes do not clog up. The drums of floating drum plants should be turned several times a day.

Experience shows that stirring and poking is hardly ever done as frequently as it should be. Farmers should be encouraged to run a trial on gas production with and without stirring. The higher gas production will convince the user more than any advice.

Controlling the overflow

A special problem of small scale fixed dome plants is the clogging up of the overflow point. This can lead to over-pressure (the hydraulic pressure increases with the slurry level in the expansion chamber) and to clogging of the gas outlet if too much slurry flows back into the digester. The overflow point should, therefore, be checked and cleaned daily.

Slurry distribution

If the slurry distribution is done directly by gravity, the slurry furrows need to be checked and slurry diverted accordingly. Slurry may be applied from the furrows directly to the plant with the help of dippers or shovels.

Weekly / monthly operation

- Controlling of the water separator
- Renewing the agents of the gas purification system (if existing)
- Mixing the swimmig and sinking layers of in the expansion chamber of fixed dome plants
- The water sealing of the lid in the man hole of a fixed dome plant should be checked and filled up
- Gentle cleaning of the drum of a floating drum plant
- Checking and filling up the water jacket of water jacket plants
- Flexible pipes above ground should be checked for porosity
- Slurry storage tanks should be checked and emptied, if required and slurry flows diverted accordingly

Annual operation

- Swimming layers should be removed from the digester
- The whole plant and digester should be exposed to a pressure test once a year to detect lesser leakages

Security

When operating a biogas plant special attention has to be paid to the following dangers:

- Breathing in biogas in a high concentration and over longer periods of time can cause poisoning and death from suffocation. The hydrogen sulfide contents of biogas is highly poisonous. Unpurified biogas has the typical smell of rotten eggs. Purified biogas is odorless and neutral. Therefore, all areas with biogas operating appliances should be well ventilated. Gas pipes and fittings should be checked regularly for their gas-tightness and be protected from damage. Gas appliances should always be under supervision during operation. Everybody dealing with biogas, in particular children, should be instructed well and made aware of the potential dangers of biogas.
- After emptying biogas plants for repair, they have to be sufficiently ventilated before being entered. Here the danger of fire and explosion is very big (gas/air mixture!). The so-called chicken test (a chicken in a basket enters the plant before the person) guarantees sufficient ventilation.
- Biogas in form of a gas-air mixture with a share of 5 to 12 % biogas and a source of ignition of 600C or more can easily explode. Danger of fire is given if the gas-air mixture contains more than 12 % of biogas. Smoking and open fire must therefore be prohibited in and around the biogas plant.
- The initial filling of a biogas plant poses a particular danger, when biogas mixes with large empty air-spaces. A farmer may want to check with an open flame how full the plant is already and cause an explosion.
- The digester of a biogas plant and the slurry storage facilities should be built in such a way that neither persons nor animals are in danger of falling into them.
- Moved and movable parts should have a protective casing to avoid catching persons or animals.

Appliances operating on biogas normally have high surface temperatures. The danger of burning is high, in particular for children and strangers. A casing of non-heat-conducting material is advisable.

The mantle of the gas lamp is radioactive. The mantle has to be changed with utmost caution. Especially the inhalation of crumbling particles must be avoided. Hands should be washed immediately afterwards.

The piping system can form traps on the farm compound. As much as possible, pipes should be laid some 30 cm underground. Pits for water traps, gas meters, main valves or test-units should be cased by a concrete frame and covered with a heavy concrete lid.

Biogas - Sludge Management

Sludge storage

To retain the maximum fertilizing quality of digested slurry, i.e. its nitrogen content, it should be stored only briefly in liquid form in a closed pit or tank and then applied on the fields. Preferably, it should be dug into the soil to prevent losses on the field.

Sludge storage is normally effected according to one or the other of the following three techniques

Liquid storage

Drying

Composting

Liquid storage

The effluent outlet of the biogas system leads directly to a collecting tank. Loss of liquid due to evaporation or seepage must be avoided. Just before the sludge is needed, the contents of the tank is thoroughly agitated and then filled into a liquid manure spreader or, if it is liquid and homogenous enough, spread by irrigation sprinklers. The main advantage of liquid storage is that little nitrogen is lost. On the other hand, liquid storage requires a large, waterproof storage facility entailing a high initial capital investment.

The practice of spreading liquid slurry also presents problems in that not only storage tanks are needed, but transport vessels as well. The amount of work involved depends also on the distance over which the slurry has to be transported. For example, loading and transporting one ton of slurry over a distance of 500 m in an oxcart (200 kg per trip) takes about five hours. Distributing one ton of slurry on the fields requires another three hours.

Drying

It is only possible to dry digested sludge as long as the rate of evaporation is substantially higher than the rate of precipitation. The main advantage of drying is the resultant reduction in volume and weight. Drying can also make the manual spreading easier. The cost of constructing shallow earthen drying basins is modest. On the other hand, drying results in a near-total loss of inorganic nitrogen (up to 90%) and heavy losses of the total nitrogen content (approx. 50%).

Figure 42: Drying of digested sludge and sludge disposal in Thailand
Photo: Kossmann (gtz/GATE)

Composting

Nitrogen losses can be reduced by mixing the digested sludge with organic material. As an additive to crop residues for composting, biogas sludge provides a good source of nitrogen for speeding up the process. At the same time it enriches the compost in nitrogen, phosphorus and other plant nutrients. Furthermore, the aerobic composting process, by its temperature, effectively destroys pathogens and parasites that have survived the anaerobic digestion treatment. The ready-made compost is moist, compact and can be spread out by simple tools. With most available transport facilities in developing countries, it is easier to transport than liquid manure.

Composition of sludge

Process of biomethanation

Anaerobic digestion draws carbon, hydrogen and oxygen from the substrate. The essential plant nutrients (N,P,K) remain largely in the slurry. The composition of fertilizing agents in digested slurry depends on the fermented substrate and can, therefore, vary within certain limits.

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For an average daily substrate feed rate of 50 kg per livestock unit (LSU = 500 kg live weight) and a daily gas yield of 1 m^3 biogas/LSU, the mass of the influent substrate will be reduced by some 2% through the process of bio-methanation (volumetric weight of biogas: 1.2 kg/m^3).

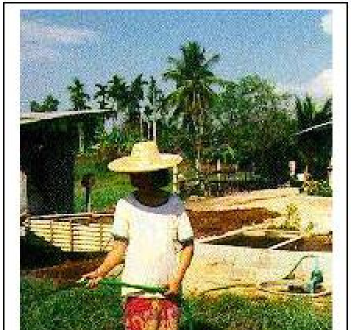
Viscosity

The viscosity of the slurry decreases significantly, because the amount of volatile solids is reduced by about 50% in the course of a stable process of fermentation. In addition, the long carbon chains (cellulose, alcohol and organic acids) are converted into short carbon chains.

Odor

The effluent sludge is much less odorous than the influent substrate (dung, urine). Given sufficient retention time, nearly all odorous substances are completely digested.

Nutrients



The fertilizing properties of digested slurry are determined by how much mineral substances and trace elements it contains. In tropical soil, the nitrogen content is not necessarily of prime importance - lateritic soils, for example, are more likely to suffer from a lack of phosphorus. All plant nutrients such as nitrogen, phosphorous, potassium and magnesium, as well as the trace elements essential to plant growth, are preserved in the substrate. The C/N ratio is reduced by the simultaneous loss of simultaneous loss of carbon, thus generally improving the fertilizing effect of the digested sludge, since a lower C/N ratio (ca. 1:15) has a favorable phytophysiological effect. Table 5 below lists the approximate nutrient contents of various substrates, whereby it should be remembered that the actual values may vary considerably, depending on fodder eaten by the animals.

Figure 43: Sludge disposal in Thailand

Photo: Kossmann (gtz/GATE)

The phosphate content ("P_2O_5" is the form of phosphorous available for plants) is not affected by fermentation. Some 50% of the total phosphorous content is available for plants in the form of phosphate. Similarly, anaerobic fermentation does not alter the rate of plant-available potassium (75 to 100% of the total potassium).

Nitrogen compounds

In contrast to the above nutrients, however, some nitrogen compounds undergo modification during anaerobic digestion. About 75% of the nitrogen contained in fresh manure is built into organic macromolecules, and 25% is available in mineral form as ammonium. The effluent sludge contains roughly 50% organic nitrogen and 50% mineral nitrogen. The stated levels can only be taken as approximate values, since they vary widely, depending on the type of animal involved, the fodder composition, the retention time, etc. Mineral nitrogen can be directly assimilated by plants, while organic nitrogen compounds must first be mineralized by microorganisms in the soil.

Fertilizing effect of effluent sludge

Digested slurry is most effective when it is spread on the fields shortly before the beginning of the vegetation period. Additional doses can be given periodically during the growth phase, with the amounts and timing depending on the crop in question. For reasons of hygiene, however, leafy vegetables should not be top-dressed.

Assuming that the soil should receive enough fertilizer to replace the nutrients that were extracted at harvesting time, each hectare will require an average dose of about 33 kg N, 11 kg P_2O_5 and 48 kg K_2O to compensate for an annual yield of 1-1.2 tons of, for example, sorghum or peanuts. Depending on the nutritive content of the digested slurry, 3-6 t of solid substance per hectare will be required to cover the deficit. For supply with a moisture content of 90%, the required quantity comes to 30-60 t per hectare and year. That roughly corresponds to the annual capacity of a 6-8 m^3 biogas plant.

Figure 44: Field experiments with sludge in Thailand
Photo: Kossmann (gtz/GATE)

Caustic effect on grassland

Digested sludge has much less caustic effect on grassland than does fresh liquid manure. Effluent sludge is also very suitable for use as a "top-dressing" whenever its application is deemed to have the best

deemed to have the best
fertilizing effect.

Eutrophication

Serious ecological damage can be done by applying fertilizing sludge in excessive amounts or at the wrong time, namely when the assimilative capacity of the plants is low. Nitrogen "washout" can cause over-fertilization (eutrophication) of ground and surface water.

Annual Manure Yield and Nutrient Content of Animal Excrements

Table 5: Annual manure yield and nutrient content of cow, pig and chicken excrements; compiled from various sources

Total annual yield [kg/LSU/a] and percentage shares							
	Total Wt.	TS		VS		N	
	kg/a kg/a [%] kg/a [%] kg/a [%]						
Cow	16,100 1850 11.6 1400 8.7 77						0.5
Pig	13,500 1130 8.4 900 6.7 102 0.8						
Chicken (fresh droppings) 18,250 4020 22.0 3170 17.4 232 1.3							
Chicken (dry droppings) 4,230	3390 80			2560 60		146 3.5	

Total annual yield [kg/LSU/a] and percentage shares					Nutritive ratio (P_2O_5= 1)	
	P_2O_5		K_2O			
	kg/a	[%]		[%]	$_2O_5$	K_2O

		kg/a		NP			
Cow	34	0.2	84	0.5	2.3 1 2.5		
Pig	56	0.4	35	0.3	1.8 1 0.6		
Chicken (fresh droppings)	194	1.0	108	0.6	1.2 1 0.6		
Chicken (dry droppings)	193	4.6	106	2.5	0.8 1 0.6		

Source: Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries, Schriftenreihe der gtz, No. 97, pp. 71-72; after: Rager, K. Th.: Abwassertechnische und wasserwirtschaftliche Probleme der Massentierhaltung; Darmstadt, FRG, 1971, p. 38

LSU = livestock unit (= 500 kg live weight)
TS = Total solids
VS = Volatile solids

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Maintainance, Monitoring and Repair

The maintenance of a biogas plant comprises all work which is necessary to guarantee trouble-free operation and a long working life of the plant. Repair reacts to breakdowns of the biogas system. Maintenance services should be carried out by the manager or main operator of the biogas plant or a well-trained biogas technician. One has to bear in mind that measurements indicating problems may be wrong. All doubtful measurements have to be verified. Often, one symptom has a variety of possible reasons.

Daily maintenance work

Control	Mistakes	Removal
gas pressure	gas pressure too high; (gas pressure rises, if gas consumption is lower than the production and if the gas storage is full)	The pressure relief valve malfunctions - it should be cleaned or renewed;
	gas pressure too low; (gas pressure falls, if the consumption (including leakage!) is higher than the production and if the gas storage is empty);	leakage in gas conducting parts: find out the leakage and seal; gas production has fallen: check the sludges quality;
substrate temperature (heated plants)		defective heating control

(bacteria are very sensitive to temperature extremes and fluctuations);	temperature too high;	system. Check control system and repair or exchange part(s) concerned;
	temperature too low;	defective heating control system. Check control system and other concerned part(s), repair or exchange; sediment layer on the heating surface: remove layer;
gas production	gas production clearly under normal levels;	biological reasons: temperature, substrate, antibiotics, change of pH-value; leakage in digester or piping system; blocked gas pipes due to water or alien elements; identify problem and act accordingly;
strong sludge odor	plant is overloaded or fermenting conditions are sub-optimal;	reduce substrate intake; correct pH-value with adequate means;

Weekly/monthly (prophylactic) maintenance work

clean gas appliances;

lubricate movable parts (slides, guiding frame of floating drum plants, taps etc.);

servicing of biogas-driven engines within the prescribed time intervals;

maintenance of pressure relief valves and under pressure valves;

maintenance of slurry agitator / mixer;

control gas appliances and fittings on tightness and function

Control of functions

Control	Mistakes	Removal
water separator non-automatic	water separator is full;	empty the water separator;
piping system	no water is collected in the water separator; gradient of the pipes is wrong;	Reinstall pipes in a way that condensation flow leads to the water separator;
pressure relief and under pressure valves	non-functioning	clean valves or renew them

Annual maintenance work

Check the plant in respect of corrosion and, if necessary, renew protective coating material;

material;

Check the gas pipes for gas tightness (pressure check). If necessary, search the leakage and repair the parts concerned. Note: minor gas leakage is usually undetected during normal operation as it is compensated by gas production

Monitoring

Monitoring subsumes all activities of data collection regarding an individual biogas unit or biogas programs. Collecting data on the performance of biogas units is necessary to

detect problems in the units performance;

to have a base for economic evaluation;

to have a base for comparing different models and different modes of operation

Measurements and other data which become necessary for the optimization of the existing biogas unit should be recorded by the owner or by a person appointed by him/her. The records should include the following data:

The amount and type of substrate, incl. the amounts of mixing water.

The substrate temperature, if necessary at various stages of the substrate flow (heated plants). By measuring the substrate temperature, faults in the heating system can be detected.

Gas production: measurements are carried out with a gas meter between the digester and the gas-holder (gas production) or between the gas-holder and the points of consumption (gas consumption). In simple plants, the gas production can be estimated during times of no consumption. Changes in gas production and the speed by which these changes occur give valuable hints on the nature of the problem.

Electricity and heat production from co-generation units;

pH-value (monthly); recorded substrate intake;

content of hydrogen sulfide in the gas (monthly);

analysis of the fertilizing value of biogas slurry (annually or seasonally) to determine the optimal amount of slurry to be spread on the fields.

Records on breakdowns and their causes. By means of previously recorded breakdowns it is easier to compare the breakdowns and detect the reasons for failure.

Beyond this, there are various institutions, associations and companies which carry out series of measurements for different kinds of biogas plants. These series of measurements, records and evaluations analyze errors with the objective to disseminate and optimize biogas technology as well as to avoid mistakes of the past.

Repair

Breakdowns which might appear when operating biogas plants are described in the following. The most frequently occurring disturbance is insufficient gas production which can have a variety of different reasons. Sometimes observations and experiments might take weeks until a perfect solution is found.

Disturbances	Possible reasons	Measures to be taken
blocked inlet/outlet pipe	fibrous material inside the pipe or sinking layer blocking the lower end of the pipe	cleaning up the pipe with a pole; removing sinking layer by frequent poking through inlet and outlet pipe.
floating drum is stuck	swimming layer	turn the dome more frequently; if turning not possible, take off the dome and remove the swimming layer
	broken guiding frame	weld, repair and grease guiding frame
sinking		if cracks in the digester do not self-seal

sludge level	digester not water tight;	within weeks; empty digester and seal cracks;
insufficient gas storage	gas store not gas-tight due to cracks or corrosion	seal cracks, replace corroded parts;
blocked taps	corrosion	open and close several times, grease or replace taps;
gas pipe is not tight	corrosion or porosity; insufficient sealing of connections;	identify leaking parts; replace corroded or porous parts; re-seal connections
sudden gas loss	8. crack in the gas pipe 9. automatic water trap blown empty 10. open gas tap	4. repair or replace 5. add/refill water, detect reason for over-pressure; check dimensioning of the water-trap 6. close tap
throbbing gas pressure	1. water in the gas pipe 2. blocked gas pipe	1. check functioning of water trap; install water traps in depressions of piping system or eliminate these depressions; 2. identify the blocked parts (start with gas outlet, connections to appliances and bends); clean the respective parts;

Repair measures are being taken in case of acute disturbances or during routine maintenance work. Repair measures which go beyond routine maintenance work have to be carried out by specialists, since the biogas plant owner in most cases does not have the required tools and the necessary technical know-how. In any case, annual maintenance

service should be carried out by a skilled biogas technician.

In industrialized countries with large plants and good infrastructure, a professional biogas service can cover a large area. In developing countries with scattered small scale biogas units, logistical problems can severely hamper the evolution of a professional and commercial biogas service. To ensure that built biogas units are maintained and, if necessary, repaired, the following approaches are conceivable:

- The farmer technician approach: out of a group of biogas farmers, an outstanding individual is encouraged to undergo maintenance and repair training to take this up as a side job. Emphasis has to be placed on management training. To make his enterprise sustainable, the farmer technician should gain a reasonable income.
- The cluster approach: if the demand for biogas plants is high, the biogas project or the biogas company can attempt to install biogas units in a regional clustering to minimize distances for the maintenance service.
- The subsidized transport approach: a professional biogas technician is supported with transport by the biogas project or government departments (e.g. agricultural extension, veterinary service). The technician can also receive a bicycle or small motorbike as an initial input, running costs can either initially be shared by the biogas project or directly be charged to the farmers.

However the logistical problems may be solved, the critical ingredient for the evolution of a professional and commercial biogas service is the training of the technicians-to-be both in technical and managerial terms. Experience shows, that this can take several years. Biogas projects should, therefore, plan with a not too narrow time horizon.

Biogas Utilization

Gas production

If the daily amount of available dung (fresh weight) is known, gas production per day in warm tropical countries will approximately correspond to the following values:

1 kg cattle dung 40 liters biogas

1 kg buffalo dung 30 liter biogas

1 kg pig dung 60 liter biogas

1 kg chicken droppings 70 liter biogas

If the live weight of all animals whose dung is put into the biogas plant is known, the daily gas production will correspond approximately to the following values:

cattle, buffalo and chicken: 1,5 liters biogas per day per 1 kg live weight

pigs, humans: 30 liters biogas per day per 1 kg weight

Conditioning of biogas

Sometimes the biogas must be treated/conditioned before utilization. The predominant forms of treatment aim at removing either water, hydrogen sulfide or carbon dioxide from the raw gas:

Reduction of the moisture content

The biogas is usually fully saturated with water vapor. This involves cooling the gas, e.g. by routing it through an underground pipe, so that the excess water vapor condenses at the lower temperature. When the gas warms up again, its relative vapor content "decreases". The "drying" of biogas is especially useful in connection with the use of dry gas meters, which otherwise would eventually fill up with condensed water.

Reduction of the hydrogen-sulfide content

The hydrogen sulfide in the biogas combines with condensing water and forms corrosive acids. Water-heating appliances, engines and refrigerators are particularly at risk. The reduction of the hydrogen sulfide content may be necessary if the biogas contains an excessive amount, i.e. more than 2% H_2S. Since most biogas contains less than 1% H_2S, de-sulfurization is normally not necessary.

For small- to mid-size systems, de-sulfurization can be effected by absorption onto ferric hydrate ($Fe(OH)_3$), also referred to as bog iron, a porous form of limonite. The porous, granular purifying mass can be regenerated by exposure to air.

The absorptive capacity of the purifying mass depends on its iron-hydrate content: bog iron, containing 5-10% $Fe(OH)_3$, can absorb about 15 g sulfur per kg without being regenerated and approximately 150 g/kg through repetitive regeneration. It is noteworthy that many types of tropical soils (laterite) are naturally ferriferous and suitable for use as purifying mass.

Another de-sulfurization process showing good results has been developed in Ivory Coast and is applied successfully since 1987. Air is pumped into the gas store at a ratio of 2% to 5 % of the biogas production. The minimum air intake for complete de-sulfurization has to be established by trials. Aquarium pumps are cheap and reliable implements for pumping air against the gas pressure into the gas holder. The oxygen of the air leads to a bio-catalytic, stabilized separation of the sulfur on the surface of the sludge. This simple method works best, where the gas holder is above the slurry, as the necessary bacteria require moisture, warmth (opt. 37C) and nutrients.

In industrialized countries and for large plants, this process has meanwhile reached satisfactory standard. For small scale plants in developing countries, however, using an electric pump becomes problematic due to missing or unreliable electricity supply. Pumping in air with a bicycle pump works in principle, but is a cumbersome method that will be

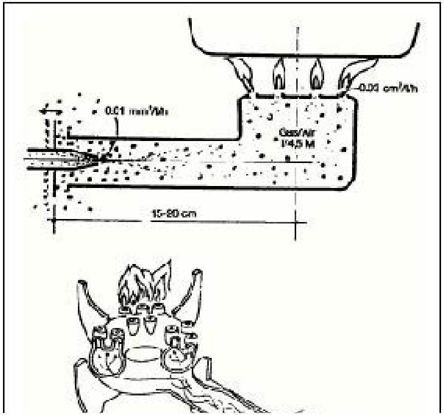
abandoned
sooner or
later.

Avoiding de-sulfurization altogether is possible, if only stainless steel appliances are used. But even if they are available, their costs are prohibitive for small scale users.

Reduction of the carbon-dioxide content

The reduction of the carbon-dioxide content is complicated and expensive. In principle, carbon-dioxide can be removed by absorption onto lime milk, but that practice produces "seas" of lime paste and must therefore be ruled out, particularly in connection with large-scale plants, for which only high-tech processes like micro-screening are worthy of consideration. CO_2"scrubbing" is rarely advisable, except in order to increase the individual bottling capacity for high-pressure storage.

Biogas burners



In developing countries, the main prerequisite of biogas utilization is the availability of specially designed biogas burners or modified consumer appliances. The relatively large differences in gas quality from different plants, and even from one and the same plant (gas pressure, temperature, caloric value, etc.) must be given due consideration.

The heart of most gas appliances is a biogas burner. In most cases, atmospheric-type burners operating on premixed air/gas fuel are preferable. Due to complex conditions of flow and reaction kinetics, gas burners defy precise calculation, so that the final design and adjustments must be arrived at experimentally. Compared to other gases, biogas needs less air for combustion. Therefore, conventional gas appliances need larger gas jets when they are used for biogas combustion. About 5.7 liters of air are required for the complete combustion of one liter of biogas, while for butane 30.9 liters and for propane 23.8 liters are required.

Figure 45: Schematic diagram of a gas burner
Source: Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries, Schriftenreihe der gtz No. 97, pg.185

The modification and adaptation of commercial-type burners is an experimental matter. With regard to butane and propane burners, i.e. the most readily available types, the following pointers are offered:

Butane/propane gas has up to three times the caloric value of biogas and almost twice its flame-propagation rate.

Conversion to biogas always results in lower performance values.

Practical modification measures include:

expanding the injector cross section by factor 2-4 in order to increase the flow of gas;

modifying the combustion-air supply, particularly if a combustion-air controller is provided;

increasing the size of the jet openings (avoid if possible).

The aim of all such measures is to obtain a stable, compact, slightly bluish flame.

Efficiency

The calorific efficiency of using biogas is 55% in stoves, 24% in engines, but only 3% in lamps. A biogas lamp is only half as efficient as a kerosene lamp. The most efficient way of using biogas is in a heat-power combination where 88% efficiency can be reached. But this is only valid for larger installations and under the condition that the exhaust heat is used

profitably. The use of biogas in stoves is the best way of exploiting biogas energy for farm households in developing countries.

appliances	gas lamps	engines gas	stoves	power-heat
efficiency [%]	3	24	55	88

Figure 46: Different types of Biogas burners at an agricultural exhibition in Beijing/China
Photo: Grosch (gtz/GATE

For the utilization of biogas, the following consumption rates in liters per hour (l/h) can be assumed:

household burners: 200-450 l/h

industrial burners: 1000-3000 l/h

refrigerator (100 l) depending on outside temperature: 30-75 l/h

gas lamp, equiv. to 60 W bulb: 120-150 l/h

biogas / diesel engine per bhp: 420 l/h

generation of 1 kWh of electricity with biogas/diesel mixture: 700 l/h

plastics molding press (15 g, 100 units) with biogas/diesel mixture: 140 l/h

Biogas can also be used for various other energy requirements in the project region. Refrigerators and chicken heaters are the most common applications. In some cases biogas is also used for roasting coffee, baking bread or sterilizing instruments.

Figure 47: Co-generation unit (electricity and heat utilisation)
Photo:

Krmer
(TBW)

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Gas demand

In developing countries, the household energy demand is greatly influenced by eating and cooking habits. Gas demand for cooking is low in regions where the diet consists of vegetables, meat, milk products and small grain. The gas demand is higher in cultures with complicated cuisine and where whole grain maize or beans are part of the daily nourishment. As a rule of thumb, the cooking energy demand is higher for well-to-do families than for poor families. Energy demand is also a function of the energy price. Expensive or scarce energy is used more carefully than energy that is effluent and free of charge.

The gas consumption for cooking per person lies between 300 and 900 liter per day, the gas consumption per 5-member family for 2 cooked meals between 1500 and 2400 liter per day.

In industrialized countries, biogas almost always replaces existing energy sources like electricity, diesel or other gases. The objective of biogas production may be less to satisfy a certain demand, but to produce biogas as much and as cheap as possible. Whatever surplus is available can be fed as electricity into the grid. The gas demand is market-driven, while in developing countries, the gas demand is needs-driven.

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Gas Yields and Methane Contents for Various Substrates

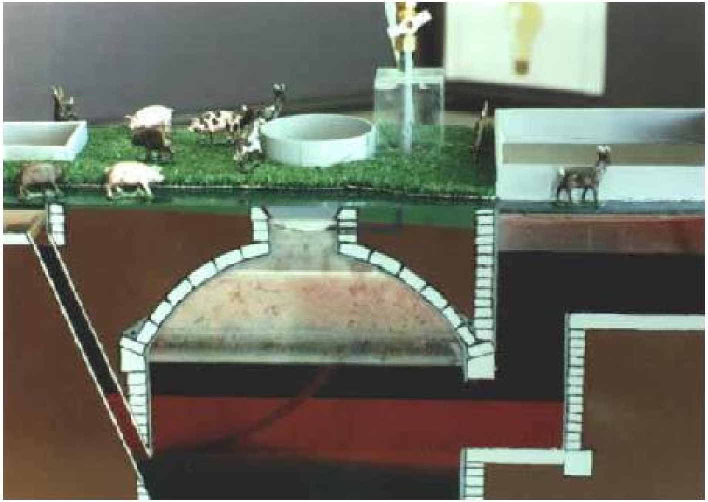
Table 6: Gas yields and methane contents for various substrates at the end of a 10-20 day retention time at a process temperature of roughly 30C.

Substrate	Gas yield (l/kg VS*)	Methane content (%)
Pig manure	340-550	65-70
Cow manure	90-310	65
Poultry droppings	310-620	60
Horse manure	200-300	
Sheep manure	90-310	
Barnyard dung	175-280	
Wheat straw	200-300	50-60
Rye straw	200-300	59
Barley straw	250-300	59
Oats straw	290-310	59
Corn straw	380-460	59
Rape straw	200	
Rice straw	170-280	
Rice seed coat	105	
Flax	360	59

Hemp	360	59
Grass	280-550	70
Elephant grass	430-560	60
Cane trash (bagasse)	165	
Broom	405	
Reed	170	
Clover	430-490	
Vegetables residue	330-360	
Potato tops/greens	280-490	
Field/sugar beet greens	400-500	
Sunflower leaves	300	59
Agricultural waste	310-430	60-70
Seeds	620	
Peanut shells	365	
Fallen leaves	210-290	58
Water hyacinth	375	
Algae	420-500	63
Sewage sludge	310-740	

Source: Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries, Schriftenreihe der gtz, No. 97, pg. 63, after: Felix Maramba, Biogas and Waste Recycling - The Phillipine Experience; Metro Manila, Phillipines, 1978

*VS = Total volatile solids, e.g. ca. 9% of total liquid manure mass for cows .



Biogas Digest

Volume III

Biogas - Costs and Benefits

and

Biogas Programme Implementation

Information and Advisory Service on Appropriate Technology

Imprint

This information service on biogas technology has been developed and produced on the order of the GTZ project Information and Advisory Service on Appropriate Technology (ISAT) for the ISAT Website in a collaborative effort of the following institutions and individuals:

Concept and contents:

Werner Kossmann, Uta Pnitz

Information and Advisory Service on Appropriate Technology (ISAT)
GATE in Deutsche Gesellschaft fr Technische Zusammenarbeit (GTZ), GmbH
(German Agency for Technical Cooperation)
Post Box 5180
D-65726 Eschborn
Federal Republic of Germany
Telephone: +49 6196/79-0
Fax: +49 6196/797352
E-

mail:
gate-
Stefan Habermehl
isat@gtz.de
Household Energy Appropriate Technologies (HEAT) GmbH
Limburger Strae 29
D-61479 Glashtten
Federal Republic of Germany
Telephone: +49 6174 964077
Fax: +49 6174 61209
E-mail: heatinternational@t-online.de

Thomas Hoerz, Pedro Krmer, B. Klingler, C. Kellner, Thomas Wittur, F. v. Klopotek, A. Krieg, H. Euler

Naturgerechte Technologien, Bau- und Wirtschaftsberatung (TBW) GmbH
Baumweg 10
60316 Frankfurt
Tel.: 069 943507-0
Fax: 069 943507-11
E-mail: tbw@pop-frankfurt.com

Design:

Utz Dornberger
Stckelstr. 20
04347 Leipzig
Tel.: 0341 2334980
E-

mail:
utz@imb
-
jena.de

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Biogas - Costs and Benefits

Economy and Financing

Techno-economic assessment

Before a biogas plant is built or a biogas program is implemented, a techno-economic assessment should be made. For this, two sets of cost-benefit analyses have to be carried out:

- The macro-economic analysis (economic analysis) which compares the costs of a biogas program and the benefits for the country or the society.
- The micro-economic analysis (financial analysis) which judges the profitability of a biogas unit from the point of view of the user.

In judging the economic viability of biogas programs and -units the objectives of each decision-maker are of importance. Biogas programs (macro-level) and biogas units (micro-level) can serve the following purposes:

- the production of energy at low cost (mainly micro-level);
- a crop increase in agriculture by the production of bio-fertilizer (micro-level);
- the improvement of sanitation and hygiene (micro and macro level);
- the conservation of tree and forest reserves and a reduction in soil erosion (mainly macro-level);
- an improvement in the conditions of members of poorer levels of the population (mainly macro-level);

a saving in foreign exchange (macro-level);

provision of skills enhancement and employment for rural areas (macro-level).

Comparison with other alternatives

After selecting objectives and counterchecking if biogas technology can fulfill the objectives at an acceptable cost-benefit ratio, it is still not certain, that expenses are invested in the best possible way. For this, a comparison with other alternatives to biogas programs and biogas plants is necessary. The expected cost and benefits are to be shown in the form of suitable investment criteria to allow statements regarding the economic advantage of the project. Often, alternatives to biogas have only a benefit-overlap with biogas and several alternatives have to be combined to produce the same quantity and quality of benefits.

On the other hand, alternatives to biogas programs may have benefits that a biogas program cannot deliver. Afforestation programs, for example, deliver energy and soil protection, but also building material.

Apart from the viability of the project, its financial effects on the decision-makers and the parties it touches financially are important: are a certain group of farmers able to invest in a long-term project like biogas generation. The cost per m^3 of biogas and the cost for the same amount of alternative energy forms the basis for most economic comparisons.

Considering development tendencies

The economic analysis should not only be limited to the initial period of operation of a biogas plant. Development tendencies should also be considered which influence the amount and structure of the costs and benefits set against the economic lifetime of the plant. Here, special attention should be paid to the development in supply from other sources of energy which compete with biogas. The national economic development of the country in question features in as well. If import substitution to save foreign currency is one of the primary objectives, biogas energy and biogas fertilizer may be valued highly. If a stronger world market integration is envisaged energy and fertilizer from biogas has to compete directly with internationally traded energy and fertilizers.

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Economic evaluation of a biogas plant

- The benefits for individual households (biogas, biodung, etc.)
- Costs of a biogas plant (production, running and capital costs)
- Cost benefit relation
- Macro-economic evaluation (ecological and social effects, etc.)
- Financing and public support

Social policies

Biogas technology not only supports national economies and the environmental protection, but as its main outcome for the local population it provides for a wide range of improvements in overall living conditions. Sanitary and health conditions improve and the quality of nutrition is enhanced by an improved energy availability. Through the provision of lighting and the reduction of time-consuming fuel gathering cultural and educational activities are supported.

Employment, professional qualification and overall food supply of the local population can be improved as well. But biogas technology can also contribute to an accentuation of existing differences in family income and property. Establishing community-level biogas systems is a way to ensure that the technology benefits a greater number of residents.

If social policies of a developing country are clearly focusing on poverty alleviation, biogas technology may not be the first choice among other "village technologies". Its place is shifting rather towards the rural agricultural middle class, communities (for waste water treatment) and industries.

Benefits for the environment

For many years the rational behind using biogas technology (or anaerobic technology) was the search for renewable sources of energy. In the meantime, other environmental protection aspects gain additional importance: A technology which previously just filled a "niche" is now becoming a key environmental technology for integrated, solid and liquid waste treatment concepts and climate protection both in industrialized and developing countries. Biogas technology is linked to the atmospheric budgets of many greenhouse gases. Another major environmental target is the mitigation of deforestation and soil erosion through the substitution of firewood as an energy source. The macro-economic benefits from biogas use in this field should be approached within the scope of the specific condition in the household energy sector and possible alternative protection measures.

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The Benefits for Biogas Users

Individual households judge the profitability of biogas plants primarily from the monetary surplus gained from utilizing biogas and bio-fertilizer in relation to the cost of the plants. The following effects, to be documented and provided with a monetary value, should be listed as benefits:

- expenditure saved by the substitution of other energy sources with biogas. If applicable, income from the sale of biogas;
- expenditure saved by the substitution of mineral fertilizers with bio-fertilizer. Increased yield by using bio-fertilizer. If applicable, income from the sale of bio-fertilizer;
- savings in the cost of disposal and treatment of substrates (mainly for waste-water treatment);
- time saved for collecting and preparing previously used fuel materials (if applicable), time saved for work in the stable and for spreading manure (if this time can be used to generate income).

Monetarizing individual benefits

The economic evaluation of the individual benefits of biogas plants is relatively simple if the users cover their energy and fertilizer demands commercially. In general, the monetary benefits from biogas plants for enterprises and institutions as well as from plants for well-to-do households should be quite reliably calculable. These groups normally purchase commercial fuels e.g. oil, gas and coal as well as mineral fertilizers. In industrialized countries, it is common practice to feed surplus electric energy, produced by biogas-driven generators, in the grid. Biogas slurry is a marketable product and the infrastructure allows its transport at reasonable cost. Furthermore, treatment of waste and waste water is strictly regulated by law, causing communes, companies and farmers expenses which, if reduced with the help of biogas technology, are directly calculable benefits.

In contrast, small farmers in developing countries collect and use mostly traditional fuels and fertilizers like wood, harvest residues and cow dung. No direct monetary savings can be attributed to the use of biogas and bio-fertilizer. The monetary value of biogas has to be calculated through the time saved for collecting fuel, the monetary value for bio-fertilizer through the expected increase in crop yields.

Both in theory and in practice, this is problematic. In practice, a farmer would not value time for fuel collection very highly as it is often done by children or by somebody with low or no opportunity costs for his/her labor. In theory, it is difficult to define the value of unskilled labor. Similarly, the improved fertilizing value of biogas slurry will not be accepted by most farmers as a basis for cost-benefit analysis. They tend to judge the quality of slurry when counting the bags after harvest. Because a monetary calculation is not the only factor featuring in the decision to construct and operate a biogas plant, other factors come in which are less tangible: convenience, comfort, status, security of supply and others that could be subsumed under life quality.

Acceptance by the target group

Besides the willingness and ability to invest considerable funds in biogas technology, there is a complex process of decision making involved when moving from traditional practices to a modern way of producing fertilizer and acquiring energy. Hopes and fears, expected reactions from the society, previous experiences with modern technology, all these feature in a decision. For a biogas program, it is important to realize that economic considerations are only part of the deciding factors in favor or against biogas technology. All these factors can be subsumed under acceptance.

Acceptance is not a collection of irrational, economically unjustifiable pros and cons that a biogas extension project is called upon to dissolve. Rural households, as a rule, take rational decisions. But rural households and biogas programs often have information deficits that lead to non-acceptance of biogas technology by the target groups. Bridging lead to non-acceptance of biogas technology by the target groups. Bridging this information

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gap from the farmer to the project and vice versa is a precondition for demonstrating the economic viability in a way that is understandable, relevant and acceptable to the farmer.

Energy

The main problem in the economic evaluation is to allocate a suitable monetary value to the non-commercial fuels which have so far no market prices. For the majority of rural households biogas is primarily a means of supplying energy for daily cooking and for lighting. They use mainly firewood, dried cow dung and harvest residues as fuel. But even if the particular household does not purchase the required traditional fuel, its value can be calculated with the help of fuel prices on the local market. Theoretically, the firewood collector of the family could sell the amount that is no longer needed in the household

As an example, the rural households in India use the following quantities of non-commercial fuel per capita daily:

- firewood: 0.62 kg
- dried cow dung: 0.34 kg
- harvest residues: 0.20 kg

For rural households in the Peoples Republic of China the daily consumption of firewood is similar: between 0.55 - 0.83 kg per person.

Which sources of energy have been used so far and to what extent they can be replaced must be determined for the economic evaluation of biogas by means of calorific value relations. The monetary benefits of biogas depend mainly on how far commercial fuels can be replaced and their respective price on the market.

1 m^3 Biogas (approx. 6 kWh/m^3) is equivalent to:

Diesel, Kerosene (approx. 12 kWh/kg)	0.5 kg
Wood (approx. 4.5 kWh/kg)	1.3 kg
Cow dung (approx. 5 kWh/kg dry matter)	1.2 kg
Plant residues (approx. 4.5 kWh/kg d.m.)	1.3 kg
Hard coal (approx. 8.5 kWh/kg)	0.7 kg
City gas (approx. 5.3 kWh/m^3)	1.1 m^3
Propane (approx. 25 kWh/m^3)	0.24 m^3

Bio-fertilizer

Improvement in quality of farmyard manure

If and to which extent biogas slurry can be monetarized as benefit, depends largely on the previous use of the substrate to be digested. The more wasteful the present method of utilizing farmyard manure is, the easier it is to monetarize benefits. In most traditional systems, for example, the urine of livestock is not collected as manure. Often, the dung and fodder residues are heaped in the open, leading to heavy losses of minerals through sun radiation and wash-out by rain. The following seven steps can lead to an approximate assessment of the monetary value of bio-fertilizer:

1. Assess quantities (tons dry matter) of farmyard manure which reaches the fields per year.
2. Analyze a cross section of the farmyard manure for plant macro-nutrients (N, P, K) per kg dry matter shortly before the manure is spread on the field.
3. Calculate the amount of NPK which is available for the farm from traditional farmyard manure.
4. Assess quantities of biogas slurry (tons of dry matter) to be expected with the given numbers of livestock, amounts of plant residues to be digested and numbers of persons using the latrine attached to the biogas plant.

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5. Analyze the biogas slurry of a comparable biogas owners nearby for plant macro-nutrients (N, P, K) per kg dry matter.
6. Calculate the amount of NPK which would be available on the farm through commercial slurry.
7. To value the monetary difference in NPK availability, the most commonly used fertilizer in the area should be chosen which can close the nutrient gap. If compost or other organic fertilizers are traded, they should be given preference (and a nutrient analysis undertaken beforehand).

The analysis above is obviously a method which cannot be employed for every potential biogas user as it is expensive and time-consuming. A biogas program would analyze the monetary value of bio-fertilizer exemplary for a number of cases and approximate others on this basis. This method, however, is superior to judging increased crop yields with the help of bio-fertilizer. Crop yields depend on a multitude of factors, the fertilizer being only one of many.

Depending on the topography, distributing slurry can save labor or add to the labor demand. The additional time needed or savings in time must feature in the calculation. In some cases, it is not possible to spread the slurry in liquid form, it has to be dried or composted first. In this case, NPK contents have to be measured in the compost or dried slurry and labor for composting or drying recorded.

Increased yield

Biogas programs, however, should not neglect the argument of improved yields. Increases in agricultural production as a result of the use of bio-fertilizer of 6 - 10 % and in some cases of up to 20 % have been reported. Although improved yields through biogas slurry are difficult to capture in a stringent economic calculation, for demonstration and to capture in a stringent economic calculation, for demonstration and extension farmer-to-farmer they are very effective. Farmers should be encouraged to record harvests on their plots, before and after the introduction of biogas.

Statements of farmers like: "Since I use biogas slurry, I can harvest two bags of maize more on this plot" may not convince economists, but they are well understood by farmers.

Saved disposal cost as benefit

Saving disposal cost as a benefit of a biogas system applies mainly in countries where the disposal of waste and waste water is regulated by law and where disposal opportunities exist. In industrialized countries, these costs are known and calculable.

In developing countries, industrial waste or waste from large agricultural enterprises are being taken increasingly serious. But often it is only after creating a conflict with local authorities or the local population, that the management is forced to consider proper waste disposal. The cost of continued conflict may be high and go as far as a forced closure of the enterprise. The entrepreneur will search for the cheapest acceptable solution to treat the waste. Taking the energy generation of anaerobic digestion into account, biogas technology may indeed offer the most economic solution.

In rural households, human feces are collected in pit latrines. Once the pit latrines are full, they are filled with soil and a new pit is dug. Normally, this happens every two years. Excavation costs and costs for shifting or casting the slab can be saved and calculated as benefit. If a septic tank is used, the emptying cost can be counted as benefit. The saved construction cost of the septic tank can only be counted as benefit, if the toilet connection to the inlet of a biogas digester competes with the construction of a septic tank, i.e. the septic tank has not been built yet.

Time consumption

A critical shortage of energy, primarily of firewood, is reflected less in the market prices than in the time the households - especially women and children - need to collect fuelwood. The time commonly spent for collection varies from several hours per week to several hours per day. In some areas of Africa and Asia, firewood collection is the single most day. In some areas of Africa and Asia, firewood collection is the single most

time consuming

activity for a housewife. The open fire has to be attended almost permanently, in particular if

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low grade fuels like cow-dung or straw is burnt. Additional work is caused by the soot of an open fire - clean, shiny pots are a status symbol in many cultures. Compared to this, the time needed to operate a biogas plant is normally low so that in most cases a considerable net saving can be realized.

A financial evaluation of this time-saving is not easy. If the additional time can be used for productive purposes, the wages or the value of the contribution to production can be calculated. Frequently there are - in the short run - no suitable employment opportunities for women or children. To come to a proxy value of the saved time either the value of the collected firewood or the most likely employment opportunity can be employed for calculation.

Even if there is no income generating utilization of time saved there is a benefit to the individual and the household which could provide a convincing argument. The utilization of biogas saves time but also makes cooking more comfortable in comparison to the traditional methods, smoke and soot no longer pollute the kitchen. Especially in the morning rush, a biogas flame is much easier to start than an open fire. Again, it is a question of life quality, something which cannot be valued in monetary terms, but for which people are willing to pay.

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Costs of a Biogas Plant

Exact estimations for the construction and operation of biogas plants serve the following purposes:

- to compare the costs of alternative models (optimal project selection)
- for the information of the users as far as future financial burdens are concerned
- the calculation of financing needs including public subsidies (budget planning)

Categories of costs

As far as costs are concerned there are three major categories:

- manufacturing or acquisition costs (production costs)
- operation and maintenance costs (running costs)
- capital costs

Production costs

The production costs include all expenses and lost income which are necessary for the erection of the plant e.g.: the land, excavation-work, construction of the digester and gas-holder, the piping system, the gas utilization system, the dung storage system and other buildings. The construction costs comprise wages and material.

The production costs of biogas plants are determined by the following factors:

- purchasing costs or opportunity costs for land which is needed for the biogas plant and slurry storage;
- model

model of the biogas plant;

size and dimensioning of the biogas unit

amount and prices of material

labor input and wages

the degree of participation of the future biogas user and his opportunity costs for labor.

Total costs

To gain a rough idea of the typical costs of a simple, unheated biogas plant, the following figures can be used: total cost for a biogas plant, including all essential installations but not including land, is between 50-75 US Dollar per m^3 capacity. 35 - 40% of the total costs are for the digester.

The specific cost of gas production in community plants or large plants is generally lower compared with small family plants. The cost for the gas distribution (mainly piping) usually increases with the size of the plant. For communal plants with several end-users of biogas, the piping costs are high and compensate the degression by economics of size partly or wholly. In regions where plant heating is necessary, large-scale plants would be more economical .

To keep the construction costs low, labor provided by the future biogas users is desirable. Often, the whole excavation work is done without hired labor. On the whole, a reduction of up to 15% of the wages can be effected by user-labor. If periods of low farm activities are chosen for the construction of the biogas plant, opportunity costs for labor can be kept low.

Running costs

The operation and maintenance costs consist of wage and material cost for:

acquisition (purchase, collection and transportation) of the substrate;

water supply for cleaning the stable and mixing the substrate;

feeding and operating of the plant;

supervision, maintenance and repair of the plant;

storage and disposal of the slurry;

gas distribution and utilization;

administration.

The running costs of a biogas plant with a professional management are just as important as the construction costs, for example for operation, maintenance, expenses for painting, service and repair.

Large-scale biogas plants

Large-scale biogas plants have a high water consumption. Investigations are necessary, if the water quantity required causes additional costs in the long run. These could be construction costs for water piping or fees for public water supply. The question of water rights has to be clarified. Steps to be taken to cover the demand for water during dry periods require thorough planning.

Capital costs

Capital costs consist of redemption and interest for the capital taken up to finance the construction costs. For dynamic cost comparison the capital fixed in the plant is converted into equal annual amounts.

Interest rate

The capital cost, apart from the depreciation rates or length of amortisation, is dependent on the interest rate at which the capital is provided. In each case current interest rates are to be laid down for the cost calculation, which reflect the opportunity costs of the invested capital. To avoid distortions of the financing costs the comparisons should always be calculated with the

the same interest rate.

Lifetime of plants

In calculating the depreciation, the economic life-span of plants can be taken as 15 years, provided maintenance and repair are carried out regularly. Certain parts of the plant have to be replaced after 8 - l0 years, e.g. a steel gas holder. The steel parts need to be repainted every year or every second year. As a rule, real prices and interest rates should be used in the calculations. For cost calculation inflation rates are irrelevant as long as construction costs refer to one point of time. However, in calculating the cash reserves put aside for servicing and repair the inflation rate must be considered.

Average costs

The cost per cubic meter of digester volume decreases as volume rises. Therefore, the appropriate size of the biogas plant should be estimated. For simple, unheated plants in tropical countries, the digester size is roughly:

120-fold the quantity of substrate put in daily at average expected digester temperatures over 25C and

180-fold the quantity of daily feeding for temperature between 20 and 25C.

Since the final method of construction is only determined during the first years of a biogas project, it is impossible to exactly calculate the building costs ahead of the actual implementation. The GTZ computer program called "BioCalc" (produced by BioSystem), can only provide an idea as it is based on only one type of plant. Consequently, the following system is sufficient for a rough calculation:

the cost of 6.5 sacks of cement x m^3 digester volume plus

the cost of 5 days work for a mason x m^3 digester volume plus

the costs of 100 m gas pipes (1/2"), plus

the costs of two ball valves (1/2"), plus

the cost of gas appliances which are feasible for this size.

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The individual prices are to be determined for the project location. The sum then includes material and wages. The distance from the biogas plant to the point of gas consumption was assumed as being 25 m (the 100 m used in the calculation include costs for connectors and wages). Where greater distances are involved, the cost for gas pipes will have to be increased in proportion.

Macro-economic evaluation

Objective

The economic analysis assesses a project in the context of the national economy rather than of the project sponsor (i.e. private enterprise or a public authority).This means that government economic policy has to take into account the effects of a project on the national or regional economy as a whole.

The decisive difference between the economic analysis and the financial analysis is the way in which inputs and outputs are valued. The financial costs of resources, which are expressed by market prices, differ from their economic values. This is due to the fact that market prices do not reflect true marginal social costs and thus do not match with the actual value of consumed scarce economic resources.

Economic effects of biogas plants

When evaluating biogas plants from a macro-economic point of view there are several reasons why price adjustments in favour of the biogas technology are required.

- The production of biogas creates external economies. It means that the biogas production influences the utility function of the consumer (i.e. better sanitary and hygienic conditions) and the social welfare function of the society (i.e. reduced health costs). Considering national wide effects on energy balance, the biogas supply creates external economies on the balance of payments to the economy (import substitution of fossil fuels). As well external diseconomies then should be included, amounting to less income of import duties because of substitution of traded fuel (i.e. petroleum)

petroleum) by biogas

- Biogas use, replacing conventional fuels like kerosene or firewood, allows for the conservation of environment. It therefore, increases its own value by the value of i.e. forest saved or planted.
- The price of supplied energy produced by biogas competes with distorted prices on the national or regional level of the energy market. Monopolistic practices, which enable energy suppliers to sell their energy at a price higher than the competition price, still dominate the energy market in many countries. A decentralized, economically self-sufficient biogas unit therefore, - under competitive conditions - provides its energy without market distortions.
- Furthermore, other macro-economic benefits arise when comparing on the one hand the benefits of decentralized energy generation (improved power system security) and the disadvantages of centralized energy generation: incremental costs of investment in additional networks and the costs of losses on the transmission network, due to the distance of energy customers, may be added to the benefits of decentralized energy generation from the macro-economic point of view.
- Labour intensive decentralized biogas units, on the regional level, improve income distribution amongst income brackets and reduce regional disparities, enhancing the attractiveness of rural life.
- Investors should aim at carrying out the construction of biogas plants without any imported materials in the long run. The lower the import content of the total plant costs (i.e. amount of steel), the less the external diseconomies which may arise in consequence of sliding exchange rates.

In a macro-economic level these effects are significant and only unfold themselves fully if biogas plants are introduced over a wide area i.e. for closed settlement areas. This refers primarily to biogas plants as an improvement for inferior sanitary and hygienic conditions for members of the poorer classes. These are problems which cannot be solved on an individual basis but only by collective decisions and measures.

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How far biogas plants in a definite case are the suitable and advantageous solution to a problem has to be discovered with reference to alternative sectoral measures. The macro-economic evaluation needs to account for effects of benefits within the fields:

- Energy and fertilizer supply
- Environment
- Health Sector
- Employment and foreign exchange

Energy and slurry

Energy

Many developing countries, especially the LLDC base their energy consumption upon traditional energy sources (wood, plants and crop residues and animal waste, as well as animal traction and human muscle power). Biomass energy use varies widely in developing countries from as little as 5% in Argentina to over 90% of the total supply of energy sources in countries like Ethiopia, Tanzania, Rwanda, Sudan and Nepal. In the case of wood, plant and animal waste, according to local necessities, the energy source is collected and used. Surplus of energy sources are traded informally on the local and regional level. In so far estimations on the potential effects of biogas use instead of the use of traditional energy sources do not have any impact on governments budget, presuming the non-existence of taxes on traditional energy sources.

Negative consequences on the income of the local traders may result, presuming less demand on traditionally traded energy sources, causing a slump of its prices. On the other side biogas users may continue with trading of traditional energy sources on more distant markets (or even will be encouraged to trade on regional levels), not willing to forego secure earnings.

Consequently, the substitution effect of biogas results primarily in environmental benefits due to less consumption of i.e. firewood, leading to less deforestation (under the presumption of a declining or constant price of firewood).

Commercially or monetarily traded sources like petroleum, coal and natural gas on the other hand have impacts on the balance of payments and therefore influence governmental budgets.

The macro-economic effect of a biogas use by import substitution of i.e. kerosene is due to decreasing duty income. On the other side petroleum import dependancy sinks, giving more relative stability to an economy.

Although only less than 10% of a countrys commercial energy is consumed by the rural population (LLDC and in some MSAC), the effects of biogas use, substituting systems for generation, transmission and distribution of electricity shall be mentioned.

The macro-economic benefits of a biogas plant result in its self-efficienciy and reliability (benefits from avoidance of black-outs and supply interruptions) and in less costs for networks and distribution infrastructure. On the other side a national wide operating power supplier competes with a biogas supplier as unserved energy implies by revenue forgone as a result of non-supplying its customers.

Slurry

On the assumption that the slurry of the biogas plant is used as fertilizer and, when spread on the fields, it increases the crop production, that is more productive than the undigested dung, the economies benefit amounts to a higher supply of fertilizer given the same output level of crops.

Moreover, the substitution of commercial fertilizers with slurry produced by biogas technology reduces the impacts on balance of payments (assuming a dependence on imports of chemical fertilizers).

The consequence of reliance on digested dung and residues (in a biogas plant) is that

valuable nutrients and organic matter are led back to the soil in an improved stage, rising agricultural productivity and soil stability (combating devegetation and desertification). The higher productivity of crop production results in higher yields, maybe keeping pace with the increase in population (maybe: because one has to estimate the balance of populational fluctuations).

Environment

Consumption of firewood

Wherever a region is confronted with acute problems of deforestation and soil erosion resulting from excessive firewood consumption, biogas plants can provide a suitable solution. Biogas is able to substitute almost the complete consumption of firewood in rural households.

Traditionally, woodfuel claims the largest proportion of biomass fuels (in some regions up to 90%) used in developing countries, where about 40% of the total wood cut anually is used for domestic purposes (cooking and heating). Estimating an average per capita consumption of 3 kg of wood per day for energy (cooking, heating and boiling water) in rural areas in Asia and Africa, the daily per capita demand of energy equals about 13 kWh which could be covered by about 2 m^3 of biogas. A biogas plant therefore directly saves forest, assuming that not only deadwood is collected for fuel.

In order to predict the direct monetary savings to an economy, two procedures are to be carried out:

If the forest has not previously been used economically, shadow pricing has to be based on the valuation of saved biodiversity, respectively on the capacity of reducing the effects of global warming.

If the forest has been used economically, several procedures of shadow pricing can be carried out, like:

Value of saved forest via price of firewood

Given the price of cut firewood on the local market, the savings of forest by substitution of biogas can be determined by multiplication of the number of trees cut, its tree growth ratio per year and the average price of firewood.

Value of saved forest as an area for nourishment (hunting, collecting fruits, etc.)

The value of the forest equals the sum of income forgone from these activities. The correct shadow pricing would be based on the prices of the goods on the formal consumer markets (i.e. price of meat).

Value of saved forest as a recreation area

The value of the forest equals the sum of the incomes obtained by charges for admission to National Parks, Wildlife Areas, etc.

Deforestation

Without any effective political measures, the problem of deforestation and soil erosion will become more and more critical. As the population increases the consumption of firewood will increase more steeply.

Without biogas the problem of deforestation and soil erosion will steadily become more critical as firewood consumption rises relative to higher density of population. The demand for nourishment also rises accordingly, which means that constant extension of agricultural land increases at the expense of forested areas.

Deforestation contributes considerably to soil erosion which, in its advanced state, reduces quantitively and qualitatively the potential of agricultural land. Finally, this leads to future increases in the cost of food production. Moreover, the advancing soil erosion increases the frequency and extent of floods and their disastrous consequences.

frequency and extent of floods and their disastrous consequences.
According to an Indian

estimation, a biogas plant of e.g. 2.8 m^3 capacity can save a forested area of 0.12 ha. In each case it has to be discovered the contribution of biogas plants to a reduction in land usage and costs for reforestation or protection of remainig forests.

Health sector

In order to estimate the impacts on the health sector, benefits arise on the individual level, as well as on the level of the society.

Biogas plants serve as methods of disposal for waste and sewage and in this way directly contribute to a better hygienic situation for individual users. By collecting centrally dung and by connecting latrines, open storage is avoided. Apart from this, pathogenes are extensively eliminated during the digestion process. All in all quite an improvement of sanitation and hygiene is achieved and therefore a biogas plant can contribute to a higher life expectancy.

In the Peoples Republic of China this effect became apparent in the bilharziosis, worm and gastro-disease endangered areas where the number of people suffering was greatly reduced. Theoretically, a reduction in the frequency of disease comprises economically a saving in medicine and consultation costs. Regarding the leakage of health services in rural areas, another approach to savings is suggested: Labour productivity rises due to elimination of potential disease-causing agents due to the better hygiene situation in consequence of biogas plants.

Applied to individual biogas projects, these economic effects cannot be credited directly to biogas projects in monetary terms, as there are plenty of influences on the health sector.

If the main goal of a biogas plant is to achieve a higher standard of hygiene, one possible method of shadow pricing would be the answer to the question:Which alternative investment in providing the same result of hygiene equals the positive hygiene results of a biogas plant.. The evaluation of sanitary and hygienic effects can be made i.e. by means

The evaluation of sanitary and hygienic effects can be made i.e. by means of the alternative costs for a purifying plant.

But the incisive doubts of "correct" shadow pricing the benefits in the health sector remain.

Employment

During construction of biogas plants unless these are built by the investors themselves, there are effects on regional/local income and employment which subsequently continue. Permanent jobs, unless users participate, are created for the operation personnel and indirect effects result in contracts with local and regional companies for the service and maintenance of a plant including the gas-burners in the households and resulting from the procuring and processing of increased agricultural production. The utilization of biogas contributes to an enlarged range of energy fuels offered on the market. In this way the local basis of the energy supply can be extended and secured, and it also simplifies the setting of additional commercial activities where the factor energy has so far proved to be a problem.

Final remarks

Biogas gained by a three-step digestion process (two hydrolysis phases followed by one acid phase) containing 60-80 per cent methane and 20-40 per cent carbon dioxide makes it a potencial source of renewable energy.

Given a heating value of about 5,5 kcal/m^3, its uses for electricity generation, as a heat resource, for internal combustion engines, boilers, as a suplementary fuel for diesel engines or substitution of firewood for cooking purposes in rural areas are widely reported.

Especially the economic benefits of biogas utilization in selected agro-industries (palm oil mills, tapioca starch factories and alcohol destilleries) amount to savings due to electricity generation by biogas, fertilizer savings and rising productivity in agriculture. Moreover, the environmental benefits due to substitution of energy sources based on wood (firewood, charcoal) or on fossil energy sources are outstanding.

To assess correctly the macro-economic benefits of biogas production in small size biogas plants is a difficult undertaking. Generally, very optimistic assumptions on positive effects on employment, balance-of-payments and health sector can cause

overwhelming expectations
planning biogas-based energy systems.

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Nevertheless, these external economies are substantially influenced by the quantity and (regional) density of biogas plants, contributing to the countries share of energy sources.

Without any doubt -even if there would be constructed only one biogas plant in a country - the following valueable assets of biogas use from the environmental point of view can be determined.

As CO_2 generation by burned biogas only amouts to 80 per cent of the CO_2 generation of fired fuel oil (per kWh electrical energy) and is even more advantageous in relation to coal (about 50 per cent), the environmental benefits of biogas in relation to fossil fuels are indisputable.

Due to the high cohere efficiency of wood (0.7 kg CO_2 per kWh gross energy), the substitution of the wood based biomasses by biogas rise the national and global storage capacity of CO_2.

Facing more and more the challenging phenomena of global warming and setting global standards of polluting potentials, environmental external economies are getting steadily very important issues and may stimulate a government to start investing in appropriate energy technologies rather than to follow the conventional way to solve the problem of generating energy in remote areas by rural electrification based on fossil fuels.

A financially viable and well structured joint implementation concept may help to generate (financial) facilities to governments in order to invest in energy generation, based on sustainable energy sources. In how far and to which partner (of the partnership) the positive effects of the project shall be ascribed to, may be determined politically. In the long run each saving of irretrievable damage of environment helps to saving the world in a whole.

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Economic Viability (Financial Analysis)

Objectives, methodology and decision criteria

As soon as the cost and benefit components of a biogas plant in planning can be quantified, and as soon as other important parameters (time horizon, interest rate, annual allowances, exchange rates, inflation rates) are determined, the economic viability of a biogas plant can be calculated.

Typically, the financial analysis of projects points out the financial viability of investment alternatives.

Three types of questions need to be answered:

8. Which project is the least expensive among an array of options that produce the same output (least cost analysis).
9. Which project shows the highest net benefit (benefit minus cost) among an array of options (cost benefit analysis).
10. Is a project a financially viable solution to the problem on hand. (absolute viability, i.e. the question is dealt with whether the projects revenues are sufficiently high to meet capital cost and operating cost), and:

    Is a specific project more economical than others. (relative viability).

Procedure of dynamic approach

Due to the fact that the same amount of a credit or debit can have a very different value depending on when the transaction takes place, dynamic analysis differ from the static methods.

methods.

The need for a dynamic approach results from the fact that, as the costs and benefits of each option arise in different years, it is necessary to make them comparable.

The value which says how much a future or past payment is worth at the present time is described as its present value (PV).

Example:

Given an investment of a biogas plant of 2000 US$ in two years (discounting), having paid three years ago 120 US$ for the necessary landed property (compounding), with a given interest rate of 8%, the PV is as follows:

$$PV = [2000/(1,08)^{2} + 120*(1,08)^{3}]$$

It is calculated from its past amount by compounding or from the future amount by **discounting with the aid of a factor which depends on the interest rate adopted and the** length of time between the payment and the present period.

Investment criteria

The dynamic approach deals with a consideration of benefits and costs over several years and therefore shall be pointed out more detailed:

Investment criteria are, as follows:

A) Net Present Value (NPV)

The most common investment criteria is the NPV and is defined as follows:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+k)^t}$$

PV- Net Present Value

C_t- Costs in year t

B_t- Benefits in year t

k- discount rate

t- number of years from the present

n-

-- total number of the years of the analysis period	18

Example:

Given a biogas plant with an investment cost of 2000 US$ within the first year of the project and assuming annual running costs of 70 US$ during the following 9 years of operation and estimating an annual benefit of 450 US$ during the operation time (due to incomes from gas production and fertilizer production), the NPV results as follows:

$NPV = 2000/(1{,}08)^{0} + [(450/(1{,}08)^{1} + 450/(1{,}08)^{2} + ... + 450/(1{,}08)^{9}) - (70/(1{,}08)^{1} + 70/(1{,}08)^{2} + ... + 70/(1{,}08)^{9})] = 374$ US$

Applying the net present value method the investment can count as being profitable as its NPV is positive. It means that the interest rate on capital is higher than the assumed discount rate. Investing in the biogas plant would allow a higher return to the investor than an investment on capital market.

The methodology described is suitable for analysing the relative viability of a project, i.e. it can tell us whether one project is more economical than another (or others). It can therefore be used for the analysis of the absolute viability of a project. This step answers the question as to whether the return on investment for a project is sufficiently high to cover its average capital costs.The net present value method is preferable for comparison of viability of different options, as it easily copes with changes of costs and revenues over time.

B) Internal Rate of Return (IRR)

A further criterion which can be applied for the purpose of viability calculation is the internal rate of return (IRR).

It is the discount rate at which the present value of cost is equal to the present value of the benefits. In other words, it is the discount rate at which the net present value is zero:

$$\sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} = 0$$

i= IRR

Example:

Assuming the project data of the example of NPV, the internal rate of return results as follows:

0 = 2000/(IRR)^0+ [(450/(IRR) ^{1}+ 450/(IRR) ^{2}+ ... + 450/(IRR) ^{9}) - (70/(IRR)^1 + 70/(IRR) ^{2}+ ... + 70/(IRR)^9)]

The resulting interest rate (IRR) at which the NPV is zero amounts to 12,45%. The investors decision to deal with a biogas plant investment leads to high capital gains, since an IRR of 12,45% exceeds the minimum acceptable rate of 8% (interest rate).

The IRR method is closely linked with the NPV-method and is recommendable for viability calculation for a single project, as the projects IRR is compared with the IRR of the market.

C) Dynamic Unit Cost criterion (C_{dyn})

To gain additional transparency, the Dynamic Unit Cost criterion (C_{dyn}) stands for the calculation of the financial analysis performed on a per unit basis (if $C_t > B_t$):

$$C_{dyn} = \frac{\sum_{t=1}^{n} \frac{C_t}{(1+k)^t} - \sum_{t=1}^{n} \frac{B_t}{(1+k)^t}}{\sum_{t=1}^{n} \frac{O_t}{(1+k)^t}}$$

C_{dyn}- Dynamic Unit Costs
O_t- Output in year t
Other parameters and index numbers like above

As this criterion is linked to the NPV-method, no differences in calculation procedure occur.This decision criterion enables the various options with different outputs to be compared on a per unit basis. The main advantage of the concept is that options of different sizes (output) can easily be compared with each other regarding to their financial viability.

D) Dynamic Annuity criterion (A_{dyn})

Another decision criterion for financial viability is the Dynamic Annuity criterion (A_{dyn}). It evaluates the relative favourability of investment projects of similar type on the basis of constant annual payments. Likewise the Dynamic Annuity criterion is a variant of the NPV-method. In the left part of the equation the present value of the costs and the present value of the benefits are converted by the recovery factor into annual payments. Additionally the annuity of investment costs and the annuity of the liquidation yield is considered. Moreover the liquidation yield represents tied capital during the useful life of the asset and therefore interest charges are accumulated during the project (L k). Then the annuity of the investment project is defined as the sum of the mentioned annuity components:

$$A_{dyn} = \left[\sum_{t=1}^{n} \frac{C_t}{(1+k)^t} \cdot RF(k,t) - \sum_{t=1}^{n} \frac{B_t}{(1+k)^t} \cdot RF(k,t) \right] + (I - L) \cdot RF(k,t) + L \cdot k$$

A_{dyn}- Dynamic Annuity

I- Investment

L- Liquidation yield (end of lifetime)

RF- Recovery factor

(Note: The amount of the recovery factor (RF) depends on the assumed interest rate and the time horizon. Given an interest rate of 8% and a project lifetime of nine years, the RF (k = 1,08; t = 9) is: [$1{,}08^{t}(1{,}08 - 1)$] / [$1{,}08^{t}-1$] = 0,16.)

Other parameters and index numbers like above

An asset is considered favourable, when its annuity is positive, meaning that interest on the capital invested involves a higher surplus than the interest rate on capital market. This method permits an evaluation of both the individual and comparative favourability of investment projects.

A shortened form of the annuity method without the inclusion of benefit payments in the calculation is the Dynamic Cost Annuity criterion (A_{dyn}).

The aim of the Dynamic Cost Annuity criterion is to identify the most cost-effective plant by contrasting the costs of two or more alternatives for a manufacture. To get more detailed results, the costs can be related to a defined output. If there are several alternative assets for providing a desired output then the asset with the lowest dynamic cost annuity (per output) should be selected.

Example:

Given the above performed example (NPV), but presuming in the ninth year of operation running costs of 80 US$ and a benefit of 470 US$ and assuming a liquidation yield of 100 US$ by the end of lifetime, the Dynamic Annuity results as follows:

A_{dyn}= [$70/(1{,}08)^{1} + 70/(1{,}08)^{2} + ... + 80/(1{,}08)^{9}$] * 0,16 - [$450/(1{,}08)^{1} + 450/(1{,}08)^{2} + ... + 470/(1{,}08)^{9}$] * 0,16 + 2000 * 0,16 - 100 * 0,16 + 100 * 0,08 = 68 - 436 + 320 - 16 + 8 = - 56.

As the equation proceeds from the costs, a negative result comes out. The asset is economically favourable, as the investor can expect annual net returns for the amount of 56 US$.

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Input data

To the calculation of the viability of a project a complete compilation of all input data should occur carefully. The costs and revenues depend on the particular project and technical system and can, therefore only be accurately determined when all the parameters of a specific application are known:

Cost data

A significant factor on the cost side is the size of the required investment. The following elements make up the total investment outlays:

- planning and surveys
- land acquisition
- civil works
- plant buildings and structure
- connecting systems
- mechanical equipment
- transport (including insurance)
- customs, duties, taxes
- other costs

Another significant cost component are the operational costs. Depending on the plant characteristics, the maintenance and repair costs they are not fully predictable.

Other important items are the costs for manpower, costs for auxiliary materials and administration costs (system attendance).

Benefit data

The annual benefits comprise the monetary flow from evaluable returns, savings, etc. yielded by the investment. If the benefits arise in financial (micro-economic) terms or already include economic (macro-economic) benefits, this is due to definition of the main goals which shall be achieved by an investment in a biogas plant. According to the main objectives of a biogas plant, in financial terms the benefits may derive from:

Power generation: Naturally, only the net energy gain can be counted, i.e. the process energy fraction (for agitators, pumps, heating, and any outside energy input) must be substracted from the total gas yield. If the generated power is sold, the returns are included in the calculation. Any energy used to replace previous outside energy inputs counts for savings. One has to take into account a certain discount of energy price if the generated power shall be sold because of linkage costs per output (due to small gas yield of small plants).

Sludge: The substitution of digested sludge for chemical fertilizers can often yield savings in developing countries, where in the past big amounts of the material used as substrate had so far not been used as fertilizer. Accurate monetary evaluation is difficult, because the fertilizing effect of digested sludge is substantially influenced by the type of storage, the climate, the techniques employed in spreading out the sludge on the fields and working it into the soil, etc.

To estimate economically the gains of digested sludge suitable for agriculture (with the same output performance as with chemical fertilizers), one has to value the benefits of not spending money on chemical fertilizers (approach of opportunity costs: see macro-economic evaluation).

Savings attributable to the superior properties to digested sludge: These may result from the improved fertilizing effect of the sludge, its hygienization, reduced odour nuisance, and more advantageous handling properties such as reduced viscosity, improved homogeneity, etc. These kind of benefits are hardly valuable. Further information on methods of shadow pricing can be achieved in: macro-economic evaluation.

Parameters and assumptions

Price basis and escalation

The financial analysis has to be performed on the same price basis, i.e. on the constant money value of a determined year. Then the costs are expressed in real terms.

Due to the fact that certain goods and input data do not increase/decrease in line with the general rate of inflation/deflation, and thus do not remain constant in real terms, a necessary analysis of adjustment of prices by escalation rates is to be performed.

Often, the costs of manpower are presumed to raise more than the general rate of inflation which implies an increase of income of employees in real terms.

Discount rate

To determine the rate of discount is a crucial problem of project evaluations.

The discount rate derives from bearing in mind the intertemporal valuation of values of costs and benefits. In one sentence: interest is what is charged for not being able to use the money for something else.

For financial analysis, interest is expressed as a percentage.

It should be noted that the discount rates used for the analysis must be real rates, i.e. nominal rates minus the rate of inflation. As all the input data are applied in real terms, the discount rate must be applied in real terms as well.

This means that the interest rates taken from the capital market (i.e. interest rate for long-term borrowing) are expressed in nominal terms and have to be reduced by the inflation rate.

The prospection of both, the "correct" nominal terms of capital market (due to market distortions) and the development of national inflation rates during the distortions) and the development of national inflation rates during the lifetime of the project remain difficult tasks for project planning.

Foreign exchange rate

The foreign exchange rate prevailing at the time of conducting a project and its future development is another element of difficulty for the investor.

There is also a close relationship between the forecast of a national rate of inflation and the forecast of the development of the foreign exchange rate.

According to the purchasing power parity theory, the development of the foreign exchange rate of two currencies reflects the difference in inflation rates of the countries (or areas).

Given a national inflation rate of 10% p.a. and a world inflation rate of 3% p.a., a depreciation of the national currency against the US Dollar can be expected.

The purchasing power parity theory means that the depreciation expected will offset the difference in infaltion rates so that the prices of imported goods in local currency will develop in line with the overall national rate of inflation.

Final remarks

The financial analysis assesses the viabiltity of the project from the investors view. The financial objective of investing funds in any activity is to maximize the resulting flow of income while remaining within the level of risk acceptable in relation to that return.

Therefore, estimations on project outcomes which represent secure data streams, "only"interfered by price escalations or changes in demand behaviour, are dominant investment criteria.

Other possible (external) economies and diseconomies of a project as well shall be included in the investors decision process. The macro-economic evaluation may reveal, in how far this can occur.

Cost benefit relation (investment calculation, sensitivity analysis)

Methods

As soon as the cost and benefit of a biogas plant in plan can be expected, collected and analysed, and as soon as a rate of interest for the calculation is determined it can be worked out with the assistance of a dynamic investment calculation if the plant is economical or not. Where there are several alternatives relative advantage can be ascertained. There are three generally accepted methods for this:

the capital value or discounting method

the internal rate of interest method

the annuity method

These methods are principally equivalent. The selection is effected according to the purpose and plausibility, e.g. distinctness of each advantage key. In practice the discounting method is used most frequently. According to this method the cost and benefit of different periods of time are concentrated onto one point in time, normally the current value or cash value, discounted and so made comparable. When comparing alternatives with different economic lifetimes and investment costs the annuity method is especially suitable. For the calculation of user fees the annuity method should be used. According to this method the non-recurring and aperiodical investment costs are converted into equal constant annual amounts for the economic lifetime of the plant and related to the quantity of gas distributed. This occurs by means of a capital return factor which states the annual amount of depreciation an interest which has to be used at the end of each year during n years to regain the original capital with interest and compound interest.

Difficulties

In order to avoid misinterpretations the basic weakness of efficiency calculations from a micro as well as macro-economic point of view have to be pointed out. For reasons of operational ability these calculations extensively comprise monetary effects. This means that cost and benefit are only determined with a view to monetary aims. There are, then, intangible aims and thus, intangible cost and benefit for which a final valuation lies within the judgement of the decisionmaker.

Further difficulties arise with the uncertainties combined with the determining of most of the basic influencing factors involved in the economic and financial profitability of biogas plants. To pinpoint the importance of possible fluctuations of any exceptions or data for the profitability calculated, sensitivity analyses should be carried out. The extent of any effects on the result of the profitability calculation should be investigated especially for the following factors:

- available quantity of substrates
- expected gas production, especially the reduction for colder seasons
- the proportion of effectively utilizable gas production on total production
- type and quantity of replaceable fuels
- price of the fuels replaced (also in time-lapse)
- type and quantity of the replaced mineral fertilizer
- price of the mineral fertilizer (also in time-lapse)
- extent of the increase in agricultural production as a result of biodung
- economic lifetime of the plant, respectively its most important components
- rate of interest for capital invested
- amount and development of the running costs

Observation of the development

It would be practical to observe the development of the most important determinants in the profitability over a period of time and compare them now and again with the assumptions made at the planning stage. A year after being taken into operation the plant should be subjected to a renewed assessment concerning the economic advantage and the financial productivity.

Further reading:

H. Finck, G. Oelert: A guide to the financial Evaluation of Investment projects in energy supply. GTZ No/63.

The Annuities Method

Compared to other approaches, the annuities method is more suitable for assessing absolute economic efficiency and for comparing various investments with very divergent projected lifetimes. The annuities method is a reliable means of comparing the economic viability of various investment options. It takes into account reinvestments and differences in system mortality.

According to the simplified approach presented here, however, a single cost increase factor is applied for all inputs, i.e. energy, services, spare parts, etc. As we have seen in the course of the past few years, though, the cost of energy and of wares with a close tie-in to the cost of energy (such as chemical fertilizers) has been increasing more rapidly than, say, the national wage index of most countries. Also, discrepancies can always be expected to be particularly pronounced in countries where the state intervenes in the price structure. Thus, if the economic efficiency of a particular system is to be projected with any real degree of accuracy, the price-increase rates for each individual product must be taken into account.

Basically, the annuities method converts the investment into fixed annual costs suitable for direct comparison with the annual benefits.

AN = B - C - I0 CR (i,T) or

AN = R - ANI

where

AN = annuity, i.e. the annual gain, calculated for the first year (year 0)
ANI=

ANI
Annuity of the investment
B = annual benefits (savings and/or returns on investment), calculated for the year 0
C = annual costs, calculated for the year 0
R = annual reflux (R = B - C)
I0 = total initial investment volume, calculated for the year 0
CR = capital recovery factor
i = assumed interest rate (discount rate)
T = projected service life or time required for amortization of the investment

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Annuity (AN)

The purpose of the annuities calculation is to convert all net payments in connection with an investment project to a series of uniform annual payments - the so-called annuities. Conversion is effected by multiplying the individual payments by the capital recovery factor CF.

AN = ANR - ANI
AnI = I0 CR (i, T)
ANR= R for constant annual benefits

As long as the annuity AN is positive, the project may be regarded as profitable in absolute terms under the postulated conditions. If it is negative, the project must be regarded as unprofitable. The annuity can be equated with the anticipated mean annual profit/loss. It is calculated for the year 0, i.e. the year in which the investment is undertaken.

Annual benefits (B)

The annual benefits comprise the monetarily evaluable returns, savings, etc. yielded by the investment. These may derive from:

Power generation

Naturally, only the net energy gain can be counted, i.e. the process energy fraction (for agitators, pumps, heating, and any outside energy input) must be subtracted from the total gas yield. If the generated power is sold, the returns are included in the calculation. Any energy used to replace previous outside energy inputs counts as savings.

The substitution of digested sludge for chemical fertilizers can often yield savings in developing countries, where in the past, much of the material used as substrate has so far not been used as fertilizer. Accurate monetary evaluation is difficult, because the fertilizing effect of digested sludge is substantially influenced by the type of storage, the climate, the techniques employed in spreading the sludge and working it into the soil, etc.

Savings attributable to the superior properties of digested sludge: These may result from the improved fertilizing effect of the sludge, its hygienization, reduced odor nuisance, and more advantageous handling properties such as reduced viscosity, improved homogeneity, etc. However, it is normally quite difficult to attach a monetary value to such benefits. Legal regulations pertaining, for example, to reducing odors or improving hygiene can be of decisive influence.

Annual costs (C)

The current annual costs are made up of the expenses incurred for:

maintenance and repair,

plant operation,

- inspection fees. etc..
- system attendance.

Most such items can only be estimated, whereby 1 - 3 % of the investment volume is generally accepted as rule-of-thumb quota for maintenance and repair. For simple biogas systems in developing countries, the percentage is usually somewhat lower, though it could be even higher for the more complicated types of systems used in industrialized countries.

Operating costs are largely attributable to the depletion of consumables (such as desulfurizer cleaning agents) and to outside energy requirements, e.g. electricity for running agitators and mixers.

Inspection fees usually arise in connection with pressurized biogas systems. (According to German standards, a system is defined as pressurized if it operates on an internal pressure of 1.1 bar, = 0.1 bar gage, or more.)

Expenses in connection with system attendance by the owner-operator himself or by his employees should usually be taken into account, whereby the hourly wage and time expenditure are subject to wide variance.

Total investment volume (I0)

The total investment volume includes the capital outlay for:

- the digester, including agitating, mixing and heating equipment,
- gas storage and safety provisions,
- gas usage, including integration into existing systems,
- linkage between the biogas system and the farm estate, i.e. liquid-manure and gas lines, structural alterations on stabling structures, etc,
- planning, construction supervision, licensing fees, etc.

Reinvestment costs for the replacement of individual components (pumps, floating gas holder, etc.) with service lives that expire prior to the end of the projected

holder, etc.) with service lives that expire prior to the end of the projected
system service life

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T must be included in the total investment volume. For the purposes of this simplified approach, the cost of such reinvestments may be quoted for the year 0:

I = I0 + I1 + I2 + ...

where

I = total investment volume
I0 = initial investment volume
I1, I2, ... = reinvestments

Capital recovery factor (CR)

CR accounts for the cost of financing a project for which the investment volume has to be raised by way of loans (interest, compound interest) . If the capital outlay is covered by cash funds, CR is used to account for ceasing gain in the form of lost interest and compound interest on assets.
CR is calculated according to the formula:

CR (i,t) = (qt (q-1)) / (qt-1) = ((1+i)t i) / ((1+i)t - 1)

where

q = 1+i
i = assumed interest rate in percent
t

-
=
time in years

Assumed interest rate (i)

The assumed interest rate must be determined with due regard to specific individual conditions. In this context, the assumed interest rate is defined as a real interest rate, i.e. after adjustment for inflation. In the case of cash outlay, the real interest rate would equal the rate of interest that the capital would have borne on the money market. Accordingly, the assumed interest rate is equal to the current mean debt interest rate demanded by the bank for the loan capital, when the entire project is financed with borrowed money. Moreover, money costs in the form of bank service charges, the owners own administrative overhead, etc. must also be included. Since, however, most projects involve a certain degree of mixed financing, the assumed interest rate will take on a value located somewhere between the debt interest rate and the credit-interest rate, depending on the case situation. (Note: All rates adjusted for inflation!).

Benefits and Impacts of Biogas Technology

Improvement of sanitary and health conditions

Reduction of the pathogenic capacity

The processing of animal and human excrement in biogas systems obviously improves sanitary conditions for the plant owners, their families and the entire village community. The initial pathogenic capacity of the starting materials is greatly reduced by the fermentation process. Each new biogas system eliminates the need for one or more waste/manure/latrine pits, thereby substantially improving the hygiene conditions in the village concerned. From a medical point of view, the hygienic elimination of human excrement through the construction of latrines, connected directly to the biogas systems constitutes an important additional asset. In addition, noxious odors are avoided, because the decomposed slurry stored in such pits is odorless.

Reduction of disease transmission

Since biogas slurry does not attract flies or other vermin, the vectors for contagious diseases, for humans and animals alike, are reduced. Furthermore, eye infections and respiratory problems, attributable to soot and smoke from the burning of dried cow dung and firewood, are mitigated.

Gastrointestinal diseases

In the rural areas of China and numerous other subtropical countries, gastrointestinal diseases are the most widespread type of affliction. Epidemics of schistosomiasis, ancylostomiasis, dysentery and others are caused by the transmission of pathogens via ova contained in fecal matter. Contagion is pre-programmed by the farmers themselves when they use night soil or liquid manure to fertilize their fields. As long as inadequate sanitary and hygienic conditions prevail, the health of the rural population will remain threatened. The anaerobic digestion of human, animal and organic wastes and effluents extensively detoxifies such material by killing most of the ova and pathogenic bacteria. It is not surprising, that the widespread popularization of biogas in China has had immediate beneficial effects on the sanitary conditions of the areas concerned. As soon as the introduction of biogas technology fully covered an area, no more human, animal or organic wastes were deposited in the open. This eliminated some of the main sources of infectious diseases. Schistosomiasis, previously a widespread, menacing disease in rural China, was reduced by 99% through the introduction of biogas technology. The number of tapeworm infections has been reduced to 13% of the pre-biogas level.

Economic value of disease reduction

For the user of biogas technology, health effects are tangible with regards to the smoke reduction in the kitchen. The reduction of parasitic diseases can only be felt if the numbers of biogas systems in an area reaches a critical threshold. Similarly, for a larger entity like village, district or nation, health impacts of biogas systems do not grow as a linear function of the numbers of biogas units installed. Biogas subsidies can compete with expenditures for other forms of health care only, if the funds are substantial enough to reach a high coverage with biogas units.

As morbidity is, generally, a multi-factor issue, impacts of widespread biogas dissemination can only be assessed by an ex-post analysis: expenditures for the treatment of key diseases before and after the widespread introduction of biogas technology. Analyses of that kind can - with caution - be used to estimate the value of health benefits in a comparable region that is targetted for a biogas program.

Nutrition

The permanent availability of cooking energy in a household with a well functioning biogas plant can have effects on nutritional patterns. With easy access to energy, the number of warm meals may increase. Whole grain and beans may be cooked longer, increasing their digestibility, especially for children. Water may be boiled more regularly, thus reducing water-borne diseases.

Culture and education

The use of biogas for lighting can lead to profound changes in the way families integrate in the cultural and educational sectors. Biogas lighting makes it possible to engage in activities at night such as reading or attending evening courses. The women and children, of whom it was previously expected that they gather fuel, now have more free time and are more likely to attend school. Experience also shows that the use of biogas systems gives women more time to devote to the upbringing of their children.

Distribution of income

One possible drawback of the introduction of biogas technology could be an accentuation of existing differences in family income and property holdings. Poor tenant farmers could be coerced into selling - or even delivering free of charge - their own manure supplies to the landlord or other more prosperous farmers for use in their biogas plants. Obviously, this would be of great disadvantage with respect to the already low yields and energy supplies of small and/or tenant farmers.

If the benefits of biogas technology are not to be limited to farmers with a number of livestock of above four TLUs (Tropical Livestock Units), biogas programs will have to consider biogas systems that integrate neighborhoods or villages, e.g. by building and operating community biogas systems.

Effects on regional employment

The construction phase of biogas systems provides short-term employment and income due to the need for excavation, metal-work, masonry and plumbing. As documented in reports from China, the construction of biogas systems encourages local industries to manufacture the requisite building materials and accessories. Practically every district in question has its own enterprises for the production of cement, lime, bricks, plastic pipes, T-bars, plugs, stoves, lamps, gas lines, etc. Obviously, the subsequent operation and maintenance of the finished systems can have long-term beneficial effects on regional employment and income. Skilled craftsmen can be recruited not only for construction, but for service and repair. Community plants require a permanent staff for plant administration, raw material procurement, plant operation and maintenance, distribution of the gas yield and disposal of the effluent sludge.

Improvement of living conditions

For the poor, the main advantage of higher crop yields is that they improve the familys nutritional basis and reduce the danger of famines. The more prosperous farmers can sell their excess crops, thereby increasing their income. This has a snowball effect in that those farmers subsequently expand their mode of living and begin to spend more on such things as household appliances. Consequently, local and/or regional employment and income also benefit. However, the number of existing biogas systems has not yet become large enough to allow accurate quantification of the type and extent of the individual effects.

Rural-urban migration

To the extent that the introduction of biogas technology generates jobs and higher income while improving living conditions, it may be assumed that fewer rural inhabitants will be drawn away to urban centers in search of employment. While, as mentioned above, no accurate quantification is as yet possible concerning the effects of biogas technology on rural-urban migration, most Indian experts agree that the available information indicates a real and noticeable influence. Further investigation is required for obtaining reliable data on the nature and extent of such effects.

Reducing deforestation as benefit

Well functioning biogas plants can replace the entire consumption of firewood or charcoal of an individual household by biogas. In macro-economic cost-benefit analyses the amount of firewood or charcoal saved is often directly translated into hectares of forest lost. The monetary benefit of biogas would then be reflected in re-afforestation costs. This simplistic approach is questionable for four reasons:

1. Rural populations use, as much as possible, dry firewood. Live trees are only harvested, if no dead wood is available. But even then, careful pruning of trees instead of felling may not cause extensive damage.
2. Afforestation sites or firewood plantations can by no means replace a natural forest. They can not re-establish the bio-diversity of a natural forest nor can they provide for the multitude of forest products that rural populations depend on for their nutritional, medical and other needs.
3. Between the destruction of a natural forest and the re-establishment of some form of tree cover lies a time gap with negative, often irreversible effects on soils, river beds, fauna and flora.
4. Firewood harvesting does not proceed by clear-felling hectare after hectare. First, dry branches, then dry twigs and leaves are collected. Then, the first green branches are harvested, followed by the cutting of smaller trees. Gradually, a large area is thinned out. Until a certain minor degree of destruction, natural regeneration is still possible, provided there is adequate protection. In this case, it is the cost of protection that determines the value of biogas.

For national or regional planning, however, the reduction of deforestation and consequent soil erosion is one of the main arguments to allocate public funds for the dissemination of biogas technology. While a ready-made formula cannot be offered to calculate the monetary value of biogas in terms of reducing deforestation, some guiding questions may assist the planner to realistically assess the profitability of biogas compared to other environmental interventions.

What part of the household energy needs is covered by green wood. How much is from forests, how much from sustainable plantations.

What part of the household energy needs of the area in question could realistically be covered by biogas.

Which interventions of damage-prevention would have similar effects (e.g. improved stoves, forest protection, firewood plantation, solar and other alternative technologies, etc.).

Which interventions of damage repair would have similar effects (reforestation, erosion control, protection of reforestation sites, etc.).

How do we value the difference in environmental quality which exists between a preserved natural forest and an area, once bare of trees and now replanted with trees.

Global Environmental Benefits of Biogas Technology

With anaerobic digestion, a renewable source of energy is captured, which has an important **climatic twin effect:**

1. The use of renewable energy reduces the CO_2-emissions through a reduction of the demand for fossil fuels.
2. At the same time, by capturing uncontrolled methane emissions, the second most important greenhouse gas is reduced:

1m^3 cattle manure = 22,5 m^3 biogas = 146 kWh gross = 36 kg CO_2- Emissions

Smaller agricultural units can additionally reduce the use of forest resources for household energy purposes and thus slow down deforestation (about 1 ha of forest per rural biogas plant), soil degradation and resulting natural catastrophes like flooding or desertification.

1 m^3 biogas (up to 65% CH_4) = 0,5 l fuel oil = 1,6 kg CO_2

1 m^3 biogas = 5,5 kg fire wood = 11 kg CO_2

When applied for industrial or municipal wastewater treatment, surface waters and other water resources (rivers, sea, ground and drinking water resources) are being protected. Often the purified wastewater can be reused, e.g. as process water in industry or as irrigation water in agriculture. Costs saved for providing additional water can be directly translated into benefits.

The introduction, promotion and broad-scale dissemination of anaerobic technology into agro-industrial, domestic and agricultural sector combined with efficient power and heat generation or household energy appliances allows by now an efficient and viable reduction of environmental pollutants.

The impact on the greenhouse effect

The greenhouse effect is caused by gases in the atmosphere (mainly carbon dioxide CO_2) which allow the suns short wave radiation to reach the earth surface while they absorb, to a large degree, the long wave heat radiation from the earths surface and from the atmosphere. Due to the "natural greenhouse effect" of the earths atmosphere the average temperature on earth is 15C and not minus 18C.

The increase of the so called greenhouse gases which also include methane, ozone, nitrous oxide, etc. cause a rise of the earth's temperature. The World Bank Group expects a rise in sea levels until the year 2050 of up to 50 cm. Flooding, erosion of the coasts, salinization of ground water and loss of land are but a few of the consequences mentioned.

Until now, instruments to reduce the greenhouse effect considered primarily the reduction of CO_2-emissions, due to their high proportion in the atmosphere. Though other greenhouse gases appear to a smaller extend in the atmosphere, they cause much more harm to the climate. Methane is not only the second most important greenhouse gas (it contributes with 20% to the effect while carbon dioxide causes 62%), it has also a 25 times higher global warming potential compared with carbon dioxide in a time horizon of 100 years.

Table 1: Relative climatic change potential caused through different greenhouse gases within a period of 100 years after the emission, data mass equivalent of CO_2

Gas	Relative global warming potential 20 years after emission	Relative global warming potential 100 years after emission
CH_4	63	24,5
N_2O	270	320
$FCKW_{12}$	n.	8.500
CF_3Br (Halon 1301)		5.600
C_2F_6(Perflourethan)		12.500

Source: 'Klimanderung gefhrdet globale Entwicklung'. Enquete-Comission "Schutz der Erdatmosphre" of German

Erdatmosphäre" of German
Bundestag, 1992

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The reduction of 1 kg methane is equivalent to the reduction of 25 kg CO_2. The reduction of greenhouse gases with a high global warming potential can be more efficient compared with the reduction of CO_2.

Sources of methane emissions in the agricultural field

The amount of worldwide methane emissions from agricultural production comprises about 33 % of the global anthropogenic methane release. Animal husbandry alone comprises 16 %, followed by rice fields with 12 % and animal manure with 5 % . While methane released through digestion of ruminants (about 80 Mil t CH_4 per year) can rarely be reduced, methane emissions from animal waste can be captured and energetically used through anaerobic treatment. The amount of methane emission mainly depends on fodder, animal type and animal waste systems. For example: the methane emission potential from dairy cattle in industrialized countries is about 0,24 $m^3 CH_4$/kg volatile solids (influence of fodder), in developing countries it is only about 0,13 $m^3 CH_4$/kg volatile solids. But taking into account the aerobic condition of solid dung systems (only 5 % of the methane emission potential is released) it is mainly the liquid waste management systems which contribute through anaerobic conditions with a high methane release to the climate change (up to 90 % of the methane emission potential is released).

From the worldwide 30 Mil t of methane emissions per year generated from the different animal waste management systems like solid storage, anaerobic lagoon, liquid/slurry storage, pasture etc. half of the emissions could be reduced through anaerobic treatment.

Eastern Europe, Asia and Far East contribute with the highest amount of 6,2 Mil t methane emissions/year each. While in Eastern Europe the emissions are caused by anaerobic animal waste management system, in the Far East they are caused by the high numbers of livestock.

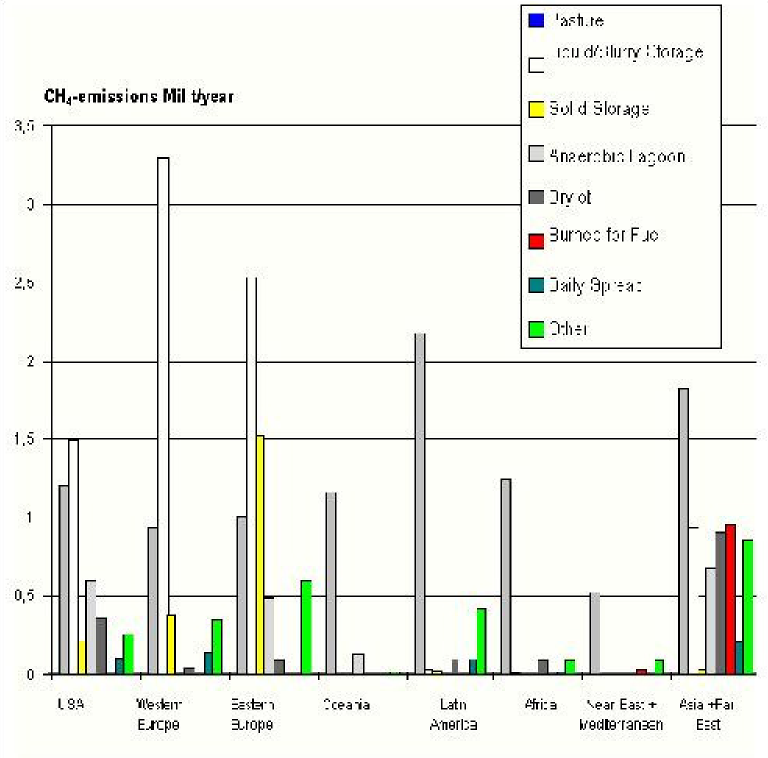

Figure 1: Methane-emissions from different animal waste management systems
Source: Cassada M. E., Safley L.M.Jr., 1990: "Global Methane Emissions from Livestock and

Poultry Manure". EPA CX-816200-010.	

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Methane reduction potential through the application of biogas technology

Through anaerobic treatment of animal waste, respectively through controlled capture of methane and its energetic use, about 13,24 Mil t CH_4/year can be eliminated worldwide. This figure includes methane emissions resulting from incomplete burning of dung for cooking purposes. By replacing dung through biogas, these emissions are avoided. In total about 4 % of the global anthropogenic methane emissions could be reduced by biogas technology.

If fossil fuels and firewood is replaced by biogas additional CO_2-emissions can be avoided including a saving of forest resources which are a natural CO_2sink. Including all these effects about 420 Mil t of CO_2-equivalents are avoidable.

Table 2: CO_2-Reduction through biogas utilization, saving of fossil fuels and fire wood resources.

		CO_2Reduction [Mil t CO_2/year]
CH_4	13,24 Mil t/year CO_2-equivalent: methane x 25	330,9
Biogas	33.321 m^3/year	
Substitution of fossil fuels		44,7-52,7
Fire wood savings		4,17 - 73,8
Total		388 - 449 = 418,5

Reduction potential of nitrous oxide emissions from agriculture

The relative climatic change potential of nitrous oxide is up to 320 times

The relative climatic change potential of nitrous oxide is up to 320 times higher as that of CO_2. Nitrous oxide generation is a natural microbial process. It is produced during nitrification and de-nitrification processes in soils, stables and animal waste management systems. In general, nitrous oxides emissions appear in soils without anthropogenic influence. Fertilizing as well as special conditions during storage can immensely increase the emissions.

Little detailed information is available about the reduction potential of nitrous oxides through anaerobic digestion of animal waste. There is still a big need for further research. Nevertheless, ongoing research results indicate that anaerobic digestion of animal waste significantly reduces nitrous oxide emissions by:

1. avoiding of emissions during storage of animal waste,
2. avoiding of anaerobic conditions in soils,
3. reducing N_2O-emissions through increased nitrogen availability for plants and a faster nitrogen absorption through crop plants,
4. reducing application of inorganic nitrogen fertilizer by which N_2O-emissions are reduced during production of nitrogen fertilizer.

Considering all these effects a N_2O-reduction potential through anaerobic treatment of about 10 % can be assumed. This means that 49.000 t N_2O/year or 15,7 Mil t CO_2-equivalents could be reduced on average.

So far, the environmental costs of greenhouse gas emissions have not been calculated. One means, proposed by the US administration on the climate conference in Kyoto, is the introduction of emission rights which can be traded. In doing so, national economies could attribute a monetary benefit to the avoidance of greenhouse gas emissions.

Financing and public support

Sources for financing

The cost necessary for the construction of biogas plants frequently exceeds the means at the disposal of the investor, in other words he cannot cover them from his regular income or savings. This could also apply to the larger replacement investments occurring at certain intervals during the economic lifetime of the plant. Besides the non-recurring i.e. a-periodical costs, the running costs of the plant have to be borne. This solvency outflow however, is set against solvency inflow in the form of regular revenue. A solvency analysis can show how far the net solvency outflow has to be financed and how much scope there will be from net solvency inflow. Usually the construction and operation of biogas plants involve a demand for financial means which can only be covered by borrowed capital. In general the following can be seen as sources:

- Grants and credits from institutes for economic aid
- Means from the national budget of the developing country (public support)
- Credits from national (developing) banks
- Resources of the project initiator
- Fees/contributions from the user

The various sources have to be individually examined for their ability to provide the means.

Running, maintenance and repair costs

The financing of investments and of the operation of the plant should be clearly settled at the preplanning stage. It has to be ensured that the quota derived from preplanning stage. It has to be ensured that the quota derived from public funds is firmly planned in the budget. Special attention has to be paid to the question of how the running, maintenance and repair costs can be financed. Means for servicing and repairing are of essential importance and have to be available in sufficient quantity and in good time in order to make full use of the possible lifetime of the plant and also to insure the confidence of the user in the reliability of the plant.

Financing by credit

When financing by credit the questions of liability and debt provisions should be clarified. The borrower should always be able to bear the possible risk or be immune to this risk by having state credit guarantees. The debt provisions should be worked out so that they conform to the development of cost and yield. Credit repayment terms are frequently much shorter than the lifetime of a project e.g. 5 years compared to 15 - 20 years. The bringing up of capital often becomes an invincible barrier for the investor.

State support

When the profitability of biogas plants are negative on a private scale, but on a national scale lead to positive results, state support measures are required.

On principle the following can be seen as starting points for the distribution of biogas plants to such an extent that would make them macro-economically feasible and socio-politically desirable:

- the creation or alteration of structural conditions for individual investment decisions in favour of biogas plants, e.g. more critical control of firewood consumption and tree-felling, regulations concerning the treatment and disposal of substrates (waste water, faeces)
- the subsidising of private and institutional community biogas plants by means of grants or inexpensive credits
- the construction and operation of biogas plants as public utility enterprises especially as municipal community plants, in appropriate instances by allocation of appropriated

means
to the
municipalities. 34

Families with low incomes

The more plants are extended to families with low incomes, the less can the costs for construction and operation of the plant be met by contributions from the users. On village community plants in India providing energy for the households practical experience has indicated that not even the running costs can be met by user fees. Consequently, not only the investment costs but also a proportion of the running costs has to be covered by general tax revenue. The resolution of the Indian Government provides a guideline for the extent of public support whereby from case to case 50 to 100% of the cost for community biogas plants are subsidised.

Since the implementation of biogas plants necessitates considerable investment from public funds, sufficient public means for parallel socio-techno-economic investigations should be provided for, which allow a suitable feedback to promotion and distribution strategy.

Biogas - Program Implementation

Dissemination of biogas technology

Even if today the technical performance of biogas plants no longer constitutes a problem, and even if regions favourable for biogas can be relatively easily identified, the establishing of an efficient and sustainable dissemination structure continues to remain the key problem of numerous biogas projects. In various countries, experiences with the dissemination of agricultural biogas systems exist. Depending on the stage of biogas development in a country or region, the structure of a biogas programme reflects the phases of implementation:

- Research and development
- Pilot programs
- Dissemination
- Networking

A criteria list with excluding, critical and ideal factors for the dissemination shows if, in a concrete case, the building of biogas plant is advisable. Reference information and addresses of organizations concerned with funding, implementation and networking in the field of biogas development can be found in chapter Organizations and Networks.

Implementation planning

Dissemination and implementation of biogas technology has to be organized and planned. Biogas projects are usually quite complex as multiple disciplines like construction, agriculture, economics, sociology besides planning and management agriculture, economics, sociology besides planning and management are involved. It is advisable to create a program of implementation that contains the problem analysis, the objectives, region of dissemination, target groups, the strategy, necessary activities, achieved outputs, required inputs etc.

Regional level

Biogas projects may have general or specific objectives. In general it has been proven that the energy aspect alone does not justify the cost for biogas technology. The overall objective, to which biogas technology contributes is the environmental amelioration which includes energy-related objectives and the improvement of living conditions (including economical conditions) of biogas users.

The following aspects have to be taken into account at regional level to prepare biogas dissemination:

- region with the favorable climatic conditions
- existence of a potential target group
- private sector involvement
- informal sector involvement
- government involvement
- organizations/networks to cooperate with
- economic viability on micro- and macro level
- financing program and the cost of program
- material requirements
- technological standards
- available know-how on planning, management, technician and artisan level
- the role of subsidies
- kinds of information, propagation, awareness creation
- assessment

assessment
of
sustainability

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Local level

The ultimate goals of any biogas program are to make maximum use of the available organic material and to provide benefits of biogas technology to as many families as possible. In particular, measures must be developed for those whose economic situation so far does not allow their participation in the biogas program.

Representatives of the local population must be involved in finding the most workable solution. The idea of constructing a community biogas plant should not be forced upon the group concerned, even if only by the power of persuasion.

If a decision is made to attempt a blanket coverage with biogas technology, various organizational measures must be taken at the local level to successfully execute the program:

- Assignment of a person responsible for the program (frequently, that person will be the promoter himself).
- Verification of basic data concerning the availability of dung and other suitable substrates, the anticipated gas consumption figures, the size of standard plants and the economic/financial aspects.
- Assessment of the capacities of local craftsmen, of the limitations of material supplies at the right time and the assignment of any work to be contracted.
- Training of personnel and organization of maintenance and repair services.
- Selection of suppliers for accessories and spare parts.
- Securing of loans and subsidies at the time required.
- Securing of binding pledges for all self-help activities.
- Stipulation of the sequential order of construction of the

- Stipulation of the sequential order of construction of the individual biogas system as agreed between all parties concerned.
- Ensuring that all those concerned are willing and able to gather sufficient amounts of substrate.

Factors for a successful dissemination

Cost of investment

An obvious obstacle to the large-scale introduction of biogas technology is the fact that the majority of the rural population cannot afford the cost of investment for a biogas plant. A further difficulty is that the overall social advantages can only take hold for the individual in the case of blanket implementation. This applies in particular to the preservation of forests, the improvement of hygiene, energy access for the poorest groups of the population and to the promotion of artisan business, training systems and service facilities. Such advantages cannot be secured for all through the installation of a few biogas plants that only better-off farmers can afford. The gap between their standard of living and that of the poor would thus become even more apparent.

Benefits of biogas technology

The essential benefits of biogas plants are not manifested in individual cost-efficiency calculations. They can only take effect on a general economic scale, and then only when entire areas have become fairly well "saturated" with biogas systems. Thus, individual decisions to invest in biogas plants can contribute little to the propagation of biogas technology, even if its introduction already appears necessary from a general economic standpoint. Public measures for the promotion of biogas technology are therefore indispensable, whereby special attention should be paid to widespread introduction.

If the installation of biogas plants is to serve as part of a social development progress, the decision in favor of biogas has to be made by the future users or owners of the plants themselves. In order to achieve that goal, the following prerequisites must first be met:

- the technology

the technology
must be made
known;

- the advantages for the economy in general and the economic benefits for the individual must be adequately quantified and publicized;
- the technical conditions for the construction of plants must be appropiate;
- maintenance and repair services must be provided within a reasonable radius and made available without an excessive amount of time-consuming official procedure;
- investment costs must be reasonable and the necessary loans and subsidies must be accessible.

Biogas programs that do not satisfy these conditions can only be materialized by persuasion, political pressure or exaggerated financial assistance.

A successful implementation strategy will require steps within the following fields of activity:

- Information and public relation campaigns
- Educational and training programs
- Financial promotion
- Politico-administrative and organizational aspects
- Social acceptance

Biogas Programme Structure

The structure of a biogas program depends on the stage of biogas development in which the program operates. We have listed below a number of typical forms of biogas programs with their important structural elements. In reality, these programs often represent stages of a longer biogas program. For example, a biogas dissemination program can have a research and development (R&D) phase, a pilot phase, a dissemination phase and a follow-up phase. Often, these phases have large overlaps.

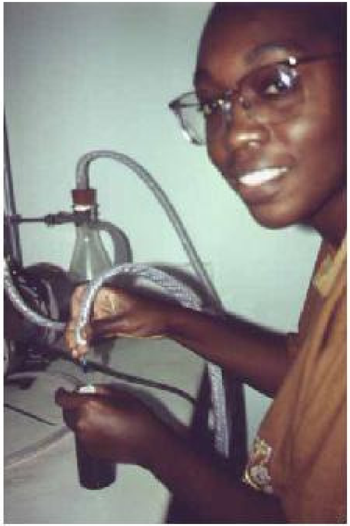


Figure 2: Test of the biochemical methane potential (BMP-Test): The bench-scale method is used to adapt and analyse wastewater and

Biogas research and development programs

R&D programs do not aim at widespread dissemination of the technology. They work on improving existing technologies, on innovative designs or on optimizing bio-technological processes. In such applied research it is desirable to communicate and cooperate closely with the potential target group. The laboratory and the research construction sites should actually be on a farm rather than in an isolated compound in town. R&D programs can be attached to implementation programs, they can be part of a national or international agricultural research center or they can be an independent supra-regional project doing research for biogas projects in the region.

an inocculum for anaerobic treatment.
Photo: Verink

Typical structural elements of an R&D program would be:

Central Laboratory to examine chemical composition of substrates, slurry, biogas. To examine qualities of building materials, paints, pipes etc. The head of the lab should be an experienced, practical chemical engineer.

Mobile Laboratory to do on-farm research.

Construction Team consisting of a civil engineer and a small team of technicians and artisans to build and test innovative technological solutions under farm conditions.

Agricultural Team consisting of an agricultural engineer and agro-technicians to research on the use of slurry and stable designs.

Data Bank and Monitoring Unit to collect and process data from the own research and from literature.

Communication Unit headed by the program manager to link the program with international research and implementation programs.

Biogas pilot programs

Pilot programs operate in countries or regions where biogas is not known and biogas technology is not tested. They rely largely on an existing and tested technology which has to be fine-tuned to be fit for widespread dissemination. At the same time the suitability of the region and the selected target groups is counterchecked. The main objective of pilot programs is to receive a constructive feedback of target groups and to alter the technology accordingly. To gain experience under a variety of conditions, typical climatic, topographic

and ethnic areas are selected. Their main objective is to make the technology and dissemination approaches fit for widespread dissemination.

Typical structural elements of a pilot program are:

Construction and Agriculture Units for the designated pilot areas, headed by a civil engineer, each consisting of a small team of technicians and artisans. The construction teams may have a store in the respective pilot area with a stock of material and appliances. They construct pilot plants, set up slurry-use facilities and follow-up closely the performance of pilot biogas units.

Training Unit organizes training courses for artisans, technicians and for the pilot farmers. The training unit also uses training facilities in neighboring countries.

Communication Unit is responsible for the communication with NGOs, churches, government institutions and private enterprise in the region. They also keep in touch with international developments.

Data Bank and Monitoring Unit collects data from pilot plants and data from research and literature.

Biogas dissemination programs

At a stage when the development of biogas technology is mature enough and target group parameters seem conducive, widespread dissemination can be envisaged. Parallel to the widening of the scope should start a reduction of direct program involvement. In particular the construction part, but also advisory service, planning and follow-up should be increasingly (and the earlier the better) handled by private entrepreneurs. Farmers do not risk technology failure anymore, for that reason they can be expected to carry most of the cost of their biogas unit.

Commercialization Unit develops approaches to make biogas dissemination increasingly independent from program inputs. Elements of their work can be the setting up of credit schemes for biogas farmers and biogas constructors, equipping biogas constructors with tools and other facilities, training entrepreneurs in pricing and accounting and linking biogas enterprise with potential customers.

Quality Control Unit monitors built biogas units and gives feedback to constructors. If necessary they advise on re-training or sanctions against unreliable constructors.

Public Relations Unit supports the biogas entrepreneurs with PR campaigns to advertise for biogas technology. The PR unit keeps in touch with various government departments to create a conducive atmosphere for biogas.

Data Bank and Monitoring Unit (see above).

Biogas networking program

Networks usually operate at a supra-national level. They support ongoing initiatives, research and private enterprise in the countries of their region. They normally do not get operational at farm level. Typical tasks would be to organize workshops, training courses or conferences to enhance a south-south technology and know-how transfer. Typical structural elements would consist of:

Documentation Center including a library and a data bank.

Organizational Unit to prepare, organize, carry out and follow up workshops, seminars and conferences. This unit supplies the communication unit with

documentation on their activities.	40

Communication Unit to lobby at a government level and with international organizations for biogas, to disseminate relevant information among biogas promoters and researchers in the region and to keep in touch with international developments.

Criteria for the Dissemination of Biogas Technology

Following, are the criteria (excluding or critical factors) which make biogas dissemination in developing countries impossible or more difficult. The ideal project location will rarely be found.

Excluding factors

If only one of the following criteria is evident, then the widespread dissemination of simple household biogas plants is not possible. As an exception, suitable farms in the region could allow individual measures that make biogas a feasible technology.

- too cold or too dry region
- very irregular or no gas demand
- less than 20 kg dung/day available to fill the plant or less than 1,000 kg live weight of animals per household in indoor stabling or 2,000 kg in night stabling
- no stabling or livestock in large pens where the dung cannot be collected
- no building materials available locally
- no or very little water available
- integration of the biogas plant into the household and farm routines not possible
- no suitable institution can be found for dissemination

Critical factors

Each of the following factors will lead to severe problems in biogas dissemination. Accompanying measures, particularly modified technical

Accompanying measures, particularly modified technical developments, high financial promotion or additional organizational structures within the dissemination program are necessary to guarantee project success.

- low income or unstable economic situation of the target group
- unfavorable macro- and micro-economic conditions
- gas appliances not available regionally or nationally
- irregular gas demand
- very good supply of energy throughout the year, therefore only moderate economic incentives for the biogas plant
- high building costs
- low qualification of artisans
- counterpart organization has only limited access to the target group
- weak structure of the counterpart
- no substantial interest of the government is evident

Ideal conditions

If each of the following conditions is fulfilled then household biogas plants will definitely be a success. A dissemination program is then strongly recommended.

- even, daily temperatures over 20C throughout the year
- regular gas demand approximately corresponding to gas production
- full stabling of animals (zero-grazing) on concrete floors
- at least 30 kg/day dung available per plant
- dairy farming is the main source of income
- use of organic fertilizer is traditionally practiced
- farmers are owners of the farm and live primarily on the farm. Farm products are their main

main
source
of
income. 42

- plants can be located in favorable positions to the stables and to the point of gas consumption
- operating the biogas plant can be integrated into the normal working routine of the house and the farm
- gas utilization and attendance of the plant can be clearly regulated within the household
- moderate price of plant in relation to the income of the target group
- economically healthy farms open to modernization
- insufficient and expensive supply of fossil sources of energy
- building materials and gas appliances available locally
- qualified artisans exist locally
- counterpart organization has access to and experience in contact with the target group
- efficient counterpart organizations with the experience in cooperating with the private sector
- counterpart organization has experience in programs comparable to biogas dissemination
- political will of the government to support biogas technology and other small and medium-scale farm technologies
- secured financing of the dissemination structure

Information and Public Relation Campaigns

Implementation campaigns

The biogas concept must be promoted at national, regional and communal levels. The basic prerequisite for successful, comprehensive introduction of biogas technology is the effective motivation and mobilization of potential target groups. Motivation and mobilization are the two main pillars of the actual development process. The subsequent factual existence of biogas systems is merely the logical result of that process.

Thus, implementation campaigns can only be advanced and materialized in a decentralized manner by those concerned. Information campaigns, in contrast, can be planned and controlled in a centralized manner and carried out with lower participation levels on the part of the target group.

A successful PR campaign builds on experience in implementation, on direct contact with the target groups and on the confidence of having developed a sound and appropriate technology. Information transmitted in such a campaign must react to the doubts, limitations, fears of the potential users as they are encountered in the field. Typically, a fully fledged PR campaign starts at the end of a pilot phase and runs throughout the implementation phase of a biogas program.

Information material and PR channels

Magazines, newspapers, films, radio programs, posters, leaflets and manuals are suitable vehicles for the dissemination of information on biogas. It is not always possible to arrive at a clear distinction between information and advertising. The best publicity effect is achieved by providing a steady stream providing a steady stream of information:

- on the technology per se
- on the economic effects for the household
- on the impacts on life quality
- on the overall economic and ecological impact

Of major importance in that context is the effective use of information vehicles such as local agricultural fairs, roadside billboards, market-square posters and, of course, the ubiquitous "grapevine". It must be regarded as unfortunate that no internationally recognizable biogas symbol or "logo" has been introduced to date; therefore, the development of national symbols is the more important.

Targeting information

Somewhat simplified, the target groups for information campaigns could be stratified on three levels: The national level, the regional or district level and the local or village level. In supporting or accepting biogas, all these levels play a role but must be approached in different ways.

The language of information should always be close to the language of the respective target groups. Those who read the printed information are more likely to be the top-echelon multipliers, not the semi-literate - or illiterate - ultimate consumers. The type of information and the complexity of information will vary from level to level, so does the presentation of information.

National level

PR work targets government (various ministries), national and international development agencies and companies with commercial interest in biogas. Vehicles for information flow would be high-level meetings like conferences and invitations to project area visits. Articles in the national press, radio programs and TV programs also contribute to create awareness on this level.

Regional or district level

The campaign targets government authorities on this level, churches and grass-root organizations working in development, environment and appropriate technologies. Suitable approaches are workshops, contribution to agricultural fairs and integration of the program into agricultural and development committees. The media (press, radio, TV) also have an impact on this level. On this level, agricultural colleges and high schools are approached as well. Demonstration plants for communal and industrial use are conceivable.

Local and village level

On this level, the end-users of biogas technology are directly approached through demonstration- or pilot plants, public meetings, billboards, leaflets and other means of mass-communication. On the village level, TV and print media are of lesser importance. Radio programs, in contrast target mainly the village level.

Costs of campaigning

Information campaigns are expensive. While the spread of general information is usually dependent on the availability of public or project funds, the private industry can often be persuaded to promote biogas plants or accessories in their commercial advertising. The media are often committed to developmentally relevant themes. Editorial contributions are not expensive but require a great deal of work. As a rule, the concept for a radio program portraying biogas farmers, for example, must be worked out by the biogas program.

The production of posters, leaflets or videos will have to be fully covered by the PR budget of the project. The most efficient, but also the most expensive and time consuming PR activity for biogas is the building of demonstration plants and organizing farmers to visit these plants. As much as possible, demonstration plants should be normal biogas plants

As much as possible, demonstration plants should be normal biogas plants operating on a farm to save on building and operation costs. The farmer operating a demonstration plant cannot be expected to be the tour guide for frequent visitors. Some kind of arrangement, e.g. free maintenance and repair, must be offered.

Demonstration plants

No potential biogas user can be expected to blindly trust in biogas technology, if none of the more respected members of the society has taken that risk before and succeeded. But demonstration plants are risky: any malfunction in a demonstration plant will have negative consequences for the entire program. Thus, demonstration plants are also a last test for the maturity of the technology. Since some demonstration plants serve no other purpose than that of a showpiece, the maintenance aspect is often in danger of being given insufficient attention, an eventual malfunction is practically inevitable. It is therefore highly recommended that several demonstration plants are installed at the same time in different locations, preferably on farms which have a keen interest in operating the plant. Organized maintenance services should be guaranteed for a period of at least the first three years. The cost of personnel, equipment and transportation must be included in the cost calculation for the demonstration plant, and it must ensured that the required funds are actually provided when needed. Past experience has shown that system malfunctions are frequently the result of minor deficiencies requiring no extensive repair work. Consequently, the housewives (and only subsequently their husbands) must from the very start be put in a position to perform minor repairs themselves, whereby the requisite knowledge base can be provided by the maintenance personnel.

Model farmers

As a rule, the more prosperous farmers need little prodding to install a biogas system, as long as they are provided with adequate information and guaranteed support in case of arising problems. The group that was targeted in early, poverty-oriented biogas programs, namely the less prosperous small farmers, are inherently reluctant in their commitment, because they cannot afford the cost of investment and are afraid that they may not be able to keep up the payments on a loan. In addition, few of them own keep up the payments on a loan. In addition, few of them own enough livestock for generating the required amount of substrate. Rich farmers do not act as a model for small-holders, they are known to have connections and funds that a small farmer will never be able to acquire. Experience of the last decade of rural biogas dissemination has closed this gap between the rich model farmer and the poor target-farmer. First, model farmers are selected from the more successful farmers among the potential users. They should be outstanding to some extent, but other farmers should be still able to accept them as a role model. Second, the target group of recent rural biogas programs has shifted upwards. Biogas technology is no longer regarded as a means to alleviate poverty.

Educational and Training Programs

Theoretical and practical training

One of the essential elements in the implementation of a biogas program is the proper training of those to be responsible for planning, constructing, operating and repairing the plants. Theoretical and practical training must therefore be regarded as an indispensable part of the implementation strategy. Training, in contrast to education, focuses on those who are actually in touch with biogas technology, either as part of the biogas program or as end-users.

Target groups for practical training

In addition to the general knowledge conveyed in vocational programs, special training centering on the practical skills required for everyday plant operation should be made available to:

- the owner-operators of biogas systems, mainly housewives and farmers;
- servicing and maintenance personnel;
- masons, fitters, plumbers and factory personnel involved in the construction or manufacture of biogas systems and system components;
- planners of biogas units and developers of biogas technology;
- organizers, promoters and multipliers, whereby the latter may be a social worker, the head of a biogas task force, foundation or self-help organization, or even a reporter or film producer working on a biogas-related project.

Teaching methods

Depending on the objectives of a particular training program, not only the content, but also the teaching methods involved must be tailored to the respective target group. The success of a training program is largely dependent on the time and duration of its presentation. The target group must be "available", i.e. most housewives can only spare time for instruction during certain hours of the day, and then only directly at or close to home, and farmers can rarely afford the time during harvesting season.

Relevance for the target group

The content of a biogas training program must also reflect the real needs of the individual for more information. The construction of biogas systems, for example, if taught to masons, should not be given mere theoretical treatment. On-the-job training combined with theoretical teaching (half day each over four weeks) has proven successful in training courses for engineers in Tanzania. The information being conveyed must be of direct and recognizable relevance for the target group. It is of particular importance that training seminars offered to craftsmen and servicing personnel, combine practical demonstration and practicing with simple theory.

The first few seminars held in a region usually involve certain difficulties due to a lack of teaching aids, illustrative material or classrooms. It may also be difficult to convince a farmer that students of a training course want to build a biogas digester on his farm. In many instances, the use of school rooms during school vacation and a single demonstration plant will have to suffice in the beginning. Most technical and agricultural schools will gladly offer their support.

Educational programs

Educational programs are defined as formal know-how transfer in schools, colleges or courses for the general public and potential users. They create awareness about biogas technology which goes beyond of what is transmitted in PR campaigns. Educational programs must be professionally supported, integrated and administered on a national, regional and communal scale by the respective ministries and authorities.

regional and communal scale by the respective ministries and authorities responsible for agriculture, education, health & hygiene and other relevant fields. Private educational institutions or the biogas program itself can as well get operational in carrying out educational programs.

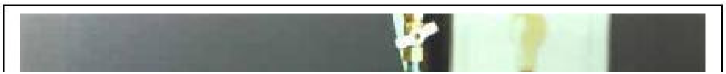
Curriculum development

Biogas technology can be included in the curricula of elementary and secondary schools in two ways: first, it can be included in subjects such as biology, physical science, chemistry or agriculture. Second, it can be taught in a block, to which the mentioned subjects donate time and teaching capacity. Teachers would need to be educated first, in order to develop a curriculum together with the biogas program.

Often, individual schools are not free to develop their own curricula. To create a conducive atmosphere for integrating biogas technology into school curricula, this has to be lobbied for on the national level, where nationwide applicable curricula are developed.

Agricultural colleges and universities are more free to offer specific biogas-courses than schools. Here, it is more the personal enthusiasm of lecturers and deans of faculties that plays the decisive role if or if not biogas technology is taught in a course. At least the practical use of biogas systems should be included in the curricula of medical schools. The professional know-how of planning and constructing a biogas plant should be conveyed within the framework of technical/vocational school training.

Demonstration models of biogas systems should be available in schools which have included biogas in their teaching. Excursions to nearby biogas plants will greatly awaken the interest of students in biogas technology.



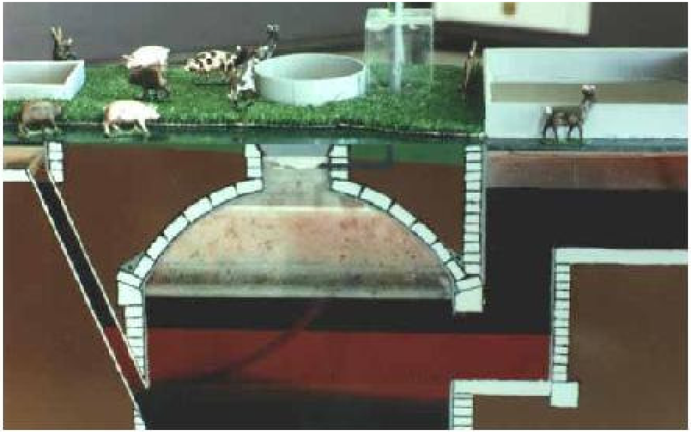


Figure 3: Model of a biogas plant for instruction purposes in schools
Photo: Bender

Financial Promotion and Public Support

Sources of financing

The investment costs necessary for the construction of biogas plants frequently exceed the means at the disposal of the investor. They cannot be covered from his regular income or savings. This could also apply to the larger investments occurring at certain intervals during the economic lifetime of the plant. Besides the non-recurring, periodical costs, the running costs of the plant have to be borne. These expenditures, however, should be set against income in the form of regular revenue. A liquidity analysis can show how far the net expenditures have to be financed from outside and how much contribution can be expected from the expected income. Usually the construction of biogas plants demands financial means which can only be covered by outside capital. In general the following can be seen as sources:

Running, maintenance and repair costs

The financing of investments and of the operation of the plant should be realistically assessed at the planning stage. It has to be ensured that the quota derived from public funds is carefully calculated in the budget. Special attention has to be paid to the question of how the running, maintenance and repair costs can be financed. Funds for servicing and repairing are often forgotten but are of essential importance in order to make full use of the economic lifetime of the plant and also to insure the confidence of the user in the reliability of the plant.

Financing by credit

When financing by credit the questions of liability and debt provisions should be clarified. The borrower should always be able to bear the possible risk or be immune to this risk by having state credit guarantees. The debt provisions should be worked out so that they conform to the development of cost and yield. Credit repayment terms are frequently much shorter than the lifetime of a biogas plant e.g. 5 years compared to 15 - 20 years. The re-payment of credits in this rather short time often becomes an invincible barrier for the farmer.

State support

When the profitability of biogas plants is negative on a private scale (financial analysis), but are favorable on a national scale (economic analysis), state support measures would make sense economically.

In principle, the following measures can be seen as supportive measures for the dissemination of biogas systems to an extent that would make them macro-economically feasible and politically desirable:

- the creation or alteration of structural conditions for individual investment decisions in favor of biogas plants, e.g. more critical control of firewood consumption and tree-felling, regulations concerning the treatment and disposal of substrates (waste water, feces)
- the subsidizing of private, institutional and community biogas plants by means of grants or inexpensive credits
- the construction and operation of biogas plants as public utility enterprises especially as municipal community plants through appropriate support to the municipalities.

Families with low income

The more biogas plants are constructed by families with low income, the less can the costs for construction and operation of the plant be met by contributions from the users. With village community plants in India, providing energy for households, practical experience has indicated that not even the running costs can be met by user fees. Consequently, not only the investment costs but also a proportion of the running costs has to be covered by general tax revenue. The resolution of the Indian Government provides a guideline tax revenue. The resolution of the Indian Government provides a guideline for the extent of public support whereby from case to case 50 to 100% of the cost for community biogas plants are subsidized.

Research and Development

Financial promotion from public or development funds is always necessary for research and development and for the organizations concerned with the implementation of biogas programs. Only in exceptional cases have private companies carried out research and product development, but even then, they sometimes relied on assistance from external donors. Research and development on the following aspects of biogas technology are particularly worthy of sponsorship:

- reducing the cost of system construction
- increasing the gas yield, most notably of dome-digester systems
- storage and application of digested sludge
- socio-economic prerequisites and consequences
- financial analysis of biogas units and economic analysis of biogas programs
- plant design and operation modifications to suit locally available materials

Subsidies

Subsidies for biogas plants may consist of grants, low-interest or no-interest loans and/or supplies in kind (materials). The response of the target group will usually depend to a large extent on the types of subsidies, the amounts available, and bureaucratic obstacles in gaining access to funding. The popularization of a subsidy program naturally plays an important role, too. The perceived reliability of the subsidy program is essential. Subsidy arrangements should therefore be underpinned by binding agreements arrangements should therefore be underpinned by binding agreements with several years validity.

Graduated subsidies, the granting of which depends on, for example, the type of fuel in use prior to system installation or on the social situation of the applicant, are conceivable. In practice, this leads to socially justifiable differentiation in the extent of support granted.

Economic benefits for the target group

The most important incentive for any potential investor are the monetary returns to be gained by installing a biogas system. Promotional programs and subsidies for biogas systems should therefore be oriented along the lines of the benefits to be expected.

The economics of a biogas system depend, first, on the type of construction and cost of operation and, second, on the resultant benefits and/or cost savings provided by the system. Since the savings can be quite considerable in relation to the cost to the individual, even modest subsidies can yield a net economic advantage for households considering biogas as an option. If, on the other hand, individual expenditures for fuel and fertilizer were relatively low, higher subsidies will be required. Thus, the subsidies should be geared to the respective regional and social situation. Financial assistance for individual households should not be based on fictitious market values for gas and fertilizer, but rather on the actual costs and benefits involved.

Financial incentives

As a rule of thumb, financial incentives can be regarded as an essential prerequisite for the success of a large scale biogas program. If at least 70% of all households within the target area are to be supplied with biogas, all investors should be granted special allowances. The process of discussion requisite to defining the range of participation within the target area or community can, in itself, have a favorable impact on the project. Nonetheless, the maximum possible personal contribution should, as a matter of principle, be demanded of each household involved in a subsidized program. A maximum of contribution from the owner during construction of the biogas plant is conducive to the personal involvement of the systems

systems
future
owner.

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home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Biogas - Organizations and Networks

Funding Organizations

International Organizations

United nations Environment Programme (UNEP)

General Services Section

P.O.Box 30552

Nairobi Kenya

National Organizations

Bangladesh: Food and Agriculture Organization of the UN

P.O.Box 5039 (NEW Market)

Dhaka

Tel.: 310311 / 2

Bolivia: Food and Agriculture Organization of the UN

CP 20479

La

Paz
Tel.: 326162, 369005

China: Food and Agriculture Organization of the UN

Jianguomenwai 4-2-151 and 152

Beijing

Tel.: 53 22 835 / 6 / 7;

Colo mbia: Food and Agriculture Organization of the UN

Apartado Aereo 5773

Bogota

Tel.: +57 1 241 1930, 242 0520

Fax: +57 1 242 2930

Cuba: Food and Agriculture Organization of the UN

PO Box 16004

La Habana 4

Tel.: 219717, 219155

Indonesia: Food and Agriculture Organization of the UN

PO Box 2338

Jakarta

Tel.:

Tel.:
+62
21
324939,
321308

51

Fax: +62 21 335516

India: Food and Agriculture Organization of the UN

PO Box 3088

New Delhi 110 003

Tel.: 693060, 690410

Jamaica: Food and Agriculture Organization of the UN

PO Box 1136

Kingston

Tel.: +1876 9294107, 9295674

Fax: +1876 9298351

Kenya: Food and Agriculture Organization of the UN

P.O.Box 30470

Nairobi

Tel.: +254 2 725128, 725440

Fax: +254 2 727584

Mauritania: Food and Agriculture Organization of the UN

PO Box 665

Nouakchott

Tel: 253157, 251172

Morocco: Food and Agriculture Organization of the UN

PO Box 1369

Rabat

Tel: +212 7 65756, 65865;

Fax: +212 7 66468

Nepal: Food and Agriculture Organization of the UN

PO Box 25

Kathmandu

Tel: 523200, 523239

Thailand: Energy Conservation & RenewableEnergy Division

National Energy Policy O ffice NEPO

394/14 Samsen 12, Dusit

10300 Bangkok

Tel.: +66 2 28009517

Fax: +66 2 282 4607, 282 4682

Tunisia: Food and Agriculture Organization of the UN

B.P. 863

Tunis

Tel: 782686, 894824;

Implementing Organizations

Bolivia: Fundacin Integral de Desarrollo

Planning and construction of biogas systems and anerobe waste water treatment

C. Guillermo Rivero Nr.9

Sta Cruz de la Sierra

Casilla 1911

Tel.: +591 3 339 607

Fax: +591 3 331243

Bolivia: GTZ Proyecto Biogas UMSS(Castillo Co)

Planning and construction of biogas systems

Av. Petrolera Casilla 2672

Cochabamba

Tel.: +591 42 41503

Fax: +591 42 41503

Burundi: Direction Generale de l'Eenergie (DGE)

Research and development advisory service

B.P. 745

Bujumbura

Tel: +257-22-2203;

China: Shanghai Biogas Engineering Development

Planning and construction

Central Jiang Xiroad 136.3

Shanghai

Tel: 212336;

China: Asia-Pacific Biogas Research and Training Centre

Research and development, training, mass dissemination of family plants

No. 13, Section 4, Remning Nan Road

610041 Chengdu - Sichuan

Tel.: +86 28 522 1571, -3032, Fax: +86 28 5227610

Email: tybrtc@acdisn.cd.sc.cn

China: Bejing Municipal Research Institueof Environmental Protection

Research and development

Fuwai Avenue

100037 Beijing

Tel: 0086 1068313146;

Fax: 0086 10683 14675;

Colo mbia: BIOTEC Colombia S.A.

Planning and construction (waste water treatment)

Calle 55 No. 69-29

Bogot

Tel.: +57 1 2632509, 2632256

Fax: +57 1 4106553;

Germany: TBW GmbH

Planning and construction of biogas plants and anaerobe technology

Baumweg 16

60316

60316
Frankfurt
Tel.: +49 69 943 5070

Fax: +49 69 440 049

Email: tbw@pop -frankfurt.com

India: Centre for Environmental Studies Anna University

Research and development, waste water treatment

600025 Madras

Fax: +91 44 2350397

India: AIC Watson Consultants

Planning and construction, waste water treatment

Nariman Point Rajeha Centre,13th floor

400021 Bombay

Tel.: +91 22 2834 052, 2843 220

Fax: +91 22 2040398

Email: AICW@giasbm01.vsnl.net.in

Indonesia: Indonesian Chamber of Commerce &Industry

Waste water treatment

Compartment of Emvrionment

Ruma Maduma, 52, Dr. Saharjo

12970 Jakarta

Tel.: 8311184

Fax: 8311185

Indonesia: Agency for the Assessment and Applicatio n of Technology BPPT

Research, development, planning

Lalan M.H. Thamrin No. 8

10340 Jakarta

Fax: +62 21 31 69760

Indonesia: Nusantara Water CentreIntercom Plaza

Planning (waste water treatment)

Jl. Marujallir Raja, Blok A3/16

Jakarta, Barat

Fax: +62 21 5490543

Jamaica: Scientific Research Council SRC

Coordination of anaerobe technology development

Hope
Gardens
Box
350

Kingston 6

Tel: +1876 927 1771-4

Fax: +1867 927 5347

LAO PDR: Renewable Energy Centre for Science,Technology and Environment (STENO)

Research and development

PO Box 2279

Veintiane

Tel.: +856 21 213471

Fax: +856 21 213472

Malaysia: Standards & Industrial Research Institute of Malaysia (SIRIM)

Research and development

40911 Shah Alan, Selangor

PO Box 7035

Tel.: +60 3 556 7565

Fax: +60 3 550 8095, 556 7757

Email: bgyeoh@sirim.my

Morocco: Programme Speciale Energie GTZ

home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Volet BIOGAZ

B.P. 21

Agadir

Tel: +212-8-840816

Fax: +212-8-841568; 846521

Morocco: Centre de Developpement des Energies (CDER)

research and development

B.P. 509

Marrakech - Gueliz

Tel: +212-4-309814, 309822

Fax: +212-4-309795

Nepal: Kathmandu Brick Landfill Gas (P) LTD.

Post Box 3164

Kathmandu

Tel.: 521 659, 524 437

Nepal: Managing Director
Development Partners Nepal

research and development waste water treatment

Kathmand u

G.P.O. Box 5517

Fax: +997 1 523155

Nepal: DevPart Consult - Nepal Pvt. Ltd.

private consulting construction of farm biogas systems

Prakash C. Ghimire

G.P.O. Box 5517

Kathmandu

Tel.: +997 1 476 264

Phillipines: ENVIROASIA Corporation

Private consulting for planning and construction

3rd Fl Skunac Bld.Alabang Zapote Rd.

Alabang Muntinlupa, Metro Manilla

Tel.: +632 842 4456

Fax: 00632 842 2180;

Phillipines: Integrated Biogas Generation and Wastewater Treatment System Cubao

Planning and construction advisory services

Alpha Bld. 77 ONI Serrano-UE

Quezon City

Tel.: 34 -786447; 782710; 798043

Fax: +632 721 5057;

Slovakia: Diretor of Department for International S&T Cooperation

Research and development

Hloboka 2

81330 Bratislava

Tel.: +42 7494583

Fax: +42 7 49 1524

Tanzania: CAMARTEC Biogas Extensio n Service

Research and development advisory service

P.O.Box 764

Arusha

Tel.: +255 57 3594, 3666

**Tanzania: Arusha Bio-
Constructors and Consultants**

private consultancy for planning and construction

Sanford Kombe

P.O.Box 8067

Usa River

Fax: +255 57 7431, 8520

Tanzania: Biogas and Solar Co. Ltd.

private consultancy for training, planning and construction

Ainea Kimaro

P.O.Box 12446

Arusha

Fax: +255 57 8256

Thailand: Biogas Advisory Unit Chiang Mai University

Planning, advisory services

50202 Chiang Mai

Fax: +66 53 210320

Email: agani005@chiangmai.ac.th

Thailand: RISE-AT Institute o f Science and Technical Research & Development

Chiang Mai University

50202 Chiang Mai

Fax: +66 53 892224

Email: cnxnsmwn@chiangmai.ac.th

Thailand: Natio nal Center for Genetic Engineering and Biotechnology BIOTEC

Research

5th fl NSTDA Bld. Rama VI Road

10400 Bangkok

Tel.: +66 2 64481 50-54

Fax: +66 2 6448107

Tunesia: Agence de Maitise de lEnergie

Research and development

8, rue Ibn El Jazzar,

B.P. 213

1002 Tunis Belvedere

T l

Tel:
787700;

Vietnam: CEFINEA Research&Training Center onWater & Environmental Technology

Ho Chi Minh City Polytechnic Univ.

288 Ly Thuong Kiet - Q.10

Ho Chi Minh City

Vietnam: Renewable Energy Center

Planning and advisory services

Can Tho University

Can Tho

Tel: 8471838757;

Fax: 8471838474;

Networks for biogas and anaerobic digestion

Networks are built to share experiences on several issues, in this case on anaerobic digestion (AD) of agricultural and industrial biomass and communal and industrial wastes. Databases can cover AD experts and organizations, biogas plant design, research and funding organizations, literature and further information. The main objective of AD networks is information exchange on the performance of technically and commercially successful AD facilities and findings of scientific research on AD.

Name (Country)	Focus	Contact
AD-Nett (Europe)	Anaerobic digestion of agro-industrial wastes, less the generation of energy; mainly network of users, producers in agriculture and agro-industry; data-bank: agricultural plants; contacts	Herning Municipal Utilities Enghavevey 10 DK 7400 Herning Tel.: +45 99 26 82 11 Fax: +45 99 26 82 12 Email: hkvadm@post4.tele.dk Dr. Pat Howes ETSU Harwell Didcot OX11 0RA UK Tel.:+44 12 35 43 28 10 Fax: +44 12 35 43 39 90 Email: pat.howes@aeat.co.uk

		pat.howes@acat.co.uk
ANESAPA (Bolivia)	Asociacin Nacional de Entidades de Servicio de Agua Potable y Alcantarillado Seminars on waste water treatment	Av. Villazon 1966 P-7 La Paz Bolivia
AT Verband (Germany)	Association of German NGOs and consultants active in the field of Appropriate Technology, also biogas technology; promotion of socially and environmentally appropriate technologies	German AT-Association Alexanderstr. 17 53111 Bonn Germany Tel.: +49 228 631421 Fax: +49 228 431427
BORD A (Germany)	Bremen Overseas Research and Development Association Promotion of low-cost biogas systems in developing countries. Newsletter: Biogas forum	Breitenweg 55 D-28195 Bremen Tel: +49 421 13718 Fax: +49 421 165 5323
CEPIS (Peru)	Centro Panamericano de Ingeniera Sanitaria y Ciencias del Ambiente dissemination of information, technical advice, promotion of regional programs, network of cooperation centers, education;	Los Pinos 259 Casilla Postal 4337 Lima 100 Tel.: +51 1 4377081 Email: scaporal@cepis.org.pe
FAO/SREN (EU)	European Sustainable Rural Environment and Energy Network working groups: 'Bio-Mass for Energy and Environment', 'Environmental Aspects of Anaerobic Treatments' publications: Newsletter; 13 volumes in FAO/REU Technical Series; organization of workshops, electronic mailing list on Anaerobic Technology	Rainer Krell FAO/Regional Office for Europe Viale delle Terme di Caracalla I - 00100 Rome Email: rainer.krell@fao.org
German Biogas Association ("Fachverband Biogas") (Germany)	Promotion and dissemination of biogas technology as a sustainable technology link within the nutrient circle; organization of excursions, seminars, conferences, exhibitions; provision of know-how and experts - technology transfer;	Biogas Association Germany Am Feuersee 8 D-74592 Kirchberg/Jagst

(Germany)	working groups: public relations, safety standards, organic	Tel: +49 7954 1270

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	waste fermentation, agriculture	Fax: +49 7954 1263
IAWQ (United Kingdom)	International Association on Water Quality anaerobic digestion; operation and costs of large/small wastewater treatment plants; pretreatment of industrial waste-waters; pulp and paper industry waste-waters; water and waste technology and management strategies for developing countries	Chairman: Prof. E.R. Hall, Dept. of Civil Engineering; University of British Columbia, CAN Secretary: Prof. K.J. Kennedy, Dept. of Civil Engineering, University of Ottawa, CAN
RECBAM (Colombia)	Red Colombiana de Biotecnologa Ambiental	Olga Rojas Ciudad Universitaria Melendez Colombia Tel.: +57 2 3312175 Fax: +57 2 3392335 Email: olgaro@petecuy.univalle.edu.co
RISE-AT	Regional Information Service - Center for South East Asia on AT Focal point for expert network South East Asia on anaerobe technology Biogas Advisory Unit	Institute for Science and Technology Research and Development (IST) Chiang Mai University P.O.Box 111 50202 Chiang Mai Thailand Tel.: +66 53 892189 Fax: +66 53 892224 Email:

		Email: cnxnsmwm@chiangmai.ac.t h
Waste for Energy Network (EU)	objective: industrial exploitation of waste for energy three sectors: wood & paper, household waste, biogas; organization of seminars and workshops	Centro da Biomassa para a Energia, Olvia Matos
WEDC (United Kingdom)	Water Engineering and Development Centre countries; dissemination to practitioners and researchers; registration possible to receive regular information	Dr. Jeremy Parr WEDC Loughborough University Leicestershire LE11 3TU Tel: +44 1509 222618 Fax: +44 1509 211079 Email: jeremy.parr@boro.ac.uk

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Biogas Digest

Volume IV

Biogas Country Reports

Information and Advisory Service
on Appropriate Technology

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Concept and contents:

Werner Kossmann, Uta Pnitz

Information and Advisory Service on Appropriate Technology (ISAT)
GATE in Deutsche Gesellschaft fr Technische Zusammenarbeit (GTZ), GmbH
(German Agency for Technical Cooperation)
Post Box 5180
D-65726 Eschborn
Federal Republic of Germany
Telephone: +49 6196/79-0
Fax: +49 6196/797352
E-

*E-
mail:
gate-
isat@gtz.de*

Stefan Habermehl

Household Energy Appropriate Technologies (HEAT) GmbH
Limburger Strae 29
D-61479 Glashtten
Federal Republic of Germany
Telephone: +49 6174 964077
Fax: +49 6174 61209
E-mail: heatinternational@t-online.de

Thomas Hoerz, Pedro Krmer, B. Klingler, C. Kellner, Thomas Wittur, F. v. Klopotek, A. Krieg, H. Euler

Naturgerechte Technologien, Bau- und Wirtschaftsberatung (TBW) GmbH
Baumweg 10
60316 Frankfurt
Tel.: 069 943507-0
Fax: 069 943507-11
E-mail: tbw@pop-frankfurt.com

Design:

Utz Dornberger
Stckelstr. 20
04347 Leipzig
Tel.: 0341 2334980

E-mail: utz@imb-jena.de

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Biogas technology in Bangladesh

Potentials of biogas

Cattle dung available from 22 million cows and buffaloes is nearly 0.22 million tons. One ton of dung can produce 37 m^3 of biogas. Available cattle dung can produce 2.97×10^9 m^3 of gas which is equivalent to 1.52×10^6 tons of kerosene or 3.04×10^6 tons of coal.

Besides, a substantial amount of biogas can be produced from human and other animal excreta, garbage and water hyacinth.

Biogas utilization

The first biogas plant (floating dome type) was constructed in 1972. Till now (1997) there have completed around 6000 biogas plants in Bangladesh. The Local Government Engineering Department (LGED) aims setting up 10,000 digesters over the next three years.

In Bangladesh biogas is a proven technology. The plants constructed under Slum Improvement Project (SIP), could show a very encouraging result. This technology now deserves attention to the Government. It is suggested to create a biogas cell, that will monitor the biogas activities. Field level staffs of these departments will be trained on biogas technology. All commercial Banks will ensure loan for the construction of biogas plants. On recommendation and assurance of supervision by the biogas cell. Some private organisations also may be encouraged to make up the responsibility. In order to extend biogas program, it is suggested that based on field information biogas cell is to supply design. The work must be supervised by some trained engineer, who will be responsible for any default.

Involvement of Local Government Engineering

Involvement of Local Government Engineering Department (LGED) in biogas technology

LGED has been created mainly to provide technical support to the local government institutions. This organization can play an important role in desseminating appropriate technology all over the country as it has setup at Thana level.

First biogas plant based on night soil was constructed by LGED in Faridpur Muslim Mission. Before construction of this plant, there was an apprehension about its acceptability. But after completion of the plant there was no social and cultural barrier. This plant could drew attention of all concerned.

Small bore sewerage system, in conjunction with biogas plant installed by LGED in Bauniabad slum in Dhaka proved to be cheaper and better solution for sewage disposal. Solid waste and water hyacinth based biogas digesters of LGED also ceated great interest among users.

LGED has trained a lot of professional engineers on biogas technology, some of them received higher training in China.

Geography, population and agriculture in Bangladesh

Geography and population

Bangladesh is one of the most densely populated countries in the world having a total population of 120 million in an area of 147570 km^2. Over 80 percent of the people live in the rural areas. The majority of the rural people remain unemployed for at least some month of the time. More than half of the rural people are landless or nearly so and another 25 percent find it difficult to ensure subsistance from their cultivable land and need to seek supplementary sources of income. Economic and social conditions for most people are extremely difficult.

Economy and agriculture

Agriculture remains the largest sector of the economy occupying three-fifths of the employed labour force and producing nearly half of the economys output. Land is the main productive asset in rural areas; it represents both economic and social status.

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Biogas technology in Belize

History

The first project of the GTZ concerning the biogas technology in Belize started in 1988. It evolved from a Caribbean biogas dissemination programme of the GTZ which was carried out with the Caribbean Development Bank. Biogas consultants and biogas technicians active in the region constructed three floating-drum plants of the BORDA model within the *Caribbean Technology Consultancy Services (CTCS).*

Since neither the market forces could take up biogas technology, nor could independent dissemination structures grow, the programme was continued in 1989 along the lines of experience gained during biogas activities in the Caribbean and Nicaragua - to anchor biogas-specific, national know-how in a local dissemination structure. On the basis of this background experience and with the financial, personnel and material support of the *Caribbean Biogas Dissemination Programme, a German under local project contract and, in* the meantime, a Belizian have been employed in Belize to build up such a structure in cooperation with the state Central Farm and to demonstrate the high performance and efficiency of biogas technology with users. The leitmotif of this involvement which found striking resonance in the socio-economy reality of Belize was:

1) The fastest possible transfer of knowledge to the productive sector
2) To induce demand extensively independent of external financing
3) To anchor biogas technology in a dissemination structure which would support itself.

To modify the technology, to provide practical demonstrations and to train local masons the construction of six fixed-dome and three floating drum plants was begun with the assistance of regional experts from Guyana, Nicaragua, Jamaica and other Caribbean islands at two biogas workshops. For larger pig producers, plants were built with the aim of reducing the pollution of surface water. Building five plants for institutions was to

a) increase awareness of biogas technology and
b) open the technology up to other areas of application (e.g. wastewater treatment).

An active demand was to be created by means of intensive advertising integrating those active in rural development and with intensive customer advisory services. By linking state interest, social involvement and economic dynamics the dissemination structure was to survive the period of external financing and sustainably anchor and disseminate biogas technology in Belize.

CAMARTEC model

In 1991 the CAMARTEC model was introduced. In comparison to the high input of material and work in plants used previously (reinforced steel vault and fundament), a cost reduction of approx. 15 - 20% was achieved. Since 1993, 20 plants have been built (of these, 5 are institution plants, 13 household plants and 2 are middle-sized plants).

Target group

The target group for the household biogas plants has so far consisted of farmers involved in commercial pig production. The majority of biogas users own 5 - 40 large pigs. The remaining pig breeders can hardly be considered as a target group: the insufficient number of pigs, inferior sties and only marginal integration into the market means that these can only be considered in particular cases for biogas utilisation. The users so far normally produce peanuts, maize and beans on cropland of between 3 and 10 acres. Until the construction of the plants, the use of organic fertiliser was uncommon. Plant nutrients are usually provided by means of slash and burn methods, and chemical fertiliser in small quantities.

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Government

Biogas technology has a good reputation on the governmental and administrative (mostly *Ministry of Agriculture) levels responsible for it. This good reputation has resulted in* significant financial involvement for the small country of Belize. In 1992, B$ 62,000 were made available for biogas dissemination and with this, the budget was taken which was financed to 50% by the Caribbean Development Bank in 1991 (budget MoA 1991: B$ 53,000) was taken over. The current budget provides for 3 established posts for the Biogas *Office of the Central Farm.*

The government classifies biogas technology particularly as part of its efforts to improve rural infrastructure (decentral energy supply) and to substitute imports (substitution of fossil energy sources). The aspect of fertilising has only been considered a side-effect of biogas technology so far.

Geography, population and agriculture in Belize

Geography

Belize, the second smallest state of America (22,695 km) borders to the north on Mexico, to the east and south on Guatemala. Belize, apart from the northern part of the country, lies in the tropics and is exposed to the northeast trade winds bringing high humidity the whole year around. The rainy season (May to November) and the dry season over the rest of the year are clearly defined. The mean annual precipitation in Belize City amounts to 1890 mm and is distinctly higher in the south. The monthly mean air temperature here in the coldest month (January) is 24.1C and in the warmest (August) is 28.8C. It is estimated that approx. one third of the land is suitable for agriculture although in 1985 only 101,000 hectares were stated as being agricultural land.

Population

The total population of Belize is estimated today to be approx. 200,000. The demography of Belize shows the following characteristics:

- an even distribution of rural and urban population
- significant emigration of young adults abroad
- an ethnic cross-section comprising descendants of three Maya groups (Yucatec, Kekchi and Mopan), Garifuna (Black Caribbeans), Europeans (Mennonites), Creoles, Mestizas and immigrants from the Near East.

This ethnic cross-section has a considerable influence on the agricultural sector.

Economy and agriculture

The economy of Belize is marked by high dependence on imports and a small domestic market. Amongst other things, this results in high sensitivity to fluctuations in the world economy and in a trade deficit of approx. 50 million US$ annually. Due to low industrial production which only makes a 20% contribution to the national income (including the agroindustry), agriculture remains the most important economic factor in Belize. It makes a contribution of 21% to the GDP at factor cost (1986). In 1984 this included approx. 32.1% of the workforce.

Until the 20th century agriculture was dominated - as the national economy of Belize also was - by forestry which had a sustainable effect on the structure of agriculture. The cultivation of sugar cane (followed by citrus fruits) has been able to develop into the most important source of foreign currency in recent decades due to special agreements with Great Britain yet stable commercial structures have only been able to establish themselves beside this export sector to a limited extent in the agricultural sector. Smallholders (Milpa farmers) with only a weak capital background and low market integration represent three quarters of agricultural producers. In 1971, 74.6% of farms had less than 21 acres. With agricultural producers. In 1971, 74.6% of farms had less than 21 acres. With slash and burn

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methods they clear the land for the cultivation of rice, maize, beans, fruits and vegetables as the main produce but also some animal husbandry, chiefly pig production is carried out.

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Biogas technology in Bolivia (region Cochabamba)

History

In 1986, the GTZ, in cooperation with the Universidad Mayor de San Simon (UMSS) in Cochabamba began a project to disseminate biogas technology. Until 1989 these activities were part of the supra-regional GTZ Biogas Dissemination Programme. From January 1990 to the end of 1992 the biogas activities were continued as a component of the Bolivia Special *Energy Programme started at that time.*

By consolidating biogas technology into the Departamento Cochabamba and into the general background of national energy and landscape planning by means of the National Biogas *Network, the aim was to integrate "biogas technology into the agricultural production* process" so that the "destruction of agricultural ecosystems" could be curbed and "energy and organic fertiliser" could be produced decentrally. 27 plants, 9 of them in the Cochabamba area, were produced by varying measures carried out by varying organisations and of which only 1 was still functioning in 1988.

In a development policy respect, the project was seen at that time to provide access for the economically weaker groups of the population to biogas technology and to improve their general economic situation. In 1988 the project purpose was defined to be "the creating of fundaments on which to extensively disseminate biogas technology through Bolivian institutions by carrying out training and building demonstration plants". Credits, training and the improvement of project management were to allow a high-performance dissemination structure. Here, one emphasis was placed on the integration of the technology into local, regional and national socio-economic structures and on the dissemination of the so-called "Integrated Farming Systems". The biogas plants were mainly understood in this connection as "fertiliser plants" which make a contribution to strengthening intensive animal husbandry and to supporting agricultural production.

In the knowledge that the project regions of higher altitude were unsuitable for biogas dissemination, the Biogas Office concentrated more and more on the migrational regions in the tropics with an inferior infrastructure. Here, approx. 35 plants were built between 1989 and 1992.

A survey carried out by the Biogas Office has identified interesting potential, particularly in Santa Cruz, in the field of industrial and communal sanitation. After having built a UASB (upflow anaerobic slugde blanket) plant for the Palmasola prison the attempt is now being made to establish consulting in the field of anaerobic wastewater treatment. At the time of the survey this target was endagered because of missing a budget, unclear legal status and only partly consolidation of the Biogas Office on the demand and supply level.

Geography, population and agriculture in Bolivia (region Cochabamba)

Geography and population

The geographical zones in Bolivia are tropical and subtropical lowlands, upland valleys and hilly areas and the Altiplano situated at 4,000 m above sea level.

The region Cochabamba extends over upland valleys as well as over tropical lowlands. It consists of 14 administrative regions. Including the districts of Carrasco and Chapare located in the tropical regions it comprises an area of 55,631 m in total. According to the 1976 census Cochabamba Valley, lying at an altitude of between 2,300 and 3,700 m, has a population of 730,358. The province capital, Cochabamba (location of the project, 2,553 m above sea level), with 377,000 inhabitants is one of the economic and commercial centres of the country. The Cochabamba Valley is divided up into the districts Valle Bajo, Valle Central, Valle Alto and "Cabecera de Valle". The mean annual temperature lies at around 17.7C with

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night frost occurring in winter. The mean annual precipitation amounts to around 477 mm. Climatic conditions allow arable farming between November and May.

The dissemination region Cochabamba Tropical is approx. 280 km northeast of the city of Cochabamba and comprises 2,500 km. The mean annual temperature is about 24.7C with temperatures of over 30C being possible during the day. The south wind "Surazo" can however make temperatures fall to less than 10C. The mean annual precipitation depending on the area is between 3,500 mm and 6,000 mm. The population amounted to approx. 350,000 in 1989 and lives mainly in scattered settlements, chiefly along the road to Santa Cruz. The region is a migration area and has been developed for approx. 20 years mainly by migrants from the highlands of the Andes. The population development is strongly dependent on the development of coca cultivation. A substantial share of the national coca production which made a contribution of 600 million US$ to the GNP in 1990 comes from here. With the decline in the price of coca and restrictions in its cultivation in 1990 the population promptly fell to approx. 91,100.

Demographically the population comprises approx. 30% Mestizas, 25% Quechuas, 17% Aymars, 12% Europeans (and Americans) and "others".

Economy and agriculture

Bolivia is considered to be one of the most politically and economically unstable countries in South America. The economy of Bolivia grew between 1987 and 1990 by approx. 2.5% annually. However this growth could not close the gap in the economic structure of Bolivia which separates the Indio population from the white population, i.e. the urban from the rural populations, and which makes the informal sector (approx. 60% of inhabitants working in cities are active here), superior to the formal sector (mainly from the export of coca) also under the aspect of added value.

Agriculture is ascribed - now that mining has lost its key position - with a substantial potential for development, in particular if a South American economic area is to be formed. Especially the Amazonas region around Santa Cruz is seen as the central agroindustrial growth area. In 1990 cattle to the value of 50 million US dollars were exported from this region. Where energy is concerned, Bolivia is independent of imports. Marketing of oil and gas energy resources on the domestic market brought 452 million US dollars in 1989. This year, the revenue from energy imports amounted to US $ 214 million. This corresponds to 26% of the total amount of exports.

Biogas technology in Burundi

Biogas Dissemination Programme

The Projet Biogas is under the control of the Ministry for Energy and Mining. The project was initiated as a Biogas Dissemination Programme of the GTZ in 1984 in the region Cankuzo, it has been part of the Special Energy Programme since 1988.

History

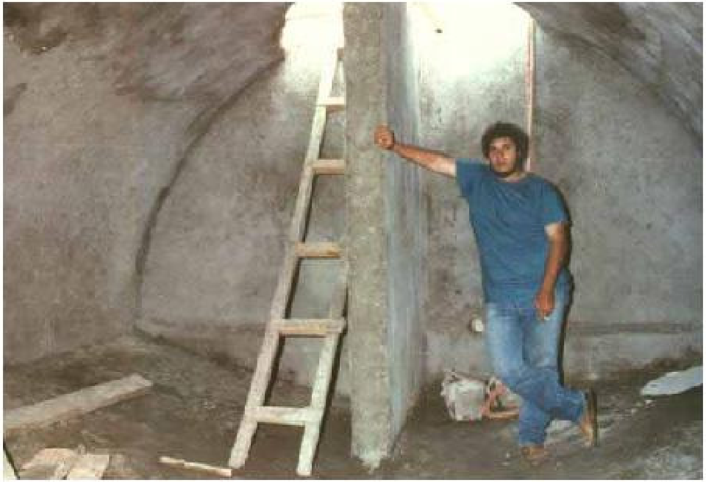
The first agricultural family plants were constructed on livestock farms in the region of Cankuzo in 1985. In 1987 the project was extended to include the Ruyigi region. At the same time the building of biogas plants started for the toilets of schools and other institutions. Private contractors were commissioned for larger plants. The training of craftsmen, the establishment of a service system and the opening of material credit funds were to provide the basis for a self-reliant dissemination concept. By 1992, 206 small-scale plants, and 84 institute plants with digester volumes of over 100 m^3 had been constructed.

Plant type

Technically, the basis was on the masoned fixed-dome plant modelled on the Chinese design from the outset. Large digesters were chosen on account of the relatively low temperatures in the digester of just over 20C so that longer fermenting times could be achieved. Gas production was an average of about 0.1 m^3/m^3 per day.

Experiments with slurry as fertilizer were carried out from the outset on land belonging to the project and to communes. Permanent stabling with grass production as fodder was propagated in cooperation with propagated in cooperation with other institutes

The directorate general for energy in the Ministry set up a committee to coordinate all biogas activities in the country. The focal area of work in the project is today centred on the construction of plants for institutes, particularly for schools during which the major aspect considered is the environment. There is close contact with the Ministry of Education.



View in a canal digester, Burundi
Photo: Mang

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Geography, population and agriculture in Burundi

Geography

Located in the eastern part of Central Africa, Burundi with 28,000 km, is one of the smallest countries in Africa but with 192 inhabitants per km it is also one of the most densely populated. Large expanses of the country are hilly to mountainous with average altitudes of between 1400 and 2200 m above sea level. The southern part near to Lake Tanganyika where Bujumbura, the capital city, is located is flat and is at an altitude of approx. 800 m above sea level. The climate is tropical here. At approx. 3 south of the equator, the seasonal differences in climate are slight, the rainy and dry seasons show comparatively little difference. Normally, precipitation is sufficient and allows arable farming throughout the year.

Population

94% of the population (about 80% Bantu, 14% Hamites) live in the rural areas, the degree of illiteracy is 50%, the GNP amounted to approx. 210 US$ per capita in 1990 and increases annually by 3.4%.

Agriculture

Agriculture contributes to 56% to the GDP. It is divided into an export-oriented sector (coffee, cotton, tea etc.), a sector which produces for the local market and subsistence farming from which about 90% of all agricultural products come. Approx. 27% of the country is used for extensive livestock farming (mainly cattle). The remaining area is inhabited mostly by smaller farmers with an average of only 0.85 hectares and hardly any livestock apart from a few goats.

Energy

The commercial consumption of energy amounted to the equivalent of 21 kg mineral oil in 1990; only 1% of exports accounts for the import of energy. The main source of energy is wood or charcoal which has led to alarming deforestation and subsequent erosion. The supply of hydro-electric power is limited to the cities; apart from this, a number of institutions and economic enterprises operate their own generator stations driven by diesel.

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Biogas technology in China (Sichuan)

History

The first household biogas plants were installed by well-off families in the forties. However, biogas was not propagated or promoted extensively until around 1970. After a phase of massive campaigns some million biogas plants were constructed, but these only functioned to a minor extent due to technical defects. The focal point of biogas dissemination was the province of Sichuan, and here especially the area around Mienyang. Due to climatic conditions, biogas only played a less significant role in Northern China. Biogas plants spread most rapidly in areas where politicians particularly devoted themselves to this task and in areas whose traffic infrastructure was well developed and which and were not, in fact, among the poorest of regions.

The interaction of the three levels, state, cooperative and household was a favourable atmosphere for the dissemination of biogas in periods of a strongly socialist tendency. The state provided the skeleton conditions, the cooperatives or communes provided material and paid for the labour for the otherwise private biogas plants. On the user side also there was hardly any coalition of interests between communes and cooperatives. This very interesting interaction of varying levels has ceased since the introduction of privatisation. For example, since privatisation straw is far less frequently used in the biogas plants as emptying of the plants involving a high work input no longer becomes necessary because the digested straw no longer has to be provided for use on communal fields as it had to be during times of communal management.

Since 1982 obligatory standards have been prescribed and applied in the construction of biogas plants. At the same time, the aggressive dissemination strategy has been cut back, scientific research has been intensified and direct subsidies have been reduced. Since subsidies were abolished the number of plants built annually has slumped. In Sichuan, in 1992 there were around 1.7 million biogas plants in operation.

Dissemination structure

Biogas dissemination is integrated into the administration structure of the Ministry for *Agriculture. Local biogas offices are the reference points for farmers. It is here where they* receive advice and where they commission the biogas plant. Technicians supervise the construction of the plant which is carried out by private companies which, in some cases have specialised in biogas plants. Costs for labour and material are borne by the farmers. The gas appliances are purchased against payment in the biogas offices.

Subsidies

Direct subsidies have been abolished but in some individual cases the farmer receives allowances from an Agricultural Supporting Fund or from state enterprises which have taken over sponsorship of biogas plants or which employ owners of plants.

Types of plants

In the biogas offices four sizes of standardised plants are offered; the most frequently built are plants with 6 m^3 digester volume. These are fixed-dome plants which are either concreted or are fixed domes built of bricks according to the availability of materials locally. The pipe connected to the compensation chamber is at medium height. Such details and similar matters have been scientifically investigated over many years and finally standardised.

Strategy of biogas dissemination

According to high-level biogas officials, the strategy of biogas dissemination is based on the recognition that biogas plants are important in saving energy, in improving agriculture and in the protection of the environment. However, it is assumed that these overriding objectives are of little significance for the potential owner of the plant in his decision to invest. It is for this reason that an increase in income, by intelligently integrating the biogas plant in the production process, is emphasised as the incentive for investment. The greater role here is played by the utilisation of slurry. Consequently, production processes involving the use of the slurry for the cultivation of edible fungi, for fish farming, pest control or as pig food are propagated which thus increase the value of the subsequent products. The use of human nightsoil as substrate is, of course, a condition of this, and in fact, it is practised in 80% of all cases.

Further reading:

A summary on the technical development is given by Cao Guo-Quiang (Overview on Biodigester Development in China, BIOGAS FORUM No. 48). An interesting case study by Hu Qichin on the rural district of Xindu (published by AIT Bangkok, 1991) describes, in addition to many details, the drastic decline in demand in recent years.

Geography, population and agriculture in China (Sichuan)

Geography and population

The province of Sichuan is in the southwestern part of the Peoples Republic of China and has an area of 570,000 km with a population of 87 million people. Sichuan is one of the most fertile areas in China.

The rural districts of Minxhu, Dujian and Xindu lie around 20 - 70 km north of the province capital Chengdu. Xindu and Dujiang are on a plain about 500 m above sea level whereas Minxhu is at the foot of the eastern Himalayas and comprises flat as well as mountainous country

country.

Agriculture and economy

The climate here is continental; temperatures are between -10 and +40C although mostly between 16 and 18C. Rain falls evenly with slight fluctuations throughout the year. Two harvests per year are possible for which rice and wheat are often grown after each other. In addition to cereals, oilseed is also produced. The banks of irrigation channels are lined with mulberry bushes used for the culture of silkworms. Any other free spaces are used for growing vegetables; water cabbage grows in stagnant waters. The growth of trees is restricted to avenues and riverbanks; Bamboo bushes often surround the houses. There are scattered and linear villages as well as scattered settlements.

About 20% of farmers have other income from cottage industry, trades and crafts in addition to their earnings from agriculture. The women normally attend to the household and the farm whilst the men follow a non-agricultural profession. Every household has less than 1 hectare of land at its disposal. The annual per capita income of the rural population amounts to 600 - 650 yuan (110 - 120 US$). In comparison, a bricklayer earns relatively well with 150 yuan per month.

China is currently undergoing radical change from a collective economy with planned targets to a free market economy. Modernisation within industry is being given first priority in development planning. Rural communes have been abolished since the mid-eighties and the land has been given to the farmers for private utilisation. Despite this, the state still partly controls the sale of staple foods through purchasing cooperatives. Only products in excess of compulsory levies or which have been approved can be sold on the free market.

In contrast to wide areas of Northern China there have never been such huge sized fields of arable land in Sichuan. Agriculture is based on family farms supported by purchasing and selling cooperatives. The producers of and selling prices for staple foods are fixed by the state. High meat prices are to increase the production of pork. Organic fertilizers are promoted as important but parallel to this the state is pushing forward the production of chemical fertilizers.

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Energy and environment

The supply of coal, natural gas, electricity and even wood fuel continues to be subject to state control and planning. The main source of energy with a share of 73% is coal which is mostly used in the form of briquets. The use of renewable energy including biogas is subsidised indirectly in that the state provides the essential infrastructure and finances research.

The significance of environmental protection has been recognised on government and administration levels. Keeping water clean and careful use of pesticides etc. are matters which are being promoted or have already been formulated into laws. The observance of these, however, is not guaranteed everywhere, mostly for economical reasons.

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Biogas technology in Columbia

Special Energy Programme Columbia

In May 1985 the Special Energy Programme Columbia located in Barranquilla began work. This resulted in the project concept "investigation of the possibilities of producing and using biogas" in the Valle de Cauca. A German consulting company (Oekotop) was commissioned with carrying out the project as a subcontractor. The executing organisation on the Columbian side was the Corporacin Autnoma Regional del Cauca (CVC). A German long-term expert was active locally within the project from November 1985 to April 1987. Another long-term expert was involved from November 1987 until the contract with the consulting company ended in March 1989. During this period, the central problem was the "pollution of water resources"; the project purpose was to "disseminate modified biogas technology". Until this time, the activities within the project were marked by a great deal of research and development. Investigations were also carried out into the use of slurry.

From November 1989 to the beginning of 1992, a new consulting company (BioSystem), closely related in a personnel aspect with the original company, was commissioned with implementing a further project phase. During this time in which a "contribution to the improvement of the rural energy situation and the conservation of water resources by the use of biogas plants" was to be attained, another long-term expert was involved locally. This phase was marked by efforts to demonstrate the efficiency of biogas technology under dissemination conditions. I.e it was mainly a rehabilitation programme for non-functioning plants and set up a central area for a dissemination structure. The building of demonstration plants on selected farms was to establish biogas technology in the rural region. The involvement which was planned in the agro-industrial sector was suspended due to its complexity (initial investigations on the fermenting of agro-industrial wastewater had been carried out). Between 1985 and the beginning of 1992 a total of 25 biogas plants were built.

Types of plants

A floating-drum plant of the BORDA type, a tunnel plant, various fixed-dome plants, a **balloon plant and a UASB (upflow anaerobic sludge blanket) plant were built during this** time. The type of plant was standardised in 1988. When the project was handed over in 1992 this consisted of 4 fixed-dome plants of 14 to 48 m^3 and three fixed-dome plants of between 67 and 115 m^3 with a separate gasholder.

In line with the heterogeneity of biogas users agricultural household and farm systems, the integration of biogas technology into agricultural and farm systems was very varied. The plants were mainly built for medium-sized and larger pig and cattle breeders who had between 20 and 2,000 head of animals. The heterogeneity of the farms was also reflected in the pattern of utilisation and the condition of the plants.

Farm management

Especially farm management had a considerable influence on the degree of effectiveness of biogas technology. The plants were normally filled by labourers. The administrator played a central role in instructing the staff in the function of the biogas plants due to the high rate of staff fluctuation in some cases. An extensively constant solids content i.e. the separation of long-fibred material (scum formation) is important for the ability of the biogas plant to function. Scum formation and the washing out of substrate could be observed on some plants. Especially uncontrolled inflow of washing water confronts conventional fixed-dome plants with "digestive problems". Labourers who were not instructed sufficiently and were not bothered, washed out the stables with large amounts of water which resulted in drastically reduced retention times. Adequate attention to the plants is impeded by different staff involved in filling and in using the gas. Not the workers, but the owner of the Finca or the administrator profits from the gas. Without the "long arm" of the farm management, proper filling and thus reliable function of the plant is not possible.

Geography, population and agriculture in Columbia

Geography and population

Columbia can be divided into several climatic zones. The regions on the Caribbean and Pacific coasts, the river valleys, the eastern plains and the Amazonas areas show mean annual temperatures of over 24C. Temperatures in the Andes fluctuate according to altitude.

With a total area of 1,410,784 km, Columbia is the fourth largest state in Latin America and had a population of approx. 30 million in 1988 of which more than 60% are Indians. The growth rate has amounted to 2% during the last ten years. The proportion of urban population is unusually high for a so-called developing country. 98% of the total population belongs to the state Catholic church.

The project region comprises the Valle de Cauca between the central and western Cordillera and borders on the Pacific Ocean. The valley covers an area of 2,200,000 hectares of which 326,983 hectares are administrated by the Departamento de Valle and 99,875 hectares by the Departamento Cauca. The Cauca river flows through the Cauca valley and is fed by numerous tributaries flowing down from the mountains through river valleys - so-called Cuencas. The annual precipitation is subject to great fluctuations of between 1,000 mm and 2,000 mm annually. The mean annual temperature amounts to approx. 23&C but can be considerably lower in higher mountainous regions.

Agriculture and economy

Considering its natural conditions, the region has a substantial potential for agricultural development. 35% of the soils are among the best in the world. Today, the region is marked by sugar-cane cultivation. In 1983, sugar-cane was grown on 400,000 hectares. 13 of the 14

Columbian sugar-cane processing companies are located in the Valle de Cauca. In 1983 they produced 1,340,190 tons of sugar.

Although Columbia has substantial natural resources the economy was dominated by coffee production for many years. With the decline of coffee prices and the increase in the production of oil, oil became the main source of income for the country in 1990. Orientation towards exports overshadowed domestic production in the agricultural sector for a long time so that in 1990, 309 million US$ worth of foodstuffs had to be imported. Nevertheless, beef production has been falling in recent years due to declining profit rates. On the other hand, there has been positive development in foul production.

The economic situation of farms in the agricultural sector is very varied. Poor farmers hardly have access to modern means of production. The farmer himself is often forced to improve his income situation by labouring. 62% of rural landowners have between 0.5 and 5 hectares which constitutes only 5% of the total land owned.

According to estimations by the Insitituto Colombiano Agropecuario, the number of pigs in Columbia currently amounts to approx. 2,300,000 and the number of cattle to approx. 22.7 million. Intensive and modern methods of animal husbandry have only spread during recent years. In the south of the Valle de Cauca, there are approx. 180 medium-sized and large pig breeders with an average of 270 head, in the north there are 94 pig breeders with an average of 100 pigs (a total of 5,636 pig breeders was recorded for Valle). A survey carried out by an expertise commission in June 1992 recorded 3,702 farms with a sufficient supply of biomass. However, the form of stabling was not taken into consideration during this calculation.

Biogas technology in India

History

Biogas technology is being promoted in India chiefly under the aspect of energy. The focus on this derives from the crucial energy supply situation for the population in the country. Besides China, India is the country where the development of uncomplicated biogas plants for the Tropics which are simple to operate started. Since the fifties the mass dissemination of biogas plants has been propagated and initiated for rural households, yet this development did not experience an upswing until the seventies so that by 1980 100,000 plants had been installed. With the beginning of the 6th 5-year plan in 1981, the National *Project for Biogas Development (NPBD) came into being following the objective of mass* dissemination of household biogas plants and also including financial support.

Biogas dissemination in India experienced a number of set-backs as a large proportion of the plants erected were not used or only used to an insufficient extent. Reasons on the one hand, were the immature technical properties of plants themselves until the beginning of the eighties and on the other hand, a dissemination strategy which was only minimally developed and which did not recognise the importance of user training and follow-up services until much later. Despite this, biogas technology was constantly supported by the Indian government. In 1982, the newly founded Department of Non-Conventional Energy Sources (DNES) as a department of the Ministry of Power and Non-Conventional Energy Sources took over central control of biogas dissemination. In the meantime, there are around 1 million household biogas plants in India of which 70-80% are assumed to be in operation.

Biogas dissemination is promoted centrally by the Ministry of Non-Conventional Energy *Sources (MNES, formerly DNES). This department consults on and resolves the guidelines* on financial support for biogas technology, commissions assignments in research and development and decides on the eligibility of new biogas plants for aid. The actual dissemination work is carried out by the governments of the Indian states, the public *corporations Khadi and Village Industries Commission (KVIC) and the National Dairy Development Board (NDDB) but mainly by countless non-governmental organisations. Within* the framework of aid prescribed by MNES each state is responsible for the guidelines applicable in its region. The individual provisions prevailing thus vary from state to state.

Types of plant

A total of seven different types of biogas plant have been officially recognised by the MNES. These are:

a) the floating-drum plant with a cylindrical digester (KVIC model),
b) the fixed-dome plant with a brick reinforced, moulded dome (Janata model)
c) the floating-drum plant with a hemisphere digester (Pragati model)
d) the fixed-dome plant with a hemisphere digester (Deenbandhu model)
e) the floating-drum plant made of angular steel and plastic foil (Ganesh model)
f) the floating-drum plant made of pre-fabricated reinforced concrete compound units
g) the floating-drum plant made of fibre-glass reinforced polyester.

Only these types of plant and only when they do not exceed a nominal gas production of 10 m^3 per day (i.e. approx. 30 m^3 digester volume) can apply for subsidies paid by the central government. This provision however, is interpreted by the governments of the Indian states and by local administration bodies so that in individual states completely different types of plants can quite often be defined by the relevant authorities to be one of the officially recognised types.

Promotion of biogas technology

The most important instrument in the promotion of biogas technology is the provision of allowances paid towards the investment costs which is of direct benefit to the farmers.

Everyone in India installing a biogas plant has the right to an allowance paid by the central government. The extent of this sum is defined by the size of the plant, the social category the user belongs to and the relevant part of the country where the plant being promoted is located. India has been roughly divided into three areas according to the average altitude: according to this, the highest allowances are paid in the mountainous northeastern region; the second category includes hilly regions or ones of high altitude in other Indian states. The remaining states are covered by the third category. Here, the allowances depend on social categories: non-caste Hindus, members of the lower castes (scheduled castes), tribes (scheduled tribes) and the category of smallholders. Marginal farmers and those owning no land receive higher allowances than farmers in the general category which includes all farmers who do not belong to any of the social categories stated but who have more than 5 hectares of land.

In addition to direct allowances for investment costs, the states and private biogas dissemination organisations reaching an annual planned target of more than 8,000 plants receive 2.5% of the total amount of construction as an allowance towards establishing and maintaining an organisational infrastructure. This promotion called "service charge" amounts to 5% for dissemination programmes with a planned target of below 8,000. One half percent of this "service charge" must be allocated to establishing follow-up services, monitoring and evaluation, the compilation of material for public relations work and to gratuities for staff who deserve these.

More informations on provinces of India:

Biogas technology in Orissa (India)

Dissemination structure

The promotion of biogas technology declared by the central Indian

The promotion of biogas technology declared by the central Indian government as a key programme is also expressly followed by the state government of Orissa. The central coordinating authority is the Orissa Renewable Energy Development Agency (OREDA) which defines the directives for promotion by the state and organises the distribution of funds provided by the central government. Apart from this, OREDA also appears as a dissemination agency. In many districts of the state there are dissemination offices equipped with technical staff who are charged with building biogas plants. An important function of OREDA is the approval of "turnkey operators". These are organisations who build biogas plants commissioned by the government and receive the state subsidies granted to builders by the central government for each newly built or repaired biogas plant. As a result of bad experience with the quality of building and insufficient follow-up service carried out by private biogas entrepreneurs these are exempted from state subsidies in Orissa.

The main objective of the organisation is to promote the development of the non-Hindu peoples in various districts of Orissa. Measures comprise the provision of basic health services, the promotion of self-help organisations on a village level, the combating of illiteracy, support of self-help groups for selling and credits, promotion of womens groups, the establishing, care and utilisation of village community forests. The dissemination of biogas plants constitutes a central point itself and also includes the Hindu population.

Gram Vikas

Gram Vikas, an Indian organisation, has been involved in the dissemination of biogas in Orissa since 1981. Biogas dissemination has established itself as the most comprehensive activity within the organisation in recent years. Gram Vikas in the meantime has become the most significant disseminating organisation in Orissa and, in addition to this, has become one of the largest and most successful biogas organisations in India. Annual output amounts today to nearly 10,000 biogas plants per year. A total of 42,000 plants - this corresponds to about 3% of all Indian biogas plants - were disseminated by Gram Vikas.

The structure of Gram Vikas organisation for disseminating biogas mirrors the structure of public administration in Orissa. Gram Vikas disseminates biogas plants in 9 of 13 administrative districts i.e. in 170 of a total of 314 blocks. According to the basic principles of their work, these are mainly the areas with a high percentage of indigenous their work, these are mainly the areas with a high percentage of indigenous population. The allocation of the regions of the state for dissemination is decided in annual negotiations with another large dissemination agency, the state-owned OREDA. Apart from these two organisations the Block Development Officers (BDOs) in state block administration also carry out biogas measures.

Whilst the upper two levels carry out general administration, acquisition of funds and material and the supervision, the actual construction work is mostly organised by the Block *Dissemination Offices. The Sub-division Coordinators assist in and supervise the work of the Block Dissemination Offices by purchasing and allocating building materials and accessories* and visiting individual customers after conclusion of the work. They also document the work within the Blocks and compile this for Programme Coordinators on a district level.

Masons

The masons are not taken on as employees as building work almost comes to a complete standstill during the monsoons. Biogas plants are mainly built between the months of March and June for this reason, i.e. prior to the monsoons when the groundwater level is at its lowest, when locally made bricks are available and when very little work can be done in agriculture.The masons are paid on a daily basis; in 1992 a biogas mason eared around Rs 40 (= DM 2.66) per day and was thus paid in line with masons in other fields.

Salaried employees on a block and district level are instructed to use the out-of-season time to carry out follow-up service of the plants. This involves not only visiting and inspecting biogas plants built by the organisation but also those which are more than 2 years old and whose guarantee has run out. Visits to newer plants are also used to make the users familiar with the operation of the plant.

Guarantee period

Within the guarantee period of two years repair becomes necessary for about 5% of the plants. Since the government provides no funds to subsidise repair work within the guarantee period, the costs directly affect the overheads of the organisation. The risk of having to rebuild only a single biogas plant with a total value of RS 5,000 means using the state subsidy of Rs 400 per plant for approx. 13 new plants. Quality assurance is thus a particularly important aspect of dissemination management.

Women

Farmers wives are ascribed a key role in the acceptance and efficient utilisation of biogas plants. For this reason there are mobile teams consisting of three women in each in various districts whose specific task it is to motivate farmers wives to use the biogas plants accurately and to train these in the operation of the plants and in the use of the gas.

Utilisation of slurry

The utilisation of slurry has not been an express element of training in the past. It is tradition to collect the dung in the South of Orissa, dry it in the sun and then to spread it on the fields shortly prior to the vegetation period when preparing the land. Composting dung is unfamiliar to many biogas farmers, and in most cases, the slurry out of the biogas plant is dried. When farmers have a kitchen garden or irrigation systems the slurry is used in a liquid form.

Types of plant

The majority (87%) are fixed-dome plants of the Deenbandhu type with a digester volume of around 6 to 9 m^3. However, there is a tendency towards an increase in the proportion of smaller 6 m^3 plants; in 1990 to 1991 these alone made up 84% of all newly built plants. As interpreted by Gram Vikas this reflects more specific aiming at poorer target groups and the increasing technical perfection and professionalism in plant construction. As the plants rarely still have problems with gas leakage in the masoned dome, smaller plants are now sufficient to meet the energy demand of a family. Investment costs for a turnkey plant of this size amount to Rs 5,800 (= DM 386) of which the material costs make up the greater part.

Dissemination costs

The high overall costs in dissemination can be justified if they are compared with the costs of alternative energies. In its annual report for 1990-91, Gram Vikas compares the performance and the costs of the 39,000 biogas plants built between 1982 and 1991 with the investments necessary to generate the same amount of thermal energy. The calculation is as follows: assuming that 80% of the plants are operated with 60% of the performance theoretically possible, daily gas production amounts to 47,586 m^3. This corresponds to the thermal generation of 4,079.9 million kWh. With the same service life of the plants, assumed to be 25 years, and a price of Rs 1.50 for the generation and distribution of one kWh of electric energy, the investment costs for the generation of electricity amount to 31 times as much (6,119.9 million RS) as the investment costs essential for biogas plants (195.3 million Rs). If the thermal energy required for power generation is used, biogas plants would only be 3.8 times cheaper. The high appreciation of biogas technology is reflected materially in the guidelines and subsidies available to farmers and project executing organisations. It is similarly reflected in how banks integrate biogas into the promotion of credits.

Geography, population and agriculture in Orissa (India)

Geography

The Indian state of Orissa lies in the eastern part of the subcontinent. The coastline of the Gulf of Bengal forms the eastern border; states bordering on Orissa are Madhya Pradesh to the west, Bihar and Bengal to the north and Andra Pradesh to the south. The geographical area of the state comprises 156,000 km The climate is tropical with hot summers and temperatures of up to 45C and mild winters with minimum temperatures

temperatures of up to 45C and mild winters with minimum temperatures of around 15C.

Orissa lies on the route of the southwest monsoon bringing a marked rainy season to this area between June and September with a precipitation of between 1,750 mm. in the south west and the coast and 1,320 mm in the west.

The land comprises a transition from the plateau of the Eastern Ghat in the north to the flat alluvial land on the coastline of the Gulf of Bengal. Three quarters of the region is hilly with maximum altitudes of 1,500 m. Three major river systems rise in the highlands in the north, the Chotanagpur Plateau. The wide branching network of the Brahmani, Baitarani and Mahanadi rivers has produced fertile alluvial land along the coastline to the Gulf of Bengal. 40% of the geographic area can be used for agriculture. The tropical forest which originally covered the whole of the territory now comprises an area of 59,960 km (= 38% of the area) according to official statements; in reality however, only about 16% of the total area can be called forest and this area too is rapidly disappearing due to extensive felling for firewood and building timber.

Population

With an average population density of 169 per km, Orissa is less densely populated than other Indian states. An estimated 32 million people live in Orissa. The state lies in the "tribal belt" of Central India, around 22% are members of non-Hindu tribes. Orissa is mainly an agricultural state: 88% of its inhabitants live in approx. 50,000 villages. 6.4 million people live in towns, the majority of these - 4.6 million or 17% of the total population - in the district Cuttack. The population is predominantly, to approx. 65%, illiterate. The growth rate of the population is 1.9% annually.

Orissa belongs to the least developed and poorest states of India. More than two thirds of the population live below the poverty line. Although this area is rich in iron ore, manganese, chromium, bauxite and coal their mining constitutes only 5.2% of the total raw materials extraction in India. Orissa has over 10% of India's water resources at its disposal (with approx. 4.75% share in the area of the state of India) but only 20% of the cultivation area is irrigated (Indian average: 27%).

Agriculture and economy

Agriculture is the most important source of income for Orissa; two thirds of the state budget is produced by agriculture which employs 80% of the population. The most significant agricultural product is rice; around 7.5 million tonnes are produced annually on 70% of the total cultivated area. The second most important products are leguminous crops taking up more than 20% of the arable area in the state. Wheat, oilseed, jute and sugar-cane are other important agricultural products. About 3.5 million agricultural enterprises are registered by the tax authorities for this state. The average size of farm amounts to 1.6 hectares and is below the average size of farm in other Indian states.

Biogas technology in Sangli (India)

Khadi and Village Industries Commission

Biogas technology is particularly evident in the south of Maharashtra due to the high level of agricultural development. In no other Indian state are there so many biogas plants as here. In 1992 they numbered around 345,000. A significant contribution to this development was made by the Khadi and Village Industries Commission (KVIC) whose headquarters are in Bombay. Considerable development work was also carried out by J.J. Patel with the famous Indian floating-drum plant ("Gram Laxmi", better known under the "KVIC Design").

Biogas dissemination

Central coordination of the biogas dissemination in Maharashtra is with the Department of *Rural Development in Bombay. Subsidies provided by the central Indian government are* handled through the District Rural Development Agencies (DRDA). The DRDA have the power to decide in their district. A large number of non-governmental organisations and private constructors build and disseminate biogas plants as "turnkey operators".

Shivsadan Griha Nirman Sahakari Society Ltd, called Shivsadan (Maharati: "house of Shiva") for short, is a commercially run factory for the production of pre-fabricated concrete compound units. The company which was established in 1969 has been building biogas plants since 1976. The initiative for the programme came from the Sangli sugar mill to which Shivsadan has good contacts. At a joint conference of KVIC and representatives of the sugar industry in Bombay in 1975, the sugar industry was called upon to propagate and disseminate biogas plants in its operation areas. Shivsadan states the maximum building capacity to be 4,000 plants per year.

To carry out research and development work, the Shivsadan Research Foundation, Sangli was established in 1989 and the Shivsadan Research Institute, Sangli (SRERI) connected to this also founded. In addition to applied (commissioned) research in agriculture, technical environmental protection and renewable sources of energy, it is also their task to discover new fields of application for ferrocement and concrete compound units.

Target group

The original target group consisted of cooperative farmers in the sugar industry. 350 plants were built for these in the mid-seventies during a three-year demonstration phase. Since then, the extensive demand for biogas plants has made biogas dissemination the most important branch of production for Shivsadan. In many villages where a large proportion of cooperative farmers live, biogas plants are almost exclusively Shivsadan plants. According to the company, 15% of all plants in the districts attended to are being built within their dissemination programme. A larger proportion, an estimated 85% of all biogas plants, are masoned Deenbandhu plants.

Types of plant

Shivsadan offers two types of biogas plant. Besides the classic floating-drum plant with a gasholder made of steel sheeting, a newly developed fixed-dome plant, called the "Krishna

Model", is offered in sizes of 6, 9, 12 and 18 m^3 digester volume. It is marked by a low price and is free from corrosion as all the components are made of concrete.

Components for both types of plant are produced in the Sangli factory, loaded onto lorries and installed at the customers farm within one day. The lorries are equipped with a crane so that all the work necessary can be carried out by the installation team without them having to obtain any extra machines or aids. Normally the biogas plants are ordered with a connected toilet.

The latest product by Shivsadan is a repair set for defective floating-drum plants. Using this, old masoned plants whose gas dome has been removed, can be converted into fixed-dome plants. After the installation of a pre-fabricated concrete part, the plants perform according to the principle of a fixed-dome plant.

Shivsadan is the only larger organisation which builds biogas plants in the districts it attends to. A great number of small construction companies and individual masons build and disseminate masoned fixed-dome plants of the Deenbandhu type. These plants are normally cheaper than the pre-fabricated models from Shivsadan, which means the masoned plants are more interesting for less financially sound farmers.

The type of household plants in demand, also with Shivsadan, shows a strong tendency towards smaller fixed-dome models. Although a completely different type of plant is disseminated here, Maharashtra also shows that fixed-dome plants (reliable performance) correspond most to the requirements of the target group of smallholders and medium-scale farmers.

The advantages and disadvantages of locally masoned Deenbandhu and pre-fabricated Krishna plants can be stated as follows:

Deenbandhu plant: low capital investment, high

flexibility in building and installation, building material is available locally but extensive quality assurance measures necessary by well trained craftsmen.

Krishna plant: easy to examine and thus a good standard of quality but high capital investment and increasing transport costs for greater distances. Additionally, large numbers are essential for economical production.

Prices for a biogas plant

If the price for a Krishna biogas plant with a digester volume of 6 m^3 is compared to the cost of a masoned Deenbandhu fixed-dome plant of the same size, as disseminated in Orissa by *Gram Vikas, it can be seen that the total costs of the Krishna plants exceed those of the* masoned fixed-dome plant by about Rs 1,000 (approx. DM 66). The difference in pure material costs is negligible; the labour costs for the pre-fabricated plant are lower by about half. In each case the costs for the transport of the pre-fabricated plant which increase with the distance between the factory and building site, must be added (for the comparison shown a minimum distance from the factory was assumed).

Geography, population and agriculture in Sangli (India)

Geography and population

Maharashtra, with 307,762 km and a population in the region of 78 million, is the third largest federal state in India. Located on the western side of the continent, the coastline to Arabian Sea forms its western border. To the north and northwest Maharashtra borders on the federal states of Gujarat and Madhya Pradesh, to the southwest lie Andhra Pradesh and Karnataka, and to the south Maharashtra borders on Goa. The region shows a variety of characteristics: to the west there are the Konkan lowlands, a narrow strip along the coast which is marked by numerous small hills. Most of the region is dissected by the Western Ghats running from north to south over a distance of 640 km whose mountains reach heights of up to 1,340 m. These continue to the east as the Deccan Plateau which is a plain dissected by fertile river valleys which rise in the Western Ghats and run eastwards crossing the Indian subcontinent to flow into the sea in the Bay of Bengal. The main project area, comprising the districts of Sangli and Kolhapur, are marked by this type of countryside: whilst Kolhapur lies in the mountainous area of the Ghats, the district of Sangli is located in the fertile lowlands of the Krishna and Sina rivers.

The climate is tropical with a mean minimum temperature of 19C in January and maximum day temperatures of around 38C in May. The monsoon brings the region a marked rainy period between June and October with an annual precipitation of around 2,000 mm on the coast and in the East of Maharashtra. Particularly the Ghats and neighbouring regions suffer from distinct periods of drought. There are four seasons: between March and May it is hot and dry, from June to September it is hot and wet, from October to November it is warm and humid and from December to February it is cool and dry.

Maharashtra in the Central Indian "Tribal Belt" is the home of countless peoples and ethnic groups who in some case have immigrated from other areas. About one third of the population belongs to varying indigenous tribes although the proportion fluctuates from district to district; in the extreme east of the country there are around 60% Adivasis.

Although Maharashtra is one of the most modern states in the country about 30% in urban centres and 40% in the country live below the poverty line.

Economy and agriculture

Bombay, the capital of Maharashtra is at the same time India's most modern and most bustling city. About half of the foreign trade of India is handled through the city harbour. The city is the most important centre in the country for the processing industry: numerous production plants for textiles, vehicles, the pharmaceutical and petrochemical industry have settled in and around Bombay; the city is also an important centre of trade for the country.

Agricultural production is thus more intensive and generally better

Agricultural production is thus more intensive and generally better organised than in other federal states; it is more developed and shows higher productivity. Despite intensive industrialisation, agriculture remains the most important source of income for two thirds of the population in this region. The main crops which are cultivated are rice, millet, sorghum, wheat, peanuts. Cash crops like cotton, sugar cane, grapes, tobacco and oranges are regionally important.

Ownership of land is unequally distributed: 8% of the rural households have about 40% of agricultural land. The majority of farms - 58% of all households - have less than 2 hectares of cropland; their share in the total area of agricultural land amounts to 14%. In the two districts with the highest number of biogas customers the majority consists of smallholders. About 50% of farmers own less than 1 hectare of land, 30% own 1 - 2 hectares and 20% have more than 2 hectares. In the project area the average area owned by biogas customers amounts to 3 acres (1.2 hectares). Their most important products are sugar cane, sorghum and wheat.

The districts of Sangli and Kolhapur in the south of the state where the Shivsadan biogas programme surveyed is located, continue to be extensively agricultural areas. The emphasis here is on the sugar industry and on the cooperative movement of Maharashtra. The Cooperative Farmers' Association has around 32,000 farmers as members. These and another 10,000 non-members from a total of 151 villages in the two districts cultivate sugar cane over a total cropland area of 40,000 acres (approx. 16,200 hectares). Every year around 1 million tonnes of sugar cane are delivered to the factory at Sangli. The Sangli Sugar Mill belongs to the cooperative and is the third largest sugar mill in India. The mill, employing approx. 2,500 workers and salaried staff, generates approx. 850 million Rs (approx. 50 million DM) annually. Apart from sugar, alcohol, acetic acid and animal feedstuffs are also produced. The cooperative not only provides an income for the 2,500 employees, the 32,000 members and the 10,000 farmers who are non-members but also for around 25,000 seasonal workers. Biogas technology is also promoted by the cooperative; a subsidy of RS 500 for building a plant is paid to members on application. Also bank guarantees allow access to credits for building biogas plants.

Environment

A negative result of the intensive irrigation system is the salinisation of the soils which leads to continuing infertility of the areas concerned. One third of the agricultural land around the district capital of Sangli has become useless due to salinisation. This intensive irrigation has also resulted in a reduction in the groundwater level which falls to more than 100 m below the surface only a few kilometres away from watercourses.

In addition, the absolutely insufficient or non-existent disposal of (agro-)industrial wastewater is leading to problems; in Sangli district the direct inflow into irrigation canals and the Krishna river of 700 m^3 of wastewater from the sugar mill every day is a permanent problem.

Biogas technology in the Ivory Coast (region of Korhogo)

History

The biogas project began at the slaughterhouse in Ferkessedougou. For this, 2 large balloon plants were developed and constructed. The gas from these was used to produce electricity for the slaughterhouse in a generator. In 1982, the first six household plants with balloon-**type gas-holders were built for the cattle herdsmen and their families in the slaughterhouse** pen. The objective of this measure was mainly to save on wood as a fuel. In the course of further dissemination it turned out that light produced by biogas played a great role in the demand for small biogas plants. For this reason, gas was promoted as providing light gas for cooking during the subsequent programme.

Problems

By March 1991, a total of 80 family biogas plants had been built. This number includes all plants, as well as the first demonstration plants and those which have been put out of operation as well as those still operating. In 1991 there were still 10 of the 80 plants in operation. Of the 70 plants out of operation, 7 could be repaired, rehabilitation for 24 is likely, the rest must be written off. The following main causes for taking the plants out of operation were determined:

1) Technical Defects:
After a certain time, the foil becomes brittle and holes appear which have occurred due to damage by animals, children or other effects. The wooden frame to which the foil is attached quickly becomes weather-worn and is eaten by termites. The stoves produced

from iron sheets by craftsmen rust quickly due to the high sulphur content and become blocked or completely break down. The flexible gas pipes become porous and leak because of the effect of sunshine.

2) Social Causes:
A lot of biogas plants were individual demonstration plants which were not really wanted by the users, but were more tolerated. Traditional sources of energy continued to receive preference. In polygamous households clear lines of responsibility were missing. The chief of the household traditionally does not get involved in disputes of the wives, and also in this case, had no direct right to issue instructions to the children. This is particularly the case in non-Islamic families where each wife cooks every day for her own children and in turn for the husband. Each wifes household should then be connected to the biogas plant, and service and daily management would have to be carried out by the husband (which would mean a completely new division of labour), or by the wives in turn. Apart from this there is also a conflict of interests between the source of energy for cooking wished for by the wives and lighting, which is the responsibility of the man.

In the demonstration phase when a large number of plants were built in many different places, there was a lack of liaison staff. Their own input at first was under 10%, later it rose to around 20%. After German participation ended, the biogas programme was integrated into the structures of the SODEPRA and put in the charge of the livestock extension officers. In line with structures of hierarchy, information flowed through 3 or 4 levels on the way from user to the biogas service. Furthermore, competence for the selection of sites was no longer with trained biogas staff, but with the livestock extension officers who did not have the necessary detailed knowledge to guarantee selection of an optimum site. Intensive training of the agricultural extension officers like, e.g. in Thailand, by the Biogas Dissemination *Programme did not take place.*

Slurry

The slurry is never used in a liquid state. When needed, the dried slurry is scratched from the ground and taken to the fields. This is never seen as an additional asset and can also not be plausibly imparted to the farmers. Even a possible reduction of weed seeds in the fertiliser is unrealistic with this method of utilisation. To make biogas technology attractive and economically feasible there will have to be far more extensive measures towards restructuring within farms which e.g. introduce controlled composting of the slurry.

Geography, population and acriculture in the Ivory Coast (region of Korhogo)

Geography

The Ivory Coast has an area of 322,000 km and a population of 12 million. In 1990 the GNP amounted to around 750 US$ per capita which means that the Ivory Coast belongs to the lower category of countries with average income. The project area comprises the region of Korhogo in the north of the country and shows all the features of a country with a low income. It is a bush savanna region with linear forests seaming watercourses. It comprises the so-called "zone dense" and the "zone transistaire".

The "zone dense" extends to the south and to the southeast of Korhogo. The area is relatively densely populated and has experienced increasing deforestation since the end of the 19th century as a result of the clearing of areas for arable farming and to obtain wood. The linear forests and trees have been extensively replaced by a grass savanna loosely interspersed with fruit and other useful trees (baobab, nr, karit

interspersed with fruit and other useful trees (baobab, nr, karit,
mango, cashew etc.)
distributed over the agriculturally used and over unused land. The relatively intensive agriculture with only short fallow periods has resulted in increasing lateritic property of the soil.

The "zone transitaire" extends along the border to the "zone dense" and is a transition between intensively used land and the scrub and tree savanna. It extends over the north and northeast of the region.

The climate is tropical with a distinct rainy season. The average precipitation amounts to about 1,500 mm in Korhogo. The annual precipitation fluctuated in the period 1975 to 1984 by between 835 and 1557 mm. The rainy season from April to October is the time of intensive agricultural activity. There is an arid period of 3 months with dry and cool winds from the north. During this period there are great differences in day/night temperatures.

Population

The whole of the north is marked by cultural and lingual homogeneity of the Snoufo to a great extent. In addition to this, the project area is inhabited by the Malink, generally called Dioula, who originally immigrated from the north and who are Moslems (the Snoufo mostly belong to their traditional natural religion). The Dioula are mainly concerned with trading, the processing of foodstuffs and itinerant trading. The third ethnic group is the Peulh, who are nomadic herdsmen and came here mainly after the great drought in 1974 from the Sahel. They live in mixed settlements with the established arable farmers and are still partly transhumant. On the whole, there are great differences in the density of the settlements which reaches 80 inhabitants per km in the "zone dense".

Agriculture

The traditional system practised by the Snoufo is arable farming which secures their subsistence. After having concentrated exclusively on the provision of foodstuffs, nowadays more and more crops which can be marketed and turned into monetary income are being cultivated (e.g. cotton). Livestock farming is more understood as a way of accumulating surpluses from arable farming and constitutes the traditional bank, since when this is necessary (burials, weddings, starting school etc.) it can be quickly accessed.

The Peulh mainly base their production on livestock and animal husbandry. Arable farming is only of a subordinate role for them. The rapid growth of the Peulh herds has lead to increased damage to the crops of the Snoufo and to tension related to this. For this reason livestock husbandry is considered by many of the Snoufo to be a destabilising factor for arable farming.

Biogas technology in Jamaica

Biogas utilization

Since the early 1980s agricultural biodigesters have been known and introduced at a very slow pace to Jamaica with the Scientific Research Council (SCR) being the major promoter as a reply to the energy crisis in the 1970s. Decentralised energy production was the crucial topic rather than waste management and environmental issues involved. The slow-down of the energy debate has further reduced application and assistance to the technology.

With an overall of 120 units existing in Jamaica a national programme was started in 1993 and based on a project progress control and finding mission solely to concentrate on dessemination of the existing small scale agricultural biogas digesters.

Potential for biogas production

The potential for biogas production has been assessed from a different perspective. On the whole it is huge, in particular for agro-industrial wastewater in Jamaica.

As biogas is commonly and frequently associated with animal residue handling at farms, there seems to be difficulties of promoting this environmentally sound approach towards wastwater treatment under the term biogas.

The total biogas production potential in Jamaica is over 20 million m^3 of gas per year. The expected energy savings for aerobic wastewater treatment are far over 100 Gwh per year.

Geography, population and agriculture in Jamaica

Geography

Jamaica is the third largest island in the Caribbean, measuring 233 km in length and 80 km in width. It is situated 145 km South of Cuba. A montain range spans its length. Over half of the island is mote than 300 m above sea level and the highest peak lies in the Blue Mounains at a heigh of 2256 m.

Population

Jamaica has a total population of 2.5 million (1992) and an area of 10,830 km^2. One third of inhabitants live in the capital Kingston. Nearly 50 percent of the people live in the rural area; 30 percent of the working population is employed in the agricultural sector.

Economy and agriculture

Tourism is the main source of foreign currency, followed by bausite and agriculture. However agriculture contributes only 9 % towards Gross Domestic Product (GDP). In Jamaica there is a rapidly expanding sector of entrpreneurs and small investors. Jamaica has a booming stock market.

In 1993 real GDP grew marginally per 1.2 percent. The sluggish growth out-turn reflected generally slower growth in most of the goods-producing and services sectors as well as contraction in the heavyly-weighted Manufacture sector and Construction and Installation. Miscellaneous Services which includes tourism-related activities and Transport, Storage and Communication were the only two sectors to register faster growth in 1993. Agriculture, Forestry and Fishing was the only goods-producing sector to perform creditably growing by 8.8 percent.

Traditional agricultural export crops are sugar-cane, bananas, citrus, cocoa, coconut, coffee and pimento. Additionally tubers, vegetables, fruits and ornamental horticultures are exported. Cereals, meat and fisch products account for the bulk of imports.

Biogas technology on Java (province of Central Java)

History

BORDA (Bremen Overseas Research and Development Association), a German consultancy, has been working since 1989 with the non-governmental organisation LPTP (Lembaga Pengembangam Teknologi Pedesan = Institute for Rural Technology *Development) on an Integrated Rural Development Project (IRDP) sponsored by the Federal Ministry for Economic Cooperation of Germany. The LPTP was founded by very involved* students in 1979 who attach great importance to participation by the target group in each case. The central field of activity was in the development and dissemination of appropriate technologies. Biogas has only been part of the LPTP programme since BORDA entered the cooperation.

At the beginning of the eighties a number of biogas plants were installed in the project area through the agricultural extension service of the regional administration. None of the plants ever supplied energy for the operators because of serious defects in the plant system. Consequently, project staff were faced with scepticism and a lack of interest on the part of members of regional administration. LPTP, in the meantime, has shown that technically perfect biogas plants can be built and are useful for farmers. The former situation has changed drastically on the basis of this, so that LPTP, in cooperation with the regional administration, was able to arrange a national conference on biogas with over 100 participants in autumn 1992.

Types of plant

After a survey of the project area, carried out by BORDA and the LPTP which data relevant to biogas, had shown the region to be basically suitable for biogas dissemination, the IRDP employed an engineer for this sector. In the late autumn of 1990 a BORDA engineer supervised the construction of the first three fixed-dome plants. In autumn 1992 there were 58 biogas plants, and by December a further 27 had been built including a large-scale plant of 93 m^3 digester volume for a dry meat producer. Otherwise, standard types with a volume of digester of 6, 9, 13 and 18 m^3 are offered. The large number of new plants can be attributed to the dissemination area being extended to include a community between Cepogo and Boyolali.

So far there has only been one case of gas leakage on a plant and this was immediately repaired by the project staff. Good quality and high gas yields (0.275 m^3/m^3 volume of digester per day) combined with an exemplary fertiliser advisory service mean that not only the biogas department, but also IRDP as a whole, has a good reputation in the region.

The CAMARTEC type

The type of plant selected and adapted to Javanese conditions was the fixed-dome plant with a "weak-ring" developed further by CAMARTEC of Tanzania. As stabling and the use of organic fertilisers was already known, the principle propagated by CAMARTEC, the "biogas unit", could be consistently adhered to. The Javanese version differs from the Tanzanian one in the following points:

- 12 cm wall thickness in the semi-spherical dome; as the bricks are only 4 - 5 cm thick it is difficult to lay them in one-quarter brick thickness.
- conical floor board; in addition to giving better static properties, the bowl-like floor serves as a water bath for the bricks.
- reinforced "strong-ring" to provide safety against the frequent, light earthquakes.

Since 1992 the "weak-ring" has been omitted as it is assumed that the change in cross-section below the "strong-ring" automatically functions as a predetermined breaking point.

When the cattle were fed on king-grass, there were frequently problems with scum in the plant. The high position of the pipe to the compensation chamber presumably made this problem worse. Since 1992, the digester and compensation chamber have been connected by a shaft running from the bottom of the digester up to under the "strong-ring". In some cases, older plants were converted by means of a by-pass shaft. Since then the problem seems to have been solved even if the scum itself cannot be avoided.

The interior plastering was carried out with the agent "Tricosal" in three layers of plaster, three intermediate brushing coats and a final coat of finishing plaster. The gas pipes consist of 1/2" PVC pipes but where these are longer than 50 m, 3/4" pipes are used. The water trap consists of a short U-pipe with a gas-tight plug which can be opened when necessary.

Geography, population and agriculture on Java (province of Central Java)

Geography

The project area consists of the rural districts of Cepogo, Selo and Ampel in the region of Boyolali in the province of Central Java. It lies on the eastern slopes of the Merbabu (3142 m) and Merapi (2911 m) volcanos of which the latter is still active, and extends over the pass at Selo (1500 m above sea-level) to the villages of Tlogolele and Klakah. The biogas project area of about 100 km is densely populated by 70,000 inhabitants carrying out intensive agriculture (the total project area is approximately twice as big). The main crops are tobacco, vegetables and cloves as cash crops, cassava for home consumption and grass as fodder for stabled cattle. Bananas and coffee are also common; crops are grown corresponding to the altitude. Rice, the staple food, is bought or obtained from fields in the plains.

The villages consisting of several hamlets, stretch along the roads which are asphalted in some cases and which follow deep valleys dissecting the countryside. The steep slopes are at risk from erosion. The climate, corresponding to its position on 7 south latitude, is tropical but at altitudes of between 500 and 1,500 m very pleasant (10 - 30 C). Dry and rainy seasons are not so extreme which means that agriculture can extend over the whole year and provide up to three harvests on the fertile volcanic soils. Each farm has between 0.5 and 2 hectares and 89% of farmers have less than 1 hectare of land. With almost 2 cows per household, this is the peak region throughout Indonesia. The annual income of the farmer amounts to between 130,000 and 210,000 IRP (64 - 103 US$ p.a.).

Population

The population is predominantly Javanese, mostly belonging to the Muslim faith. Christians and members of traditional religions only form a minority. Social differences are less severe due to traditional patronage of richer farmers.

The greatest problem evident in Java is the dense population (813 inhabitants per km with a growth rate of 1.8%). The state is attempting to motivate the population with migration programmes to move to other, less densely populated islands (Kalimantan, Sulawesi, Sumatra and other small islands).

Economy and agriculture

Goods needed on a daily basis are mainly produced in Indonesia although the electronics, mashinery and vehicle markets are still dominated by foreign goods. The project region itself is only slowly beginning with industrialisation from the plain. Agriculture will continue to constitute the main economic factor for a long time. Livestock husbandry and verification of agriculture are being strongly supported by promotion programmes and propaganda. An insidious tobacco disease in the soil and the fall of prices due to market losses necessitates new orientation of the farmers towards other cash crops or towards the production of meat and dairy goods.

On principle, farmers have access to agricultural investment credits and use their land as security for these. The price of rice is guaranteed for the farmers, there are fixed consumer prices for milk in the towns. Stabling and the use of organic fertiliser is promoted publicly and

is traditionally common. So far, chemical fertilisers have been subsidised but this is slowly being abolished.

Biogas technology in Kenya

History

There were already first attempts to use biogas technology to gain energy from coffee pulp in Kenya in the mid-fifties. In the following 25 years, more than 100 plants of varying types were sold mainly to large-scale farmers by a private entrepreneur. After the energy crisis, interest in this technology boomed. A number of Indian floating-drum plants and Chinese fixed-**dome plants were installed particularly for public institutes, like schools and other education** centres by private organisations often with foreign sponsors. However, since not only did the technical quality leave much to be desired, but also the social and economic conditions were not taken into consideration during implementation of the plants, the plants themselves soon were no longer filled and/or were out of operation due to technical problems. In the context of the Special Energy Programme (SEP) Kenya in 1983/4 several craftsmen were trained in the construction of biogas plants by GTZshort-term experts and these went on to build around 40 biogas plants in the Mount Meru region. However it was soon evident that training craftsmen in the construction of plants alone was not sufficient to guarantee permanent function of the plants or the extension of dissemination into other regions. Shortcomings evident were no kind of quality assurance, no advice for the customer on how to operate the biogas plant and no dissemination strategy. To alleviate this, a long-term expert was employed to provide advice in Kenya in 1985. Around 250 floating-drum plants were installed in various regions by the SEP in cooperation with the Ministry for Energy by 1988.

Financial supports

The budget of the Biogas Section for 1992 amounts to approx. K 25,000. This corresponds to about US$ 2,500 per year for training, infrastructure and public relations work and about K 200,000 (approx. US $ 15,500) for the wages of 10 members of staff who are not only involved in biogas work. Approx. KSh. 50,000 (US $ 1,500) for training, infrastructure, monitoring and public relations work were made available for 1992 from SEP funds. These funds will however not be provided from 1993 onwards.

Function of the plants

Of the 49 biogas plant owners, around 1/4 (13) stated that plants had functioned without any problem since they had been built. 8 of these plants are no older than 2 years, the oldest has been operating for 7 years. 9 plants built between 1984 and 1988 are no longer in operation. The reasons for this are stated as being:

- is no longer filled: 5
- inferior gas production: 1
- gas leaks and pipes defect: 2
- inlet pipe broken: 1

Geography, population and agriculture in Kenya

Geography

Kenya, on the eastern coast of Africa, is dissected across the centre by the equator. The majority of the population (85%) lives in the southwestern part of Kenya which comprises of a rising elevated plateau with Mount Kenya (over 5,000 m) falling to Lake Victoria in the west. Along the coast there is a mean temperature of 27C but in the interior of the country it is cooler. April to June and October to December are the rainy seasons and can come with annual precipitation of 1,250 mm in the uplands and around 1,000 mm on the coast. The lowest precipitation occurs in the north with a maximum of 600 mm and the highest is in the west, around Lake Victoria with about 1,780 annually.

Population

According to official estimations in 1989 there are approximately 24.5 million inhabitants over an area of 571,416 km (approx. 42 inhabitants/km). 22% of the population lives in towns and the tendency is increasing. The annual growth rate of the population in Kenya is about 3.5% (1990). 98.5% of the population is African of which most belong to the Bantu peoples like the Kikuju with 21% and the Luo with 13%, but also to Nomad peoples e.g. the Massai. The remaining 1.5% comprises Asian, Arab and European nationalities.

Economy and agriculture

The strengths of the Kenyan economy lie in the production and processing of agricultural and pastoral products. The contribution of agricultural, forestry and fisheries to the GDP in 1988 was around 32%. The industrial sector contributed 19% of which 13% was contributed by the processing industry. The services sector contributed around 35% to the GDP. The central problems in the Kenyan economy are high population growth and an unemployment rate of around 40%. An economic upswing which started in 1986 slowed down in 1989/90 due to lower prices on the world market for coffee and tea and the effects of the crisis in the Golf which cost the country around 125 million US$.

Kenya has no mineral resources worth mentioning and depends on agriculture to a great extent. Although wide expanses of Kenya, particularly in the north-east, north-west and in the south-east are arid and infertile and can thus only be used for agriculture sporadically, 3/4 of the population live from agriculture. Small farms are predominant which are normally attended to by women alone (27%) or by women in the absence of their husbands (47%). Subsistence farming is combined with market-oriented production. The staple food is maize and is subsidised by the government. Other subsistence crops are manioc, potatoes and millet. Crops grown for the market are mainly coffee, tea, sisal millet. Crops grown for the market are mainly coffee, tea, sisal, pyrethrum, wheat, sugar, pineapple and cotton. Coffee and tea are the most significant export products with 25.6% and 19.5% (1988) respectively. The total number of cattle in Kenya is estimated to be 10 million. In recent years, agriculture has experienced a decline in the production of the most important agricultural products.

Energy

Power generated for the country by hydro-electric and thermal power stations is below demand. In 1988, energy amounted to about 14% of total imports. The connecting of rural regions to the electricity supply is being subsidised. Electricity however, accounts for only 3.3% of the total consumption of energy in the country. About 83% of household energy is met by firewood and charcoal.

Environment

According to the report issued by the World Bank in 1992, Kenya like other countries south of the Sahara, is facing the effects of environmental damage on the economy and on health. Apart from increasing air pollution in the cities, and the development of smoke in households during the use of firewood which is a hazard to health, what is centrally stated is the effect on agricultural production. The rapid growth in the population has led to forest resources and the fertility of the soil becoming exhausted and thus to a fall in agricultural production in densely populated areas. According to the Ministry for the Environment, the development and dissemination of technologies for the utilisation of natural resources has been given top priority. Previous alternatives to the use of firewood and charcoal are considered to be too expensive to have a significant effect on environmental damage occurring from the use of firewood.

Biogas technology in Morocco (region of Souss-Massa)

History

The first activities concerned with biogas date back to 1983. Within an agreement between the CDER (Centre de Dveloppement des Energies Renouvellables) and the ORMVA (Office *rgionale de mise en Valeur Agricole) Haouz, three experts took part in a 20-day training* course for biogas technology in China. During the course of various programmes between 1983 and 1990, 60 biogas plants alone of the Chinese fixed-dome plant type were built by ORMVA Haouz. In one cooperation with UNICEF lasting from 1984 - 91 (which was to improve sanitary conditions in rural areas) the Ministry of Agriculture (with the intention of protecting the forests and improving the general living conditions of farmer families) provided approx. 600,000 Dh for biogas technology. The aim of these efforts was to embed biogas technology in all ORMVAs and Division Provinciale de l'Agriculture (DPA) by means of intensive training programmes and the establishing of a national dissemination structure. At the same time a Centre de Formation was set up at the Ecole Nationale de l'Agriculture. In 15-day courses mostly carried out in Marrakesh, a total of 70 masons, 115 technicians and 61 agricultural extension officers were familiarised with biogas technology (Information ORMVA-Haouz). According to records held by the CDER, in 1992 there were 255 biogas plants in Morocco mostly with digester volumes of 10 m^3. In addition, other individual biogas activities were carried out within the scope of various agreements, for example the 150 m^3 **batch plant built by CDER for research purposes. In 1989-90 a Chinese team constructed a** 150 m^3 community plant in Marrakesh.

Problems

The results of these efforts are disillusioning. According to an investigation carried out by CDER, 63 of the 130 plants (Chinese models) were completely at a standstill in 1990, 37 showed weak or just satisfactory production and only 39 were classified as "good". The ORMVA Haouz stated 40 of the 80 plants they had built to be completely incapable of function. A systematic analysis of the causes taking a differentiation between technical reliability and problems originating in social acceptance into consideration, is not yet available.

Special Energy Programme of the GTZ

The dissemination of biogas technology in the Souss-Massa region is a sub-project of the **GTZs Special Energy Programme Morocco which has been carried out since 1988. The** purpose of the Special Energy Programme Morocco at that time was to improve the energy situation in rural areas - threatened by ecological degradation - by modifying and disseminating "renewable sources of energy". The focal point of project planning was to reinforce national project executing organisations for renewable energies, particularly the *Centre de Dveloppement des Energies Renouvellables (CDER).*

In the field of biogas, the project concept sees the activities in Souss-Massa to have a pilot function for other regions of Morocco. Over the medium term the various regional ORMVAs and the Divisions Provinciale d'Agriculture (DPA) which are not actively involved in irrigated areas are to carry out concrete implementation and dissemination. The CDER is then to take over the role of the institution involved in research, development and advisory services and that of the actual national source of know-how. A Biogas Committee set up in spring 1992 on which decision-makers from various institutions affected by biogas dissemination are represented, is over the medium term, to constitute a legal link between the political decision-making levels and the corporations commissioned with biogas dissemination and is to be equipped with the relevant competence to define directives. The rehabilitation of 3 fixed-dome plants, the construction of three 12 m^3 plants, five 20 m^3 plants and two 85 m^3 plants (mainly to drive motors) have demonstrated the technical efficiency biogas plants can provide with qualified construction planning and execution. It is the objective to integrate biogas technology into the structure of the ORMVA/Souss-Massa so that in future it will be offered to farmers as a normal (i.e. also highly subsidised) service of the ORMVA. It is intended to have biogas plants included in the credit framework for agricultural inputs of the agricultural bank Caisse Nationale de Crdit Agricole.

Potential for biogas

The potential for biogas in the Souss-Massa region defined by the Biogas Office according to biomass available is approx. 20,000 biogas plants. This quite enormous potential is a projection of the data available on livestock numbers at the ORMVA, which would ultimately result in 7,146 12 m^3 plants; 4,422 20 m^3 plants; 4,584 30 m^3 plants; 2,346 50 m^3 plants and 1,416 85 m^3 plants. The actual potential however is likely to be far lower although many of these farms have a relatively strong background of capital. Particularly larger farms have high-performance, pure-bred (3,000 farms in 1990) or cross-bred cattle.

Geography, population and agriculture in Morocco (region of Souss-Massa)

Geography and population

The Project region of Souss-Massa lies in the south of Morocco and consists of the administrative regions of the Agadir province and Taroudant. Bordered in the west by the Atlantic, in the east by the Atlas mountains from north to south, i.e. the Anti Atlas, its total area amounts to approx. 12,000 km. Of this, the Souss-Massa plain takes up approx. 575,000 hectares. The total population amounted to 1,037,400 in 1982, the Arabian population making out around 20% and the Berbers 80% (Taroudant 40% and 60%) in Massa.

The climate on the Souss-Massa plain is semi-arid and influenced by three factors: the opening to the Atlantic Ocean, the chains of mountains converging to the east and the desert zone. Protected by the massif, a moderating influence of the Atlantic Ocean can be observed up to 30 km into the interior of the plain and thus allows the cultivation of early crops. In Taroudant annual precipitation amounts to 228 mm, January having the highest precipitation with 144 mm. This low degree of precipitation mostly concentrated into only a few days proves to be very limiting to agriculture. The mean temperatures in Taroudant amount to 13.6C in January and 27.1C in July. Atmospheric humidity is 1,407 mm in Taroudant.

Agriculture and economy

Agriculture is of major importance to the Moroccan economy and employs 40% of the working population. Its contribution to the GNP amounts to between 15% and 20% depending on the harvest, and to approx. 25% to exports. The tertiary sector, extensively marked by trade, is with 35% a major contributor to employment. The differentiated producing sector contributed 18% to the GNP in 1989. Phosphate and its industrial derivatives form the most important source of foreign currency followed by agricultural products (mainly citrus fruits). Considerable fluctuations in the GNP are chiefly a result of agricultural yields being extensively influenced by fluctuations in precipitation. Agriculture is mainly pursued along the coastline although the Central Atlas also shows significant agricultural production.

Agriculture in the project region of Souss-Massa is significant in supplying the domestic markets and for export and, in line with this significance, was highly subsidised. In 1988 it produced 413,000 t citrus fruits (50% for export) and 381,000 t vegetables which corresponds to 30% and 17% of national production. (In addition, a production of 156,000 t cereals and 61 million litres of milk). The fact that more than half of the 228,000 hectares of intensively cultivated arable land is irrigated shows the success of the irrigation policy pursued by the ORMVA Souss-Massa in the so-called "Golden Triangle" since 1978. In 1990 the number of cattle was estimated to be 122,000.

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Energy and environment

The region is confronted by a rapid decline in the Argania forests which are important for the climate of the region. This shows that the most important traditional source of energy in Morocco (particularly in rural areas) remains to be wood. More than 80% of the primary national energy production is gained from wood. An efficient control of wood felling by the authorities despite legal regulations does not exist. The substitution of wood as a source of energy is formulated politically and supported by the subsidy of bottled gas, yet the protection of the forests has not yet found any efficient concept. As evident in the region of Souss-Massa for example, the technical competence of the organisations responsible is directed more to extensive conservation of the resource water.

Biogas technology in Nepal

History

The beginning of biogas activities in Nepal was a programme carried out by the United *Missions to Nepal within the context of the Agricultural Year 1974/1975 whose objective was* to introduce biogas plants similar to in India. The Agricultural Development Bank of Nepal (ADB/N) assisted in financing the plants by providing a special credit framework. The Gobar *Gas Tatha Krishi Yantra Vikas (P.) Ltd. (Biogas and Agricultural Equipment Development (Pvt) Ltd.), normally called Gobar Gas Company (GGC), was founded in 1977 by the ADB/N,* the United Missions to Nepal (UMN) and the Nepal Fuel Corporation (today: Timber *Corporation Nepal - TCN).*

During the history of the company various foreign sources have been involved in promoting biogas dissemination through the GGC. Since 1988 the Netherlands Development *Organisation (SNV Nepal), has been working with the GGC with the involvement of two* Dutch experts in the "Research Unit" and "Workshop" divisions. This cooperation was expanded into a financially more extensive Biogas Support Programme at the beginning of 1992.

GGC biogas programme

The GGC biogas programme is the only supra-regional dissemination programme in Nepal. The building of plants is organised by two regional offices in western (Butwal) and eastern Terai (Biratnagar) and by 11 district offices belonging to these as well the dissemination office in Kathmandu belonging to the main office. Each of the dissemination offices of the company sells, installs, repairs and services biogas plants. The research department is responsible for the development of technical solutions and dissemination structures where possible cost reduction, improvement of customer service and the solution of specific problems in daily use are concerned.

In 1992,there were approximately 6,000 biogas plants in Nepal. Of these, about 4,500 were installed by the Gobar Gas Company in various parts of the country. About 70% of biogas plants are located in Terai. Not counting the biogas plants in upland valleys, only approximately 13% are in mountainous regions. This is explained by difficult access conditions to farms in the mountains which makes the transport of building material very expensive so that farmers in mountainous regions can hardly afford biogas plants.

Types of plant

So far, mainly two types of plant have been built and disseminated in Nepal. These are the **floating-drum plant based on the Indian type (with an overflow at the top rim of the** cylindrical digester instead of an outlet pipe) and fixed-dome plants with a flat floor, cylindrical digester and a dome made of concrete. The market-oriented procedure soon led (and earlier than in India) to fixed-dome plants becoming the standard model: since 1980 fixed-dome plants have primarily been disseminated mainly for reasons of cost. These are offered in digester sizes of between 4 m^3 and 50 m^3.

The Nepali fixed-dome plant is a development peculiar to Nepal which has been modified in various ways over the years. The construction reflects the particular dissemination conditions of the country:

- The form of the digester, the compensation chamber and inlet are simple geometrical figures which, if bricks are not available on site or are difficult to transport there, can be built from natural stones.

- The dome storing gas is plastered or moulded out of concrete on a clay mould. In this case, the building material necessary (normally only concrete since gravel and sand are often available locally) can be brought to the site packed in sacks.

Construction of a fixed-dome plant in Nepal

Building a fixed-dome plant - with regard to the work invested by the farmer - involves a great amount of work. After a cylindrical pit has been excavated to the prescribed depth, the floor slab is laid and the cylindrical wall of the digester is erected on it. In cases where the ground is very firm or rocky, a masoned digester wall is dispensed with; the wall is then only plastered from the inside. The digester is subsequently filled with the excavated earth. At the top the inside form of the dome is shaped in clay using a template. Finally, the concrete is applied on a layer of sand with a trowel and smoothing board. After the dome has hardened, the earth is shovelled out through the large opening in the compensation chamber.

The majority of newly installed plants by far have a nominal digester volume of 10 m^3 which includes the total volume of the digester and gas storage tank but not the compensation chamber. According to the definition of average digester volume of fixed-dome plants, this corresponds to a digester volume of 7.8 m^3. (With fixed-dome plants the level of liquid varies according to how much gas is in the dome. To determine an average value for digester volume half of the maximum gas storage volume plus permanently present digester volume is assumed - i.e. at the highest volume of gas and lowest level of liquid in the digester - according to the BORDA definition). The other sizes offered show no clear tendency as not only smaller 8 m^3 plants but also larger 15 m^3 plants were sold in almost the same numbers. The smallest plants with 4 m^3 digester volume were not ordered in 1991/92.

The plants are designed for a hydraulic retention time of 65 - 70 days. With a daily filling of 60 kg dung (from around 4 - 6 cattle) - in the climatic conditions of Terai - a gas yield of 2.4 m^3/d is to be expected. This quantity provides sufficient energy for cooking for a household of 7 - 9 people. If a toilet is connected the expected gas yield rises by about 15%.

In Nepal the construction material is also the largest cost factor in a biogas plant. It amounts to between 71% (for digester to between 71% (for digester volume = 20 m) and 83% (digester volume = 4 m) of the total costs according to the size of plant. The most expensive individual item is cement, followed by the gas pipes.

The GGC plants fulfil the same requirements on reliability of operation as fixed-dome plants in other countries which have been constructed in a different way. Their type of construction however, seems somewhat exotic (especially in Terai where bricks are the normal building material) in the face of existing experience throughout the world with masoned gas domes. Savings could be made in constructing the dome as, with masoned domes, the extra work involved in re-filling the excavated pit and re-digging is dispensed with.

Despite an unfavourably positioned gas outlet which is too low, the plants mostly operate without any trouble. The gas outlet in the dome is located - depending on the size of the plant - between 11 and 17 cm lower than the overflow at the compensation chamber and, for this reason, can become blocked with sludge if the gas is let out at the same time as the plant is being filled with dung. Problems are reported only during the colder months of the year when sludge is occasionally pressed into the gas pipes with the gas and blocks these.

Geography, population and agriculture in Nepal

Geography

Nepal lies on the southern flanks of the central Himalayas as an 835 km long and 90 to 230 km wide strip of land comprising an area of 147,181 km. Within this small area, Nepal has differences in altitude of over 8,500 m like no other country on earth. From the border to India in the south the land rises from the humid-hot plains of the Terai with an altitude of around 100 m above sea level upwards towards the north. Over the foothills of the Churia Range and the Mahabharat Range with altitudes of up to 2,000 m, the country opens up into the broad upland valleys of the central country which lies at altitudes of between 1,000 and 2,000 m, has a temperate sub-tropical climate and provides settlement area for the majority of the population. Further north then come the mountainous regions of lower and the central Himalayas. In the central Himalayas or upper Himalayas where the country

Himalayas. In the central Himalayas or upper Himalayas where the country
borders on Tibet,

with eight mountains of over 8,000 m, is also Sagarmatha, or Mt. Everest, which at 8848 m is the highest mountain on earth. Expressed in percentages, the Terai covers 17%, the central mountains 68% and the uplands 15% of the total area of land.

Like in India, the climate is dominated by the monsoons bringing rain from June to September from the south. During the rest of the year dry winds from Central Asia are predominant and prevent precipitation. The amount of precipitation depends on the altitude. Between 2,000 and 3,000 mm of rain fall on the central mountains; precipitation in the upland valleys amounts to 1,500 mm annually. Temperatures too show a similar variation: in the upland valleys the minimum temperature in December and January falls to freezing point at night in December and January with temperatures during the day of between 16 and 20C. In the hills and the high Himalayas temperatures vary far more. Settlement reaches altitudes of up to 4,000 m where minimum temperatures of -10C are reached. Biogas plants are operated up to altitudes of 1,500 m.

Population

Nepal has a population of about 18 million. The calculated density of the population amounts to 115 inhabitants per km, however, the area which can be settled is far smaller so that the true density amounts to around 440 inhabitants per km. Population growth is 2.7% per year.

Agriculture and economy

Agriculture and tourism are the main sources of income in the country. Agriculture contributes around two thirds to the GDP; income from tourism amounts to about 17%. The state budget is in deficit and is financed by means of funds from international development aid to approx. 40%. With an annual per capita income of approx. 300 DM, Nepal is one of the poorest countries in the world. These figures, however, considering the living majority of the population are not an adequate indicator of prosperity since most of the inhabitants in rural areas carry out subsistence farming. The inadequate infrastructure of the country is considered to be the main reason for the low productivity in agriculture.

Over 90% of the population in Nepal live from agriculture. Rice, sugar cane, maize, sorghum, oilseed, barley, wheat, tobacco and tea are the most important products. 80% of all exports are or are based on agricultural products. Agricultural production is not sufficient to provide adequate foodstuffs for the inhabitants due to the geographical and climatic conditions and the rapid growth rate of the population. The structure of Nepal's agriculture is mainly that of small-scale farms. The average size of farm is around 0.5 hectares in the "hills" (central mountains and lower Himalayas) and about 1.5 hectares in Terai. Animal production is not an inconsiderable factor in enhancing the arable crops, but meat production for religious reasons is limited to sheep and goats; cattle and water buffalo are mainly kept for dairy products and as draught animals. There are estimated to be around 12 million of the latter; stabling is widespread due to difficult terrain conditions. Cattle dung is sought after as a raw material for fuel and fertiliser.

Energy

The total energy requirements of the country is estimated to be 252 million GJ annually. The largest proportion is used for consumption. The primary source of energy used for productive purposes in agriculture is still human and animal labour.

Environment

Decades of ruthless exploitation of the forests in the Himalayas which are endangered by erosion as it is, have left behind massive, ecological imbalance. The increasing pressure of the population is affecting isolated parts of the country where organised timber thefts are diminishing the resources of local populations to a great extent. Subjected to uncontrolled felling and sparse re-afforestation measures, the countryside is falling victim to erosion. Also the use of existing forests as pastures for cattle or for obtaining feedstuffs is causing great damage. Also the Terai, which was densely forested until well into the fifties, the claiming of land for cultivation has led to a situation equal to land for cultivation has led to a situation equal to complete deforestation.

Biogas technology in Tanzania

History

The history of biogas dissemination in Tanzania dates back to 1975 when the Small *Industries Development Organisation built 120 floating-drum plants up to 1984. In the* Arusha region the Arusha Appropriate Technology Project constructed traditional Chinese **fixed-dome plants and "floating-seven-drum digesters", their own development consisting of** a gas holder made of 7 oil drums connected together. The objective of this project was to build biogas plants at the lowest investment costs possible. In 1982 the newly founded parastatal Organisation Centre for Agricultural Mechanization and Rural Technology (CAMARTEC) continued the dissemination of this technology in the Arusha area. About one year later Technical Cooperation between Tanzania and Federal Republic of Germany led to the introduction of the Biogas Extension Service (BES). CAMARTEC and the Deutsche Gesellschaft fr Technische Zusammenarbeit (GTZ) were in charge of implementing this project and the latter seconded an interdisciplinary team (social scientist, mechanical engineer and agriculturist) to Tanzania. Only a few of the more than 100 biogas plants built were still in operation at this time.

In the initial years the BES disseminated biogas plants mainly in the so-called "Coffee and Banana Belt", the region around Arusha where particularly positive conditions promised a high dissemination density for biogas plants:

- a fertile region with high productivity and a dense population (192 inhabitants/km cf. national average of 25/km)
- smallholding structure, farm households own an average of 1.5 acres of land
- extensive animal husbandry

- extensive animal husbandry for dairy production
- relatively well-off farmers as widespread additional income from other jobs

Standardisation

Concentration on a project area which could be easily observed with good conditions led relatively early in project history to standardisation not only of the plant design, of administrative procedures, of guarantees (2 years) but also of user advice which in view of the high dissemination density could be carried out village for village. In 1984/85 household plants were offered with a digester volume of 8, 12 and 16 m^3, in 1990 the programme comprised standardised plants of sizes with 12, 16, 30 and 50 m^3 for households and institutions as well as a toilet biogas plant for an institution.

Technical development

A variety of technical development work was necessary to guarantee long-term performance of the plant. The fixed-dome plant initially disseminated by the BES proved to be non-reliable in practice. After 3 years of operation cracks allowing gas to leak out appeared on many plants with a digester volume of over 8 m^3. The cause of this was seen to be in that the dome construction was not statically determined and cracking from the digester region up to the gas storage area could not be prevented. The solution to this problem was a pre-determined breaking point, the so-called "weak ring". Later a reinforcing ring, the "strong ring" made of concrete was added over this. This guaranteed that the gas storage area remained free of cracks. Another technical innovation which proved to be beneficial was the use of an additive in the cement for the gas-proof plaster. In the meantime the experience gained by CAMARTEC has been used successfully in many biogas dissemination programmes.

During cooperation work with a Kenyan organisation gas burners were developed which were reliable, easy to service and which corresponded to the cooking habits of the region. Supply problems and inferior performance of imported gas lamps led to an own model being developed and to the modification of petroleum pressure lamps for operation by gas. A kit developed for this purpose was exported to other GTZ projects. In other projects only the idea was taken up and this led to more simple solutions, e.g. in Java. The use of biogas for

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large-scale consumers necessitated the development and distribution of a gas cooker for institutions which only works with primary air and thus burns stably.

The development work towards sustainable reliability and user friendliness resulted in extensive integration of biogas plants into the work routines of farmers. As a "biogas unit", a system of coordinated components was developed to include not only the plant but also integration into the farm system. This included livestock housing with a concrete floor and direct connection of the urine channel to the digester, slurry tank, distribution channels for the slurry or a slurry cart, advice on the utilisation of slurry, gas pipeline systems, burners and lamps. Women were specifically instructed during initial years in Tanzania but this process suffered when the GTZ social studies expert left the project.

By 1990 around 200 "biogas units" had been constructed directly by the BES or on its authority by trained craftsmen. In 1992 there were 600 biogas plants in the whole of Tanzania.

Special Energy programme

Dissemination strategy and project structures underwent decisive changes mainly around 1990. These were chiefly a result of financial and personnel withdrawal of the GTZ from the BES and the subsequent extensive transfer of the project to the counterpart organisation. In the course of this transfer phase from 1990 to 1992 and with a further extension from 1992 to 1994, the project receives financial support within the scope of the Special Energy *Programme (SEP) which apart from the biogas component also includes fuelwood-saving* stoves. Personnel involvement of the GTZ is reduced to one person for both components and the main task of this person is to see that the locally provided funds of the BES are used for the purpose intended and the SEP funds are applied to overriding measures which the customer cannot finance (e.g. training).

Financing

Orders which cannot be covered by the standardised range of plants and services and which necessitate additional research and development work have to be financed completely by the customer. This increased orientation towards privatisation of the BES has sent the costs for a Biogas Unit from around TSh 300,000 in 1989 to TSh 400,000 to 7000,000 according to the region. Despite this, the number of units constructed until 1992 has increased to about 400.

Further dissemination programmes

Apart from the CAMARTEC dissemination programme there are two other relatively extensive dissemination programmes: one is being carried out by the church organisation (ELCT) in Arusha and one by the Ministry of Water, Energy and Minerals in Dar es Salaam. On all sides there is sporadic cooperation in the field of training and upgrading with the animal husbandry department of the Ministry of Agriculture in Arusha and the Ministry of *Water, Energy and Minerals in Dar es Salaam which primarily supports the dissemination of* biogas technology in the region of Dar es Salaam. It ensures training for private craftsmen, builds demonstration plants and is in charge of monitoring and evaluation.

There has been no cooperation with the active church organisation ELCT which has been active in dissemination since 1988. The reason may be the almost contrary dissemination concept of the ELCT in comparison to the BES. In ten decentral church centres there are contacts trained in biogas technology who coordinate advice, training of biogas craftsmen and construction etc. The target group is made up of farmers with at least two head of cattle. Chinese fixed-dome plants with conical fundaments are disseminated. The farmers receive 50% of the investment costs as a credit on conditions depending on their socio-economic situation. To keep the investment costs low the farmer families are included in the construction of plants. The costs for a 12 m^3 plant, for example, amount to an average of TSh 100,000. Biogas accessories (lamps, stoves) are imported from India and China and are around half the price of those from CAMARTEC. CAMARTECs commercially oriented, strictly standardised dissemination programme is considered by ELCT as not adapted to Tanzanian conditions as it only serves

Tanzanian conditions as it only serves
the rich farmers.

Geography, population and agriculture in Tanzania

Geography

Tanzania lies in the East of Africa between 1 and 12 south and between the Indian Ocean and the East African rift valley. From the eastern coast the land slopes upwards to the west where tableland and mountainous country 900 and 1,200 m are marked characteristics formed by the East and Central African rift valleys and vulcanos which have formed in the rift zones. The highest of these vulcanos is Kilimanjaro at 5,895 m which is also the highest mountain in Africa. A tropical-humid climate predominates along the coast whilst the interior of Tanzania has a moderate tropical highland climate. In the eastern rift zones and on the southeastern slopes of the vulcanos precipitation of 1,500 mm to 2,000 m occurs due to orographic rain with more than 10 wet months. Along the coast, the monsoon brings moderate rainfall (500 to 1,000 mm) with 5 to 6 wet months. The highland in the interior is relatively dry with 3 to 4 wet months and annual precipitation of below 500 mm.

Population

According to official estimations in 1988, 23,997 million inhabitants live on 945,087 km (25.4 inhabitants per km). Although the population in urban areas is constantly rising, around 85% of the Tanzanian population lives in the country in approx. 8,700 villages. 98.5% of the population are Africans belonging to 120 different tribes. 1.5% of the population are Asian, Arabian and European.

Economy and agriculture

According to the World Bank in 1992, the economic situation in Tanzania continued to deteriorate in the past year, and the country is now second on the list of the poorest countries in the world. Per capita income among the Tanzanian population fell from US$ 130 in 1991 to US$ 110. Reasons stated for this are, amongst others, the lack of incentives for agricultural production, industry not working to capacity which only contributes 8% of the GDP, a lack of consideration for environmental problems in economic development and a high population growth rate (1990: 3.5%).

The Tanzanian economy is primarily marked by agriculture. The agricultural sector contributes around 44% to the GDP and the majority of the population are dependent on this for their existence. In addition to providing food for the population, agriculture makes a contribution of almost 60% to earnings from exports. Important export products are coffee, cotton, cashew nuts and tea. 90% of cropland is cultivated by smallholders, the rest by export-oriented plantation and state-owned companies. 6% of the total area is arable land and 37% pastureland of which a considerable area can only be used occasionally for grazing (dependent on seasonal precipitation). Only about 2% of the arable land is irrigated. Mixed farming with arable farming and animal husbandry is not widespread in Tanzania. As the yields are centrally dependent on the quality of soil and on precipitation the best arable land is situated northeast of Kilimanjaro.

A reduction in reliance on foreign oil is the major priority as Tanzania had to spend 60% of its foreign currency income on purchasing oil up to 1985. For this reason the development and utilisation of domestic energy resources and the efficient utilisation of energy have been given a major priority in the second "Union" 5-year development plan from 1988-89/1992-93.

Environment

According to the National Environmental Management Council and the 1992 World Bank Report, Tanzania is facing a series of very serious environmental problems. The central problem is an insufficient supply of water at all for the population and in particular, a supply of clean water. Erosion is leading to diminished fertility of the land. This is assumed to result in a 0.5 - 1.5% reduction annually in the GNP. Smoke emissions in the households stemming from the use of firewood, dung and straw as energy for cooking are already showing adverse effects on women and children. The World Bank Report compares this to a health risk of

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smoking several packets of cigarettes per day and is taken far more seriously than the increasing air pollution in cities.

Biogas technology in Thailand

History

Up to 1982 there were approximately 1,000 biogas plants in Thailand which were built by various state and private organisations. Greatest involvement here was by the Ministry for *Public Health with its Sanitation Division which had good infrastructure through the Preventive Health Centres, and which disseminated fixed-dome plants of the Chinese type.* After disencouraging experience with floating-drum plants mainly erected in Buddhist monasteries which had an average service life of less than two years according to a report in 1979, the emphasis was obviously changed to fixed-dome plants. Due to the high level of groundwater in the south, floating-drum plants were erected above ground and "red mud plastic" fermenters were built. Apart from these classic types of construction there were a large number of home developments and experiments which did not turn out to be suitable for dissemination. The activities have today all extensively died down or have been completely stopped.

Thai-German Biogas Programme

In 1988, the GTZ/GATE began cooperation with the Chiang Mai University in the Department *of Mechanical Engineering and the Department of Agricultural Extension of the Ministry of Agriculture in the form of the Thai-German Biogas Programme. Until 1992, 150 biogas plants* were in operation of which some were large-scale plants for pig farms. The total potential of household plants is estimated to be approx. 200,000 in the 5 provinces.

The Thai-German Biogas Programme is assigned to the university and the Department of *Agricultural Extension of the Ministry of Agriculture. Work division* *has, in fact, arisen* whereby the university with its Department of Mechanical Engineering is responsible for R & D and for the larger-scale biogas plants and the Ministry of Agriculture with its District *Agricultural Extension Service is in charge of disseminating the standardised household* plants.

Type of plant

The CAMARTEC plant from Tanzania was taken over with only minor changes. The plants, as a standard, are to be connected directly to stabling with a hard floor.

Household plants are offered in standard sizes of 8, 12, and 16 m^3 digester volume of which 12 m^3 is the most frequent. The standard ratio digester volume/gas storage volume amounts to 8:1. In addition to the household plants, larger units of 30 - 80 m^3 digester volume were built for pig farms according to the same technical principle to which two or three flat compensation chambers as vault constructions are connected.

Geography, population and agriculture in Thailand

Geography and population

Thailand, located between the 10 and 20 north, comprises an area of 513,000 km and has a population of 56 million of which 85% belong to the Thai peoples. Its neighbouring countries are Burma in the northwest, Laos in the northeast, Cambodia in the east and Malaysia in the south.

The project area (5 provinces, about 12,000 km, 4 million inhabitants) lies in the northeast with the centre of Chiang Mai which after Bangkok is the largest city in the country (150,000 inhabitants). The climate is tropical with temperatures of between 14 and 36C. It is marked by a summer monsoon, the months of December to March are dry with only insignificant precipitation.

The areas important for the biogas dissemination programme are flat and lie at an altitude of about 200 m above sea level. Mostly rice, maize and manioc are cultivated on the fields. The settlements are mostly scattered villages.

Economy and agriculture

Thailand belongs to the countries with an average income in the lowest category. The GNP amounted to 1,420 US$ in 1990 and has grown by 7.6% annually in the last decade. The services sector made a contribution to the GDP of 48%, industry 39%, processing industry 26% and agriculture only 12%. 35% of all imports are capital goods, the largest proportion of exports comes from agriculture and forestry (rice, maize, tapioca, vegetables, spices, caoutchouc, jute and teak). Thailand is the largest rice exporter throughout the world. All chemical fertilisers and oil products have to be imported. Electricity is exported to Laos.

In addition to production for exports, agriculture is expected to secure nourishment for the domestic population. The supply of wheat and chiefly rice is already sufficient for the home market. The production of pork and poultry is to be increased further. Pig-breeding farms are the central target of the biogas dissemination programme.

The 5-year plant begun in 1992 is devoted to the promotion of organic fertiliser. It is to be intensified mainly by improved training of the agricultural extension officers.

Environment

Environmental protection is a subject which is gaining in interest among the public. A new law on keeping the air and water clean is to be passed in 1992. This law applies centrally to the agroindustry and to large and medium-scale animal husbandry farms. At present however there is no extension service linked to the Ministry for the Environment.

Biogas technology in Tunisia (Sejenane, El Kef)

History

The first biogas activities date back to the Tunisian-German cooperation in the Sejenane region in 1982 when an 11 m^3 floating-drum plant was built by the project Dveloppement *Rgional Sejenane. In autumn 1983 an agreement was concluded between this project* and the Ecole Nationale d'Ingnieurs (ENIT) in which ENIT engaged to carry out research into and dissemination of biogas technology for this region. In 1986 the first fixed-dome **plant (6 m^3**) was built. Until the engineer who had mainly been responsible for biogas at the ODESYPANO left in July 1987, a further 7 fixed-dome plants (BORDA models) had been constructed.

At the end of 1987, ODESYPANO expressed a wish to establish a cooperation with the *Entreprise Tunisienne des Activits Petrolires (ETAP) and the Agence de Maitrise de l'Energie (AME) to reassume biogas activities and this was realised in 1989 by pilot* measures of the Special Energy Programme Tunisia. In this phase, the non-functioning plants in the region were rehabilitated and 10 further biogas plants were built. The centre of activities was constituted, besides modification of the technical side (mainly gas appliances), by training measures and slurry experiments. From December 1991 to December 1992 a further measure was carried out in El Kef with the construction of another 11 demonstration plants (between 16 and 25 m^3) and the establishing of a Biogas Office at ODESYPANO in Le Kef. In April 1992 the Special Energy Programme withdrew from biogas activities. Although the ODESYPANO general and regional managements concerned had stated their interest in continuing biogas dissemination, activities in this area almost came to a complete standstill. Both central sources of know-how saw their demands for a description of tasks as not having been fulfilled in accordance with their status and consequently searched for other areas of activity.

End of the Special Energy Programme

The dissemination activities in Sejenane as well as in El Kef almost came to a complete standstill when the direct Special Energy Programme involvement ended. In autumn 1992 plants were planned and built only in isolated cases. This decline is in direct conflict with the explicitly formulated interest of decision-makers (mainly at the ODESYPANO) in biogas technology. That this interest and the positive demonstration effects of plants built have not led to consolidation of a sustainable dissemination structure indicates the presence of a multi-level socio-economic complex of problems.

Geography, population and agriculture in Tunisia (Sejenane, El Kef)

Geography and population

The project regions of Sejenane and El Kef belong geographically to the Le Tell region. The border to the north and east is formed by the Mediterranean coastline and to the south, the 400 mm precipitation limits. Whilst El Kef is administratively its own gouvernourat with an area of approx. 5,000 km, Sejenane is in the gouvernourat of Bizerte and comprises an area of approx. 400 km.

The climate in Sejenane is influenced by the Mediterranean and has a mean annual temperature of 17.8C with an average in July of 27C and in January of 10C. Annual precipitation falling mostly between October and March amounts to between 800 and 900 mm. According to the census in 1984, 33,212 people lived in the region.

The climate in the region of El Kef belonging to the Tell Haute region, is continental and semi-arid in the south. In the capital of the El Kef gouvernorat, mean annual precipitation amounts to 512 mm. Average temperatures are between 7.1C in

amounts to 312 mm. Average temperatures are between 7.1C in
January and 26.5C in

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July. Annual precipitation is subject to considerable fluctuation making it a serious factor of uncertainty for agriculture. Approx. 250,000 people lived in the Le Kef region in 1984.

Economy and agriculture

In 1990 the GDP at factor cost of the well-differentiated Tunisian economy comprised: agriculture and fisheries 16.4%, oil and gas production 6.9%, tourism 4.5%, processing industry 16.8% and services 47.1% (including public administration). Fluctuations on the oil market and in the tourist industry and drought are considered to be the factors of uncertainty in an economy which is aiming for a growth rate of 6% for the 5-year plan from 1992 to 1996. Although the proportion of agriculture in Tunisia has declined constantly since independence (from 56% in 1960 to 14.1% in the drought years 1883), it still occupies a key position in development planning: reduction of cereal imports (1990: 191 million TD, 1 TD = 1.12 US$), expansion of the export sector and stabilisation of rural areas marked by country-to-city migration by means of integrated rural development. Rain-fed agriculture is predominant (approx. 9 million hectares) which partly explains the considerable fluctuations in agricultural yields. Irrigated agriculture is practised on only approx. 250,000 hectares constitutes a significant part of the national overall yield. Extensive irrigation projects are to reinforce its position further. Despite the inefficiency complained about on all sides, the parastatal agricultural development bodies have contributed significantly to progress in dairy and meat production. 40% and 90% respectively of domestic demand is met by home production.

An emphasis in Tunisian development policy will continue - despite over-proportionally increasing development costs - to be the electrification of rural areas by the Societ Tunesienne de l'Electricit et du Gaz (STEG). Despite this, there are large areas of rural regions - particularly scattered settlements - which cannot hope for a connection to the central electricity supply. Despite this long-term gap which will remain, the STEG has showed little interest in supply concepts involving renewable energy sources.

The project region of Sejenane has been undergoing profound economic and social transformation in the last twenty years. Whilst in 1984 9.5% of the population were living in small town settlements, in 1966 settlement was exclusively in the rural milieu. In 1966 settlements in a village structure with more than 10 houses made up 12%, in 1984 it had already reached 29%. Parallel to this change, there was a transformation of the once communal property into individual ownership. The number of farms with a title to their own property rose from 891 in 1963 to 3,435 in 1984. The economy of the region has begun to diversify. More and more farmers are finding additional occupations with the state, in crafts and in trade. This shift was mainly brought about by development efforts to promote the penetration of rural areas by the monetary economy. Nevertheless, bartering is still a dominant element of the regional economy. At the same time, formal financing systems are underdeveloped. Monetary income in the region is weak. Less than 5% of households have an annual income in excess of 3,000 DT. Animal husbandry, dominant in the region due to poor soils has undergone great qualitative and quantitative improvement due to efforts by the Office de Developpement Sylvo-Pastoral de Nord Ouest (ODESYPANO) and thus, dairy farming and meat production have been expanded. Nevertheless, underemployment and country-to-city migration remain characteristic for this structurally weak region.

2,000 years ago the Le Kef region was the "granary" for the Roman Empire and despite the increasing degradation of natural resources, this still marks agricultural structure today. Of the total agricultural area amounting to 380,000 hectares, approx. 250,000 hectares are cultivated. More than 55% of cropland is reserved for cultivating cereals (hard wheat, wheat, barley). Intensification of agricultural production is restricted not only by natural conditions but also by the limited working capital/equipment available. Animal husbandry is semi-extensive. Together with cereal production, animal husbandry makes up over 90% of added value in agriculture. In 1987 the number of cattle amounted to 51,200 head. The number of sheep was 538,142 and of goats 43,140. Approx. 4,000 farmers in the region have more than 4 animals. Cattle raising is mostly carried out in the northern delegations where the water supply is far better than in the south.

Biogas technology in Vietnam

Biogas utilization

The utilization of biogas is common in the Mekong Delta and sustainable in animal husbandry as a supplement, to farm activities on a household-scale (up to about 20 pigs, for instance). Using gas instead of other types of fuel is well accepted by local farmers because of its savings on fuel and the convenience of biogas compared with fire wood or kerosene. However, in the Mekong delta, there is much less attention and attraction from the owners of larger scale animal farms to the utilisation of biogas and, in consequence, anaerobic treatments. Animal farms with a scale of 100-200 pigs and about 1000-5000 chickens become more and more common in Vietnam.

Waste treatment, especially with anaerobic technology, is needed to be given more attention in the operation of intensive and spezialized farms, which cause more pollution than the micro scale. The biogas digester seems to be the most suitable solution to treat the waste from animal farms. However, in this small and medium scale, the amount of biogas produced is much higher than the domestic demand for cooking, lighting etc.

A large surplus of biogas is expected. Only when some economical ways to use this biogas can be introduced, farm owners will be willing to pay for anaerobic technology.

A new study showed, that

- running engines with biogas can be technically and economically feasible and suitable for farms with 80 pigs or more.
- burning biogas for direct-heated driers can be feasible for farms with 120 pigs or more. Futural economical feasibility is expected.

- burning biogas for driers with heat exchanger can be technically feasable for pig farms with 120 animals, but not economically.

The benefits of biogas systems within integrated farming systems

The original intensive farming model VAC integrates crops (V), fish (A) and pigs (C) into a symbiotic system that reduces the dependence on external inputs, while increasing productivity. However, the system does not provide a proper treatment of animal waste.

The VACB farming model is, therefore, a much improved version of VAC. It yields more profit for the farm while improving the whole environment. In order to contribute to poverty alleviation, hunger eradication and ensure sustainable rural development, the Renewable Energy Center (REC) of Can Tho University in the Mekong Delta has established about 20 VACB models.

After three years complementation (1993-1996) the following conclusions have been achieved:

- To establish VACB system, the role of well trained pilot VACB owners, the extension workers and self-help group leaders should be to cooperate in a combined spirit in order to support the poor.
- The target group is to upgrade members in the self-help group, to become members of VAC groups and later owners of integrate farming systems, which include biogas system (B). This can increase the family income considerably, contribute to the provision of a renewable energy source, and provide fertilizer in the rural areas.
- Last but not least, the biogas system diminishes organic pollution in rivers and channels, which is of great importance in the Mekong River Delta.
- In order to reach this target, the assistance from the government, universities, and the local authorities to organize the farmers self-help group, is the most important factor.

Geography, population and agriculture in Vietnam

Geography and population

The Socialist Republic of Vietnam is a multiethnic state with 79 Mill. inhabitants (87% Kinh, 13% other nationalities) and an area of about 329.566 km^2. With an average income of about 200 US$ per person, Vietnam is one of the poorest of the Asian countries. The population increases 2,2% every year.

The objective of the national planning for the future is an income of 400 US$ per person and a reduced increase of population of 1,7%. The agriculturally utilized area of 70.000 ha (1993) shall be increased to 122.000 ha.

Economy and agriculture

In 1994, the economic growth of the vietnamese industry was 11,5% and in 1995 13,1%. The growth in the service sector was 9,7% (1994) and 11,9% (1995).

25 million tons of grain were produced in 1993. Predominant exports are rice, latex, coffee, tea, peanuts, meat, cashews and silk-yarn.