

Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?

Matthias Plöchl and Monika Heiermann

Leibniz Institute of Agricultural Engineering Potsdam-Bornim, Max-Eyth-Allee 100,
14469 Potsdam, Germany, mploechl@atb-potsdam.de

ABSTRACT

In this contribution we want to look at the chances of biogas production as a renewable energy source especially in rural regions and the developing countries. The recent development in Europe is taken as example of the opportunities of biogas technology. And we want to focus on the opportunities to include residues of crop production but also especially cultivated energy crops into the feedstock for anaerobic digestion. Further the appropriate scale of biogas production should be raised as well as the most appropriate pathway for the conversion of biogas to usable energy. There are many options, like conversion to electricity and heat, to transform this heat to coldness, to purify and to compress the gas and use it for cooking, refrigerating or as car fuel. Finally it is discussed how and what is transferable of the European experiences to the developing world.

Keywords. Anaerobic digestion, Biogas, Energy farming, Utilisation of biogas

1. INTRODUCTION

Beside of water, energy is the crucial resource demanded for the further development in many parts of the world and especially in developing countries. In order to prevent further climate change the growth of the energy market should be based on renewable sources. Renewable energies are usually small-scale and distributed systems and rely on many different sources. It is also a question whether the systems used in developed countries are directly transferable to developing countries.

Although biogas technology has been subject to development aid and energy policy in several countries biogas only delivers small fractions of energy consumption in these countries (Akinbami et al., 2001; Omer and Fadalla, 2003; Reddy, 2003). E.g. in 2000 only 0.32% of rural households in India use biogas for cooking and water heating (Reddy, 2003). There are many reasons of economic, technical and social background for the marginal use of biogas (Akinbami et al., 2001) of which the height of investment costs is certainly of great significance. Therefore national and international programmes should emphasize on applicable subsidy schemes.

But on the other hand biogas plants in developing countries have a low efficiency – approx. 0.5 m³ biogas per m³ digester volume – especially compared to biogas plants in Europe – approx. 1.0 m³ biogas per m³ digester volume. Biogas plants also demand a certain effort of maintenance and control which often doesn't meet the literacy skills of rural population.

In contrast, in Central and Northern Europe, namely Switzerland, Germany, Austria, The Netherlands, Denmark, Sweden, the anaerobic digestion has considerably increased during recent years. Especially in Germany and Austria production of biogas and other renewable energy sources has been linked strongly to agriculture. Therefore, it is increasingly talked of energy farming and biogas farming in particular (NorthSeaBioEnergy, 2005).

Facing this European trend, it should be tried to answer the question whether it is possible to transfer the sophisticated biogas technology available in Europe to developing countries to implement structures or to use existing structures able to handle these installations. Or at least technology should be developed combining both the efficiency of European biogas plants and the simplicity, i.e. absence of moving parts prone to failure.

In the following brief overview will be given on existing biogas technology in developing countries, current and approaching technology of biogas production and utilisation in Europe will be given. In a further section it is tried to show possible development in the biogas sector with regard to developing countries.

2. TECHNOLOGY OF ANAEROBIC DIGESTION

2.1 Up-to-now Biogas Technology in Developing Countries

During recent years of biogas production three major types of digesters have emerged in developing countries: the Chinese fixed dome digester (Fig. 1) and the Indian floating drum digester (Fig. 2) and very recently tube digesters (Fig. 3). These digesters are usually in the size to convert the human and animal waste of one household and to deliver the energy demand of this household for cooking and lightning. I.e. the average volume of the digester is approx. 5 - 10 m³ and delivers approx. 0.5 m³ biogas per m³ digester volume (Akinbami et al., 2001; Omer and Fadalla, 2003). The floating cover digester is constructed with concrete and steel, whereas the fixed dome digester is usually build with the locally available materials, which even can be bricks. Tube digesters are constructed with folded polyethylene foils and porcelain pipe as inlet and outlet.

Although there are substantial differences between these types of digester their working principle is very much the same. The feedstock enters through the inlet pipe either directly or after a mixing pit the digester tank. This is either a one-compartment tank or a two-compartment one where the substrate has an average retention time of 10 to 30 days. The gas is collected above the slurry and leaves the tank through a gas pipe in the top of the cover. In the case of the fixed dome type, the top is made of concrete or bricks and as the rest of the digester below ground. The floating cover type has steel cover floating on the slurry, which is above ground, whereas the rest of the digester is also below ground. The digested slurry leaves the digester through an outlet pipe and is collected in an outlet pit or a displacement tank.

Each type of digester does not have facilities for agitating the slurry or for maintaining a certain temperature in the digester and controlling it. There are also no facilities to remove sand, stones or other inert materials, which will, over some years, decrease considerably the volume of the digester and hence will reduce its efficiency. It is also expected that the concentration of non-degradable organics increase and that these will build either a sludge sinking to ground or a crust at the top of the slurry both reducing the effective volume of the digester and the latter even blocking the gas flow to the gas storage. The expansion of inert and non-degradable material

makes it necessary to stop the process from time to time and to remove these materials. The very low cost of the tube digesters makes it rather easy to exchange this in the case of increasing inefficiency.

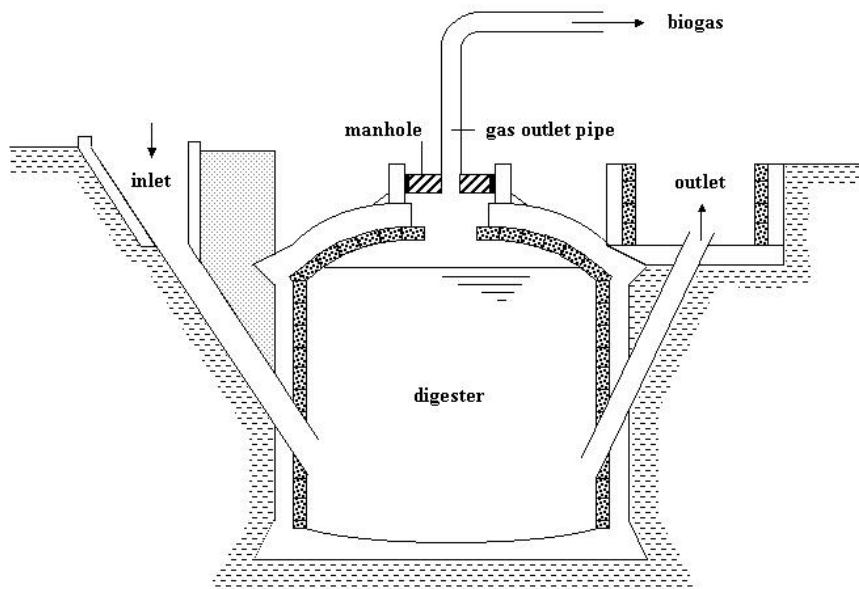


Figure 1. Fixed dome digester (Chinese type), slurry, dung and night soil are added through the inlet pipe (left), the digested slurry can be intermediately stored in the outlet pit from where it can be taken for fertilisation. The gas is stored above the digesting slurry, because of the limited space the opening and the gas outlet pipe have to be sealed carefully. The digester can be build of different material e.g. clay for the outer wall and brick stones for the inner wall (figure adopted from Gunnerson and Stuckey, 1986).

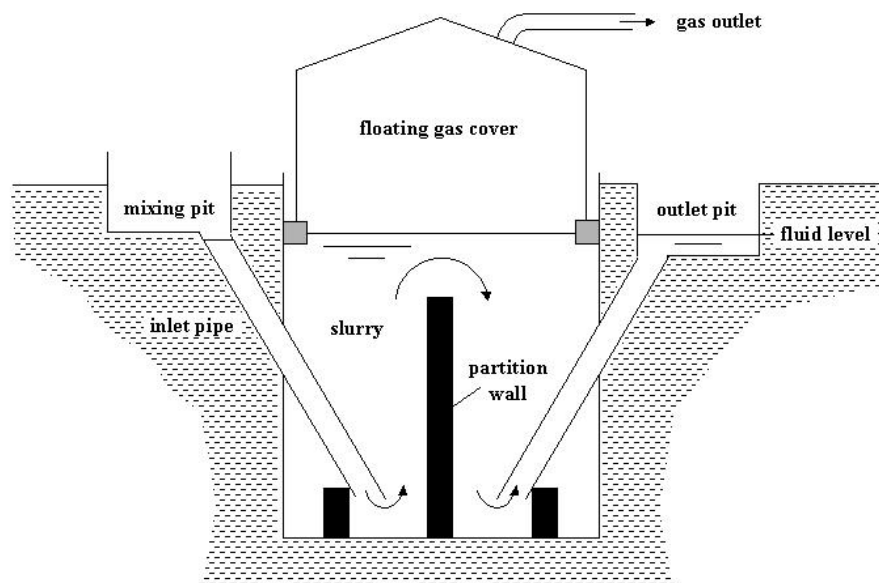


Figure 2. Floating cover digester (Indian type), slurry, dung and night soil are collected in a mixing pit from where the slurry enters the digester through the inlet pipe. In the example shown

here there is a partitioning wall between inlet and outlet. The digested slurry is collected in a outlet pit. In difference to the Chinese type the gas storage is a floating gas cover, which allows to enlarge or to diminish the space of gas storage depending on the amount of gas produced. As this gas cover is made of steel there is less risk of uncontrolled gas outflow (figure adopted from Gunnerson and Stuckey, 1986).

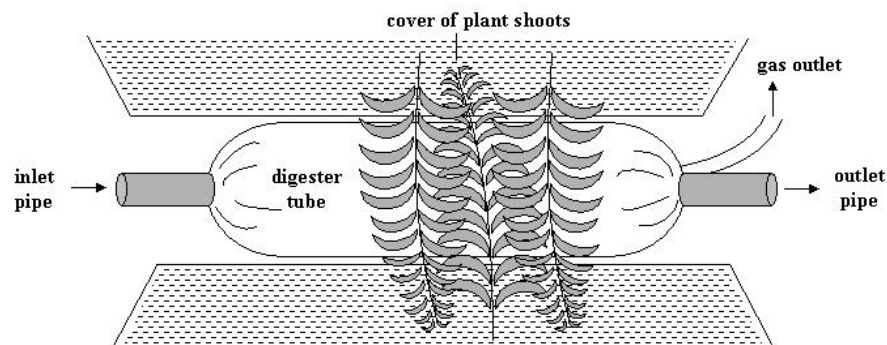


Figure 3. Tube digester: slurry, dung and night soil enter the digester through the pipe on the one side. The substrate flows slowly through the tube while the biogas is formed and transferred through a separate pipe to its storage. Liquid digested slurry quits the digester through the pipe on the other side, whereas non-digested solids stay in the tube. The tube is usually covered with plant shoots like palm leaves or banana leaves to prevent a destruction of the foil.

Nevertheless, the digesters described have also considerable advantages, they

- are inexpensive compared to sophisticated systems
- can be built with locally available material
- are easy to handle
- do not have moving parts prone to failure

2.2 Biogas Technology in Europe

2.2.1 Overview

In Europe the biogas sector is mainly linked to agriculture (Holm-Nielsen and Al Saedi, 2001). About 30 years ago the development and construction of first biogas plants was due to remove the odour of animal waste, but also to provide electric energy and heat to farms. These first installations were with sizes of approx. 50 - 100 m³ digester volume and 10 - 20 kW electric power of the attached combined heat and power facilities (CHP) quite small compared to nowadays biogas plants. Soon it was recognised that the evaluation of biogas could be enhanced through adding other organic wastes, like residues from food processing or large-scale kitchens, to the digester. This also led to the development that the sale of electricity became the main purpose of the biogas plants and these increased in size. In areas with quite small farms biogas plants were set-up as cooperative and/or centralised ventures. The scale of biogas plants also

increased. Nowadays on large farms or centralised plants have two or three digesters of several thousand cubic metres volume and CHPs with an electrical capacity level of 500 to 1,000 kW.

2.2.2 Digester Technology

In Europe digesters are mainly made of concrete with a steel skeleton or of steel. Their sizes vary between 500 and 3,000 m³, although there are still smaller units for small farms. The digesters have usually a cylindrical form standing upright in most cases. Not only because of the climatic conditions in Europe but also in order to control temperature conditions inside the digester tanks are equipped with an insulation and a heating system. Digesters are also equipped with a system to agitate or to stir the digesting slurry. There are many systems available to stir the system: some with slow moving propellers stirring for longer periods or such with fast turning propellers switched on only for short periods; others use the biogas pressed through the slurry for agitation (Fig. 4). The biogas is collected either in an external plastic bag or in the space above the slurry covered with a folio.

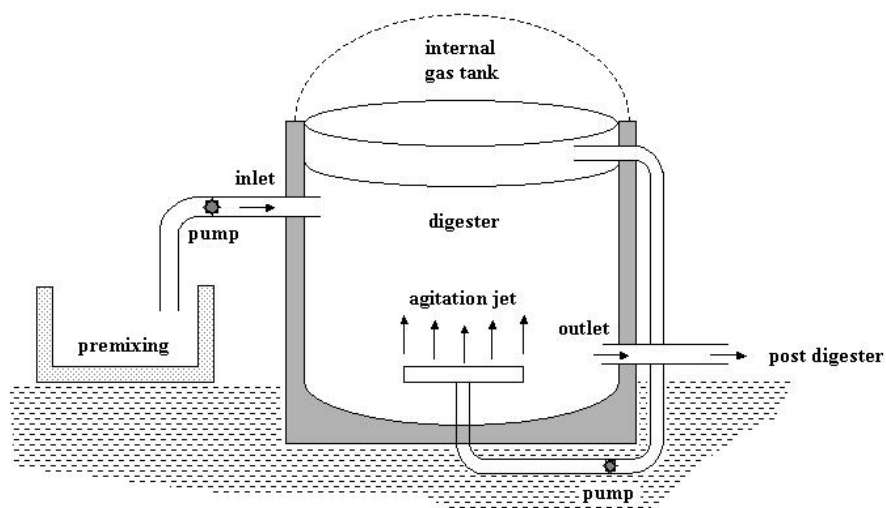


Figure 4. Digester for wet anaerobic digestion (European example), slurry, organic waste, crop residues and energy crops are added to the mixing pit from where the feedstock is pumped into the digester tank. The slurry in the digester tank is stirred (not shown here) or agitated by pressurised biogas (shown here). Digested slurry is pumped from digester to post digesting or storage. The digester is usually made of reinforced concrete, the pipes are made of steel, inlet and outlet are controlled with pumps. Gas storage is often made of impermeable folios covering the digesters and storage tanks.

These digesters are flow through systems, which are fed several times per day. In the case of agricultural biogas plants the slurry comes directly from the stables or is collected in small storages before entering the digester. There is often a premixing pit where other feedstock can be added to the slurry. Sometimes the bulk feedstock can be added directly to the digester through an extra input system. The outlet works in parallel to the inlet. The digested slurry is often pumped to a post digester and/or to a storage tank. These storage tanks must have, by national legislation, the capacity to store the slurry for several, often six to nine, months.

The average retention time in the main digester is usually approx. 28 days. But it can be easily demonstrated that, especially if crops and crop residues were added, biogas evaluation can be detected still after 90 days. Therefore, at many biogas plants it is worked with a post digester and/or the slurry storage tank is also covered with a foil, which works as gas storage. During post-digesting process and storage approx. 30% of the total biogas evaluation is captured.

One of the trace gases in biogas is hydrogen sulphide, which converts during combustion to sulphurous acid. This acid leads to enhanced corrosion of the engines therefore hydrogen sulphide is removed from the biogas. This can be done either through controlled inflow of air to the digester where hydrogen sulphide or it is removed by external filters.

In addition to the described technology of wet anaerobic digestion there is a growing interest in dry anaerobic digestion (Köttner, 2002). The wet technology works with slurries of less than 12% dry matter content whereas the dry process can handle dry matter contents of 30% and more which would enable the user to use mainly crops and crop residues as feedstock. In the past dry anaerobic digestion was limited to waste processing biogas plants. Dry continuous-flow systems are very expensive and the income from waste disposal fees was necessary for an economic business. In recent times a number of batch technologies have been developed for dry anaerobic digestion which are less expensive in investment costs. But these are still lacking proof that they working with sufficient efficiency and acceptable operation costs.

3. FEEDSTOCK FOR ANAEROBIC DIGESTION

3.1... in Europe

Especially in Germany and Austria, promoted by national policy, there is an ongoing separation of agricultural biogas plants using solely agricultural residues and produce as feedstock from biogas plants for waste treatment converting the wastes from food processing industry, from canteen kitchens or from municipal waste collection. This kind of biogas plant is also very common in Switzerland.

Over the last decades European farmers have increased the production of crops far beyond the demand on food in Europe. Furthermore it is expected that the productivity of farms will still increase by an annual average rate of 1% per unit land. At the same time world market prices for food have been decreasing dramatically such that many farmers are afraid their income cannot balance any longer their expenses for producing the food. Therefore farmers tend to look for alternatives. One of these alternatives is to produce energy crops and to use them as feedstock for anaerobic digestion. These energy crops are used either as additional feedstock to liquid manure for co-digestion or as solely feedstock, i.e. without liquid manure as substrate, which is called mono-digestion.

This opens the question which crops are suitable as energy crops and what determines suitability? The usefulness of a crop as feedstock for anaerobic digestion depends on its yield capacity compared to the effort for cultivation and on the quantity and the quality of the biogas produced, such as the methane content achievable. From this point of view, the most suitable plant species are those rich in easily degradable carbohydrates, such as sugar and protein matter and poor in hemicelluloses and lignin which have a low biodegradability. Furthermore, crops shall be easy to store to make them available for digestion all year round. Hence, the optimum harvest time as

well as preservation and storage methods are of particular interest. Another aspect for suitability is determined by the means of cultivation and their availability on the particular farm.

Up to now the preferred cultivated energy crops are maize (*Zea mays*), different cereals like rye (*Secale cereale*) and triticale (*Triticum X Secale*), and to some extent sugar beet (*Beta vulgaris*). In addition to the cereals already in use wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) are of interest as input material. Viewing on growing conditions plants like hemp (*Cannabis sativa*) or alfalfa (*Medicago sativa*) are remarkable substrates as well. Experiments have demonstrated that maize and cereals harvested at milk ripeness gain the highest yields in biogas (Heiermann et al., 2002). This trend is enhanced through ensiling the material. Ensiling fulfils also the demands of preserving the material and its year round availability.

Under laboratory conditions these crops produce within approx. 28 days 450 to 920 m³ biogas per ton dry matter (DM) with an average methane content of 50 to 60% (table 1). Under practice conditions the time period within a remarkable biogas production can be detected might be up to 90 days. Within shorter periods the biogas yields might reach approx. 80% of the biogas yields from lab-scale experiments.

Table 1. Biogas and/or methane yields from whole crop (silage) of batch digestion experiments after approx. 28 days under mesophilic conditions. The average methane content ranges from 50 to 60%.

Energy crop	DM [% FM]	ODM [% DM]	Biogas yield [Nm ³ t ⁻¹ ODM]	Methane yield [Nm ³ t ⁻¹ ODM]
Forage mix ¹	10 - 16	86 - 91		297 - 370
Paddock mix ¹	10	88		246
Clover ¹	9 - 17	88 - 91		290 - 390
Alfalfa ²	14 - 35	84 - 88	514 - 737	283 - 405
Maize ¹	30 - 48	96 - 97		247 - 375
Maize ⁴	20 - 42	95 - 97		330 - 400
Barley ²	25 - 38	90 - 93	694 - 920	382 - 506
Rye ²	33 - 46	91 - 93	733 - 734	403 - 404
Triticale ²	27 - 41	93 - 95	740 - 807	407 - 444
Sugar beet ³	22	90	840	504
Turnip ⁴	23	95		400
Hemp ²	28 - 36	92 - 93	452 - 485	250 - 267

DM = dry matter; FM = fresh matter; ODM = organic dry matter, Nm³ = norm cubic metre, i.e. volume is standardized to norm conditions of 0 °C, 1023 mbar air pressure and 0% relative humidity; ¹ Amon *et al.*, 2004; ² Heiermann and Plöchl, 2004; ³ Linke *et al.* 2003; ⁴ Oechsner *et al.*, 2003

These yields of energy crops compare to the biogas yields obtained from animal manure and animal slurry, which ranges from 370 m³ per ton DM cattle manure to 450 m³ per ton DM pig manure with average methane contents of 60 to 65% (Linke *et al.*, 2003).

3.2... in Developing Countries

In developing countries food production is much more important than in Europe and competes out completely the production of herbaceous energy crops. Nevertheless, there is a wide range of

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residues from crop production with considerable methane production potential from anaerobic digestion. Crop residues are all parts of plants not supposed for human nutrition or as animal feed and which usually remain on the field or are composted.

In table 2 dry matter content and organic dry matter as well as methane or biogas yields are summarised for a whole range of tropical substrates. These recent experiments prove the results obtained by Maramba, 1978. He determined methane yields of 200 - 400 m³ per ton DM from crop residues like straw, corn stalks and cobs, bagasse, peanut shell and others. As many of these residues are readily available biogas production in family biogas plants can considerably be increased.

Table 2. Methane or biogas yield from different tropical substrates after approx. 28 days of batch digestion experiment under mesophilic conditions.

Substrate	DM [% FM]	ODM [% DM]	Methane yield [Nm ³ t ⁻¹ ODM]	Biogas yield [Nm ³ t ⁻¹ ODM]
Bagasse ¹				165
Banana peel ²		87 - 94	243 - 322	
Citrus waste ²		89 - 97	433 - 732	
Coriander waste ²		80 - 86	283 - 325	
Mango peel ²		89 - 98	370 - 523	
Oil palm fibre ³	37	94	183	
Onion peels ²		88	400	
Pine apple waste ²		93 - 95	355 - 357	
Pommegranate ²		87 - 97	312 - 430	
Rice				
straw ³	87	86	210	
seed hull ³	86	84	17- 22	
Sapote peels ²		96	244	
Tomato waste ²		93 - 98	211 - 384	
Water hyazinth ³	7	81	211 - 310	

Data from: ¹ Maramba, 1978; ² Gunaseelan, 2004; ³ own measurements; abbrev. *cf.* Table 1

Methane yields from tropical crop residues cover a wide range of values. Rice seed hull produce very little methane through anaerobic digestion, where as the residues from citrus, mango, pomegranate or tomato show comparable high values to European energy crops.

4. UTILISATION OF BIOGAS

4.1 Current and near future use of biogas in Europe

At present there are two major pathways of biogas utilisation in Europe. The first example is from Sweden and Switzerland (www.kompogas.ch/en/index.html). In these countries the biogas is usually upgraded to more than 95% methane and then used as car fuel and to a lower extend fed into a gas grid as substitute to natural gas. In Austria, Denmark and especially in Germany the biogas is combusted in a combined heat and power facility (CHP). The electricity is than fed to the national grid and the heat is mainly used for the own purposes of the farmer.

The CHPs work usually with a gas engine. For very small units (<30 kW_{el}) engines with spark ignition are used while larger installations use diesel engines either with assisting oil combustion or pure gas engines. The latter need slightly compressed gas and should run at constant capacity level. While the investment for engines with spark ignition and engines with assisting oil combustion is low the operation costs and the maintenance work are high. Pure gas engines need less maintenance work, operation costs are low but investment is high.

Just recently the availability and functionality of micro-turbines have increased. Micro-turbines have three advantages compared to gas engines:

- exhaust of nitrous oxide and carbon monoxide is very low
- maintenance is very comfortable
- exhaust temperature is above 500 °C which opens a broad range of heat utilisation which of course leads to lower electrical efficiencies

but are still expensive in purchasing.

Currently several working groups and industries are investigating the suitability of biogas for fuel cells. The results are rather promising, so that we can expect either fuel cell stacks in a CHP with an enhanced efficiency compared to current engines, or that the gas is upgraded on the farm and fed into the gas grid. In houses fuel cell may replace old heating equipments and produce both heat and electricity directly at home.

Table 3. Available types of fuel cells and some of their characteristics

AFC	Alkaline fuel cell: works at 150 - 200 °C, developed already in the fifties of last century, very expensive in operation, needs ultra clean hydrogen
PE(M)FC	Polymer electrolyte (membrane) fuel cell: works at approx. 80 °C, highly efficient, up to 60% electrical efficiency, but needs very clean hydrogen
PAFC	Phosphoric acid fuel cell: works at 150 - 200 °C, broadest application in pilot installations, needs external reforming, electrical efficiency above 40%
MCFC	Molten carbonate fuel cell: works at approx. 650 °C and works with internal reforming process, electrical efficiency more than 50%
SOFC	Solid oxide fuel cell: works at 800 to over 1,000 °C, internal reforming process, electrical efficiency 40 - 45%, can be enhanced by downstream gas turbine or steam turbine

Available fuel cell with some of their characteristics are summarised in table 3. In the meantime PEMFC, PAFC, MCFC, and SOFC are installed in pilot-scale experiments and use biogas as fuel source (Langnickel, 2000; Bischoff and Huppmann, 2002; Hedström et al., 2004; Van herle et al., 2004; Zhang et al., 2004). The low temperature fuel cells need very clean hydrogen as fuel, i.e. that the biogas has to be purified and reformed to hydrogen in separate external processes. The high temperature fuel cells and especially the SOFC can work directly with upgraded biogas as the reforming process is integrated in the fuel cell. SOFC can also cope with impurities but not with hydrogen sulphide. Therefore hydrogen sulphide has to be eliminated during the upgrading process. Van herle et al., 2004 could demonstrate that efficiency of SOFC is increasing with fraction of carbon dioxide in the biogas.

The upgrading of biogas increases the methane content of the biogas to more than 95% and hence, enhances its energy efficiency. There is also the advantage that the biogas produced is

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suitable as car fuel or can be fed to (national) gas grid. The upgrading removes carbon dioxide and impurities like hydrogen sulphide. There are five different pathways available (Schulte-Schulze Berndt, 2003):

- through a water based process where methane and carbon dioxide are separated due to their differences in solubility
- through electrostatic adsorption of carbon dioxide
- through a cryogenic process relating to the higher freezing point carbon dioxide
- through differences in permeation through a membrane and either solution in an adsorbing liquid or
- adsorption to the membrane

If biogas is converted to electricity the available technologies have an average efficiency of 30% increasing to approx. 35% with modern engines. With fuel systems efficiencies of more than 60% can be reached depending on the fuel cell type. Nevertheless, there is a considerable amount of heat, which is often wasted. But this heat can be converted to coldness by adsorption technology. Therefore biogas production and conversion to electricity becomes even more attractive for farming systems with significant demand for coldness e.g. dairy cattle farms.

Figure 5 gives an overview on current biogas production and its utilisation in near future in Europe.

4.2 Current and Near Future Use of Biogas in Developing Countries

In developing countries biogas is currently used mainly for cooking and lighting and in some cases also for heating. For these purposes the gas is stored in simple plastic bags or directly in the digester above the substrate. There is only a reduced capacity for storage and the gas is only slightly compressed. I.e. gas exceeding the current need has to be left off and the efficiency of the stove and other equipment is low due to the low pressure of the gas.

This low efficiency of gas utilisation and the lack of storage capacity can be counteracted by the installation of simple compressors, the compression of the gas and filling it into gas bottles. This also opens the opportunity to provide the neighbourhood with biogas as an energy source for cooking and lighting.

On the one hand side there is an increasing demand for electricity on the other hand the supply of electricity is rather unstable in rural areas. Therefore, the generation of electricity from biogas, even on a small scale, becomes increasingly valuable. There are a few attempts to construct gas-combustion driven generators with an electrical capacity of 0.5 to 5 kW_{el}. These mini-scale generators could easily be driven by the biogas production derived from one to two 10 m³ digesters fed with manure and organic residues.

Biogas produced in medium to large-scale biogas plants can be used similar to the European way of utilisation. The localisation of these biogas plants next to large-scale agricultural enterprises or food processing industry makes it preferable to convert the biogas to electricity in combined heat and power units. The heat produced can be used either directly or indirectly through the further conversion to cold and be used for the cooling purposes present in these enterprises and industries.

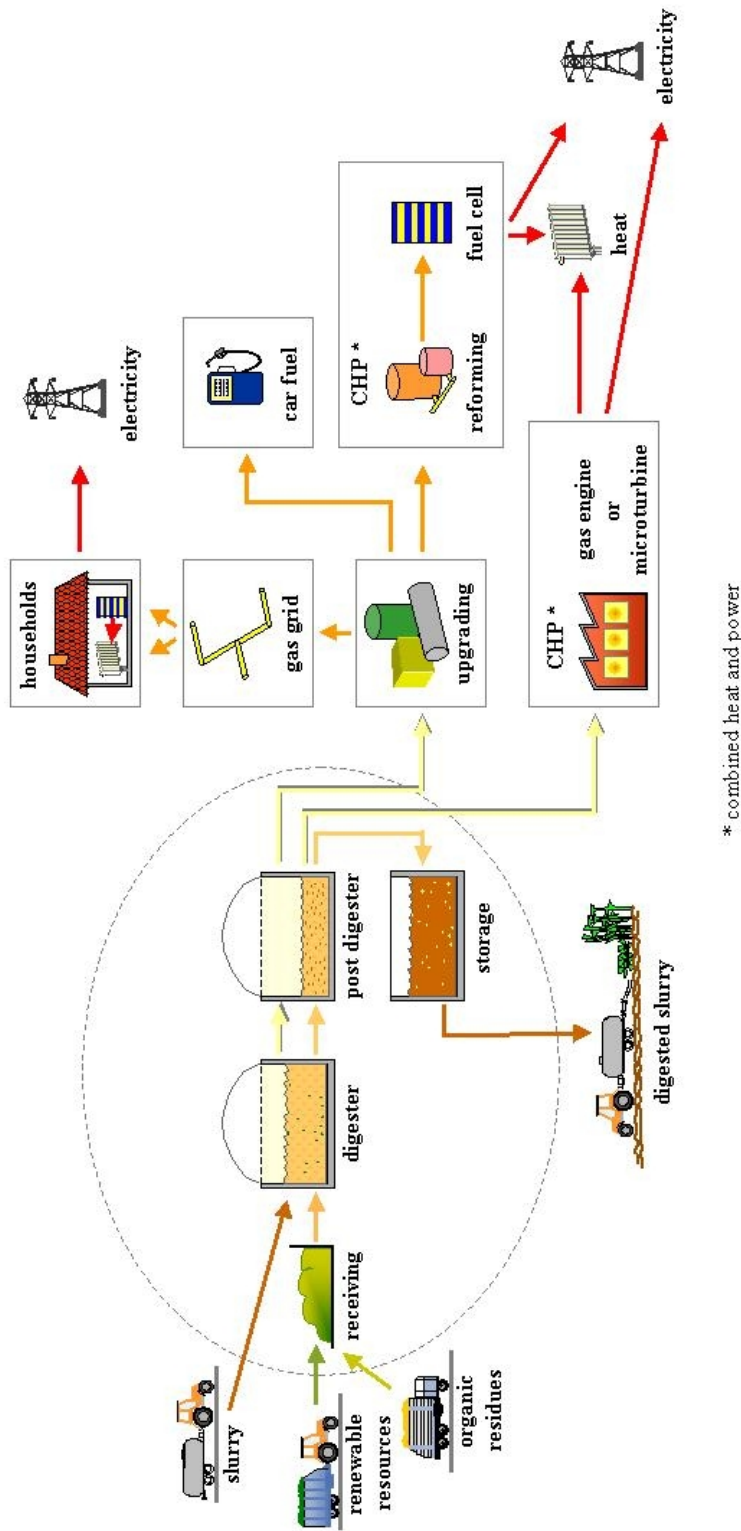


Figure 5. Scheme of agricultural biogas plant including slurry, energy crops and organic residues as feedstock and including different pathways of biogas utilisation.

5. DISCUSSION

In order to meet the target of increasing energy availability especially in rural areas the development of biogas technology is one of the central issues. Biogas is a multi-purpose energy source that is obtained from local resources. There are at least two benefits from using biogas:

- as a renewable energy source it mitigates the emission of greenhouse gases
- as a local resource it diminishes the dependence on imports of energy sources

Local resources for biogas production are, in addition to organic wastes and excrements, crop residues and energy crops. In contrast to Europe in developing countries emphasis will be put on crop residues rather than energy crops. Although the biogas forming potential is known for a number of crop residues, there is still a large need for the identification of crops and crop residues degradable by anaerobic digestion and especially their regional distribution and availability (El Bassam, 1998).

In addition to the provision and installation of simple biogas plants it becomes necessary to develop also more sophisticated medium-scale biogas plants suitable for the conditions in developing countries and the increasing number of medium-scale agricultural enterprises as well as for the developing food processing industry. They must be easy to handle, easy to maintain, but should convert the substrate with high efficiency.

At first biogas production helps to decrease the sheer volume and the amount of organic wastes. The sanitation of these wastes is done through anaerobic digestion, this is especially important if animal manure and night soil is used as fertiliser. The digested slurry is also a more effective fertiliser than undigested slurry. Using the digested slurry instead of mineral fertilisers will also decrease the costs of fertilising and replenish the fertility of soils lacking otherwise the input of fertilisers.

Biogas can be converted to many easy to handle energy forms. It can be used directly for cooking and boiling water. It can be used to drive refrigeration systems. It can be compressed and put into gas bottles, than it has almost the same comfort like using LPG. The biogas can be converted to electricity and heat using a diesel engine or more sophisticated CHPs.

In more sophisticated environments the biogas can be upgraded, i.e. separated into methane and carbon dioxide. The upgraded biogas can be used as car fuel or fed to a gas grid, if applicable.

Another option is the installation of biogas plants in the context of food processing industries. On the one hand side in these complexes there is demand on electricity and heat and on the other hand side it can be expected that technical skills are available to handle and maintain even the more sophisticated biogas plants and utilisation technologies. Such that these food processing industrial complexes could become energy centres of the region.

It is also discussed to increase biogas production in context with municipal waste disposal (Ambulkar and Shekdar, 2004). This would have two advantages:

- the reduction of waste amount, it is expected that in Indian cities more than 50% of municipal waste is of organic origin which is easy degradable through anaerobic digestion, biogas production would decrease the demand for landfill by 90% (Ambulkar and Shekdar, 2004)

- similar to food processing industries, it can be expected to find enough technical skill in cities to process most sophisticated biogas plants

A further option may be the development of fuel cell applications to biogas as well as to other bioenergy sources (Dellepiane et al., 2003). Fuel cells convert biogas with high efficiency to electricity and heat. They have the advantage that there are no moving parts, which would have to be maintained and which are prone to failure. The different characteristics of the fuel cell types enable the user to select the optimum technology. So SOFC seem to be most appropriate for small installations, i.e. <10 kW_{el}, whereas PAFC and PEMFC are more suitable for large plants. Under the conditions of large plants the external reforming is less dominating investments and operation and PAFC and PEMFC have higher efficiencies.

Despite all developments of biogas technology in Europe, it is still necessary to decrease costs for the installation of biogas systems. The simple biogas plants of Chinese or Indian type have investments of approx. 500 to 1,000 €/per plant. The simple tube digester is with an investment of approx. 30 to 50 €incomparable economical. In contrast, the costs of European biogas plants are of approx. 200 - 300 €/per m³ digester volume but only for larger installations. The investment for technology to produce electricity is of approx. 500 - 700 €/kW in the case of combustion engines and more than 1,000 €/kW for fuel cells.

A provisional conclusion from the above, which might be true for developing countries as well as for the developed ones agriculture has the potential to become a major supplier for energy. The anaerobic digestion of energy crops and agricultural residues can contribute considerably to national energy balances. The digested slurry derived from energy crops contributes also to the rehabilitation of degraded and marginal lands increasing soil fertility, decreasing greenhouse gas emissions and evolve rural sustainable development. However, it is important to prevent this form of energy production from entering into competition with land for food production, which must take precedence.

6. ACKNOWLEDGEMENTS

The authors wish to thank Mrs. Ines Ficht for technical support and the preparation of figure 5.

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