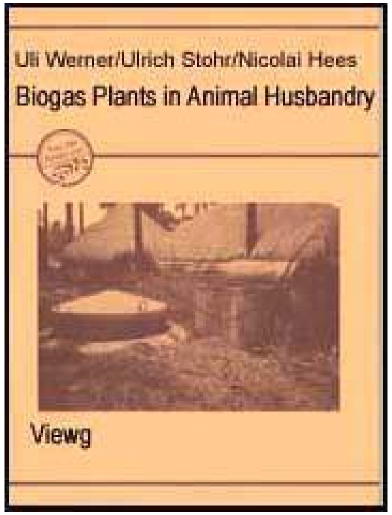

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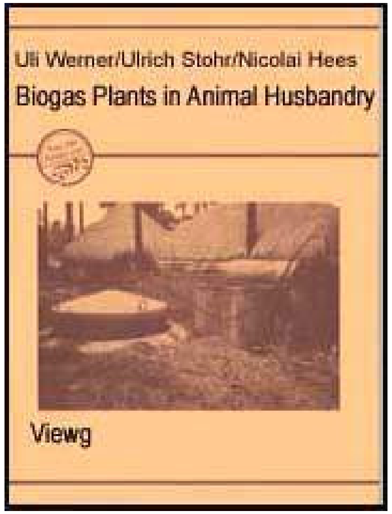

Uli Werner/Ulrich Sthr/Nicolai Hees

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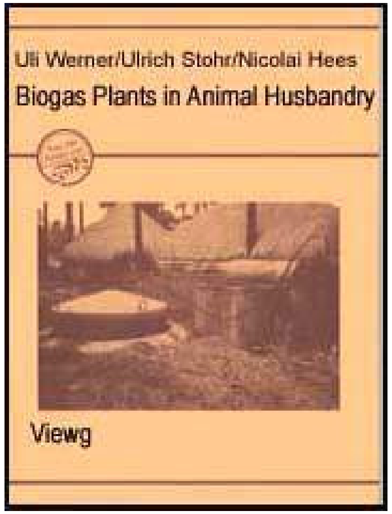
8. Economic analysis and socioeconomic evaluation



Biogas plants in Animal Husbandry (GTZ, 1989, 153 p.)

8. Economic analysis and socioeconomic evaluation

8.1 Procedures and target groups

Any decision for or against the installation and operation of a biogas plant depends on various technical criteria as well as on a number of economic and utility factors. The quality and relevance of those factors are perceived differently, depending on the respective individual intrest:

- Users want to know what the plant will offer in the way of profits (cost-benefit analysis) and other advantages like reduced workload, more reliable energy supplies or improved health and hygiene (socioeconomic place value).

- Banks and credit institutes are primarily interested in the economic analysis as a basis for decisions with regard to plant financing.

- Policy-makers have to consider the entire scope of costs and benefits resulting from introduction and dissemination, since their decisions usually pertain to biogas extension programs instead of to individual plants.

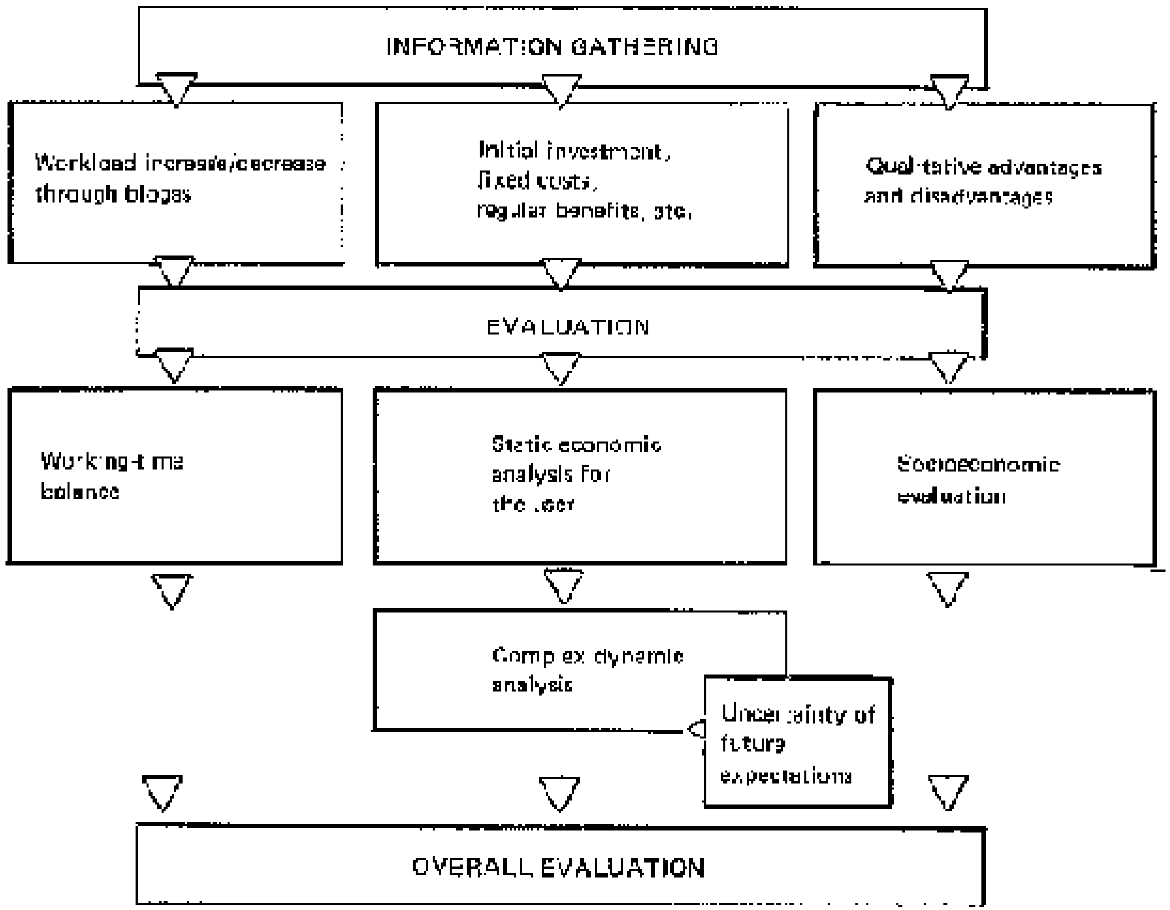


Fig. 8.1: Basic elements of an economic analysis (Source: OEKOTOP)

The evaluation of biogas plants must include consideration not only of the monetary cost/ benefit factors, but also of the ascertainable nonpecuniary and unquantifiable factors. Time and again, practical extension work with the owners of small and medium-sized farms shows that a purely monetary approach does not

reflect the farmers' real situation. For a farmer who thinks and works in terms of natural economic cycles, knowing how many hours of work he stands to save is often more important than knowing how much money he stands to gain. A similar view is usually taken of the often doubtful monetary evaluation of such a plant's qualitative and socioeconomic impact.

Figure 8.1 surveys the essential parts of an economic analysis. In practice, however, the collecting of information and data can present problems: experience shows, for example, that an exact breakdown of cost and benefits can hardly be arrived at until the plant has been in service long enough for the user to have gained some initial experience with its operation. Economic prognoses therefore should give due regard to such limitations by including calculations for various scenarios based on pessimistic, average-case and optimistic assumptions. Consequently, the data stated in the following calculations and considerations are intended to serve only as reference values. Any attempt to convert local plant & equipment costs into DM-values is seriously complicated by the fact that exchange rates are often set more or less arbitrarily and that the figures used may derive from unstable black-market prices.

8.2 Working-time balance

For the users of family-size plants - primarily the operators of small to medium-size farms - the following three elements of the biogas plant evaluation have the most relevance:

- **working-time balance**
- **micro-economic analysis and**
- **socioeconomic and qualitative considerations.**

Working-time balancing is most important when the farm is, at most, loosely involved in cash-crop markets, so that the cost/benefit factors are more likely to be reflected in terms of hours worked, as in money.

Table 8.1 exemplifies a comparison of time expenditures for a farm with a biogas plant and for a similar one without a biogas plant. The unit of calculation is hours worked per year (h/a) by the farmer and his family. Any expenses for external assistance, e.g. "hired hands", appear only in the monetary (cashflow) calculation (cf. chapter 8.3).

Table 8.1: Comparison of working time with and without biogas utilization (Source: OEKOTOP)

Working time with biogas plant	**h/a**	**Working time without biogas plant**	**h/a**
Planning/know-how acquisition	.....	Mucking out the stables	.....
Plant construction and installation of appliances		Hauling off/disposal of organic wastes	.....
	.....	Collecting, hauling and preparing fuel	.....
Feeding/collecting manure	.....	Cooking	.....
Fetching water	.....	Cleaning and repair of fireplace	.....
Cooking	.....	Spreading of NPK-fertilizer	.....
Maintenance and repair work	.....	Tending of animals	.....
Spreading of digested slurry/fertilizing			

Spreading of digested slurry/fertilizing	.....		
Tending of animals	.....		
Total	.....	Total	.....

The best indication of a successful biogas plant is a significant reduction in the average amount of time worked - especially by women and children who tend the plant and cook with the gas. If, for example, the family used to cook on wood gathered on the way back from the fields, a practice that involved little extra work, biogas technology can hardly expect to find acceptance under the heading "time saved".

The actual value of time saved depends not only on the quantity saved but also on the quality, i.e. whose workload is reduced at which time of day.

Real-time savings let the target group:
- expand their cash-crop and/or subsistence production
- intensify and improve their animal-husbandry practice
- expand their leisure time and have more time for their children, education, etc.

It should be noted that all time expenditures and time savings pertaining to anyone participating in the farm/household work, and which can be expressed in real monetary terms as cash-flow income or expenses must appear both in the above working-time balance and in the following micro-economic analysis (wage labor during the time saved by the biogas plant).

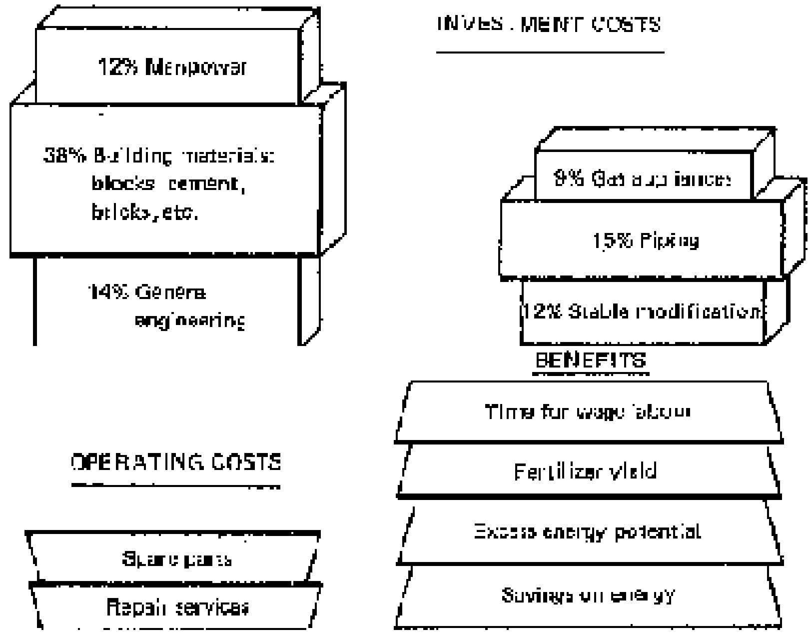


Fig. 8.2: Costs and benefits of a fixed-dome biogas plant (Source: OEKOTOP)

8.3 Micro-economic analysis for the user

The following observations regarding micro-economic analysis (static and dynamic) extensively follow the methods and calculating procedures described in the pertinent publication by H. Finck and G. Oelert, a much-used reference work at Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH that should be consulted for details of interest.

Table 8.2: Investment-cost comparison for various biogas plants (Source: OEKOTOP)

Cost factor	Water-jacket. Plant	Fixed-dome plant	Plastic-sheet plant
Cost per m³ digester (DM)	200-400	150 - 300	80-120

including:Gasholder	23 %	(part of digester)	8%
Digester/slurry store	35%	50%	42%
Gas appliances/piping	22%	24%	36%
Stable modification	8%	12%	-
General engineering	12%	14%	14%

Surrey of the monetary costs and benefits of a biogas plant

Figure 8.2 shows a breakdown of the basic investment-cost factors for a - presumedly - standardized fixed-dome plant. The cost of material for building the digester, gasholder and displacement pit (cement, bricks, blocks) can, as usual, be expected to constitute the biggest cost item. At the same time, the breakdown shows that the cost of building the plant alone, i.e. without including the peripherals (animal housing, gas appliances, piping) does not give a clear picture.

For a family-size plant, the user can expect to pay between 80 and 400 DM per m³ digester volume (cf. table 8.2). This table shows the total-cost shares of various plant components for different types of plant. While the average plant has a service life of 10-15 years, other costs may arise on a recurrent basis, e.g. painting the drum of a floating-drum plant and replacing it after 4 - 5 years. Otherwise, the operating costs consist mainly of maintenance and repair work needed for the gas piping and gas appliances. At least 3% of the initial investment costs should be assumed for maintenance and repair.

The main benefits of a biogas plant are:

- savings attributable to less (or no) consumption of conventional energy sources for cooking, lighting or cooling

- the excess energy potential, which could be commercially exploited

- substitution of digested slurry in place of chemical fertilizers and/or financially noticeable increases in crop yields

- savings on time that can be used for wage work, for example.

Usually, a biogas plant will only be profitable in terms of money if it yields considerable savings on conventional sources of energy like firewood, kerosene or bottled gas (further assuming that they are not subsidized).

Financially effective crop-yield increases thanks to fertilizing with digested slurry are hard to quantify, i.e. their accurate registration requires intensive observation of the plant's operating parameters.

Such limitations make it clear that many biogas plants are hardly profitable in monetary terms, because the relatively high cost of investment is not offset by adequate financial returns. Nonetheless, if the user considers all of the other (non-monetary) benefits, too, he may well find that operating a biogas plant can be worth his while. The financial evaluation (micro-economic analysis), the essential elements of which are discussed in the following chapter, therefore counts only as one of several decision-making instruments to be presented to the potential user.

The main advisory objective is to assess the user's risk by calculating the payback period ("How long will it take him to get back the money he invested?") and

comparing it with the technical service life of the plant. Also, the user must be given some idea of how much interest his capital investment will carry (profitability calculation).

The micro-economic analytical methods described in the following subsections require the highest achievable accuracy with regard to the identification of costs and benefits for the biogas plant under consideration. Chapter 10.4 in the appendix includes an appropriate formsheet for data collection. With a view to better illustrating the described analytical methods, the formsheet (table 10.10) includes fictive, though quite realistic, data concerning a familysize biogas plant. Those data are consistently referred to and included in the mathematical models for each of the various sample analyses.

Calculation of the static payback period according to the cumulative method (data taken from the appendicized formsheet, table 10.10).

Input parameters:
- investment costs
- annual revenues
- less the yearly operating costs
- less the external capital costs
- annual returns

The cumulative method allows consideration of different annual returns.

Calculatory procedure: The investment expenditures and annual returns are added together until the line-3 total in table 8.3 either reaches zero (end of payback

period) or becomes positive.

Evaluation: As far as risk minimization is concerned, a short payback period is very valuable from the standpoint of the plant's user ("short" meaning significantly less than 10 years, the data listed in table 8.3 pegs it at 5.5 years). Should the analysis show a payback period of 10 years or more, thus possibly even exceeding the technical service life of the plant, building the plant could not be recommended unless other important factors are found to outweigh that disadvantage.

Item / Year	0	1	2	3	4	5	6 etc.
1. Investment expenditures	−1,100						
2. Annual returns		+200	+200	+200	+200	+200	+200
3. Cumulative value	−1,100	−900	−700	−500	−300	−100	+100

Table 8.3: Schedule of data for calculating the plant payback period (with case example; data taken from the appendicized formsheet, table 10.l0) (Source: OEKOTOP)

Static calculation of profitability (data taken from table 10.10 in the Appendix)

Input parameters:
- average capital invested per time interval, KA

$$K_A = \frac{\text{initial investment}}{2} = \frac{I_O}{2}$$

- net profit, NP = annual return

- less the external capital servicing costs
- less the depreciation

Calculatory procedure: The profitability, or return on investment, ROI, is calculated according to the following formula

$$ROI = \frac{NP}{K_A} \cdot 100$$

The linear annual depreciation amounts to:

$$\frac{I_o}{\text{service life}}$$

The technical service life of a biogas plant generally amounts to 10-15 years. It is advisable to calculate twice, one for a pessimistic assumption (10-year service life) and once for an optimistic assumption (15-year service life). Similarly, the net profit should also be varied under pessimistic and optimistic assumptions.

Evaluation: The user can at least expect the biogas plant to yield a positive return on his invested capital. The actual interest should be in the range of locally achievable savings-account interest. Also, the results of profitability calculation can be used to compare the financial quality of two investment alternatives, but only if their respective service lives and investment volumes are sufficiently comparable.

Calculating the profitability using the appendicized data

Initial investment, Io = 1100

Average capital invested, KA =Io / 2 = 550
Annual returns = 200
Loan servicing costs = none (internal financing)
Depreciation for 10 year service life = 110(case 1)
Depreciation for 15 year service life = 73.3 (case 2)
Net profit, NP1, for case 1 = 90
Net profit, NP2, for case 2 = 126.7
Return on investment in case 1 = NP_1 /K_A = 16%
Return on investment in case 2 = NP_2 /KA = 23%

Thus, this sample calculation can be expected to show positive results regarding the achievable return on invested capital.

8.4 Use of complex dynamic methods

Dynamic methods of micro-economic analysis are applied to biogas plants primarily by:

- extension officers, for the purpose of checking, by a dynamic technique, their own results of static monetary analysis (cf. chapter 8.3), as already explained to the small farmers and other users of biogas plants

- banks, as a decision-making criteria in connection with the granting of loans

- operators of large-scale biogas plants, for whom the financial side of the investment is an important factor in the decision-making process.

Item / Period	0 19..	1 19..	2 19..	3 19..	...	10 19..
Investment expenditures	−1.100					
Returns		+200	−200	+300	..	+200
Discounting factor[1] (for i = 10%)		0.909	0.826	0.751	..	0.386
Present value		+182	+165	+150	..	+77
Cumulative value[2]	−1.100	−918	753	603	..	+129

[1] As taken from table 10.11 in the Appendix
[2] Simultaneously enabling dynamic payback calculation

Table 8.4: Schedule of data for net-present-value calculation (with case example, data taken from the appendicized formsheet, table 10.10; Source: OEKOTOP)

The importance of the dynamic methods lies in the fact that the results obtained using the simpler static methods of calculation described in chapter 8.3 can become problematic, if the point in time at which payments become due is of increasing importance. Any investor naturally will set a lower valuation to revenues that are due a decade from now than to those which are coming in at present. Consequently, he would want to compound past payments and discount future payments to obtain their respective present values.

Net-present-value method

The most commonly employed method of dynamic micro-economic analysis is the net-present-value method used by many extension officers. It enables evaluation of both the absolute and relative advantages of a biogas-plant investment (as compared to other investment alternatives) on the basis of the anticipated minimum interest rate above and beyond the net present value of the investment.

Simultaneously, the netpresent-value method also serves as a basis for calculating the dynamic payback period and for calculations based on the annuities method. (For details on the net-present-value and other dynamic methods of calculation, please refer to the aforementioned publication by Finck/Oelert.)

The inflation problem: Either the entire calculation is based on nominal incomes and expenditures, and market interest rates (= calculatory interest) are assumed, or the income and expenditures are presumed to remain constant, and the calculation is based on the real interest rate. The latter is calculated according to the following formulae (p = market rate of interest and a = rate of inflation):

$$i = \frac{100+p}{100+a} \cdot 100 - 100$$

Example: market rate of interest = 48%; rate of inflation = 34%

i = [(100 + 48)/(100 +34)]* 100-100=10.4%

Discounting factors: The compounding and discounting factors for the net-present-value method are shown in table 10.11 (Appendix) for interest rates of 1-30% and service lives of 1-15 years.
Calculatory procedure: The following information is drawn from the appendicized data survey: calculatory rate of interest, i (item 1.3); investment costs, I (item 2) and the returns (item 8). Much like the static mathematical models discussed in chapter 8.3, the calculatory procedures are again made more readily understandable by inserting the appropriate data from the formsheet (table 10.10, Appendix). In a real case, those data naturally would have to be replaced by the actual on-site data.

Results: The biogas plant can be regarded as profitable, if its net present value is found to be equal to or greater than zero for the minimum acceptable interest rate, e.g. i= 10%. The net present value is arrived at by cumulating the cash-flow value. Among several alternative investments, the one with the highest net present value should be chosen.

Sample calculation: For a plant service life of 10 years (conservative estimate), the cash flow values reflecting the annual returns times the discounting factor need to be determined and cumulated (cf. table 8.4). In this example, the net present value, at 129, would be positive, i.e. the potential investment would be worthwhile. The effects of discounting future income to its present value are substantial. For example, the return listed as 200 in item 10 would have a cash-flow value of 77 for a calculatory interest rate of 10°,to.

8.5 Qualitative evaluation by the user

Biogas plants have numerous direct and indirect advantages - and, under certain circumstances, disadvantages - that cannot be expressed in terms of money, but which can be very important for the user. Even when a biogas plant is not financially profitable, meaning that it costs the user more than it yields, it can still have such a high socioeconomic value as to warrant its installation. Table 8.5 lists the essential socioeconomic biogas-plant evaluation factors, including plus, neutral and minus symbols to allow individual-aspect evaluation.

Table 8.5: Socioeconomic benefits and drawbacks of biogas production and utilization (Source: OEKOTOP)

Benefits	Possible drawbacks	

Benefits	Possible drawbacks	
Assured, regular supply of energy rating: + o -	Direct handling of feces rating: + o -	
Improved hygienic conditions through	Limited communication potential, e.g. no	
better disposal of feces, no smoky cooking fires, less nuisance from flies rating: + o -	more gathering of wood together rating: + o -	
General improvement of the agricultural production conditions, e.g. better live stock hygine/care, improved soil structure		
rating: + o -		
Upgrading of women's work		
rating: + o -		
Better lighting		
rating: + o -		
Higher prestige		
rating: + o -		
+ applicable	o possibly applicable	- not applicable

8.6 Macro-economic analysis and evaluation

The main quantifiable macro-economic benefits are:

- national energy savings, primarily in the form of wood and charcoal, with the latter being valued at market prices or at the cost of reforestation

- reduced use of chemical fertilizers produced within the country.

Additionally, foreign currency may be saved due to reduced import of energy and chemical fertilizers.

Macro-economic costs incurred in local currency for the construction and operation of biogas plants include expenditures for wages and building materials, subsidy payments to the plant users, the establishment of biogas extension services, etc. Currency drain ensues due to importing of gas appliances, fittings, gaskets, paints, etc.

In addition to such quantifiable aspects, there are also qualitative socioeconomic factors that gain relevance at the macroeconomic level:

- autonomous decentralized energy supply
- additional demand for craftsmen's products (= more jobs)
- training effects from exposure to biogas technology
- improved health & hygienic conditions, etc.

Considering the present extent of biogas-plant diffusion, such effects should be viewed realistically, i.e. not overvalued. While a substantial number of biogas plants may be installed in one or more regions of a given developing country, they cannot be expected to have much impact at the national level. At the regional and

local levels, however, the multipartite effects described in this subsection are definitly noticeable.

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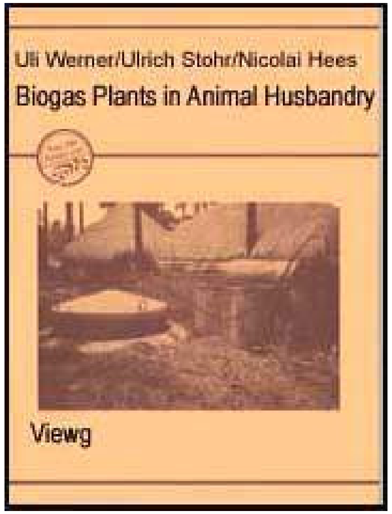

Biogas plants in Animal Husbandry (GTZ, 1989, 153 p.)

9. Social acceptance and dissemination

In many cases, the successful commissioning of a few biogas plants generates a keen demand for more plants among local farmers and other interested parties. Consequently, the responsible extension officer often sees himself confronted with the prospect of planning and building more plants. However, before any decision is made in favor of launching a biogas extension program, the extension officer should make an additional detailed analysis of all positive and negative information concerning experience to date with the plants that have already been built. Only if the results so indicate, should he decide to engage in further building and dissemination activities.

9.1 Determining factors of acceptance for biogas plants

On the whole, the question of acceptance covers all aspects of biogas technology discussed in this book (agriculture, engineering/ construction, operation and maintenance, economic viability). In order to avoid redundancy, this chapter is therefore limited to a discussion of general aspects that have not yet been accounted for.

Biogas extension efforts should include special consideration of the role played by women, since it is they and their children who perform much of the important work needed to keep a biogas plant running. This includes tending cattle, collecting substrate, fetching water, operating gas appliances, cooking, spreading digested slurry, etc. In many cultures, however, they are by tradition hardly directly involved in the process of decision making, e.g. the decision "biogas plant: yes/no and how". Nor are they often allowed for in connection with external project planning. In other regions, though, e.g. many parts of West Africa, women are economically independent of their husbands, i.e. they have their own fields, animals and farm-produce marketing channels.

Extension officers charged with planning and building biogas plants often have little or no awareness of the specific local and regional social conventions. Thus, the promotion of participation, the articulation of user interests, and the

involvement of local extension workers are all very important for doing them at least some degree of justice.

In general, a general willingness to accept the construction and operation of biogas plants can be expected and/or can be increased by:

Planning/project organization
- involving the users, especially the women, in all decisions concerning "their" biogas plant
- coordinating all essential program measures with target group representatives
- keeping the user/target group informed
- establishing trustworthy, reliable implementing agency;

Sociocultural
- existing willingness to handle feces and gas
- identicality of users (beneficiaries) and operators of the respective biogas plants
- positive image of biogas technology, or image polishing through biogas plants;

Engineering/construction
- well-functioning, durable and good-looking plants from the very start
- availability of well-functioning, inexpensive, modern gas appliances (burners, lamps, refrigerators, etc.)
- user friendliness of plants and appliances
- guaranteed supply of materials and spare parts and assured repair and maintenance;

Agriculture

- stabling practice or tendency toward such practice
- effective time savings, e.g. by direct connection of the biogas plant to the barn
- willingness to use digested slurry as fertilizer, knowledge of storage and spreading techniques, and appreciation of the positive effects of fertilizing
- availability of suitable, inexpensive slurry spreading implements;

Economy
- reasonable expense in terms of money and work involved (as viewed from the user's standpoint)
- real and, for the user, obviously positive cost-bereft ratio (not necessarily just in terms of money)
- favorable financing(loans,subsidies),

Household advantages
- improved working conditions in the kitchen (less smoke and flies, better appearance, modernization)
- introduction or improvement of artificial lighting
- effective workload reduction
- complete, reliable supply of energy through biogas.

It is very important that the biogas extension officer seek intensive contact with the potential plant users and local decision makers in order to maximize the chance of early detection of any deficits regarding the acceptance of biogas technology in order to promptly modify and improve the project strategy as necessary.

9.2 Dissemination strategies

Ideally, there are two basic strategies for disseminating family-size biogas plants (cf. table 9.1). The original "classic" approach to biogas dissemination - the self-helporiented approach - has in many regions now taken a backseat to the newer professional-artisan approach. While the "do-it your self 7' approach has the advantage of reaching target groups with relatively little capital and of being applicable in regions with a few or more scattered biogas plants, recent project experience has shown that the professional-artisan strategy leads to a faster and numerically more substantial process of dissemination (once the artisans have been adequately familiarized with the work involved) and that it does more to promote self-supporting local structures.

Since biogas technology is still regarded as "something new" in most developing regions - even though some pilot plants may already be in operation - the extension officer must very carefully study the regional preconditions for a successful approach to biogas dissemination. This involves getting answers to the following questions:

- What kind of infrastructure does the region have in the way of roads, highways, means of transportation, etc.? The biogas dissemination concept and its timetable must be designed to conform to the given situation.

- How much of the required material is locally available? How much locally unavailable material can be imported without difficulty? Naturally, as much locally available material as possible should be used for building, maintaining and repairing the plants.

Table 9.1: Biogas dissemination strategies (ideal case) (Source: OEKOTOP)

A. Professional-artisan approach	**B. Self-help-oriented approach**
Dissemination of "turnkey" biogas plants, primarily through professional artisans	Motivated, interested users do part of the construction work
Preconditions:	Preconditions:
Adequate capital on the part of the owners/users	Willingness to contribute own efforts (building, main tenance, etc.)
Motivated, qualifiable artisans	User training is highly relevant
High plant density with good income prospects for the artisans	Government or development aid assumes part of the cost for low-income users
Good supply of materials to the artisans, possibly through cooperation between the statal and private sectors; statal sector functions as source of know-how	Well-organized biogas project with adequate presence (despite low plant density) for giving advice, helping to build the plants, and offering technical solutions for a wide diversity of task situations
Measures:	Measures:
Offering a complete biogas plant, i.e. a standardized, tested type of plant of a size adequate to the needs of the user, including gas appliances	Offering both standard-type systems and solutions for special problems; reaching out to remote areas
Repair and supply of spare parts by and through local artisans	The project provides the plant elements that can't be built by the users themselves
Qualification of local artisans for planning, building and repairing	In addition to local artisans, the users themselves are given training in building, repair and

standardized biogas plants	maintenance
Cost reduction through standardization	The project secures locally unavailable materials
	Provision of assistance to the user in the form of subsidies/loans

Table 9.2: Innovation cycle of biogas dissemination (Source: OEKOTOP)

Regional studies/target groups (ethnological, socioeconomic)

Market analysis (biomass potential, energy demand, purchasing power, market potential, prior state of development, biogas technique, suppliers)

Analysis of implementation (general make-up and organizational structure, finances, personnel qualifications, relation to target group(s)/regional anchorage, political weight)

Formulation of concept

R & D phase, development and adaptation of suitable type of plants to accommodate different areas of service

Installation and operation of pilot plants

Establishment of local partners (artisans, self-help organizations)

Familiarization and training of users, artisans, engineers/planners, advisors, financing institutions, political decision-makers, Media/means: workshops, on-

the-job training, handbills, manuals, demonstration models, pictorial material, radio, television

Continuous improvement and sophistication of solutions found (technology, dissemination strategy, organization)

- Are enough adequately qualified and motivated extension workers and craftsmen readily availabe?

- Is there an implementing agency with adequate performance potential and access to the future plant users, thus providing a basis for mutual-thrust cooperation?

Ascertainment of the extent to which the above preconditions are either being met already or could be satisfied through appropriate measures is part of the "biogas innovation cycle" outlined in table 9.2.

9.3 Implementing agencies

As a rule, biogas programs are implemented by national, state or parastatal institutions. As detailed in chapter 9.4, construction is done by artisans.

In selecting a implementing agency, it is advisable to consider the criteria listed in table 9.3 as a basis for evaluating the qualifications of the implementing agency. This catalogue can be used to examine existing project partners for real or potential shortcomings with regard to biogas-related task accomplishments with a view to helping them reorganize in order to better handle the job at hand.

Table 9.3: Catalogue of attributes for partners in biogas dissemination projects (Source: OEKOTOP)

Legal form/institutional category (ministry, bank, research institute, rural development institution, etc.)

Work scopes/specialties
- experience with biogas and other renewable energy systems
- experience in rural development

Institutional action principle (break-even operation, maximization of profits, heavy dependence on subsidies)

Managerial organization
- organizational structure (entrenched hierarchy? teamwork? codetermination?)
- classification and-institutional significance of the biogas program within the executing organization
- institutional flexibility

Staff endowment for the biogas project - number and qualifications (special emphasis on agricultural engineers, farmers, technicians, social economists, masons and plumbers, office workers/administrators) - training offered or possible - wage and salary structure - fluctuation, migration

Sundry institutional appointments
- office space, vehicles, telephone, teletex, workshops
- financial endowment of the biogas project (for personnel, transportation, materials and spare parts, public relation

activities, etc.)
- potential for providing complementary services in connection with biogas (financing, technical and socioeconomic consultancy, maintenance & repair services, etc.)

Interest in the biogas project
- own commercial interest in biogas
- connection with and proximity to the target group and/or to artisans, probability of target group participation
- chances of implementing a national or regional biogas extension program
- domestic importance/prevailing power

Table 9.4: Institutional breakdown of biogas-dissemination tasks and activities (applies in particular to the professional-artisan approach discussed in chapter 9.2) (Source: OEKOTOP)

Task/Activity	Local artisans	Users	Proj.-executing organization
Biogas-program planning; R&D (appropriate gas applicances and equipment); dissemination strategy concept	participation	participation	respponsibility
Individual-plant planning, possibly including the development of standardized plant components	responsibility	participation	respponsibility
Provision to users of info and advice	responsibility	-	suppport

Financing	-	own capital	loans/subsidies
Plant construction:			
- digester excavation	implementation	assistance	plannning
- masonry and metalwork	implementation	assistance	plannning
- installation of gas pipes and appliances	implementation	assistance	plannning
- adaptation of animal housing	implementation	assistance	plannning
Procurement of materials and appliances	local materials	-	imported/rationed goods
Commissioning/operational advice	responsibility; plant-specific	recipients	suppport; agricultural extension services
Maintenance	support	implementation	-
Repair	implementation	assistance	assistance
Artisan training	recipients	-	implementation
Establishment and development of purchasing and marketing channels for biogas artisans	need promotion	-	responsibility
Establishment of a legal framework, e.g. war			
ranties, liabilities, etc.	-	-	respponsibility

9.4 Artisan involvement

From past experience with inefficient public sponsors and their distance to small-farm target groups, many biogas projects strive to coordinate the activities of private businesses and govermental project organisations through:

- local-scale biogas dissemination work by involving local artisans through personal~ initiative and customer orientation

- securing the political and organizational framework through regional/supraregional state/parastate sponsors.

The main objective of providing assistance to artisans in connection with biogas projects is to build up self-supporting local structures and promote the formation of regional business cycles with the appropriate effects on technological innovation, employment and income. An efficient form of biogas dissemination, i.e. one based on a good cost/ benefit ratio, is envisaged.

Nonetheless, the following points should be heeded when trying to get local artisans involved in the process of biogas dissemination:

- How many qualified craftsmen (masons, welders, plumbers, etc.) are available for work on the project and/or in the villages? To the extent possible, the biogas extension officer should rely on artisans who live and work within the project area.

- How much interest do the artisans have in the project, and how well-motivated are they? What are their expectations regarding income? What is the least number

of plants that have to be built in order to guarantee a craftsman a full income or at least a satisfactory sideline income?

- How many and what kind of tools and implements do the artisans have and need? How can the lacking equipment be financed?

Important workscopes for artisans

Depending on the local situation, the artisans' workscopes and competences can vary substantially from place to place. Still, a general breakdown of task scopes can be drawn up for the local craftsmen, the biogas project, the official implementing agency and the user when it comes to planning and operating a biogas plant (cf. table 9.4). The biogas artisans are generally responsible for the following tasks:

- detailed planning of plants for individual sites (presupposing the availability of standardized or modular plant components that are adequate for the situation and can be installed with no substantial degree of modification at any suitable site)

- providing advisory services and information to the users

- all work in connection with building and starting the plant, from the digester excavation to the masonry and plumbing - for which the requisite tools and materials must be procured

- any necessary maintenance and repair work.

Both the quality standards for the work to be done and the success of the biogas

dissemination efforts are heavily dependent on the presence of qualified craftsmen, particularly masons, in the project region.

9.5 Training

The training measures address different target groups, each with their own specific training contents and methods (cf. table 9.5):

- the engineers and extension officers, who are to do the planning and assume advisory duties

- the artisans, who are to build the plants and keep them in repair

- the owners, who require qualification for operating the plants efficiently and,possibly, know-how for performing at least some of the building, maintenance and repair work on their own.

The following items require consideration in connection with biogas training measures:

- Training courses and training material must be held/written in the national or regional language.

- The training material must correspond to the specific targetgroup situation, e.g. experience has been good with loose-leaf material that can be compiled and revised as necessary to fit the needs of each particular target group.

- The demonstration models must agree with the types of plant actually proposed,

i.e. do not dry to explain the abstract principle of an oil-drum model or put a fixed-dome on display, when floating-drum plants are supposed to be installed.

- A great deal of practical training must be provided. Positive experience has been made with integrated workshops in which theoretical training is combined with hands-on experience in the construction of a real plant.

- Women must be included in the training measures.

Supraregional workshops, even going beyond the country's borders (allowing the exchange of experience from country to country) are a worthwhile training device for engineers, extension officers and, to some extent, artisans. Training/attendance certificates are recommended as a means of developing training standards and motivating trainees to participate in the courses offered.

Table 9.5: Target-group-oriented biogas training measures (Source: OEKOTOP)

Target group	Training elements	Contents	Duration	Instructor
Engineers, local extension officers	Seminars and field trips, national workshops, supra-regional conferences serving to effect technology transfer	Function of various types of biogas plants and peripheral equipment, use of digested slurry, maintenance and repair problems, macro- and microeconomic analysis/evaluation, project management	several blocks of approx. 1 week each	biogas experts, agricultural experts, social economists

Artisans	Integrated workshops with theoretical + practical training, incl. On- the-job training (OJT)	Function of selected types of plants, design and construction per drawing, use of local materials, maintenance & repair	workshops lasting several days, participation in plant construction	engineers, experienced artisans
Users	Field trips to operable plants, participation in workshops On-the-spot training (own plant)	Function of selected types of plants, operation and optimal use, fertilizing with digested slurry, maintenance & repair	2-3 days, regular on-site back-stopping	local biogas/ agricultural extension workers
Women	On-the-spot training (own plant), local evening courses	Plant function, operation and optimal use, working with biogas cookers	continuous familiarization (women!)	local biogas extension workers

9.6 Financing

Small farmers in particular rarely have the DM 1000 - 2500 or more it takes to cover the cost of a biogas plant. Consequently, "mixed-financing models" with the three elements own capital/contribution, subsidy and loan must be available.

Own capital/contribution

While a potential user may not be able to fully finance a biogas plant by himself,

he must be expected to carry at least 30 - 40% of the initial outlay, possibly in the form of contributed work like digester excavation, procuring building materials, etc.

Subsidies

The economic benefits of a biogas plant can be quite modest, e.g. when it serves as a substitute for wood that can be gathered for free. The overall benefits, however, including such environmental factors as the protection of forests, can be very substantial. Consequently, the user of the plant should be eligible for subsidies to make up the difference. Such subsidies may consist of:

- contributions to the cost of construction in the form of needed materials (metal gasholder, cement, fittings, etc.), such frequently scarce goods and materials also including those needed for repairs and replacements, e.g. rustproofing for the gasholder,

- free planning and consulting

- assumption of interest debt on loans.

On the whole, however, subsidies have the following drawbacks:

- Market prices can become distorted, and needed capital can be falsely invested.

- Subsidies intended explicitly for the needy may end up in the hands of well-todo groups.

In addition, prior project experience has shown that user motivation is frequently lower in the case of heavily subsidized plants than in the case of plants that have been evaluated and built on a commercial basis.

Loans

The monetary returns from a biogas plant, particularly those from a small family-size one, are often meagre in comparison to the cost of investment. In other words, the plant hardly pays for itself in terms of real income. Additionally, since most small farmers have no access to commercial loans, but should not be expected to accept an excessive risk of indebtedness, it can be quite difficult to arrange biogas-plant credit financing for that group of users. The following conditional factors therefore should be investigated prior to setting up any particular credit program:

- first, check out all other funding alternatives, e.g. owned capital;

- then, conduct a detailed socioeconomic analysis of the target group and farms, e.g. which farm can afford how much debt burden?;

- next, clarify the institutional tie-in, i.e. involvement of rural development banks or credit unions;

- and, lastly, establish the program quality, e.g. isolated or integrated credit programs, the latter including technical and economic extension services, training, plant maintenance and repair.

If the appraisal shows that there is available within the region a credit program

that is open to the financing of biogas plants and would offer favorable conditions, e.g. a soft-loan program, then the biogas program should rely on it. Establishing an independent credit program without the assistance of an experienced institution is usually so complicated as to overtax an individual project.

A pragmatic loan-tendering model could be designed along the following lines:

- Development-aid funds are put in a time-deposit account at a rural development bank. The bank agrees to provide loans amounting to several times the deposited amount for the purpose of financing biogas plants.

- The loans are not given directly to the beneficiary (plant owners), but channeled through a biogas extension office.

- The office does not issue the loans in cash, but in the form of materials (cement, metal gasholders, etc.).

- The material is issued on the basis of construction progress.

- Repayment of the loans is supervised by the biogas extension office with the assistance of the aforementioned rural development bank.

- A loan guarantee fund into which, say, 10% of each granted loan is fed helps out in case of loan arrears.

This model involves the following risks:

- The biogas extension office may be overburdened by the task of investigating

creditability, granting loans and helping to monitor repayment of the loans.

- The guarantee fund could dry up due to default on the part of the beneficiaries, or because the loans were not properly calculated on a break-even basis (inflation, inadequate interest).

Such problems can be overcome in the medium-to-long term by establishing credit unions. That process, though, demands lots of experience and can normally be expected to by far surpass the project terms. Credit unions backed by the plant owners could gradually replace the development-aid part of the lending program. Also, the credit unions could assume responsibility for the aforementioned loan guarantee fund, thus gaining a say in the control of repayment. In most cases, that would improve the lending program's reflux quota while helping to establish rural self-help organizations - a goal that should be viewed as an implicit element of any biogas program.

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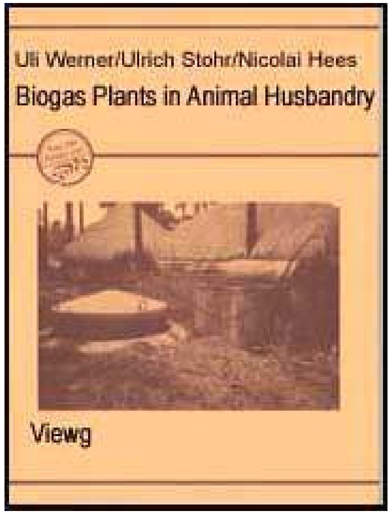


Biogas plants in Animal Husbandry (GTZ, 1989, 153 p.)

10. Appendix

10.1 Design calculations and drawings

10.1.1 Floating-drum plants

Design calculation

Sizing factors	Example
Daily substrate input, Sd	= 115 l/d
Retention time, RT	= 70 days
Daily gas production, G	= 2.5 m^3/d

Storage capacity,Cs	= 60%
Digester volume, Vd	= 8 m³
Gasholder volume, Vg	= 1.5 m³

Calculating formulae after Sasse, 1984

1. Vg = Cs • G

2. ha = design-dependent

3. Vg= r • p • h

4. rg = $\sqrt{Vg/(\pi \cdot h)}$

5. rd = r + 0.03

6. Vd1 = p • d^2 • p • h

7. Vd2 = R^3 • p • 2/3

8. R = $\sqrt[3]{Vd2/(\pi \cdot 2/3)}$

9. Vd3 = R^2 • p • H/3

10. H = R/5

11. Vd3 = R3 • p • 1/15

12. Vd2 : Vd3 = 10 : 1

13. Vd(2+3) = 1.1 Vd2

14. Vd(2+3) = Vd - Vd1

15. hd = hg

16. hdk = hd + structurally dependent free board (0.1 . . . 0.2 m)

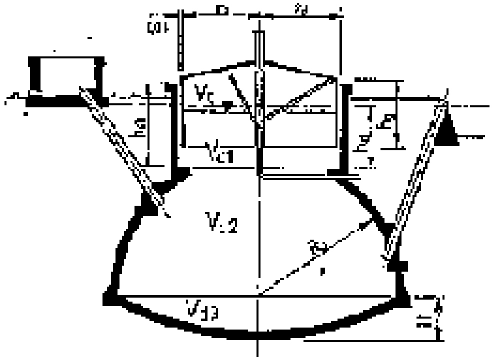


Fig. 10.1: Conceptual drawing of a floating-drum biogas plant

Vd = Vdl +Vd2 +Vd3
= digester volume
Vg = gasholder volume
Index g = gas holder
Index d = digester

Sample calculation	**Results**
1. Vg = 0.6 • 2.5	= 1.5 m³
hg = (specified)	= 0.7 m
4. r = $\sqrt{1.5 / 3.14 \cdot 0.7}$	= 0.82 m
5. r = 0.85 (chosen)	
6. Vdl = 0.852 •3.14 • 0.7	= 1.58 m³
14. Vd (2+3) = 8.45 - 1.58	= 6.87 m³
8+ 14. R = $\sqrt[3]{6.87 / (1.1 \cdot 3.14 \cdot 2/3)}$	= 1.45 m

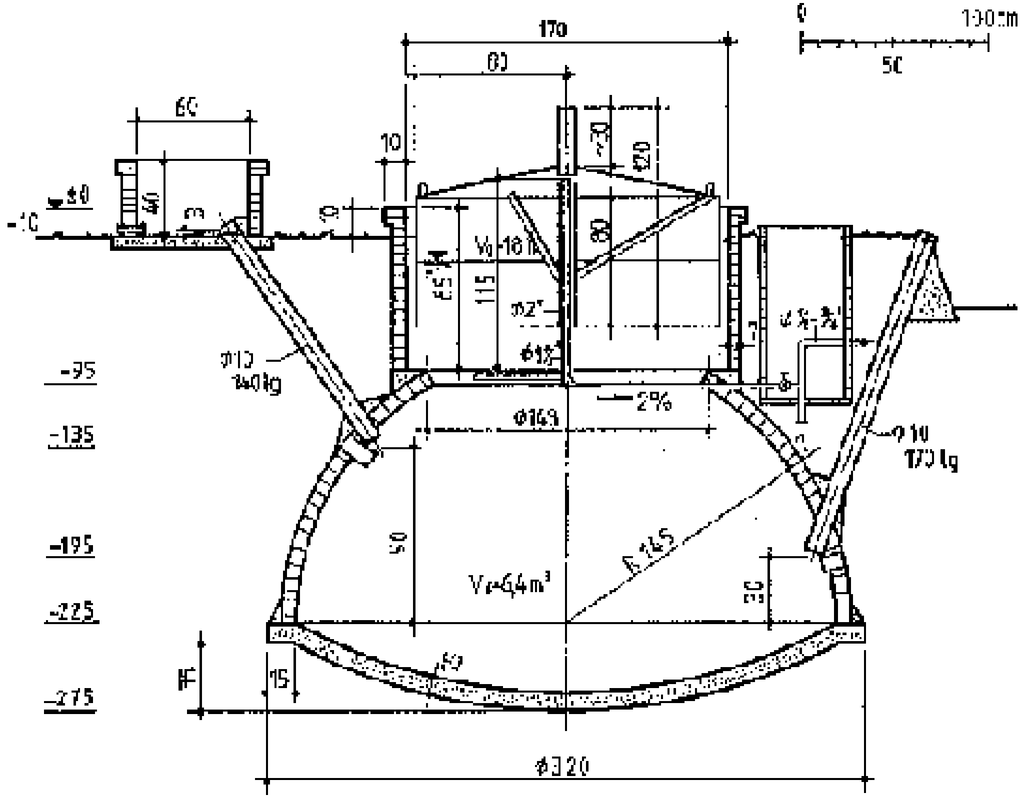


Fig. 10.2: Constructional drawing of a floating-drum plant. Vd = 6.4 m³, Vg = 1.8 m³. Material requirements: Excavation 16.0 m³, Foundation 1.6 m³, Masonry 1.1 m³, Rendered area 18.0 m², Sheet steel 5.7 m². (Source: OEKOTOP, Sasse)

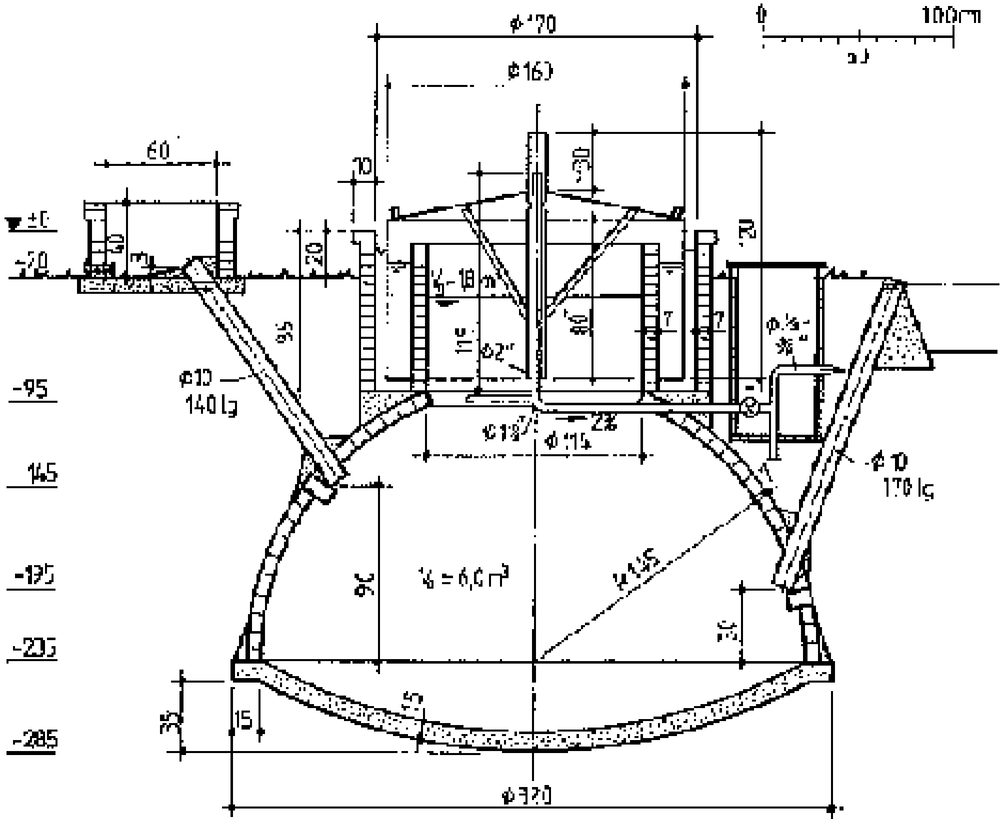


Fig. 10.3: Constructional drawing of a water-jacket plant. Vd = 6.0 m³, Vg = 1.8 m³. Material requirements: Excavation 16.0 m³, Foundation 1.6 m³, Masonry 1.6 m³, Rendered area 21 m², Sheet steel 5.7 m². (Source: OEKOTOP, Sasse)

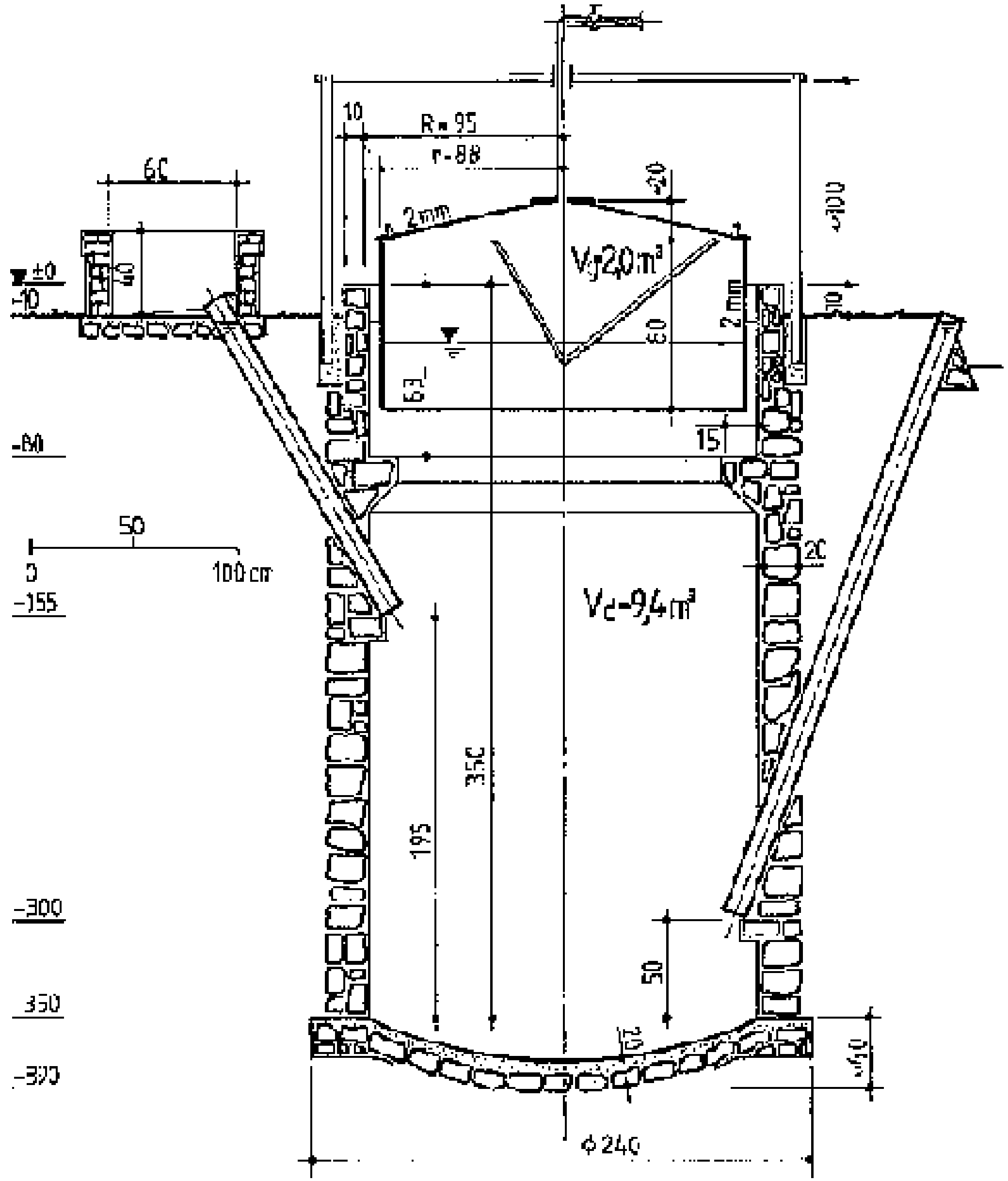


Fig. 10.4: Constructional drawing of a cylindrical floating-drum plant for quarrystone masonry. Vd = 9.4 m³, Vg = 2.5 m³. Material requirements: Excavation 21.0 m³, Foundation 1.0 m³, Masonry 5.4 m³, Rendered area 27.3 m², Sheet steel 6.4 m². (Source: OEKOTOP, KVIC)

10.1.2 Fixed dome plants

Design calculation

Sizing factors	Example	Sample calculation
Daily substrate input, Sd	= 115 l/d	R = $(0.76 \bullet 8)^{1/3}$= 1.85 m
Retention time,RT	= 70 days	r = 0.52 R= 0.96 m
Daily gas production, G	= 2.5 m^3/d	h = 0.40 R= 0.72 m
Storage capacity, Cs	= 60%	p = 0.62 R= 1.14 m
Digester volume, Vd	= 8 m^3	
Gasholder volume, Vg=G•Cs	= 1.5 m^3	
Vd : Vg	= 5.3 : 1	

Tab. 10.1: Calculating parameters for fixed-dome biogas plant (Source: Sasse 1984.OEKOTOP)

Vg : Vd	1:5	1:6	1:8
R	$(0.76 \bullet Vd)^{1/3}$	$(0.74 \bullet Vd)^{1/3}$	$(0.72 \bullet Vd)^{1/3}$
r	0.52 R	0.49 R	0.45 R
h	0.40 R	0.37 R	0.32 R
p	0.62 R	0.59 R	0.50 R

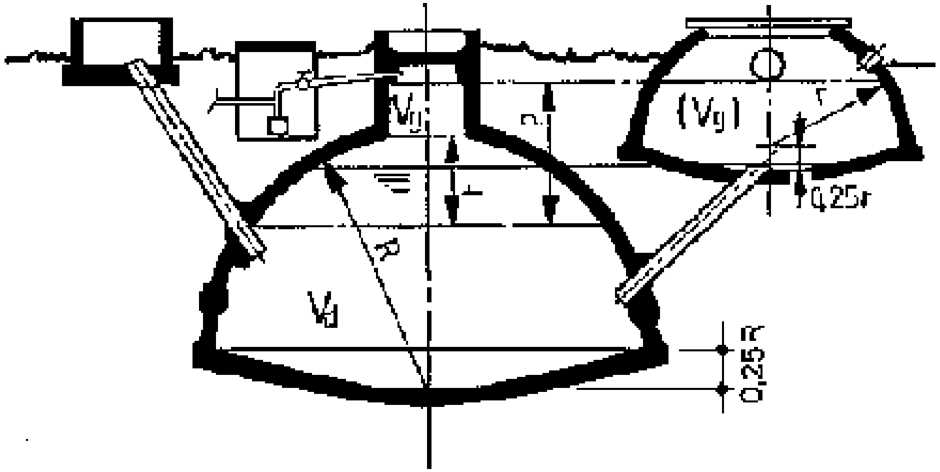


Fig. 10.5: Conceptual drawing of fixed-dome biogas plant. Vg gasholder volume, Vd digester volume. (Source: OEKOTOP, Sasse)

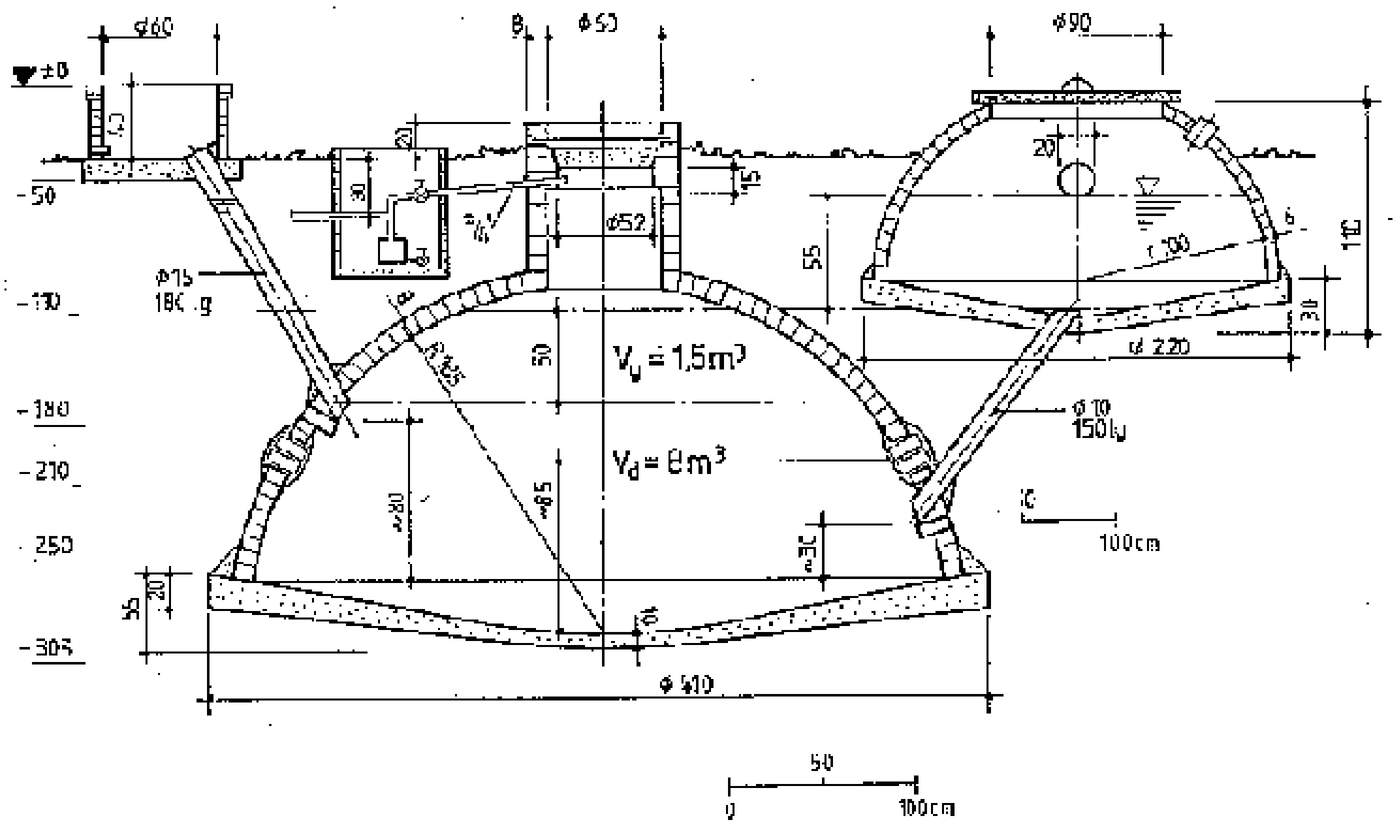


Fig. 10.6: Constructional drawing of a fixed-dome plant. Vd = 8 m³, V = 1.5 m³. Material requirements: Excavation 25 m³, Foundation 2.2 m³, Masonry 2.0 m³, Rendered area 22.0 m², Sealed area 7.0 m². (Source: OEKOTOP, Sasse, BEP Tanzania)

10.1.3 Earth pit with plastic-sheet gasholder

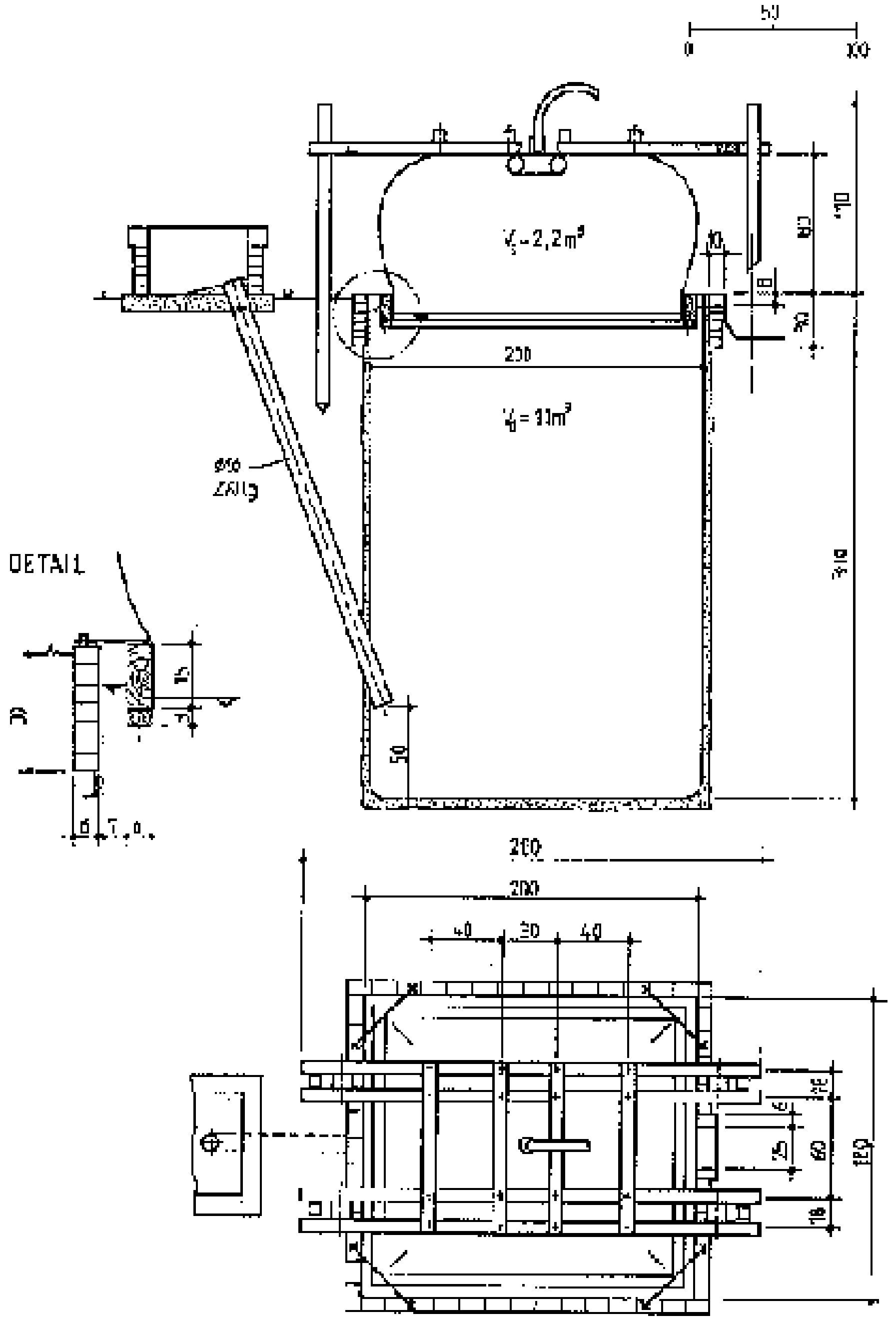


Fig. 10.7: Constructional drawing of an earth-pit biogas plant with plastic-sheet

gasholder. Vd = 11 m³, Vg = 2.2 m³. Material requirements: Excavation 16 m, Rendered area 28 m², Sheeted area 10 m² (Source: OEKOTOP)

10.1.4 Estimating the earth-pressure and hydraulic forces

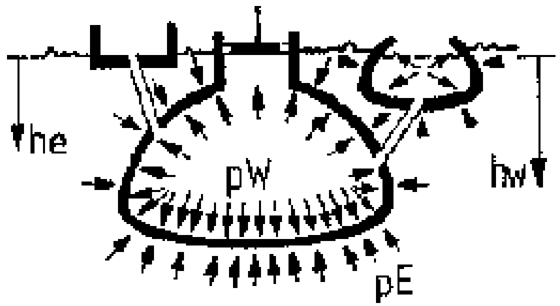


Fig. 10.8: Schematic diagram of earth-pressure and water-pressure forces

In-depth forces, h (e, w)

pW = wW • hw
pW = hydrostatic pressure at depth hw (m) wW = specific weight of water
= 1000 kp/m³ pW = 1000 • h (kp/m²)
pE = wE • ce • he
pE = active earth pressure, i.e. force of pressure of dry, previously loose but now compact column of earth on a solid vertical wall
wE = specific weight of dry backfill earth
= 1800 . . . 2 100 kp/m³
he = height of earth column (m)
ce = coefficient of earth pressure for the earth column in question
= 0.3 . . . 0.4 (-)
pE = (600 . . . 700) • h (kp/m²)

Force acting on a surface

P(E, W) = p • A (kp = (kp/m²) • m²)

Note: The above formulae are simplified and intended only for purposes of rough estimation.

10.2 Gas-law calculations

10.2.1 Calculating the pressure drop in a gas pipe

dp = FL + Ztot
dp = pressure drop (N/m^2)
FL = friction losses in the gas pipe (N/m^2)
Ztot = sum total of friction losses from valves, fittings, etc. (N/m^2)
dp = cp l/D • D/2 v2
+ (cfl D/2 • v2 + . . . + cfn • D/2 • v2)
(approximation formula)
cp = coefficient of pipe friction (-)
l = length of pipe section (m)
D = pipe diameter(m)
g = density of biogas (1.2 kg/m^3)
v = velocity of gas in the pipe (m/s)
cf = friction coefficients of valve, fittings, etc.
Q = v • A

Q = gas flow (m^3/s)
v = velocity of gas in the pipe (m/s)
A = p r^2 = cross-sectional area of pipe

The coefficient of pipe friction (cp = non. dimensional) is a function of:
- the pipe material and internal surface roughness
- pipe diameter
- flow parameter (Reynolds number)

For pipe diameters in the 1/2" . . . 1" range, the coefficients of friction read:
PVC tubes approx. 0.03
steel pipes approx. 0.04

Some individual friction-loss factors (cf; nondimensional)

elbow	0.5	valve 3.0
constriction	0.02-0.1	water trap 3 - 5
branch	0.8-2.0	

10.2.2 Calculating gas parameters

Temperature-dependent change of volume and density

D = DN • P • TN / (PN • T)
V = VN • PN • T / (P • TN)

where:
D = density of biogas (g/l)
DN = density under s.t.p. conditions (0 °C, 1013 mbar)
V = volume of biogas (m³)
VN = volume of biogas under s.t.p. conditions
P = absolute pressure of biogas (mbar)
PN = pressure under s.t.p. conditions (1013 mbar)
T = absolute temperature of biogas (measured in ºKelvin = ºC + 273)
TN= temperature under s.t.p. conditions (0 0ºC = 273 °K)

Table 10.2: Atmospheric pressure as a function of elevation (Source: Recknagel/Sprenger, 1982)

Elevation (km)	0	0.5	1.0	2	3	4	6	8
Atm.pressure (mbar)	1013	955	899	795	701	616	472	365

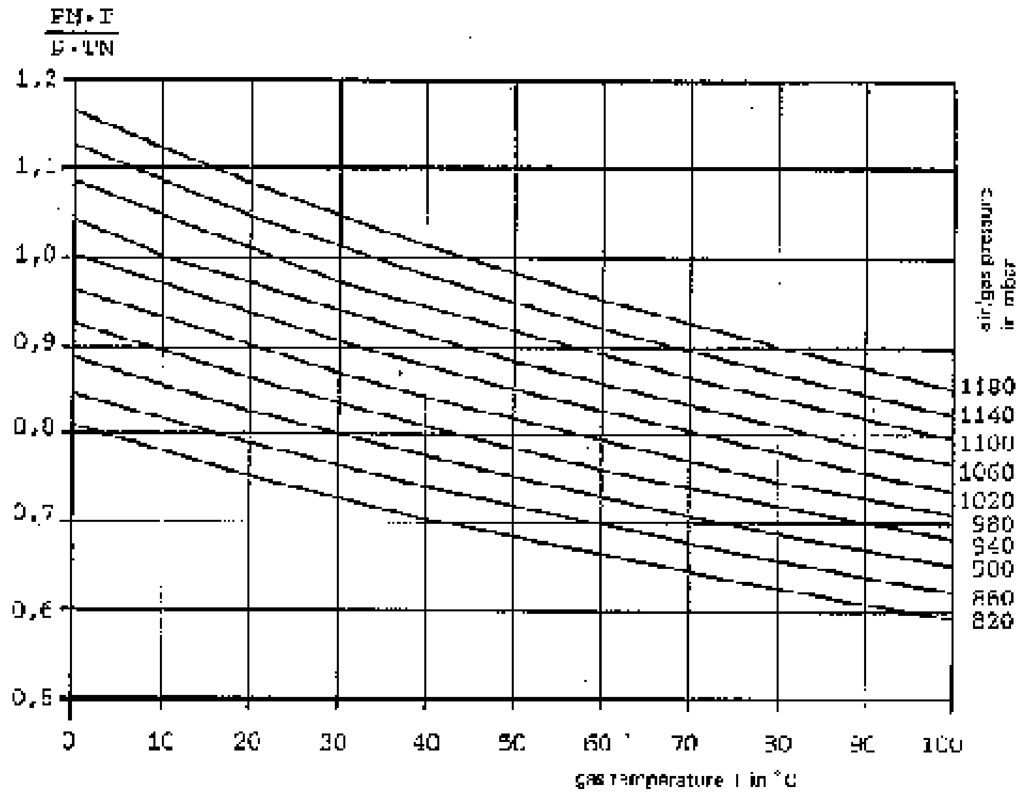


Fig. 10.9: Nomogram for correcting gas pressures/temperatures (Source: OEKOTOP)

Determining the calorific value

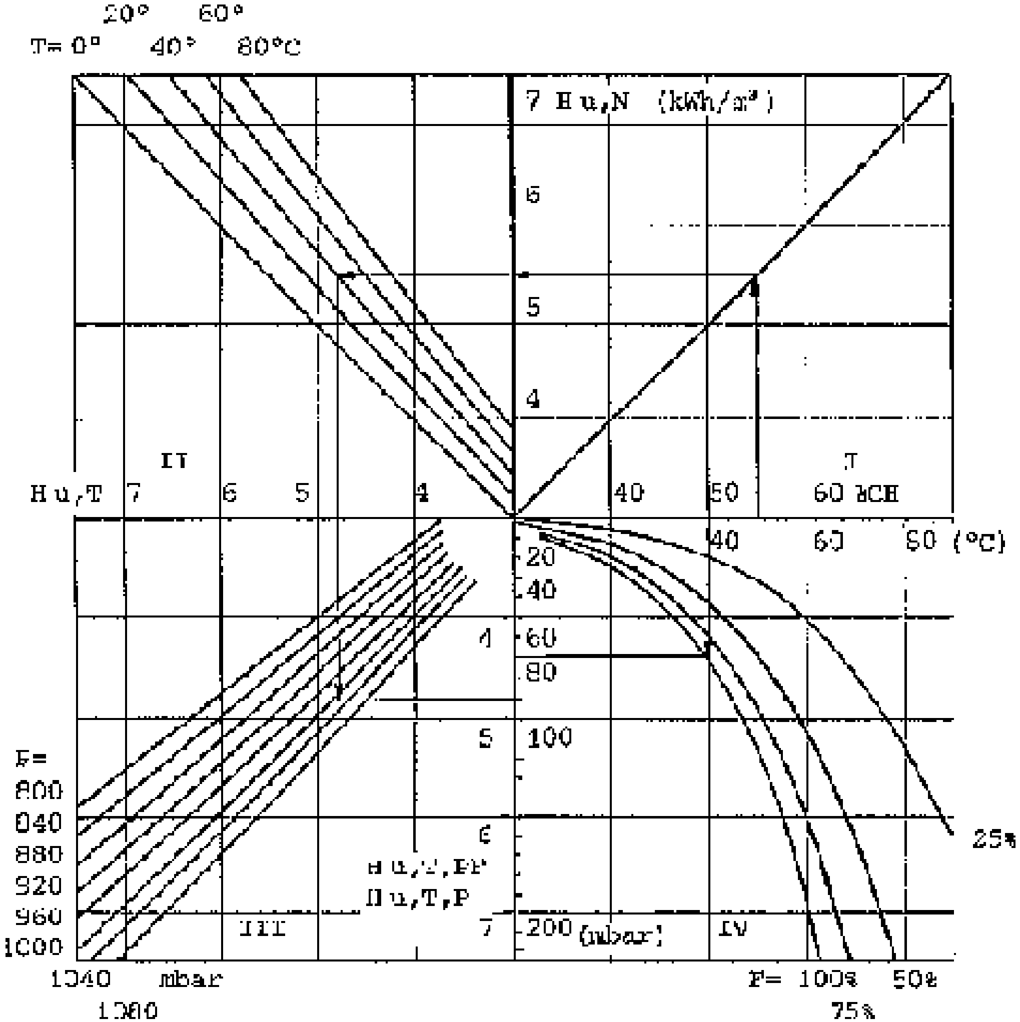


Fig. 10.10: Nomogram for finding the net calorific value of biogas as a function of temperature, pressure and moisture content. T gas temperature (°C), F relative dampness of biogas (%), Hu, N net calorific value (n.c.v.) of biogas under s.t.p. conditions (0 °C, 1013 mbar), Hu, T net calorific value (n.c.v.) at gas temperature, P gas pressure (mbar), Hu, T, P net calorific value (n.c.v.) at gas temperature and pressure, PW partial pressure of water vapor, Hu, T, PF net calorific value (n.c.v.) of biogas at gas temperature, corrected to reflect the water-vapor fraction

(Source: OEKOTOP)

Using the nomogram

1. Quadrant I: Determine the net calorific value under standard conditions as a function of the CH_4-fraction of the biogas

2. Quadrant II: Determine the net calorific value for a given gas temperature

3. Quadrant III: Determine the net calorific value as a function of absolute gas pressure (P)

4. Quadrant IV: Interim calculation for determining the partial water-vapor pressure as a function of gas temperature and relative dampness. This yields the gas pressure (PF) = absolute pressure (P) - partial pressure of water vapor (PW); PF = P - PW. The expanded calorific value determination with account for the moisture content occurs via quadrant III.

Sample calculation

Given:	
Biogas	55 vol. % CH4
Gas temperature	T = 40 °C
Gas dampness	F = 100%
Gas pressure	P = 1030 mbar

Results:		

Results:		
Hu, N	= f (CH4-vol. 70)	Quadrant I
	= 5.5 kWh/m³	
Hu,T	= f(T)	QuadrantII
	= 4.8 kWh/m³	
Hu,T,P	= f(T, P)	Quadrant III
	= 4.6 kWh/m³	
PF	= f(P, T)	Quadrant IV
- f(PW)	Quadrant III	
	Hu, T, PF = 4.3 kWh/m³	

Table 10.3: Partial pressure of water vapor, PW, and absolute humidity, GM, at the saturation point (Source: Recknagel / Sprenger, 1982)

T (°C)	PW (mbar)	GM (g/m³)
.0	6.1	4.9
10	12.3	9.4
20	23.4	17.3
30	42.4	30.4
40	73.7	51.2
50	123.3	83.0
60	199.2	130.2

70	311.6	198.2
80	473.6	293.3
90	701.1	423.5
100	1013.3	597.7

10.3 Conversion tables

Table 10.4: SI units of calculation (selection) (Source: OEKOTOP, compiled from various sources)

Quantity	Symbol	Unit	Conversion
Length	1	m	1 m = 10 dm = 100 cm = 1000 mm
Area	A	m^3	1 m^3 = 100 dm^3 = 10000 cm^3
Volume	V	m^3	1 m^3 = 1000 dm^3 = 1 mill. cm^3
Mass	M	t; kg	1 t = 1000 kg
Density	D	t/m^3	1 t/m^3 = 1 kg/dm^3
Force, load	F	kN	1 kN= 1000 N ~100 kp
Stress	d	MN/m^2	1 MN/m^2 = 1 N/mm^2 ~10 kp/cm^2
Pressure	p	MN/m^2	1 MN/m^2 = 1 MPa ~10 kp/cm^2
Energy	E	kWh	1 kWh = 3.6 • 106 Ws ~3.6 • 105 kpm
Work	W	kNm	1 J = 1 Ws = 1 Nm 1 kNm ~ 100 kpm

Quantity of heat	Q	kWh	1 kWh = 3.6 X 106 Ws; 1 kcal = 4187 Ws
Power	P	kW	1 kW ~100 kpm/s = 1.36 PS
Temperature	t	°C, K	0ºK = -273 °C; 0ºC = 273 °K
Velocity	v	m/s	1 m/s= 3.6 km/in
Acceleration	b	m/s	1 m/s^2, acceleration due to gravity: 9.81 m/s^2

Table 10.5: Conversion of imperial measures (Source: Sasse, 1984)

Length	1 m = 1.094 yrd	1 yrd = 0.914 m
	1 cm = 0.0328 ft	1 ft = 30.5 cm
	1 cm = 0.394 inch	1 inch = 2.54 cm
Area	1 m^2 = 10.76 sqft	1 sqft = 0.092 m^2
	1 cm^2 = 0.155 sq.in	1 sq.in = 6.452 cm^2
	1 ha = 2.47 acre	1 acre = 0.405 ha
Volume	1 1 = 0.220 gall.	1 gall. = 4.55 1
	1 m^3 = 35.32 cbft	1 cbft = 28.31
Mass	1 kg = 2.205 lb	1 lb = 0.454 kg
Pressure	1 MN/m^2 = 2.05 lb/sqft	1 lb/sqft = 0.488 MN/m^2
	1 cm Ws = 205 lb/sqft	1 lb/sqft = 70.3 cm Ws
Quantity	1 kcal = 3.969 BTU	1 BTU = 0.252 kcal
of heat	1 kWh = 3413.3 BTU	1000 BTU = 0.293 kcal
	1 kcal/kg = 1799 BTU/lb	1 BTU/lb = 0.556 kcal/kg
Power	1 PS = 0.986 HP	1 HP = 1.014 PS

Power	1 PS = 0.986 HP	1 HP = 1.014 PS
	1 kpm/s = 7.24 ft.lb/s	1 ft.lb/s = 0.138 kpm/s

Table 10.6: Conversion factors for work, energy and power (Source: Wendehorst, 1978)
Comparison of work units (work = power X time)

	kpm	**PSh***	**Ws = J**	**kWh**	**kcal**
1 kpm =	1	3.70 X 10^{-6}	9.807	2.7 X 10^{-6}	2.342 X 10^{-3}
1 PSh*=	270 X 10^{3}	1	2.648 X 10^{6}	0.7355	632.4
1 Ws = J =	0.102	377.7 X 10^{-9}	1	277.8 X 10^{-9}	239 X 10^{-6}
1 kWh =	367.1 X 10^{3}	1.36	3.6 X 10^{6}	1	860
1 kcal =	426.9	1.58 X 10^{-3}	4186.8	1.163 X 10^{-3}	1

*** PS = 0.986 HP**
UNDEFINED PAGEof_v">
Table 10.7: Energy content of various fuels (Source: Kaltwasser, 1980)

Fuel	**Calorific value**		**Unit**
	MJ	**kWh**	
Plants	16-19	4A- 5.3	kg TS
Cow dung	18-19	5.0 - 5.3	kg TS

Chicken droppings	14-16	3.9- 4.4	kg TS
Diesel, fuel oil, gasoline	41-45	11.4-12.5	kg = 1.1 1
Hard coal (anthracite)	30-33	8.3- 9.2	kg
Wood	14-19	3.9- 5.3	kg
Producer gas	5-7	1.4 - 1.9	Nm^3
Pyrolysis gas	18-20	5.0- 5.6	Nm^3
City gas	18-20	5.0- 5.6	Nm^3
Propane	93	25.8	Nm^3
Natural gas	33-38	9.2-10.6	Nm^3
Methane	36	10.0	Nm^3
Biogas	20-25	5.6- 6.9	Nm^3

Table 10.8: Conversion factors for units of pressure (Source: Wendehorst, 1978)

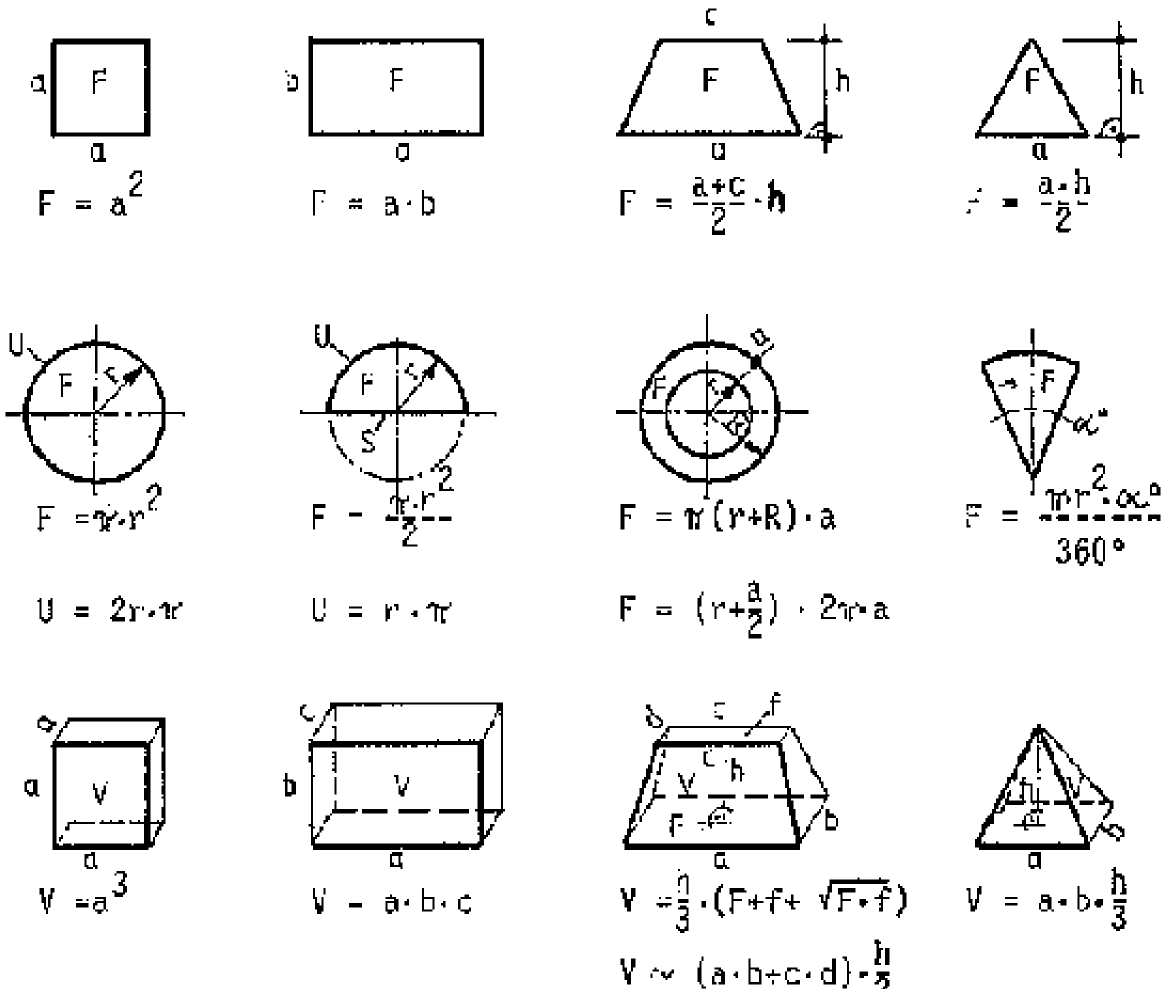
	kp/m^2	**N/m^2**	**pa**	**cm WG**	**mbar**	**at**
kp/m^2	1	10	10	0.1	0.1	0.0001
N/m^2	0.1	1	1	0.01	0.01	10^{-5}
pa	0.1	1	1	0.01	0.01	10^{-5}
cm WG	10	100	100	1	1	0.001
mbar	10	100	100	1	1	0.001
at	104	105	1000	1000	1000	1

Table 10.9: Table of powers and radicals

n	n^2	n^3	n	n^2	n^3	n	n^2	n^3	n	n^2	n^3
0.60	0.36	0.22	1.10	1.21	1.33	1.60	2.56	4.10	2.10	4.41	9.26
0.65	0.42	0.27	1.15	1.32	1.53	1.65	2.72	4.49	2.15	4.62	9.94
0.70	0.49	0.34	1.20	1.44	1.73	1.70	2.89	4.91	2.20	4.84	10.65
0.75	0.56	0.42	1.25	1.56	1.95	1.75	3.06	5.36	2.25	5.06	11.39
0.80	0.64	0.51	1.30	1.69	2.20	1.80	3.24	5.83	2.30	5.29	12.17
0.85	0.72	0.61	1.35	1.82	2.46	1.85	3.42	6.33	2.35	5.52	12.98
0.90	0.81	0.73	1.40	1.96	2.74	1.90	3.61	6.86	2.40	5.76	13.82
0.95	0.90	0.86	1.45	2.10	3.05	1.95	3.80	7.41	2.45	6.00	14.71
1.00	1.00	1.00	1.50	2.25	3.38	2.00	4.00	8.00	2.50	6.25	15.63
1.05	1.10	1.16	1.55	2.40	3.72	2.05	4.20	8.62	2.55	6.50	16.58

n	$n^{1/3}$	n	$n^{1/3}$	n	$n^{1/3}$	n	$n^{1/3}$	n	$n^{1/3}$	n	$n^{1/3}$
0.001	0.10	0.22	0.60	1.33	1.10	4.10	1.60	9.26	2.10	17.58	2.60
0.003	0.15	0.27	0.65	1.53	1.15	4.49	1.65	9.94	2.15	18.61	2.65
0.008	0.20	0.34	0.70	1.73	1.20	4.91	1.70	10.65	2.20	19.68	2.70
0.016	0.25	0.42	0.75	1.95	1.25	5.36	1.75	11.39	2.25	20.80	2.75
0.027	0.30	0.51	0.80	2.20	1.30	5.83	1.80	12.17	2.30	21.95	2.80

0.043	0.35	0.61	0.85	2.46	1.35	6.33	1.85	12.98	2.35	23.15	2.85
0.064	0.40	0.73	0.90	2.74	1.40	6.86	1.90	13.82	2.40	24.39	2.90
0.091	0.45	0.86	0.95	3.05	1.45	7.41	1.95	14.71	2.45	25.67	2.95
0.125	0.50	1.00	1.00	3.38	1.50	8.00	2.00	15.63	2.50	27.0	3.00
0.166	0.55	1.16	1.05	3.72	1.55	8.62	2.05	16.58	2.55	28.37	3.05



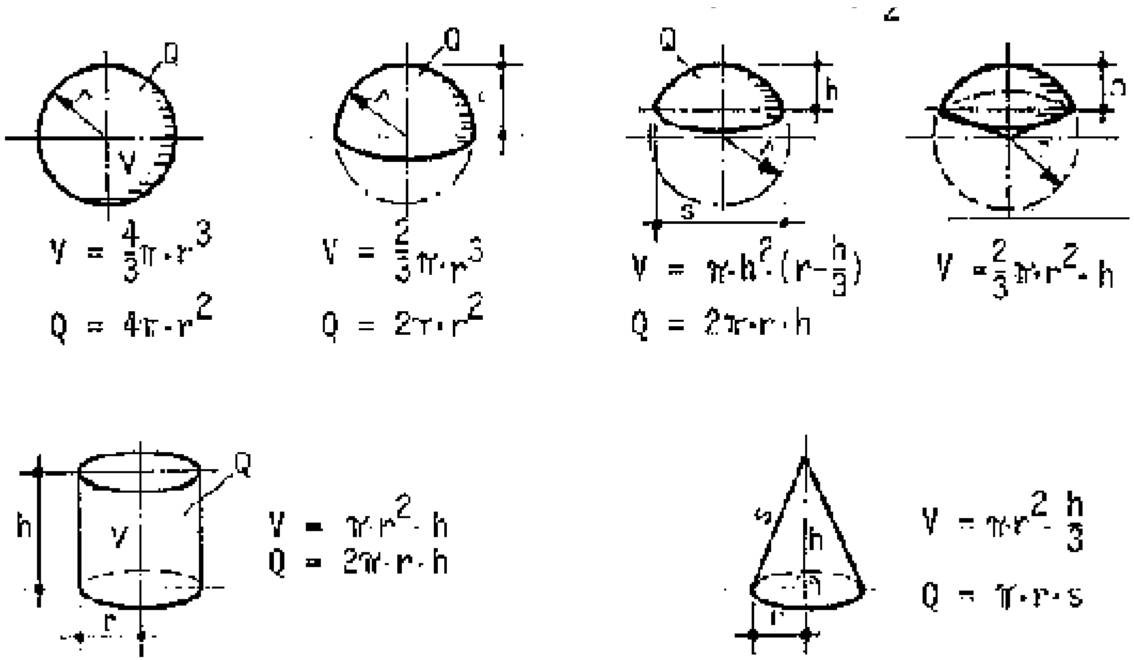


Fig. 10.11: Fundamental geometric formulae (Source: Sasse 1984)

10.4 Charts and tables for use in performing micro-economic

Notes on using the data sheet (table 10.10)

The data survey (data sheet, table 10.10) contains fictive, but nonetheless substantially realistic, data on a family-size biogas plant. Those data are reffered to for explaining and calculating the arithmetic models described in chapter 8. Such data must be ascertained separately for each project site.

Notes on the individual data-sheet items

1. In order to keep the calculations uncomplicated, an unrealistically constant annual rate of inflation is assumed. It is possible to account for different inflation

rates in the various analytical procedures. For explanatory details beyond those offered in this guide, please refer to Finck/Oelert, chapter C III.

2. Calculatory interest rate, i: assumed rate of interest for evaluating the cash flows (income and expenditure) generated by a biogas plant during its technical service plant. Proceeding on the assumption that the expenditures are all the more burdensome, the earlier they fall due, while income is all the more valuable, the earlier it is earned, all cash flows occuring in connection with the investment are compounded/discounted at an assumed rate for a fixed point in time. Please refer to chapter 8.4 for the calculation procedure.

3. Investment costs (incl. wages):
- planning
- land aquisition/leasing (as applicable)
- civil works
- building and structures/digester
- modification of animal housing
- gas appliances/aggregates
- slurry spreading implements
- assembly and commissioning
- customs, taxes, duties, fees
- transportation

4. Manpower costs for:
- feeding the plant
- spreading the digested slurry

5. Maintenance and repair:
- spare parts/materials
- wages for maintenance/repair work

6. Energy revenues
- market value of replaced energy
- energy supplied
- production induced with extra energy (market value)

7. Revenues from fertilizer:
- market value of replaced inorganic fertilizer
- revenues from sales of digested slurry
- higher cash-crop yields due to fertilizing with digested slurry

8. Time saved (real financial income only) for additional:
- wage work
- work on the farm (included additional incom)

9. Depreciation (annual for linear depreciation):
= investment costs / n (technical service life)

In this example, the technical service life of the plant is conservatively estimated at only 10 years.

10. Depreciation and capital-servicing costs (interest on loans): neither of these two factors is included as a cost factor in the dynamic models presented in chapter 8, because the cost of investment is equal to the sum of cash values from depreciation and interest (cf. Brandt, 1982, for details). In this example, it is

assumed that no external capital is needed, i.e. that the biogas plant is fully financed with internal capital.

Table 10.10: Data sheet for economic analysis (Source OEKOTOP; Finck/Oelert, Table 1)

Project title:	**Location:**		**Owner:**			**Type of plant/digester volume:**						
Technical service life:	**years**											
Item Period		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Year		**19...**	**19...**	**19...**	**19...**	**19...**	**19...**	**19...**	**19...**	**19...**	**19...**	**19...**
1.1 General inflation rate 1)	%	34	34	34	34	34	34	34	34	34	34	34
1.2 Market interest rate, p	%	48	48	48	48	48	48	48	48	48	48	48
1.3 Assumed interest rate, i 2)	%	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
2. Investment costs, I 3)	CU	1100										
3.1 Manpower costs 4)	CU	-	-	-	-	-	-	-	-	-	-	
3.2 Maintenance and repair 5)	CU	-	30	30	30	30	30	30	30	30	30	30
spare-parts requirement												
4.1 Taxes and levies not	CU	-	-	-	-	-	-	-	-	-	-	-

linked to profit												
4.2 Other expenditures	CU	-	50	50	50	50	50	50	50	50	50	50
5. Total operating costs,	Co		35	35	35	35	35	35	35	35	35	35
6.1 Energy-related revenues 6)	CU	-	210	210	210	210	210	210	210	210	210	210
6.2 Revenues from fertilizer 7)	CU	-	250	250	250	250	250	250	250	250	250	250
6.3 Time saved 8)	CU	-	-	-	-	-	-	-	-	-	-	-
6.4 Other income	CU	-	-	-	-	-	-	-	-	-	-	-
6.5 Subsidies	CU	-	-	-	-	-	-	-	-	-	-	-
7. Total income	CU	-	235	235	235	235	235	235	235	235	235	235
8. Returns (item 7- item 5)	CU	200	200	200	200	200	200	200	200	200	200	200
9. Depreciation 9)	CU	110	110	110	110	110	110	110	110	110	110	110
10. Capital servicing costs 10)	CU	-	-	-	-	-	-	-	-	-	-	-
11. Profit	CU	-	90	90	90	90	90	90	90	90	90	90

CU = currency unit; in local currency or DM/US $ (conversion to DM/US $ rarely advisable due to fluctuating exchange rates)

Table 10.11: Discounting factors for interest rates of i = 1 -30% and periods of t = 1 - 30 years

ti	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	.990	.980	.971	.962	.952	.943	.935	.926	.917	.909	.901	.893	.885	.877	.870
2	.980	.961	.943	.925	.907	.890	.873	.857	.842	.826	.812	.797	.783	.769	.756
3	.971	.942	.915	,889	.864	.840	.816	.794	.772	.751	.731	.712	.693	.675	.658
4	.961	.924	.888	.855	.823	.792	.763	.735	.708	.683	.659	.636	.613	.592	.572
5	.951	.906	.863	.822	.784	.747	.713	.681	.650	.621	.593	.567	.543	.519	.497
6	.942	.888	.837	.790	.746	.705	.666	.630	.596	.564	.535	.507	.480	.456	.432
7	.933	.871	.813	.760	.711	.665	.623	.583	.547	.513	.482	.452	.425	.400	.376
8	.923	.853	.789	.731	.677	.627	.582	.540	.502	.467	.434	.404	.376	.351	.327
9	.914	.837	.766	.703	.645	.592	.544	.500	.460	.424	.391	.361	.333	.308	.284
10	.905	.820	.744	.676	.614	.558	.508	.463	.422	.386	.352	.322	.295	.270	.247
11	.896	.804	.722	.650	.585	.527	.475	.429	.388	.350	.317	.287	.261	.237	.215
12	.887	.788	.701	.625	.557	.497	.444	.397	.356	.319	.286	.257	.231	.208	.187
13	.879	.773	.681	.601	.530	.469	.415	.368	.326	.290	.258	.229	.204	.182	.163
14	.870	.758	.661	.577	.505	.442	.388	.340	.299	.263	.232	.205	.181	.160	.141
15	.861	.743	.642	.555	.481	.417	.362	.315	.275	.239	.209	.183	.160	.140	.123
16	.853	.728	.623	.534	.458	.394	.339	.292	.252	.218	.188	.163	.141	.123	.107
17	.844	.714	.605	.513	.436	.371	.317	.270	.231	.198	.170	.146	.125	.108	.093
18	.836	.700	.587	.494	.416	.350	.296	.250	.212	.180	.153	.130	.111	.095	.081
19	.828	.686	.570	.475	.396	.331	.277	.232	.194	.164	.138	.116	.098	.083	.070
20	.820	.673	.554	.456	.377	.312	.258	.215	.178	.149	.124	.104	.087	.073	.061
21	.811	.660	.538	.439	.359	.294	.242	.199	.164	.135	.112	.093	.077	.064	.053

22	.803	.647	.522	.422	.342	.278	.226	.184	.150	.123	.101	.083	.068	.056	.046
23	.795	.634	.507	.406	.326	.262	.211	.170	.138	.112	.091	.074	.060	.049	.040
24	.788	.622	.492	.390	.310	.247	.197	.158	.126	.102	.082	.066	.053	.043	.035
25	.780	.610	.478	.375	.295	.233	.184	.146	.116	.092	.074	.059	.047	.038	.030
26	.772	.598	.464	.361	.281	.220	.172	.135	.106	.084	.066	.053	.042	.033	.026
27	.764	.586	.450	.347	.268	.207	.161	.125	.098	.076	.060	.047	.037	.029	.023
28	.757	.574	.437	.333	.255	.196	.150	.116	.090	.069	.054	.042	.033	.026	.020
29	.749	.563	.424	.321	.243	.185	.141	.107	.082	.063	.048	.037	.029	.022	.017
30	.742	.552	.412	.308	.231	.174	.131	.099	.075	.057	.044	.033	.026	.020	.015

ti	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**229**	**30**
1	.862	.855	.847	.840	.833	.826	.820	.813	.806	.800	.794	.787	.781	.775	.769
2	.743	.731	.718	.706	.694	.683	.672	.661	.650	.640	.630	.620	.610	.601	.592
3	.641	.624	.609	.593	.579	.564	.551	.537	.524	.512	.500	.488	.477	.466	.455
4	.552	.534	.516	.499	.482	.467	.451	.437	.423	.410	.397	.384	.373	.361	.350
5	.476	.456	.437	.419	.402	.386	.370	.355	.341	.328	.315	.303	.291	.280	.269
6	.410	.390	.370	.352	.335	.319	.303	.289	.275	.262	.250	.238	.227	.217	.207
7	.354	.333	.314	.296	.279	.263	.249	.235	.222	.210	.198	.188	.178	.168	.159
8	.305	.285	.266	.249	.233	.218	.204	.191	.179	.168	.157	.148	.139	.130	.123
9	.263	.243	.225	.209	.194	.180	.167	.155	.144	.134	.125	.116	.108	.101	.094
10	.227	.208	.191	.176	.162	.149	.137	.126	.116	.107	.099	.092	.085	.078	.073
11	.195	.178	.162	.148	.135	.123	.112	.103	.094	.086	.079	.072	.066	.061	.056

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	.168	.152	.137	.124	.112	.102	.092	.083	.076	.069	.062	.057	.052	.047	.043
13	.145	.130	.116	.104	.093	.084	.075	.068	.061	.055	.050	.045	.040	.037	.033
14	.125	.111	.099	.088	.078	.069	.062	.055	.049	.044	.039	.035	.032	.028	.025
15	.108	.095	.084	.074	.065	.057	.051	.045	.040	.035	.031	.028	.025	.022	.020
16	.093	.081	.071	.062	.054	.047	.042	.036	.032	.028	.025	.022	.019	.017	.015
17	.080	.069	.060	.052	.045	.039	.034	.030	.026	.023	.020	.017	.015	.013	.012
18	.069	.059	.051	.044	.038	.032	.028	.024	.021	.018	.016	.014	.012	.010	.009
19	.060	.051	.043	.037	.031	.027	.023	.020	.017	.014	.012	.011	.009	.008	.007
20	.051	.043	.037	.031	.026	.022	.019	.016	.014	.012	.010	.008	.007	.006	.005
21	.044	.037	.031	.026	.022	.018	.015	.013	.011	.009	.008	.007	.006	.005	.004
22	.038	.032	.026	.022	.018	.015	.013	.011	.009	.007	.006	.005	.004	.004	.003
23	.033	.027	.022	.018	.015	.012	.010	.009	.007	.006	.005	.004	.003	.003	.002
24	.028	.023	.019	.015	.013	.010	.008	.007	.006	.005	.004	.003	.003	.002	.002
25	.024	.020	.016	.013	.010	.009	.007	.006	.005	.004	.003	.003	.002	.002	.001
26	.021	.017	.014	.011	.009	.007	.006	.005	.004	.003	.002	.002	.002	.001	.001
27	.018	.014	.011	.009	.007	.006	.005	.004	.003	.002	.002	.002	.001	.001	.001
28	.016	.012	.010	.008	.006	.005	.004	.003	.002	.002	.002	.001	.001	.001	.001
29	.014	.011	.008	.006	.005	.004	.003	.002	.002	.002	.001	.001	.001	.001	.000
30	.012	.009	.007	.005	.004	.003	.003	.002	.002	.001	.001	.001	.001	.000	.000

10.5 List of pertinent suppliers and institutions

Plant engineering, construction and consultancy services in developing countries

AIT Asian Institute of Technology - Division for Energy Technology, P.O. Box 2754, Bangkok 10501, Thailand

AVARD Association of Voluntary Agencies for Rural Development, c/o Safdarjung Development Area, New Delhi, India

BORDA Bremen Overseas Research and Development Association, Bahnhofsplatz 13, 2800 Bremen, Federal Republic of Germany

Biogas projects: BORDA/UNDARP Poona, India

CEMAT Centro Mesamericano de Estudios sobre Tecnologia Apropiada, A.P.1160, Guatemala-City, Guatemala

GATE/GTZ German Appropriate Technology Exchange/Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Postfach 5180, 6236 Eschborn, Federal Republic of Germany

GATE/GTZ Biogas Extension Program Projects:
Projecto de Biogas c/o ENPRA, km 11.5 vieja a Leon, A.P.4772 Managua, Nicaragua
Biogas Extension Service c/o CAMARTEC, P.O. Box 764, Arusha, Tanzania Projet Biogaz Cankuzo, D/S 148, Bujumbura, Burundi

CDB/GATE Biogas Team c/o CDB, P.O. Box 407, Wildey St. Michael, Barbados
Proyeto Biogas PAAC-UMMS-GATE, Casilla 4740, Cochabamba Bolivia

Special Energy Program biogas projects (GTZ-Div.34) GTZ Special Energy Program, P.O. Box 41607, Nairobi, Kenya Projet Special de l'Energie, c/o I.V.E., B.P. 5321 Ouagadougou, Burkina Faso

KVIC Khadi and Village Industries Commission, Gobar Gas Scheme, Ivla Rees, Vila Parle, Bombay 400 056, India

Maya Farms Angona, Rizal, Philippines

OEKOTOP Gesellschaft fur Angepate Technologien in Entwicklungsgebieten, Bingerstr. 25a, 1000 Berlin 33, Federal Republic of Germany

Biogas projects (by order of GTZ): Projet Biogaz c/o SODEPRA Ferkessedougou, Cote d'Ivoire Proyecto Biogas Colombo-Aleman c/o CVC, Apto. A2366, Cali, Colombia

RED-Latino Americana de Biogas, Emprater, W3 Norte Q515, Brazilia, Brazil

Equipment producers / suppliers

Elster AG, Postfach 129,6500 Mainz, Federal Republic of Germany
Products: gasmeters

Kromschroder AG, Postfach 2809,4500 Osnabruck, Federal Republic of Germany
Products: full range of gas valves

Metallurgica Jackwal Ltd., Rua Braz Cardoso 674, Vila Nova Canceicao, Sao Paulo, Brazil

Products: lamps, burners, reducing valves

OEKOTOP GmbH, Berlin
Product: portable biogas measuring set

Patel Gas Crafters Ltd., Shree Sai Bazar, Mahatma Gandhi Road, Bombay 400 054, India
Products: lamps, burners

Saron Vdyog, Shanghai, PR China
Products: gasmeters, lamps, burners

Service Centre for Development on New Energy, NO. 33 Fugiun Skeet, Shijiazkuang, PR China
Products: burners, motors

Shanghai Bioenergy, Shanghai, PR China
Products: gasmeters, lamps, burners, motors

T.A. Schiller, Postfach 1224, 2072 Bargteheide, Federal Republic of Germany
Products: lamps, burners, motors

Producers of biogas-fueled engines

Ford AG, Edsel-Ford-Str., 5000 Cologne 71, Federal Republic of Germany
- Type 2274 E, 15-25 kW, 1500 - 3000 min-1, 4-cylinder, water-cooled, spark ignition

Henkelhausen, Postfach 9149, 4150 Krefeld 12, Federal Republic of Germany
- Series GFL 912, 19~0 kW, 1500-2300 min-1, 3-, 4-, 5-, 6-cylinder, air-cooled, spark ignition
- Series GFL 413, 55 - 140 kW, 1500 - 2300 min-1, 5-, 6-, 8-, 10-, 12-cylinder, air-cooled, spark ignition

Kirloska, India, German representative: Schule Co., Postfach 260620, 2000 Hamburg 26,
Federal Republic of Germany
- Series AVG, TVG, CAG, TAG, 5 - 12 kW, 1200 - 2000 min-1, 1-, 2-cylinder, air-cooled or water-cooled, dual-fuel

MWM AG, Carl-Benz-Str., 6800 Mannheim, Federal Republic of Germany
- Series G 227, 18 - 40 kW, 1500 - 2200 min-1, 3-, 4-, 6-cylinder, water-cooled, spark ignition

10.6 Selected literature

Biotechnical fundamentals and plant engineering

Anaerobic Digestion, Proceedings of the Fourth International Symposium on Aerobic Digestion, held in Guangzkou, China on 11 -15 November 1985
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Hohlfeld, J. et al., Production and Utilization of Biogas in Rural Areas of Industrialized and Developing countries, GTZ Eschborn 1986
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10.7 Lists and indexes

10.7.1 Illustrations

10.7.2 Tables

Tab. 10.11 : Discounting factors for interest rates of i = 1 - 30% and periods of t = 1- 30 years

10.7.3 Abbreviations

A	area
a	inflation rate
a	year (per annum)
at	atmosphere
B	biomass
B.D.C.	bottom dead center
BEP	GATE/GTZ Biogas Extension Program
BOD	biochemical oxygen demand
C	carbon
C	circumference
CaO	calcium oxide
cd	candela (candle power)
ce	coefficient of earth pressure
cf	coefficient of friction
CH_4	methane
cmWG	cm water gage
C/N	carbon/nitrogen ratio
CO_2	carbon dioxide

CO_2	carbon dioxide
COD	chemical oxygen demand
cp	coefficient of pipe friction
cP	heat capacity
CS	crankshaft
Cs	storage capacity
D	density of biogas
D	energy demand
D, d	pipe diameters
d	day
d	stoichiometric air ratio
DN	density of biogas under normal (s.t.p.) conditions
dp	pressure drop
Dr	digestion rate
E	illuminance
E	compression ratio
E	energy
Ee	energy input
Es	specific illuminance
F	luminous flux
F	relative dampness of biogas

$Fe(OH)_3$	ferric hydrate
FL	friction losses
G	gas production
gc, max	max. gas consumption per hour
GM	moisture content of gas
Gp	specific gas production
GRP	glass-reinforced plastic
Gy	gas yield
H, h	height
H_2	hydrogen
he	height of earth column
hp	horsepower
hph	horsepower-hour
H_2S	hydrogen sulfide
I	luminous intensity
i	discounting factors/calculatory (assumed) interest rate
Io	initial investment
J	joule
K	potassium
KA	average capital invested (per time interval)
kcal	kilocalorie
K_2O	potassium oxide

K_2O	potassium oxide
kWh	kilowatt hour
L	latent heat of evaporation
I	length of pipe
Ld	digester loading
Irn	lumen
mbar	millibar
MgO	magnesium oxide (magnesia)
mWG	meter water gage
N	nitrogen
N	burner efficiency
N	Newton
n.c.v.	net calorific value (in diagrams: n.c.v. = Hu)
NP	net profit
P	pressure/gas pressure
P	phosphorus
p	market rate of interest
p	biogas/energy production
pa	Pascal
PE	polyethylene
pE	active earth pressure
PN	normal pressure

P_2O_5	phosphorus pentoxide
PVC	polyvinyl chloride
PW	partial pressure of water vapor
pw	hydrostatic pressure
Q	gas flow
QW	quantity of heated water
R, r	radius
Re	luminous efficiency
ROI	return on investment (profitability)
RT	retention time
Sd	daily substrate input
T, t	temperature
tc, max	maximum consumption time
T,D.C.	top dead center
tz, max	maximum period of zero consumption
TN	temperature under normal (s.t.p.) conditions
TS	total solids content
V	volume
v	velocity/speed
vc	maximum gas consumption
Vd	digester volume

Vd	digester volume
Vg	gasholder volume
Vh	compression volume
VN	volume of biogas under normal (s.t.p.) conditions
Vn	swept volume
VS	volatile solids content
Vtot	total volume of a cylinder
W	water
W	watt
Wd	daily water input
wE	weight of dry earth
Wl	water loss (leak testing)
wW	weight of water
Ztot	sum total of friction losses

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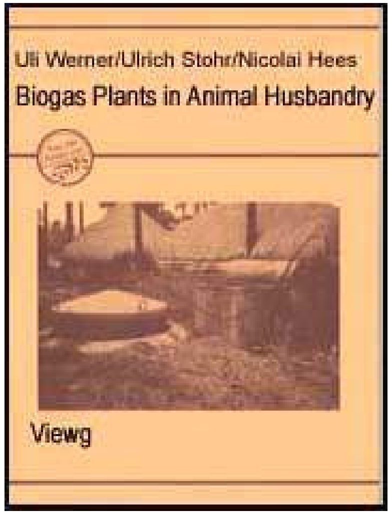

Foreword

Biogas plants have become something of a permanent fixture in Technical Cooperation between the Federal Republic of Germany and partners in developing countries. Dating back to 1977, the first such projects were incorporated into cooperative efforts with Indian and Ethiopian organizations. At about the same time, the first GTZ project dealing solely with the transfer of biogas technology and the construction of biogas plants was launched in Cameroon.

In the meantime, GTZ has assisted in building and commissioning several hundred biogas plants in Asia, Africa, South and Central America. While most of the systems, in question are on a small scale intended to supply family farms with energy and organic fertilizer, some large-scale systems with the capacity to generate more than 100 m³ of biogas daily have been installed on large stock farms and agroindustrial estates.

In general, biogas technology is for rural areas. In addition to generating energy, biogas systems help stimulate ecologically beneficial closed-loop systems in the agricultural sector while serving to improve soil quality and promote progress in animal husbandry. Consequently, the promotion of biogas technology is regarded as an integral part of technical cooperation in rural areas and, hence, as a key sector of development cooperation on the part of the Federal Republic of Germany.

Within the GTZ, biogas activities center on

- the Biogas Extension Program (GATE), with interdisciplinary teams of extension officers presently working in four different countries:

- the Special Energy Program (Mineral and Energy Resources Division), with rural energy-supply projects now ongoing in ten countries, and

- projects engaged in by Division 14(animal production, animal health and fisheries), within which the importance of biogas technology as a flanking measure in animal husbandry is steadily increasing.

By concentrating the engineering and operational experience gained in numerous biogas projects, this handbook is intended to serve project practicians and advisors as a valuable practical guideline with regard to technical, agricultural and socioeconomic aspects.

Deutsche Gesellachaft fur Technische
Zusammenarbeit (GTZ) GmbH

Authors' Foreword

Biogas plants constitute a widely disseminated branch of technology that came into use more than 30 years ago in Third World countries. There are hundreds of thousands of simple biogas plants now in operation, and each one of them helps improve the living and working conditions of people in rural areas.

While this guide deals only with biogas systems of simple design, the technology is nonetheless sufficiently complex and rewarding to warrant one's close attention to its proper application, planning and construction. The only good biogas system is a well-planned, carefully executed and properly functioning one that fulfills its purpose.

This guide addresses the planners and providers of stock-farming and agricultural-extension services in developing countries. It is intended to serve as:

- a source of information on the potentials of and prerequisites for biogas technology,
- a decision-making and planning aid for the construction and dissemination of biogas plants
- a book of reference for information on practical experience and detailed data.

While consulting experts, extension officers and advisors with little experience in biogas technology will find this guideline useful as an initial source of information, biogas practicians can use it as a hands-on manual. The tables and engineering drawings contained herein provide standard values for practical application. They were compiled from numerous extraneous and proprietary works of reference and then modified as necessary for practical use. The informational content draws chiefly on the latest know-how and experience of numerous associates involved in the various biogas projects of the GTZ Special Energy Program and the GATE/GTZ Biogas Extension Program, of L. Sasse and a great many Third World colleagues and, last but not least, OEKOTOP's own project experience.

We would like to take this opportunity to thank all of our colleagues for their cooperation and the constructive criticism that attended the writing of this handbook. Our appreciation also to GATE and the GTZ division Animal Production, Animal Health and Fisheries, who made this guideline possible. Special thanks also to Klaus von Mitzlaff for the section on gas-driven engines and to Uta Borges for her special elaboration of the aspects economic evaluation, social acceptance and dissemination.

We wish every success to all users of this guide. Feedback in the form of suggestions and criticism is gratefully welcomed.

The OEKOTOP Authors

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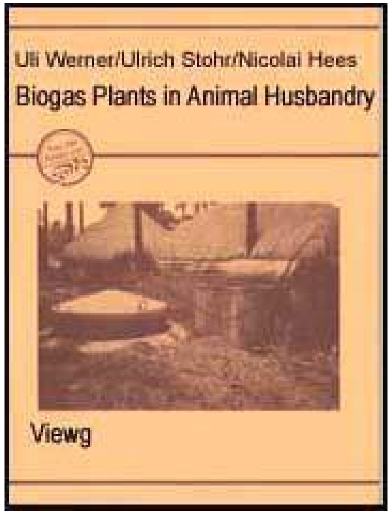

1. An introduction to biogas technology

Biogas technology

. . . is a modern, ecology-oriented form of appropriate technology based on the decomposition of organic materials by putrefactive bacteria at suitable, stable temperatures. A combustible mixture of methane and carbon dioxide, commonly referred to as biogas, develops under air exclusion (leaving behind digested slurry) in the digester - the heart of - any biogas plant.

To ensure continuous gas production, the biogas plant must be fed daily with an ample supply of substrate, preferably in liquid and chopped or crushed form. The slurry is fed into the digester by way of the mixing pit. If possible, the mixing pit should be directly connected to the livestock housing by a manure gutter. Suitable

substrates include:

- dung from cattle, pigs, chickens, etc.,
- green plants and plant waste,
- agroindustrial waste and wastewater.

Wood and ligneous substances are unsuitable.

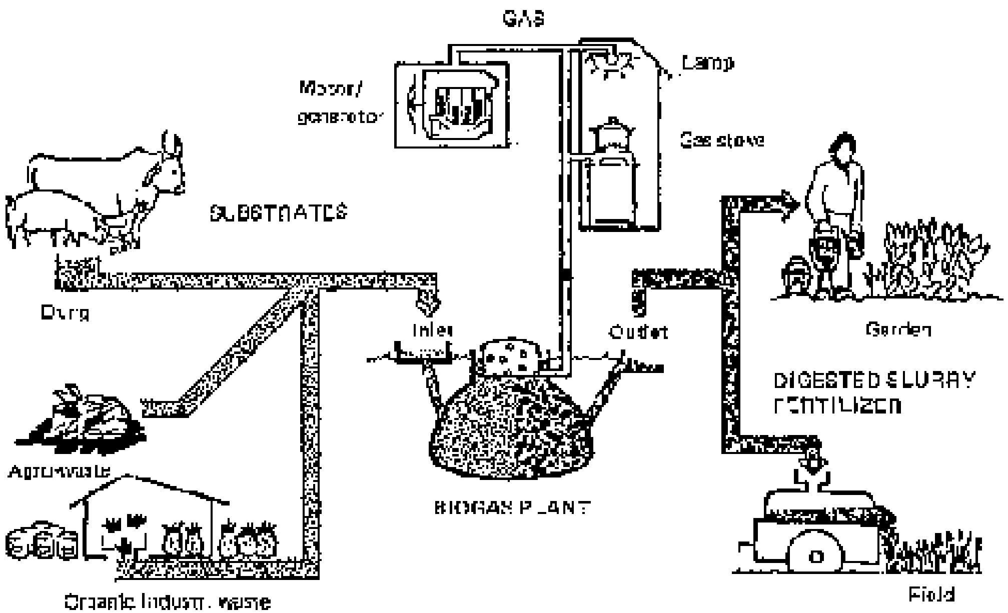

Fig. 1.1: A typical biogas-system configuration (Source: OEKOTOP)

Biogas guideline data	
Suitable digesting temperature:	20 - 35 °C
Retention time:	40 - 100 days
Biogas energy content:	6 kWh/m³ = 0.61 diesel fuel
Biogas generation:	0.3-0.5 m³ gas/m³ digester volume x day

Biogas generation:	0.3-0.5 m^3 gas/m^3 digester volume x day
1 cow yields:	9-15 kg dung/day = 0.4m^3 gas/day
1 pig yields:	2-3 kg dung/day = 0.15 m^3 gas/day
Gas requirement for cooking:	0.1-0.3 m^3 /person
for 1 lamp:	0.1-0.15 m^3 /h
for engines:	0.6 m^3/kWh

A simple 8 - 10 m^3 biogas plant produces 1.5-2 m^3 and 1001 digested-slurry fertilizer per day on dung from 3-5 head of cattle or 8 - 12 pigs. With that much biogas, a 6 - 8 person family can:

- cook 2-3 meals or
- operate one refrigerator all day and two lamps for 3 hours or
- operate a 3 kW motor generator for 1 hour.

Of the many alternative forms of agricultural biogas systems, two basic types have gained widespread acceptance by reason of their time-tested reliability and propagability:

- floating-drum plants with a floating metal gasholder,
- fixed-dome plants with gas storage according to the displacement principle.

The main difference between the two is that the biogas generated in a fixed-dome plant collects in the domed roof of the digester, while that produced in a floating-drum plant collects in a metal gasholder. The gasholder, the purpose of which is to cover peak demand, is directly hooked up to the consumers (kitchen, living quarters, refrigerator, motor generator, . . .) by way of pipes.

Plant construction is effected with as much local material as possible, i.e.:

- bricks, rocks, sand, cement for the digester,
- metal or plastic tubes for the gas pipes,
- metal for the gasholder,
- gas valves, fittings and appliances.

Target groups and applications

The prime field of application for biogas plants is family farms, particularly those engaging in animal husbandry. Also, biogas plants are a proven successful means of disposal for wastewater and organic waste. Differentiation is made between the following groups of users:

- Small and medium-sized farms equipped with family-size plants (6-25 m^3 digester) use biogas for cooking and lighting. The installation of a biogas plant usually goes hand in hand with a transition to either overnight stabling or zero grazing. The modified stabling, coupled with the more intensive care given to the animals, improves the quality of animal husbandry as an inherent advantage of biogas technology.

- Specialized stock-farming operations involving the medium to large-scale production of cattle, pigs and/or poultry can use medium-to-large biogas systems with digester volumes ranging from 50 m^3 upward. The resultant safe disposal of fresh manure is a real contribution toward environmental protection, particularly with regard to the prevention of water pollution. Moreover, that contribution is rewarding for the farmer, too, since the biogas constitutes an autonomous source

of energy for production processes.

- For agroindustrial estates and slaughterhouses, the pro-biogas arguments are similar to those mentioned above in connection with stock farms: safe disposal of potentially hazardous solid and liquid waste materials, coupled with a private, independent source of energy for generating electricity, powering coolers, etc.

- Biogas plants in schools, hospitals and other public institutions provide a hygienic means of toilet/kitchen-waste disposal and a low-cost alternative source of energy. Schools in particular can serve as multipliers for the dissemination of information on biogas.

Gas appliances

A number of Third World manufacturers offer specially designed cooking burners and lamps that operate on biogas. Standard commercial cookers and lamps can also be converted to run on biogas.

Diesels and spark-ignition engines can be fueled with biogas following proper modification; diesel engines prefer a mixture of biogas and diesel fuel. Biogas-fueled refrigerators, though not very efficient, are attractive alternatives for hospitals, schools and restaurants without electrification.

Slurry utilization

The digested slurry from biogas plants is a valuable organic fertilizer, since most of the main nutrients (N, P, K) are preserved. In areas where regular fertilizing is uncommon, the use of digested slurry for that purpose requires intensive

counseling of the farmer. Biogas technology can play an important role in self-sustaining ecofarming.

The advantages of biogas technology

. . . for the user consist chiefly of direct monetary returns, less work and various qualitative benefits.

The monetary returns consist mainly of:

- savings on kerosene, diesel fuel, bottled gas and, possibly, wood or charcoal,
- an additional energy supply for commercial activities,
- savings on chemical fertilizers and/or additional income from higher agricultural yields.

The qualitative benefits are:

- easier, cleaner cooking and better hygiene,
- better lighting during the evening hours,
- energy independence,
- improved stock-farming practice,
- good soil structure thanks to fertilization with digested sludge.

The regional and overall domestic significance derives from the following merits and aspects:

- development of a reliable, decentralized source of energy operated and monitored by the users themselves,

- less local deforestation,

- improved conditions of agricultural production,

- more work and income for local craftsmen,

- infrastructural development,

- expanded indigenous technological know-how.

While the absolute figures corresponding to the above effects may often be marginal as compared to the overall economy; they nonetheless have a noticeable impact within the project region.

Cost of construction, amortization

As a rule, it costs DM 1000 or more to install a masonry biogas plant, including all peripheral equipment, i.e. improved stabling, gas appliances, piping, etc. A favorable payback period of less than 5 years can be anticipated for such an investment, if the biogas is used in place of a commercial energy source like kerosene or firewood, but not if it is used as a substitute for "free" firewood.

Dissemination of biogas technology

Thanks to the broad scale of potential uses for biogas, in conjunction with an increasingly advanced state of technical development' numerous developing countries are intensively promoting the dissemination of biogas plants. The undisputed leaders are the PR China (4.5 million plants), India (200 000 plants)

and Brazil (10 000 plants). Other countries also have launched biogas dissemination programs with some or all of the following components:

- development of appropriate appliances and plants,
- establishment of technology and advisory-service centers,
- continuous support for the users,
- training of biogas practicians,
- advertising and promotional activities,
- assistance for private craftsmen,
- provision of financing assistance.

Criteria for the utilization of biogas technology

Building a biogas plant is not the kind of project that can be taken care of "on the side" by anyone, least of all by a future user with no experience in biogas technology. The finished plant would probably turn out to be poorly planned, too expensive and, at best, marginally functionable - all of which would disappoint the user and spoil the prospects for the construction of additional plants. Consequently, the following rules of thumb should be observed:

- There are workable alternatives to biogas technology:

Regarding energy: energy-saving cookstoves, afforestation, wind/solar energy, small-scale hydropower, etc.; better access to commercial energy supplies

Regarding fertilization: spreading or composting of fresh dung

Regarding animal husbandry: pasturing instead of stabling in combination with a

biogas plant.

Any decision in favor of or against the installation of a biogas plant should be based on due consideration of how it compares to other alternatives according to technical, economic, ecological and socioeconomic criteria.

- Both the available supply of substrate and the energy requirements must be accurately calculated, because the biogas plant would not be worth the effort if its energy yield did not cover a substantial share of the energy requirements.

- The system must be properly built in order to minimize the maintenance & repair effort.

- Siting alternatives must be painstakingly compared, and only a really suitable location should be selected for the biogas plant.

The financial means of the plant's user must not be overextended (risk of excessive indebtedness).

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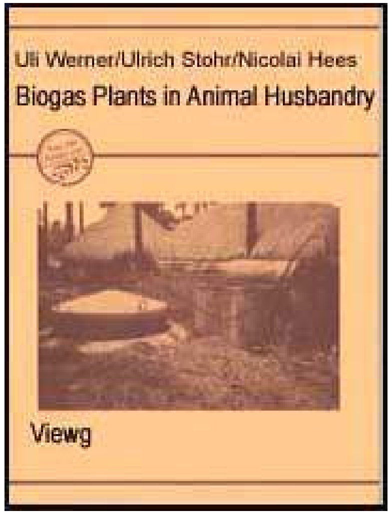
Biogas plants in Animal Husbandry (GTZ, 1989, 153 p.)
2. A planning guide
2.1 Introduction
2.3 Checklist for building a biogas plant



Biogas plants in Animal Husbandry (GTZ, 1989, 153 p.)

2. A planning guide

2.1 Introduction

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-size biogas plants. The essential siting con-ditions capable of influencing the decision for or against a biogas plant are covered (cf. figure 2.1 for a summary survey). The detailed planning outline (table 2.1) has a ´'data" column for entering the pertinent information and a "rating" column for noting the results of evaluation.

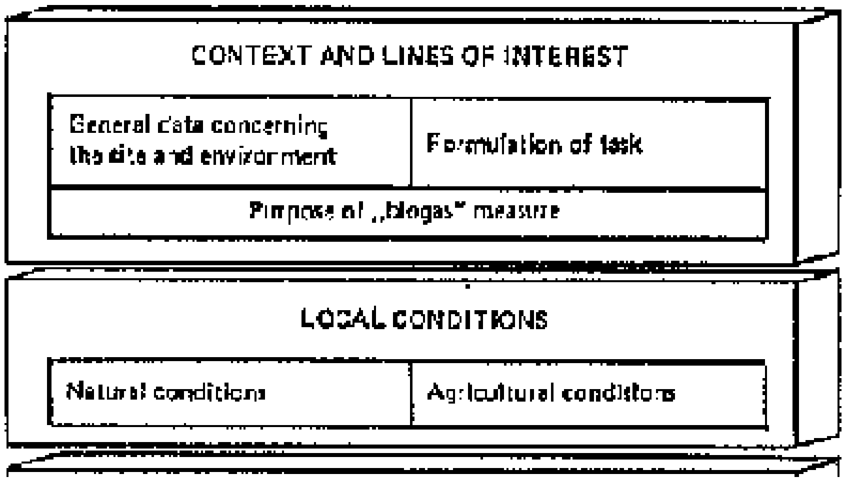
Evaluation criteria

+ Siting condition favorable

o Siting condition unfavorable, but
a) compensable by project activities,
b) not serious enough to cause ultimate failure,
- Siting condition not satisfied / not satisfiable

Information on how to obtain and evaluate the individual data can be found in the corresponding chapters of this manual by following the pointers provided in the "reference" column. .

Despite its detailed nature, this planning guide is, as intended, nothing more than 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 his 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.



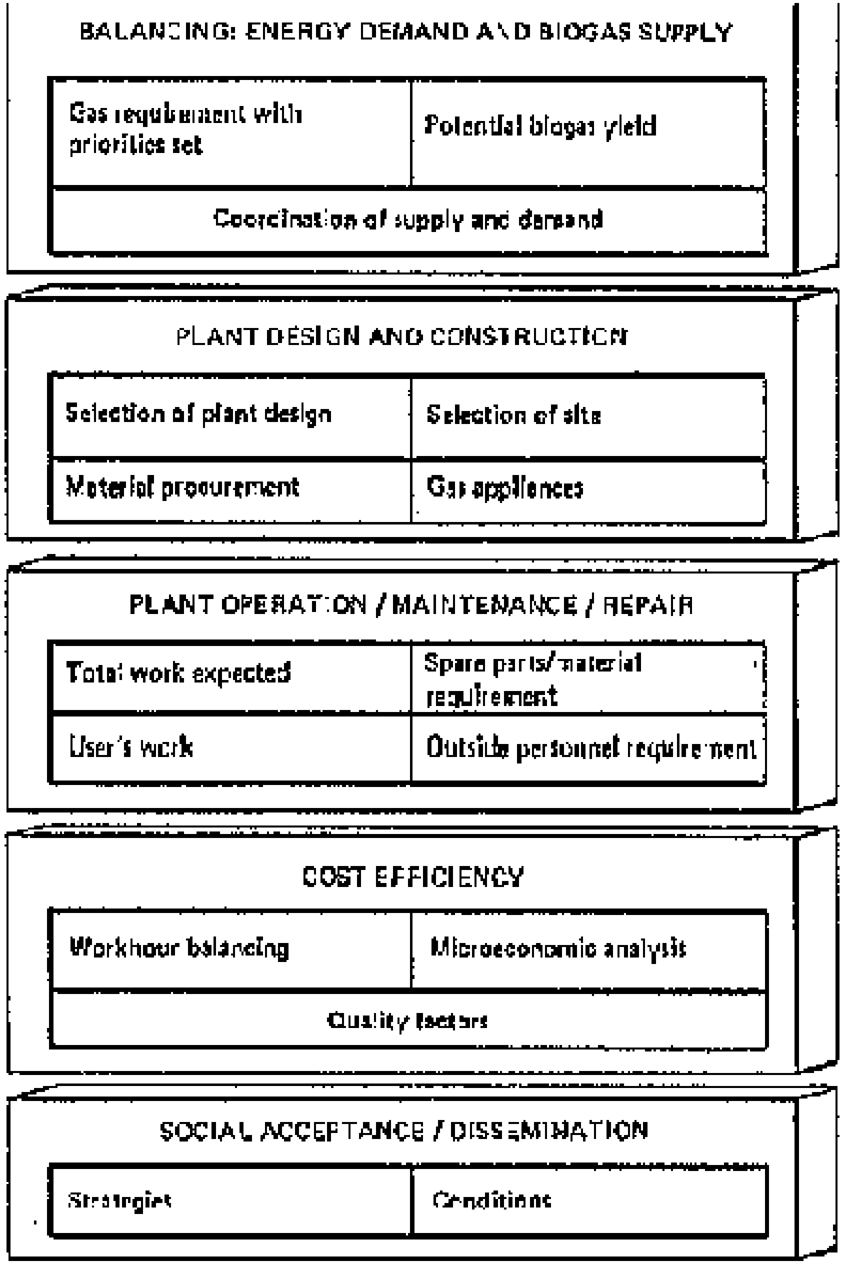


Fig. 2.1: Biogas planning modules (Source: OEKOTOP)

2.2 Detailed Planning Guide

Table 2.1: Detailed planning guide for biogas plants

Item	Reference	Data	Rating
0. Initial situation			
Addresses/project characterization			
Plant acronym:		....	
Address of operator/customer:		....	
Place/region/counky:		....	
Indigenous proj. org./executing org.:		....	
Extension officer/advisor:		....	
General user data			
Household structure and no. of persons:		....	
User's economic situation:		....	
Animals: kind, quantity, housing:		....	
Crops: types, areas, manner of cultivation:		....	
Non-agricultural activity:		....	
Household/farmincome:		....	
Cultural and social characteristics of user:		....	
Problems leading to the "biogas" approach			
Energy-supply bottlenecks:		....	
Workload for prior source of energy:			

Workload for prior source of energy:		....	
Poor soil structure/yields:		....	
Erosion/deforestation:		....	
Poor hygiene . . ., other factors:		....	
Objectives of the measure "biogas plant"			
User interests:		....	
Project interests:		....	
Other interests:		....	
1. Natural / Agricultural conditions			
Natural conditions	Chapter 3.1		
Mean annual temperature:		....	
Seasonal fluctuations:		....	
Diurnal variation:		....	
Rating:		....	+ o -
Subsoil	Chapter 3.1		
Type of soil:		....	
Groundwater table, potable water catchment area:		....	
Rating:			+ o -
Ratings: + Siting condition favorable			
o Siting condition unfavorable but compensable and/or not too serious			
- Siting condition not satisfied / not satisfable			

Water conditions	Chapter 3.1		
Climate zone:	Table 3.1	....	
Annual precipitation:		....	
Dry season (months):		....	
Distance to source of water:		....	
Rating:			+ o -
Livestock inventory, useful for biogas	Chapter 3.2/3.3		
production		....	
Animals: kind and quantity:		....	
Type and purpose of housing:		....	
Use of dung:		....	
Persons responsible for animals:		....	
Rating:			
Vegetable waste, useful for biogas production	Chapter 3.2/3.3		
Types and quantities:		....	
Prior use:		....	
Rating:			+ o -
Fertilization	Chapter 3.4		
Customary types and quantities of fertilizer/areas fertilized:		....	

Organic fertilizer familiar/in use:		....	
Rating:			+ o -
Potential sites for biogas plant	Chapter 3.3		
Combined stabling/biogas plant possible:		....	
Distance between biogas plant and livestock housing:		....	
Distance between biogas plant and place of gas consumption:		....	
Rating:			+ o -
Overall rating 4			+ o -
2. Balancing the energy demand with the biogas production	Chapter 4		
Prior energy supply	Chapter 4		
Uses, source of energy, consumption:		....	
Anticipated biogas demand (kWh/day or l/d)	Chapter 5.5.3		
for cooking:	Table 5.17	....	
for lighting:	Table 5.20	....	
for cooling:	Table 5.22	....	
for engines:	Chapter 5.5.4	....	
Total gas demand	Chapter 4.1		
a) percentage that must be provided by the biogas plant:		....	
b) desired demand coverage:		....	
Ratings: + Siting condition favorable			
o Siting condition unfavorable but compensable and/or not too			

serious			
- Siting condition not satisfied / not satisfiable			
Available biomass (kg/d) and potential gas production (l/d)	Chapter 3/4		
from animal husbandry	Table 3.2	....	
...pigs:	Table 3.5	....	
...poultry:	Table 4.3	....	
...cattle:	Figure 5.2	....	
Night soil	Table 3.2	....	
Vegetable waste (quantities and potential gas yield)	Table 3.3		
1..............................	Table 3.5	....	
2..............................			
Totals: biomass and potential gas production	Chapter 4.2		
a) easy to procure:		....	
b) less easy to procure:		....	
Balancing	Chapter 4.4		
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		....	

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	Chapter 5		
Selection of plant design	Chapter 5.3		
Locally customary type of plant:		....	
Arguments in favor of floating-drum plant:	Chapter 5.3.1	....	
Arguments in favor of fixed-dome plant:	Chapter 5.3.2	....	
Arguments in favor of other plant(s):	Chapter 5.3.3	....	
Type of plant chosen:		....	
Selection of site		....	
Ratings: + Siting condition favorable			
o Siting condition unfavorable but compensable and/or not too serious			
- Siting condition not satisfied / not satisfiable			
Availability of building materials			
Bricks/blocks/stone:		....	

Cement:		....	
Metal:		....	
Sand:		....	
Piping/fittings:		....	
Miscellaneous:		....	
Availability of gas appliances			
Cookers:		....	
Lamps:		....	
....		....	
....		....	
Overall rating 3			+ o -
4. Plant operation / maintenance / repair	Chapter 7		
Assessment of plant operation	Chapter 7.1		
Incidental work:	Chapter 7.2	....	
Work expenditure in h:		....	
Persons responsible:		....	
Rating with regard to anticipated implementation:			+ o -
Plant maintenance	Chapter 7.3		
Maintenance-intensive components:		....	
Maintenance work by user:	Table 7.2	....	
Maintenance work by external assistance:		....	

Rating with regard to anticipated implementation:			+ o -
Plant repair	Chapter 7.4		
Components liable to need repair:		....	
Repairs that can be made by the user:		....	
Repairs requiring external assistance:		....	
Requisite materials and spare parts:			
Rating with regard to expected			
repair services:			+ o -
Overall rating 4			+ o -
5. Economic analysis	Chapter 8		
Time-expenditure accounting	Chapter 8.2		
Time saved with biogas plant	Table 8.1	....	
Time lost due to biogas plant		....	
Rating:			
Ratings: + Siting condition favorable			
o Siting condition unfavorable but compensable and/or not too serious			
- Siting condition not satisfied / not satisfiable			
Microeconomic analysis	Chapter 8.3		
Initial investment:	Table 8.2	....	
Cost of operation/maintenance/repair:			

Cost of operation/maintenance/repair:		....	
Return on investment:energy, fertilizer, otherwise:		....	
Payback time (static):	Table 8.3	....	
Productiveness (static):		....	
Rating:			+ o -
Quality factors, useful socioeconomic effects and costs	Chapter 8.5		
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	Chapter 9		
Anticipated acceptance	Chapter 9.1		
Participation in planning and construction:		....	
Integration into agricultural setting:		....	
Integration into household: .		....	
Sociocultural acceptance:		....	
Rating:		....	
Establishing a dessemination strategy	Chapter 9.2		
Conditions for and chances of the professional craftsman approach:		....	+ o -

Conditions for and chances of the self-help oriented approach:		......	+ o -
General conditions for dissemination			
Project-executing organization and its staffing:	Chapter 9.3	......	
Organizational structure:		......	
interest and prior experience in biogas technology:		......	
Regional infrastructure for transportation and communication:		......	
material procurement:		......	
Craftsman involvement, i.e.	Chapter 9.4		
which activities:		......	
minimum qualifications:		......	
tools and machines:		......	
Training for engineers, craftsman and users:	Chapter 9.5	......	
Ratings: + Siting condition favorable			
o Siting condition unfavorable but compensable and/or not too serious			
- Siting condition not satisfied/not satisfiable			
Proprietary capital, subsidy/credit requirement			
on the part of	Chapter 9.6		
user:		......	
craftsmen:		......	
Rating:		......	+ o -
Overall rating 6		......	+ o -

Overall rating 6		......	+ o -
7. Summarization			
Siting conditions		No.	Rating
Natural/agricultural conditions		1	+ o -
Balancing the energy demand and the biogas production		2	+ o -
Plant design and construction		3	+ o -
Plant operation/maintenance/repair		4	+ o -
Economic analysis		5	+ o -
Social acceptance and potential for dissemination		6	+ o -
Overall rating of siting conditions			+ o -
Ratings: + Siting condition favorable			
o Siting condition unfavorable but compensable and/or not too serious			
- Siting condition not satisfied / not satisfiable			

Following assessment as in table 2.1, the biogas-plant site in question can only be regarded as suitable, if most of the siting factors have a favorable (+) rating. This applies in particularly to item 2, the positive energy balance, meaning that the potential biogas production must cover the gas demand.

If the favorable and unfavorable ratings are fairly well balanced, the more decisive factors should be re-evaluated to determine the extent to which supplementary measures could provide the missing conditions for building and operating a biogas plant despite some reservations but without injustifiable effort. Then, if the overall

evaluation does not swing toward the positive side, the plant should not be built. If the site is given a favorable rating, further planning hints can be taken from the following checklist.

2.3 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., ail in accordance with the above planning guide.

2. Stipulate the plant's 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, gasholder, 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**
- **cement/lime**
- **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
- workshops for metal (gasholder) and pipe installation.

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

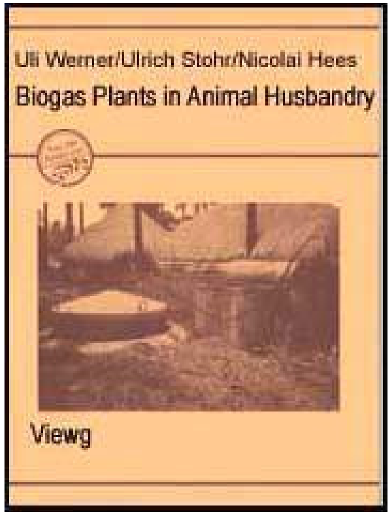
- excavation
- foundation slab
- digester masonry
- gasholder
- rendering and sealing the masonry
- mixing pit
- slurry storage pit
- drying out the plant
- installing the gas pipe
- acceptance inspection.

6. Regular building supervision.

7. Commissioning
- functional inspection of the biogas plant and its components - starting the plant

8. Filling the plant.

9. Training the user.



Biogas plants in Animal Husbandry (GTZ, 1989, 153 p.)

3. The agricultural setting

3.1 Natural parameters for biogas plants of simple design

Climate zones

A minimum temperature of 15 °C is required for anaerobic fermentation of organic material (cf. chapter 5.1). Since simple biogas plants are unheated, they can only be used in climatic zones in which the minimum temperature is not fallen short of for any substantial length of time. In general, this is true of the area located between the two tropics, i.e. in the geographic region referred to as the "Tropics".

In the climatic sense, however, the Tropics are inhomogeneous, containing various climatic zones with their own typical forms of vegetation and agricultural practices. Proceeding on that basis, it may be said that a particular zone does or does not qualify as a "biogas zone'' (cf. table 3.1).

With the exception of subtropical arid regions (deserts and semideserts), all tropical climates are characterized by:

- increasingly small diurnal and seasonal temperature variation in the direction of the equator,
- decreasing annual rainfall and number of humid months with increasing distance from the equator.

This basic zonal breakdown, though, is altered in several ways by other climatic factors such as wind, elevation and ocean currents. Consequently, the climatic zones serve only as a basis for rough orientation with regard to the climatic evaluation of potential sites for biogas plants. The locally prevailing climatic conditions are decisive and must be ascertained on the spot.

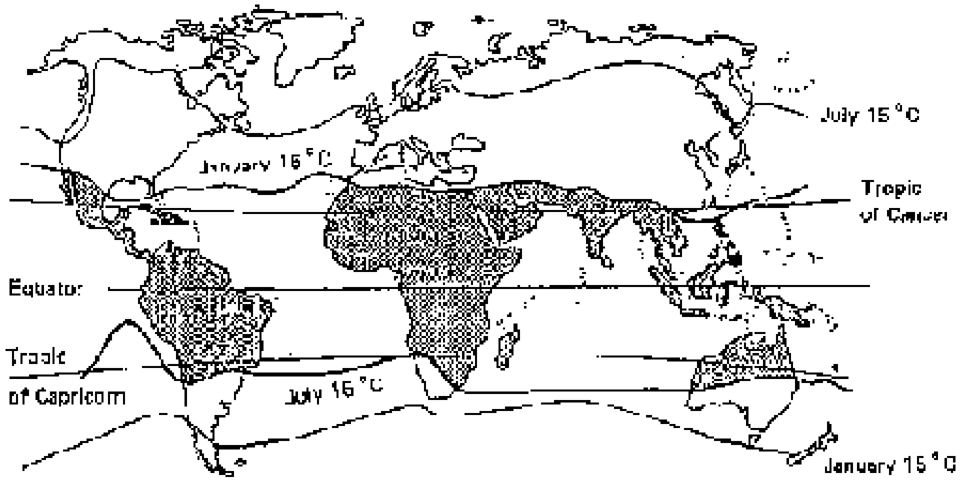


Fig. 3.1: Global 15ºC isotherms for January and July, indicating the biogas-conductive temperature zone (Source: OEKOTOP)

Table 3.1: Climatic zones and their suitability for biogas plants (Source: OEKOTOP)

Climatic zone	**Factors of relevance for biogas generation**	**As biogas zone:**
Tropical rain forest	Annual rainfall > 1500 mm;unfavorable	
	temperature fairly constant at 25-28 °C; little animal husbandry due to various diseases, i.e. scarcity of dung; vegetable waste from permacultures and gardening	
Wet savanna	Water usually available all year (rainfall: 800-1500 mm), livestock farming on the increase, integral farms (crop farming + livestock)	favorable
Dry	Short rainy season, long dry season; most livestock pastured, but	possible

savanna	some integral farming	
Thornbush steppe	Short rainy season (rainfall: 200400 mm) extensive-type pasturing (nomads, cattle farmers), dung uncollectable; shortage of water	unsuitable
Dry hot desert	- - -	unsuitable

Soil conditions

Since the digesters of simple biogas plants are situated underground, the temperature of the soil is of decisive importance. It depends on the surface structure, the type of soil and the water content. The soil temperature usually varies less than the air temperature, e.g. tropical soils show nearly constant temperature at a depth of 30-60 cm. Due to lower absorption, the temperature amplitude of light soils is smaller than of dark soils. Since moist soil appears darker than dry soil, the same applies with regard to temperature amplitude. As a rule of thumb, the region's mean annual temperature may be taken as the soil temperature in tropical areas.

For biogas plants with unlined digesters and/ or underground masonry, it is important to know the stability of the soil structure. The stability of a given soil increases along with the bedding density. Natural soils are generally stable enough for biogas plants. Caution is called for, however, in the case of alluvial and wet, silty soils. Most of the laterite soil prevailing in the tropics shows high structural stability and is therefore quite suitable for biogas plants with unlined digesters. Unlined earth pits usually become more or less impermeable within a short time, but preparatory seepage trials should be conducted in exploratory holes, just to make sure. Previous experience has shown that seepage can drop to

below 5% of the initial rate within a week. In the case of large-scale biogas plants, it is always advisable to have an expert check the soil stability.

Biogas plants should never be located in groundwater, areas subject to flooding, or near wells. On the other hand, an adequate supply of water must be available in the immediate vicinity of the biogas plant, because the substrate must be diluted. If the direction of groundwater flow is known, the biogas plant should be placed downstream of the well.

3.2 Suitable types of biomass and their characteristics

Practically any kind of watery organic substance is suitable for anaerobic digestion. The agricultural residues and waste materials that can be used as substrate for biogas plants consist chiefly of:

- waste from animal husbandry, e.g. dung, urine, fodder residue and manure, .
- vegetable waste, e.g. straw, grass, garden residue, etc. (though such materials do not ferment well alone),
- household waste like night soil, garbage, wastewater, etc.

Solid and liquid agroindustrial waste materials, from slaughterhouses for example, and wastewater from sugar/starch processing are not gone into here, since small-scale biogas plants of simple design would not suffice in that connection (cf. chapter 6).

Waste from animal husbandry

Most simple biogas plants are "fueled" with manure (dung and urine), because

such substrates usually ferment well and produce good biogas yields. Quantity and composition of manure are primarily dependent on:

- the amount of fodder eaten and its digestibility; on average, 40 - 80% of the organic content reappears as manure (cattle, for example, excrete approximately 1/3 of their fibrous fodder),

- quality of fodder utilization and the liveweight of the animals.

It is difficult to offer approximate excrement-yield values, because they are subject to wide variation. In the case of cattle, for example, the yield can amount to anywhere from 8 to 40 kg per head and day, depending on the strain in question and the housing intensity. Manure yields should therefore be either measured or calculated on a liveweight basis, since there is relatively good correlation between the two methods.

The quantities of manure listed in table 3.2 are only then fully available, if all of the anirnals are kept in stables all of the time and if the stables are designed for catching urine as well as dung (cf. chapter 3.3).

Thus, the stated values will be in need of correction in most cases. If cattle are only kept in night stables, only about 1/3 to 1/2 as much manure can be collected. For cattle stalls with litter, the total yields will include 2 - 3 kg litter per animal and day.

Table 3.2: Standard liveweight values of animal husbandry and average manure yields (dung and urine) as percentages of liveweight (Source: Kaltwasser 1980,

Williamson and Payne 1980)

Species	Daily manure yield as % of liveweight		Fresh-manure solids		Liveweight (kg)
	dung	urine	TS (%)	VS (%)	
Cattle	5	4-5	16	13	135 - 800
Buffalo	5	4-5	14	12	340-420
Pigs	2	3	16	12	30- 75
Sheep/goats	3	1 - 1.5	30	20	30 - 100
Chickens	4.5		25	17	1.5 - 2
Human	1	2	20	15	50- 80

Table 3.3: TS and VS-contents of green plants (Source: Memento de l'agronome 1984)

Material	TS	VS
	(%)	(% of TS)
Rice straw	89	93
Wheat straw	82	94
Corn straw	80	91
Fresh grass	24	89
Water hyacinth	7	75

Bagasse	65	78
Vegetable residue	12	86

Vegetable waste

Crop residue and related waste such as straw, cornstalks, sugar-beet leaves, etc. are often used as fodder and sometimes processed into new products, e.g. straw rnats. Consequently, only such agricultural "waste" that is not intended for some other use or for composting should be considered.

Most green plants are well-suited for anaerobic fermentation. Their gas yields are high, usually above that of manure (cf. table 3.5). Wood and woody parts of plants resist anaerobic fermentation and should therefore not be used in biogas plants. Due to the poor flow properties of plant material and its tendency to form floating scum, it can only be used alone in a batch-type plant. In practice, however, batch plants are unpopular because of the need for intermittent charging and emptying.

In continuous-type family-size biogas plants, crop residue therefore should only be used as an addition to animal excrements. Any fibrous material like straw has to be chopped up to 2 - 6cm - and even that does not fully preclude scum formation.

Table 3.4: Digestion characteristics of animal-husbandry residues (Source: OEKOTOP)

Substrate	Scum	Digestion	Recommended	Gas yield

	formation/ sedimentation			**retention time (days)**	**compared to cattle manure**
Cattle manure	none	none	very stable	60- 80	100%
ditto, plus 10% straw	heavy	slight	very stable	60-100	120%
Pig manure	slight to heavy	heavy to slight	Danger of "tilting", i.e. acidification, at the beginning; slow run-up with cattle manure necessary	40 - 60	200%
ditto, plus 10% straw	heavy	slight	ditto	60 - 80	. . .
Chicken manure	slight to heavy	heavy	Slow run-upwith cattle manure advisable; danger of "tilting"	80	200%
Sheep/gcat manure manure	medium to heavy	none	stable	80-100	80%

Table 3.5: Mean gas yields from various types of agricultural biomass (Source: OEKOTOP, compiled from various sources)

Substrate	Gas-yield range (1/kg VS)	Average gas yield (1/kg VS)
Pig manure	340-550	450

Cow manure	150-350	250
Poultry manure	310-620	460
Horse manure	200-350	250
Sheep manure	100-310	200
Stable manure	175-320	225
Grain skew	180-320	250
Corn straw	350-480	410
Rice straw	170-280	220
Grass	280-550	410
Elephant grass	330-560	445
Bagasse	140-190	160
Vegetable residue	300-400	350
Water hyacinth	300-350	325
Algae	380-550	460
Sewage sludge	310-640	450

Table 3.6: C/N-ratios of varios substrates (Source: Barnett 1978)

Substrate	**C/N**
Urine	0.8
Cattle dung	10-20

Pig dung	9-13
Chicken manure	5-8
Sheep/goat dung	30
Human excrements	8
Grain straw	80-140
Corn straw	30-65
Fresh grass	12
Water hyacinth	20-30
Vegetable residue	35

Digestion characteristics and gas yields

As long as the total solids content of the substrate does not substantially exceed 10%, simple biogas plants can be expected to operate smoothly on a mixture of animal excrements and plant material (straw, fodder waste).

Manure from ruminants, particularly cattle, is very useful for starting the fermentation process, because it already contains the necessary methanogenic bacteria. On the other hand, the gas yield from cattle dung is lower than that obtained from chickens or pigs, since cattle draw a higher percentage of nutrients out of the fodder' and the leftover lignin complexes from high-fiber fodder are very resistant to anaerobic fermentation. Urine, with its low organic content, contributes little to the ultimate gas yield but substantially improves the fertilizing effect of the digested slurry and serves in diluting the substrate.

The carbon(C)/nitrogen(N)-ratio of animal and human excrements is normally favorable for the purposes of anaerobic fermentation (9 - 25:1), while that of plant material usually indicates an excessive carbon content.

In many cases, various substrates should be mixed together in order to ensure a favorable gas yield while stabilizing the fermentation process and promoting gas production. The following formulae can be used to calculate the C/N-ratio and total-solids content of a given mixture:

MC/N = [(C/N1 x Wl) + (C/N2 x W2) + . . . + (C/Nn x Wn)]/(W1 + W2 + . . . + Wn)

MTS = [(TSI x Wl) + (TS2 x W2) + . . . + (TSn x Wn)]/(W1 +W2 + ... + Wn)

MC/N = C/N-ratio of mixed substrate, MTS = TS-content of mixed substrate, C/N = C/N-ratio of individual substrate, W = weight of individual substrate, TS = TS-content of fresh material.

3.3 Agricultural/operational prerequisites and stock-farming requirements

In order to fulfill the prerequisites for successful installation and operation of a biogas plant, the small farm in question must meet three basic requirements regarding its agricultural production system:

- availability of sufficient biomass near the biogas plant,
- use for digested slurry as fertilizer,
- practical use(s) for the biogas yield.

Farms marked by a good balance between animal husbandry and crop farming offer good prerequisites for a biogas tie-in. Unfortunately, however, such farms are rare in tropical countries. In numerous Third World countries, animal husbandry and stock farming are kept separate by tradition.

As the world population continues to grow, and arable land becomes increasingly scarce as a result, the available acreage must be used more intensively. In wet savannas, for example, the fallow periods are being shortened, even though they are important for maintaining soil fertility. In order to effectively counter extractive agriculture, animal husbandry must be integrated into the crop farming system, not least for its fertilizing effect. On the other hand, systematic manuring is only possible as long as collectible dung is allowed to accumulate via part-time or full-time stabling.

The installation of a biogas plant can be regarded as worthwhile, if at least 20-40 kg manure per day is available as substrate. This requires keeping at least 3 - 5 head of cattle, 8-12 pigs or 16-20 sheep/goats in a round-the-clock stabling arrangement. The achievable gas yield suffices as cooking fuel for a family of 4-6 persons. That, in turn, means that the farm must be at least about 3 hectares in size, unless either freely accessible pastures are available or extra fodder is procured. Crop residue like rice straw, sorghum straw, cornstalks, banana stalks, etc. should be chopped up, partially composted and mixed with animal excrements for use in the fermentation process (cf. chapter 3.2).

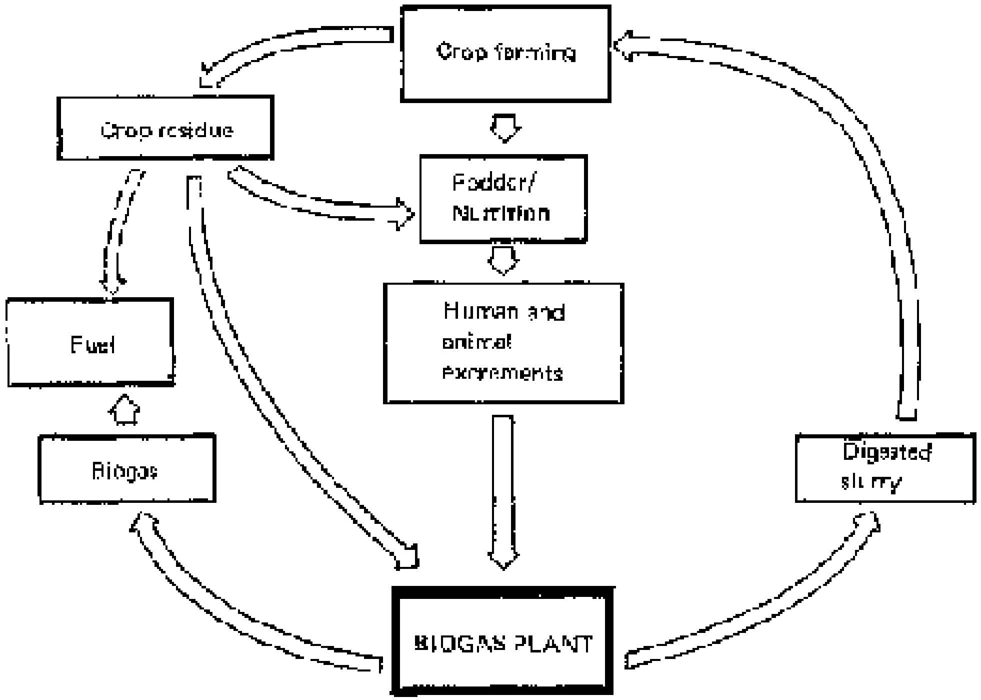


Fig. 3.2: Integration of a biogas plant into the agricultural production cycle (Source: OEKOTOP)

Table 3.7: Biogas compatibility of farm types (Source: OEKOTOP)

Type of farm	Characteristics of relevance to biogas generation	Rating as site for biogas plant
Stock farming only	Pasturing (nomadic, ranching, etc.) Intensive stationary fattening	unsuitable suitable
Crop farming only	Crop residue only; fermentation difficult	normally unsuitable

Mixed Agriculture		
Stock farming for:		
- animal power	Mostly nighttime stabling; only a few animals; 50% of dung collectible	possible
- meat production		
extensive	Pasturing; no stabling; dung wasted	unsuitable
intensive	Fattening in stables; dung directly usable	suitable
- milk production	Frequently permanent stabling; all dung and urine usable	suitable
Crop farming:		
- vegetables	Near house; crop residue and water available year-round	possible!
- field-tilling		
unirrigated	1 harvest per year, scarcity of fodder, long-distance hauling of water and manure	unsuitable
irrigated	2-3 harvests per year; water available, small fields	possible

Adding a biogas plant to an integrated agricultural production system not only helps save firewood and preserve forests, but also contributes toward sustained

soil fertility through organic fertilization and ensures the long-term crop-bearing capacity of the soil. Work involving the dissemination of biogas. technologies must account for and call attention to that complex relationship. If no organic fertilizing has been done before, a biogas plant will mean more work. Organic waste has to be collected and afterwards spread on the fields. Only if the owner is willing to invest the extra effort can the biogas plant be expected to serve well in the long term.

There are two central demands to be placed on the stock-farming system in relation to biogas utilization:

- permanent or part-time stabling or penning and
- proximity of the stables or pens to the place of gas utilization (usually the farmhouse).

If the distance between the stables/pens and the place of gas utilization is considerable, either the substrate must be hauled to the biogas plant (extra work) or the gas must be transferred to the place of use (cost of installing a supply pipe). Either of the two would probably doom the biogas plant to failure. The best set of circumstances is given, when

- the animal excrements can flow directly into the biogas plant by exploiting a natural gradient,
- the distance of flow is short, and
- the stables have a concrete floor to keep contamination like soil and sand from getting into the plant while allowing collection of urine.

Cattle pens

Dung from earth-floor pens has a very high total-solids content (TS up to 60%), and the urine is lost. Daily collection is tedious and there is no way to prevent sand from getting into the digester. Consequently, at the same time a biogas plant is being installed, concrete floors should be installed in such pens and provided with a collecting channel. This increases the total cost of the biogas plant, but is usually justified, since it lowers the subsequent work input, helps ensure regular feeding of the plant, reduces the chance of hoof disease and keeps sand and stones out of the digester. The overall effect is to enhance acceptance of the biogas plant.

The collecting channels can be designed as open gutters or covered ducts. Concrete split tiles serve well as construction material for the second (more expensive) version. The slots should be about 2 - 3 cm wide, i.e. wide enough to let the dung pass through, but not wide enough to cause injury to the animals.

Cattle dung dries rapidly in a hot climate, particularly if the pen has no roof. The cleaning water also serves to liquefy the dung and reduce its TS content to 5-10%. for the purposes of fermentation. The main advantage of this system is that the pens can be cleaned and the biogas plant filled in a single operation. The collecting channel should be designed to yield a floating-manure system with gates at the ends, so that a whole day's dung and cleaning water can collect at once. The advantages:

- easy visual control of the daily substrate input,
- prevention of collecting-channel blockage due to dung sticking to the walls and

drying out,

- adding the substrate at the warmest time of day, which can be very important in areas with low nighttime temperatures.

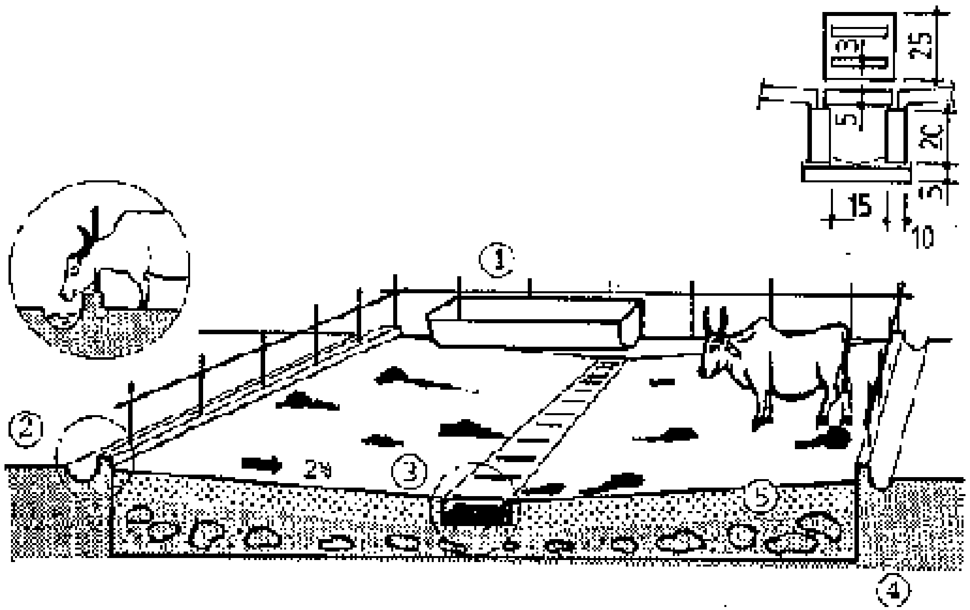


Fig. 3.3: Pen with concrete floor and collecting channel for dung and urine.

1. Water through, 2 Feeding through, 3 Collecting channel, 4 Sand and rocks, 5 Concrete (Source: OEKOTOP)

Intensive forms of animal husbandry often involve the problem of excessive water consumption for cleaning, which leads to large quantities of wastewater, dilute substrate and unnecessarily large biogas plants (cf. chapter 6). In areas where water is scarce, the digester drain-water can be used for scrubbing down the pens and diluting the fresh substrate, thus reducing the water requirement by 30-40%.

Stables

Differentiation is generally made between:
- stabling systems with litter and
- stabling systems without litter, with the design details of the stalls appropriate to the type of animal kept.

For use in a biogas plant, any straw used as litter must be reduced in size to 2-6 cm. Sawdust has poor fermenting properties and should therefore not be used.

Cattle shelter

Variants suitable for connection to a biogas plant include:
- Stanchion barns with a slurry-flush or floating removal system (no litter) or dung collecting (with litter),
- Cow-cubicle barns with collecting channel (no litter).

Piggeries

The following options are well-suited for combination with a biogas plant:
- barns with fully or partially slotted floors (no litter),
- lying bays with manure gutter (no litter),
- group bays (with or without litter).

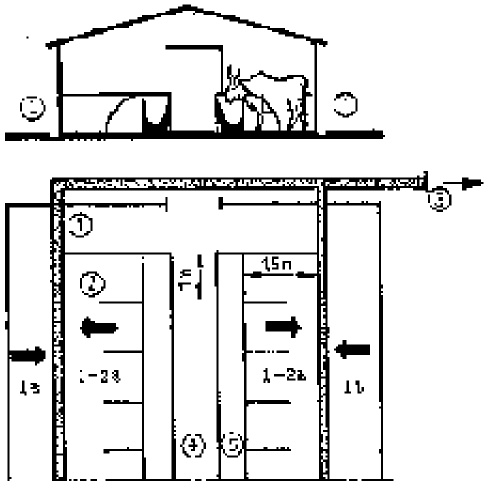


Fig. 3.4: Stanchion barn with floating gutter. 1 Collecting channel, 2 Stable, 3 Floating gutter leading to the biogas plant, 4 feeding aisle, 5 Feeding trough (Source: OEKOTOP)

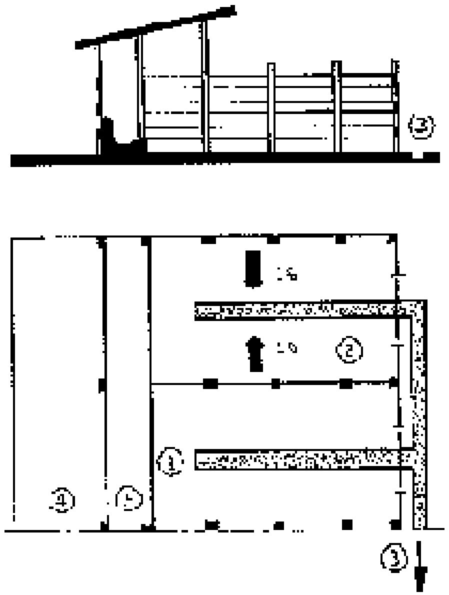


Fig. 3.5: Cow-cubicle barn with floating gutter. 1 Collecting channel, 2 Cubicle, 3 Floating gutter leading to the biogas plant, 4 Feeding aisle, 5 Feeding trough

(Source: OEKOTOP)

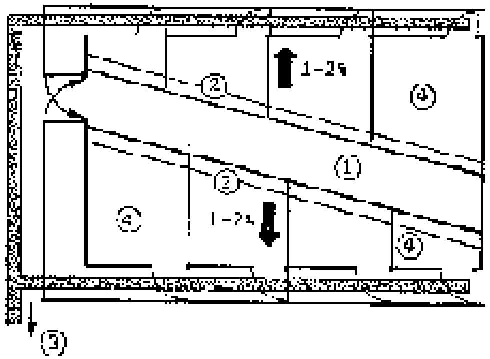


Fig. 3.6: Piggery with group bays (no litter). 1 Feeding aisle, 2 Feeding trough, 3 Floating gutter leading to the biogas plant, 4 Bay (pigpen) (Source: Manuel et Preas D levage No. 3, 1977)

Liquid manure from swine normally has better flow properties than liquid manure from cattle, the main reason being that swine eat less fibrous material. Additionally, though, swine drop more urine than dung.

In tropical countries, few pigsties have fully or partially slotted floors. Most pigs are kept in group bays. Figure 3.6 shows a schematic representation of a piggery with bays of different size to accommodate animals of various weight categories. The animals are moved in groups from one bay to the next as they grow.

Chicken coops

Hens kept in battery-brooding cages never have litter. Despite the name, straw yards can be managed with or without litter.

In either system, the dry droppings are collected, transferred to the biogas plant

and diluted to make them flowable. Feathers and sand are always problematic, since they successfully resist removal from the substrate. In many cases, the coop is only cleaned and disinfected once after the entire population is slaughtered. As a rule such systems are not suitable as a source of substrate for biogas plants.

3.4 Fertilizing with digested slurry

The practice of regular organic fertilizing is still extensively unknown in most tropical and subtropical countries. Due, however, to steady intensification of agricultural methods, e.g. abbreviated fallow intervals, some form of purposeful organic fertilizing, naturally including the use of digested slurry as fertilizer, would be particularly useful as a means of maintaining tropical soil fertility. Since Third World farmers have little knowledge of or experience in organic fertilizing methods, particularly with regard to the use of digested slurry, the scope of the following discussion is limited to the general plantgrowth efficiency factors of digested slurry.

Fermentation-induced modification of substrate

- Anaerobic digestion draws carbon, hydrogen and oxygen out of the substrate. The essential plant nutrients (N, P, K) remain, at least in principle, in place. The composition of fertilizing agents in digested slurry depends on the source material and therefore can be manipulated within certain limits.

- For all practical purposes, the volume of the source material remains unchanged, since only some 35 - 50% of the organic substances (corresponding to 5 - 10% of the total volume) is converted to gas.

- Fermentation reduces the C/N-ratio by removing some of the carbon, which has the advantage of increasing the fertilizing effect. Another favorable effect is that organically fixed nitrogen and other plant nutrients become mineralized and, hence, more readily available to the plants.

- Well-digested slurry is practically oderless and does not attract flies.

- Anaerobic digestion kills off or at least deactivates pathogens and worm ova, though the effect cannot necessarily be referred to as hygienization (cf. Table 3.8). Ninety-five percent of the ova and pathogens accumulate in the scum and sediment. Plant seeds normally remain more or less unaffected.

- Compared to the source material, digested slurry has a finer, more homogeneous structure, which makes it easier to spread.

Table 3.8: Survival time of pathogens in biogas plants (Source: Anaerobic Digestion 1985)

Bacteria	Thermophilic fermentation		Mesophilic fermentation		Psycrophilic fermentation	
	53-55 °C		35-37 °C		8-25 °C	
	Fatality		Fatality		Fatality	
	Days	Rate	Days	Rate	Days	Rate
		(%)		(%)		(%)
Salmonella	1-2	100.0	7	100.0	44	100.0
Shigella	1	100.0	5	100.0	30	100.0

Shigella	1	100.0	5	100.0	30	100.0
Poliviruses			9	100.0		
Schistosoma ova	hours	100.0	7	100.0	7-22	100.0
Hookworm ova	1	100.0	10	100.0	30	90.0
Ascaris ova	2	100.0	36	98.8	100	53.0
Colititre	2	10^{-1} - 10^{-2}	21	10^{-4}	40-60	10^{-5} -10^{-4}

Table 3.9: Concentration of nutrients in the digested slurry of various substrates! (Source: OEKOTOP, compiled from various sources)

Type of substrate	**N**	**P_2O_5**	**K_2O**	**CaO**	**MgO**
	—% TS—				
Cattle dung	2.3 - 4.7	0.9 - 2.1	4.2 - 7.6	1.0 - 4.2	0.6 - 1.1
Pig dung	4.1 - 8.4	2.6 - 6.9	1.6 - 5.1	2.5 - 5.7	0.8 - 1.1
Chicken manure	4.3 - 9.5	2.8 - 8.1	2.1 - 5.3	7.3 - 13.2	1.1 - 1.6

Fertilizing properties

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. The organic content of digested slurry improves

the soil's texture, stabilizes its humic content, intensifies its rate of nutrient-depot formation and increases its water-holding capacity. It should be noted that a good water balance is very important in organically fertilized soil, i.e. a shortage of water can wipe out the fertilizing effect.

Very few data on yields and doses are presently available with regard to fertilizing with digested slurry, mainly because sound scientific knowledge and information on practical experience are lacking in this very broad domain. Table 3.10 lists some yield data on digested-slurry fertilizing in the People's Republic of China.

For a practician faced with the task of putting digested slurry to good use, the following tendential observations may be helpful:

- While the nitrogen content of digested slurry is made more readily available to the plants through the mineralization process, the yield effect of digested slurry differs only slightly from that of fresh substrate (liquid manure). This is chiefly attributable to nitrogen losses occurring at the time of distribution.

- Digested slurry is most effective when it is spread on the fields just prior to 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, lettuce and vegetables should not be top-dressed.

- The recommended quantities of application are roughly equal for digested slurry and stored liquid manure.

- The requisite amount of digested-slurry fertilizer per unit area can be determined

as a mineral equivalent, e.g. N-equivalent fertilization. The N, P and K doses depend on specific crop requirements as listed in the appropriate regional fertilizing tables.

With a view to improving the overall effect of slurry fertilizer under the prevailing local boundary conditions, the implementation of a biogas project should include demonstration trials aimed at developing a regionally appropriate mode of digested-slurry application. For information on experimental systems, please refer to chapter 10.6 - Selected Literature.

Proceeding on the assumption that the soil should receive as much fertilizer as needed 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, say, 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 slurry 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 m³ biogas plant.

Like all other forms of organic fertilizing, digested slurry increases the humic content of the soil, and that is especially important in low-humus tropical soils. Humus improves the soil's physical properties, e.g. its aeration, water retention capacity, permeability, cation-exchange capacity, etc. Moreover, digested slurry is a source of energy and nutrients for soil-inhabiting microorganisms, which in turn make essential nutrients more available to the plants. Organic fertilizers are indispensable for maintaining soil fertility, most particularly in tropical areas.

Table 3.10: Effects of digested slurry on crop yields (Source: Chengdu 1980)

Plants tested	**Quantity of digested slurry**	**Yield**		**Increase**	
		with digested slurry	**with liquid manure**		
	(m³ /ha)	**(kg/ha)**		**(kg/ha)**	**(%)**
Sweet potatoes	17	24000	21500	21500	12
Rice	15	6500	6000	500	8
corn (maize)	22.5	5000	4600	400	9
Cotton	22.5	1300	1200	100	8

The importance of digested slurry as a fertilizer is underlined by the answers to the following questions:

- How much chemical fertilizer cap be saved with no drop in yield?

- Which yield levels can be achieved by fertilizing with digested slurry, as compared to the same amount of undigested material, e.g. stored or fermented liquid manure?

- By how much can yields be increased over those from previously unfertilized soil? Depending on those answers, a certain monetary value can be attached to digested slurry, whereas the labor involved in preparing and applying the fertilizer must be given due consideration.

Storing and application of digested slurry

With a view to retaining the fertilizing quality of digested slurry, it should be stored only briefly in liquid form in a closed pit or tank and then applied to the fields. Liquid storage involves a certain loss of nitrogen due to the evaporation of ammonia. For that reason, and in order to limit the size of the required storage vessels (a 30-day supply corresponds to about 50% of the biogas plant volume), the storage period should be limited to 2-4 weeks. The resultant quasi-continuous mode of field fertilization (each 2-4 weeks), however, is in opposition to the standing criteria of optimum application, according to which fertilizer should only be applied 2-4 times per year, and then only during the plants' growth phase, when they are able to best exploit the additional nutrient supply.

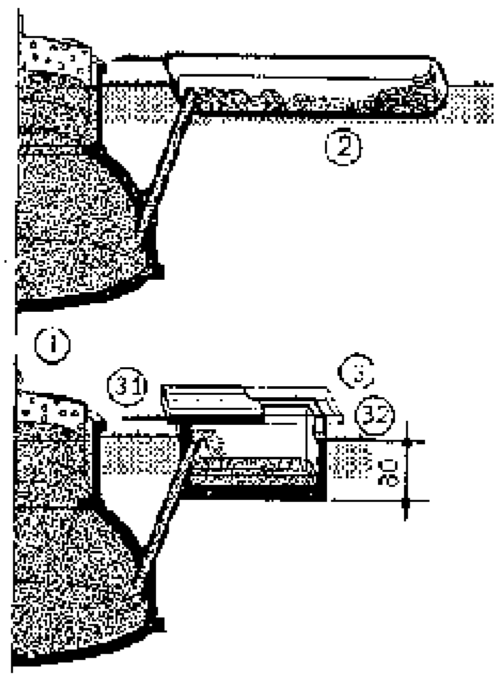


Fig. 3.7: Slurry storage and composting. 1 Biogas plant, 2 Slurry composting pit

with green cover 3 Masonry storage pit (V = 10 Sd), 31 Sturdy wooden cover, 32 Overflow (Source: OEKOTOP)

The practice of spreading liquid digested slurry also presents problems in that not only storage tanks are needed, but transport vessels as well, and the amount of work involved depends in part on how far the digested slurry has to be transported. For example, transporting 1 ton of dung a distance of 500 m in an oxcart takes about 5 hours (200 kg per trip). Distributing the dung over the fields requires another 3 hours or so.

If, for reasons of economy and efficiency, liquid fertilizing should appear impractical' the digested slurry can be mixed with green material and composted. This would involve nitrogen losses amounting to 30 - 70%. On the other hand, the finished compost would be soil-moist, compact (spade able) and much easier to transport.

If irrigated fields are located nearby, the digested slurry could be introduced into the irrigating system so that it is distributed periodically along with the irrigating water.

3.5 Integral agriculture

Integral agriculture, also referred to as biological or ecological farming, aims to achieve effective, low-cost production within a system of integrated cycles. Here, biogas technology can provide the link between animal husbandry and crop farming.

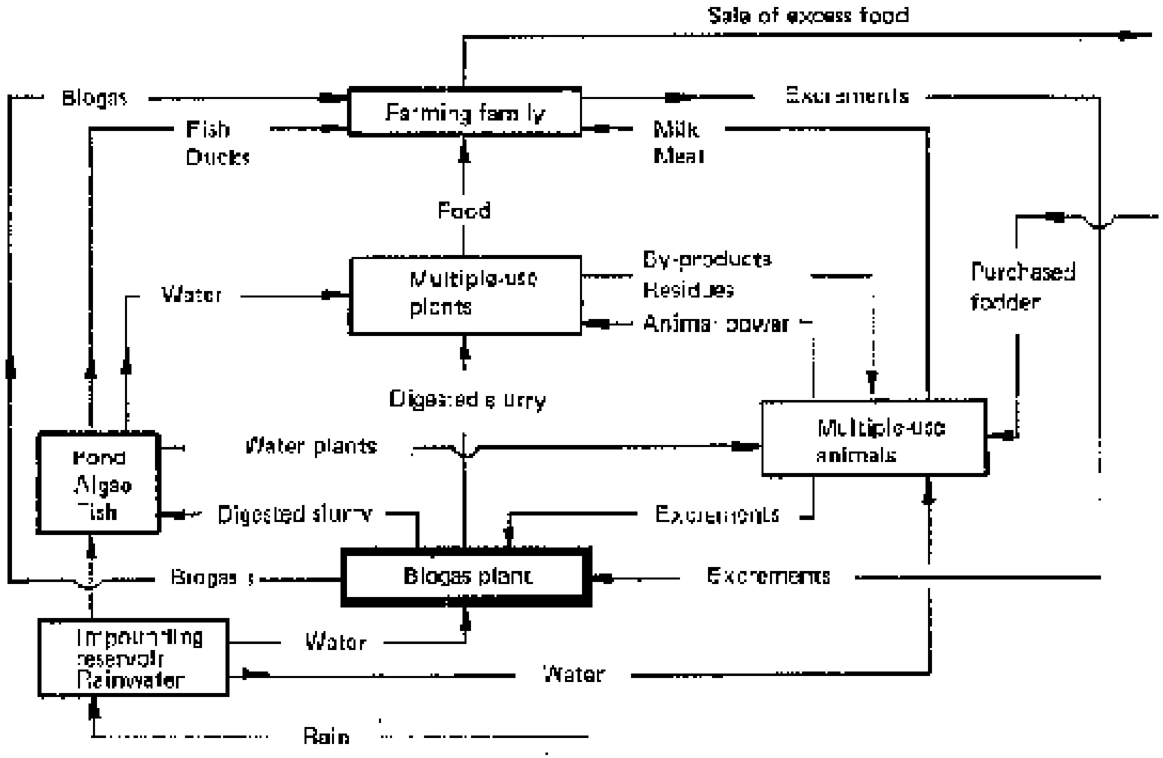


Fig. 3.8: Flow diagram for integral farming with a biogas plant (Source: GTZ 1985)

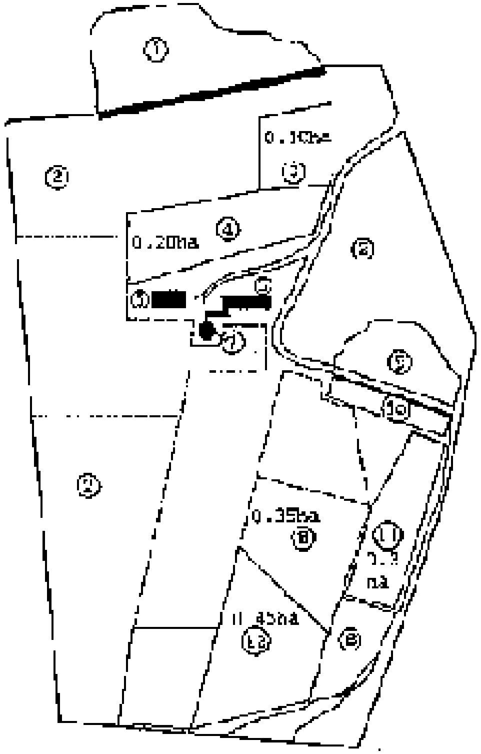


Fig. 3.9: Site plan of the Bouak Ecofarm in Cte d'lvoire. 1 Impounding reservoir for rainwater, 2 Fallow land, 3 Manioc (1st year), 4 Yams and Manioc (2nd year), 5 Farmhouse, 6 Stables, 7 Biogas plant, 8 Sugar cane, 9 Water reservoir, 10 Fishpond, 11 Vegetable garden, 12 Various food plants (Source: GTZ 1985)

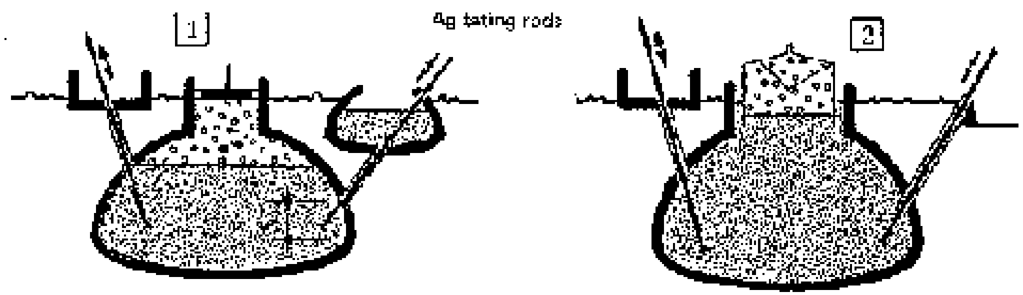
Consider, for example, the planning of a GTZ project in Cote d'Ivoire. The project included the development of a model farm intended to exploit as efficiently as possible the natural resources soil, water, solar energy and airborne nitrogen.

The integral agricultural system "Eco-ferme" (ecofarm) comprises the production elements gardening, crop farming (for food and animal fodder), stock farming (for meat and milk) and a fishpond. A central component of such closed-loop agricultural production is the biogas plant, which produces both household energy

and digested slurry for use in the fishpond and as a fertilizer.

The average family-size "eco-ferme" has 3 ha of farmland with the following crops:

Fodder plants	
Panicum (for the rainy season)	0.15 ha
Sugar cane (for the dry season)	0.50 ha
Leucaena and brachiaria (mixed culture)	0.50 ha
Panicum, brachiaria and centrosema (mixed culture)	0.50 ha
Food plants	
Manioc	0.20 ha
Corn	0.40 ha
Yams	0.10 ha
Potatoes - beans	0.10 ha
Vegetables	0.20 ha
Rice and miscellaneous crops	0.17 ha



Figure

Four milk cows and three calves are kept year-round in stables. The cattle dung flows via collecting channels directly into a 13 m^3 biogas plant. The biogas plant produces 3.5-4 m^3 biogas daily for cooking and lighting. Part of the digested slurry is allowed to flow down the natural gradient into an 800 m^2 fishpond in order to promote the growth of algae, which serves as fish food. The remaining digested slurry is used as crop fertilizer.