Small-scale Electricity Generation from Biomass

Experience with Small-scale Technologies for Basic Energy Supply

Part II: Biogas

gtz HERA Poverty-oriented basic energy services

commissioned by

Federal Ministry for Economic Cooperation and Development

Small-scale Electricity Generation from Biomass
Part II: Biogas

1st edition, August 2010

Author: Elmar Dimpl
Editor: Michael Blunck
Published by GTZ-HERA – Poverty-oriented Basic Energy Service

Small-scale Electricity Generation from Biomass

Part II: Biogas

Contents

Preface

Energy is essential for human development. Without an adequate basic energy supply people cannot cook their food, light their homes or keep essential medication chilled. Alongside the introduction of efficient and clean thermal use of traditional biomass for cooking, the provision of electricity from renewable energy sources can provide basic energy services for lighting and communication and promote local economic growth.

Renewable energy from photovoltaics, wind turbines and small hydro plants is highly suitable for off-grid electricity supply and has been successfully introduced in countless cases in developing countries. However, although the application of biomass as a sustainable electricity source seems promising, it is still seldom perceived as an option for providing electricity for the rural poor.

In order to generate electricity, biomass can be combusted, gasified, biologically digested or fermented, or converted to liquid fuels propelling a generator. Several research institutions and international agencies rate biomass as one of the cheapest available renewable energy sources for power generation. Furthermore, conversion from biomass to electricity is a low-carbon process as the resulting CO_2 is captured by plant regrowth. In contrast with solar PV or wind power, biomass power technology can generate electricity on demand at any time, as long as a sufficient supply of biomass stocks is assured. Many agricultural and forest product residues can provide feedstock for energy conversion without increasing land requirements. Local farmers can generate additional income by providing biomass fuels for small local power plants.

However, despite the apparent benefits, there has been little experience of implementing small electricity-generating biomass plants in off-grid areas of developing countries. In approaching this issue, the GTZ programme “Poverty-oriented Basic Energy Services” (HERA) assessed the lessons learned from GTZ and non-GTZ pilot activities and thus identified the most important potentials of and obstacles to different biomass power technologies. This assessment resulted in a **three-part series of papers on “Small-scale Electricity Generation from Biomass”** covering **biomass gasification (part I)**, **biogas (part II)**, and **plant oil (part III)** for electric power generation.

1 Introduction

Biogas technology, the generation of a combustible gas from anaerobic biomass digestion, is a well-known technology. There are already millions of biogas plants in operation throughout the world.

Whereas using the gas for direct combustion in household stoves or gas lamps is common, producing electricity from biogas is still relatively rare in most developing countries. In Germany and other industrialised countries, power generation is the main purpose of biogas plants; conversion of biogas to electricity has become a standard technology.

This document will discuss the potentials, obstacles and necessary framework conditions for the utilisation of biogas for small and medium scale electricity generation in developing countries. This paper will not address the biogas production process in general but focus uniquely on electricity generation.

The findings presented here are based mainly on available experience from GTZ-related pilot biogas power plants in different countries. They focus on more or less well-documented existing country cases even though little extensive documentation of practical long term operating experience is available. Besides the cases described here, we know of further examples from other GTZ projects (e.g. Bolivia, Tunisia and the Ivory Coast). However, there is not yet sufficient information concerning these to merit inclusion in this assessment.

2 The Technology

Biogas is gas resulting from an anaerobic digestion process. A biogas plant can convert animal manure, green plants, waste from agro industry and slaughterhouses into combustible gas. For further information on the biogas production and fermentation process please refer to the Biogas Portal on Energypedia.info:
http://www.energypedia.info/index.php/Portal:Biogas

Biogas can be used in similar ways to natural gas in gas stoves, lamps or as fuel for engines. It consists of 50-75% methane, 25-45% carbon dioxide, 2-8% water vapour and traces of O_2 N_2, NH_3 H_2 H_2S. Compare this with natural gas, which contains 80 to 90% methane. The energy content of the gas depends mainly on its methane content. High methane content is therefore desirable. A certain carbon dioxide and water vapour content is unavoidable, but sulphur content must be minimised - particularly for use in engines.

The average calorific value of biogas is about 21-23.5 MJ/m³, so that 1 m³ of biogas corresponds to 0.5-0.6 l diesel fuel or about 6 kWh (FNR, 2009).

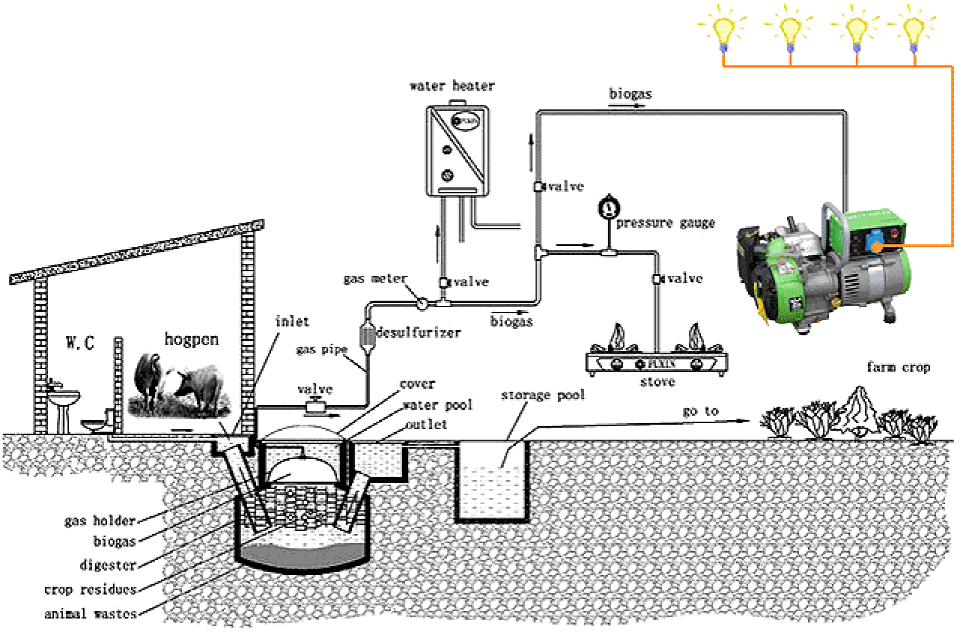
The biogas yield of a plant depends not only on the type of feedstock, but also on the plant design, fermentation temperature and retention time. Maize silage for example - a common feedstock in Germany - yields about 8 times more biogas per tonne than cow manure.

In Germany, cow manure and energy crops are the main forms of feedstock. About 2 livestock units (corresponding to about 2 cows or 12 rearing pigs) plus 1 ha of maize and grass are expected to yield a constant output of about 2 kW_{el} (48kWh_{el} per day).

In the South Asian context, ESMAP uses a typical specific input-output relation of about 14 kg of fresh cattle dung (the approximate production of one cow on one day) plus 0.06 l diesel fuel to produce 1kWh electricity.

2.1 Conversion to Electricity

Theoretically, biogas can be converted directly into electricity using a fuel cell. However, very clean gas and an expensive fuel cell are necessary for this process. This is therefore still a matter for research and is currently not a practical option.



Schematic of a biogas plant used for power generation. Source: www.Greenpower.cn

In most cases, biogas is used as fuel for combustion engines, which convert it to mechanical energy, powering an electric generator to produce electricity.

Appropriate electric generators are available in virtually all countries and in all sizes. The technology is well known and maintenance is simple. In most cases, even universally available 3-phase electric motors can be converted into generators.

Technologically far more challenging is the first stage of the generator set: the combustion engine using the biogas as fuel. In theory, biogas can be used as fuel in nearly all types of combustion engines, such as gas engines (Otto motor), diesel engines, gas turbines and Stirling motors etc.

Gas turbines are occasionally used as biogas engines, especially in the US. They are very small and can meet strict exhaust emissions requirements. Small biogas turbines with power outputs of 30-75 kW are available on the market, but are rarely used for small-scale applications in developing countries as they are expensive. Furthermore, due to their spinning at very high speeds and the high operating temperatures, the design and manufacturing of gas turbines is challenging and maintenance requires specific skills.

External combustion engines such as Stirling motors have the advantage of being tolerant of fuel composition and quality. They are, however, relatively expensive and characterised by low efficiency. Their use is therefore limited to a number of very specific applications.

In most commercially run biogas power plants today, **internal combustion motors** have become the standard technology either as gas or diesel motors.

2.2 Appropriate Combustion Engines

In general, **diesel engines** operate on biogas only in dual fuel mode. To facilitate the ignition of the biogas, a small amount of ignition gas - often diesel fuel - is injected together with the biogas. Modern pilot injection gas engines (“Zündstrahlmotoren”) need about 2% additional ignition oil. Almost every diesel engine can be converted into a pilot injection gas engine. The advantage of these motors running in dual fuel mode is that they can also use gas of low heating value. However, in such cases, they consume a considerable amount of diesel. Up to engine sizes of around 200kW, pilot injection engines seem to have an advantage over gas motors due to their slightly higher efficiency (3-4% higher) and lower investment costs.

By contrast, **gas motors** with spark ignition (Otto system) can operate solely on biogas. In practice, a small amount of petrol (gasoline) is often used to start the engine. This technology is used for very small generator sets (~ 0.5-10 kW) as well as for large power plants. Especially in Germany, these engines are advantageous as they do not require additional fossil fuels, leading to lower feed-in tariffs according to the Renewable Energy Law (EEG).

Today, experience of the use of combustion motors to produce electricity from biogas is extensive; this can be regarded as a proven standard technology. Over 4,000 biogas plants with internal combustion motors are in operation in Germany.

However, it has taken lengthy and determined effort to make this technology as durable and reliable as it is today. Internal combustion motors have high requirements in terms of fuel quality. Harmful components - especially hydrogen sulphide (H_2S) - in the gas can shorten the lifetime of a motor considerably and cause serious damage. This must be addressed in two ways:

- Production of clean biogas; and

- Use of appropriate and robust motors and components.

In theory, most engines originally intended for cars, trucks, ships or stationary use can run on biogas as fuel and are available almost everywhere within a power range between 10 and 500 kW. This holds true especially in the case of dual fuel use. Robust engines with a certain sulphur resistance are mostly free of non-ferrous metal (German: “Buntmetalle”), as these materials are highly prone to damage through sulphur-rich biogas.

2.3 Appropriate Gas Quality

For use in gas or diesel engines, the gas must fulfil certain requirements:

- The methane content should be as high as possible as this is the main combustible part of the gas;
- The water vapour and CO_2 content should be as low as possible, mainly because they lead to a low calorific value of the gas;
- The sulphur content in particular, mainly in form of H_2S, must be low, as it is converted to corrosion-causing acids by condensation and combustion.

The **water vapour** content can be reduced by condensation in the gas storage or on the way to the engine.

The reduction of the **hydrogen sulphide (H_2S)** content in the biogas can be addressed via a range of technical methods. These can be classified as chemical, biological, or physical and divided into internal and external methods. Much experimentation has been carried out in the last two decades. However, as complete elimination is unnecessary for use in robust engines, the following simple methods have generally established themselves as standard:

- An **optimised steady fermentation process** with continuous availability of appropriate feedstock is important to produce a gas of homogenous quality.
- The **injection of a small amount of oxygen** (air) into the headspace of the storage fermenter leads to oxidation of H_2S by microorganisms and hence the elimination of a considerable part of the sulphur from the gaseous phase. This is the most frequently used method for desulphurisation. It is cheap and can eliminate up to 95% of the sulphur content in the biogas. However, the right proportioning of air still seems to be a challenge.
- Another option is **external chemical treatment in a filter**. The active material may be:
    - Iron-hydroxide: $Fe(OH)_2 + H_2S \rightarrow FeS + 2\,H_2O$. This process is reversible and the filter can be regenerated by adding oxygen. Adsorption material may be iron-rich soils, waste material from steel or aluminium production;
    - Activated carbon: Certain companies provide activated carbon filters as a standard component in their gensets.

  Standard quality sulphur filters and filter material can be purchased on the market.

3 Existing Experience in Different Countries

3.1 Germany

The technologies of anaerobic fermentation and electricity generation from the resulting biogas have been well known for a long time. Such plants have been in operation for many years—particularly for sanitation purposes. However, power generation from biogas using agricultural feedstock became more common shortly after the introduction of a feed-in tariff. Around 0.11 € per kWh (plus specific bonuses) was the guaranteed base price for plants up to 150 kW (EEG 2009).

In 2009, more than 4,500 biogas power plants were in operation in Germany with more than 1,500 MW installed power capacity. Specific know-how and technological solutions are thus available to a very high standard.

However, despite the guaranteed feed-in tariff, the profitability of the plants has not always been guaranteed. With fluctuating prices for feedstock, often especially for plants and grains produced specifically for power generation, the profitability of the plants has varied from year to year.

The size of power plants has grown rapidly over the years. While the average size of a biogas power plant was 60 kW in 1999, it was 300 kW only 10 years later (2009). The reason for this lies in the decreasing specific cost of bigger plants - about 50% lower for a 300kW plant than for a 60kW plant.

Today, the profitability of biogas plants in Germany depends greatly on the potential to sell heat as well as producing electricity. The heat output of combined heat and power (CHP) generators is used to provide hot water for community heating systems for households, schools, public swimming pools etc. Furthermore, special bonuses, such as bonuses paid for the use of renewable raw material (NaWaRo), are also important for the profitable operation of the plants.

3.2 Developing and Newly Industrialised Countries

Millions of biogas plants have been installed all over the world within the last two decades, financed or supported by national and international programmes. It is not possible to give a comprehensive overview of these activities within the context of this paper. However, the following chapter will focus on activities carried out in co-operation or at least in close contact with GTZ as well as selected promising activities that might prove relevant for future approaches.

Since the late seventies, GTZ has launched several projects for the dissemination of biogas technology:

- Bilateral projects with Ethiopia, Cameroon and Lesotho;
- The Biogas Dissemination Programme active in Belize, Bolivia, Jamaica, Nicaragua, Burkina Faso, Tanzania, Kenya, Burundi and Thailand; and
- Special Energy Programmes with Biogas activity in Tanzania, Burundi, Kenya, Ivory Coast, Burkina Faso and Mali.

Most of the plants installed by these programmes were designed for households, hospitals and farmers, mainly using the gas directly as fuel for cooking and lighting. The principal focus of bigger plants constructed for slaughterhouses or similar applications is sanitation.

However, the generation of electricity has also played a role and several pilot plants were installed in the 1980s und 1990s, mostly in the power range 10 kW to 100 kW. Nevertheless, it appears that very few of these plants are still in operation or have worked successfully over the years. Such plants doubtless faced many technical problems as a standard technology for electricity generation from biogas could not be established at the time.

Activity continued, however, and the final conclusions of this paper are based on the following examples of more recent approaches, although it is still very difficult to obtain substantial operational data.

3.2.1 China

China is the world's leading country in the application of anaerobic biomass digestion technology in quantitative terms. Besides millions of small biogas plants in farms, there are over one thousand bigger plants, many of which use industrial waste from paper, sugar and the pharmaceutical industry as feedstock. The main purpose of these plants is to reduce waste and slurry problems. The gas is used directly for cooking, lighting or heating purposes and only few of the plants installed in China are destined for electricity production - in general big plants - as only those with capacities higher than 0.5 MW are allowed to connect to the grid. However, power generation from biogas has become the focus of support programmes in recent years. A tenfold increase in electricity generation from biogas is planned between 2005 and 2013.

The GTZ Sino-German Project on Optimisation of Efficient Biomass Utilisation (2009-2013) aims to improve the technical standard and performance of medium and large-scale biogas plants producing energy from biomass. The programme recommends shifting financial support from an investment-oriented to an output-oriented scheme, supported by demonstration projects, policy support and capacity.

3.2.2 India

India has extensive experience of biogas plants. Over 1.8 million cattle dung digesters had been installed in India by the mid 1990s. However, around one third of these were inoperative by early 2000 (ESMAP, 2005) and there is little experience of commercial electricity generation at small and medium level.

The GTZ Project Indo-German Energy Programme (IGEN) recently started a rural electrification programme with biogas plants of around 60 kW_{el} output.

3.2.3 Bangladesh

More than 25,000 biogas plants have been set up in Bangladesh. However, most of them are family-sized and used only for cooking burners. Over 2,000 of these biogas plants have been constructed on poultry farms. In such cases, the main purpose of the plants is not only the generation of gas; the plants are also necessary owing to the bad odour caused by poultry droppings and for other environmental reasons.

Feasibility studies

A feasibility study (GTZ-PURE, 2005) with financial analyses of plants with 100–50,000 birds came to the following conclusions:

- Larger farms may opt for electricity production, but selling gas is more profitable.
- Selling electricity is economically viable only with the additional sales of at least one of the other two products: gas or fertiliser (assumption: only 50% of the gas is used for electricity generation).

These feasibility findings from 2005 correspond quite well with actual development as evidenced by the first examples of electricity generation from biogas in poultry farms.

AAS poultry farm

The Advance Animal Science Co. Ltd. (AAS), a dairy and poultry farm in Kashimpur of Gazipur district, supported by GTZ, has an electricity grid connection but also generates power from biogas using cow dung and chicken droppings as feedstock. In order to generate power, the biogas is passed through a traditional gas generator set with minor modifications.

Only one-third of the plant's capacity is used for electricity generation. According to press reports (http://bangladesheconomy.wordpress.com/2009/04/20/poultry-farm-sets-unique-example/), this electricity co-generating unit is rendered profitable by the savings involved in reducing the electricity bill. The financial contribution of the by-products, such as bio-fertiliser and the gas provided to some cooking burners in the neighbourhood, is obviously considerable.

From a financial perspective, certain additional effects are not easily measurable:

- Enhancement of environmental security in the farm area and the removal of bad smells.

- Independence of the erratic power supply from the national grid.

This Advance Animal Co. biogas power plant is the second of its kind, following one from a similar pilot project in Faridpur started two years earlier.

In the wake of these first pilot projects, expectations in Bangladesh are high. AAS estimates that a poultry farm of 5,000 birds could generate 5 kW of electricity. Selling electricity in the neighbouring areas seems to be economically viable from an output of 10 kW.

3.2.4 East Africa, Tanzania and Kenya

In Kenya, Tanzania and neighbouring countries, biogas is traditionally used in small and very small installations for providing household energy and for supplying social institutions with gas as fuel for cooking, heating and lighting. With GTZ support, over 1,000 small and medium-size plants and one bigger digester of over 100m³ have been installed by CARMATEC in Tanzania from 1983 on. However, potentials for industrial biogas and electricity generation in East Africa remain largely untapped.

Hale Sisal Farm, Tanzania

In **Tanzania** a pilot project managed and partly financed by the United Nations Industrial Development Organisation (UNIDO) entitled 'Cleaner Integral Utilisation of Sisal Waste for Biogas and Biofertilisers' involved a biogas pilot plant with a capacity of 150 kW_{el} at the **Hale Sisal Estate in the Korogwe District of Tanga region**.

According to UNIDO statements, the project showed that sisal residues constitute an efficient substrate for anaerobic digestion, generating gas, electricity, and bio-fertiliser. In 2007, UNIDO announced that the results will be transferred to other interested sisal growing nations for replication.

However, the originally planned second and third phases of plant development were never realised (Practical Action, 2009). This can be seen as an indicator of the plant's potential lack of profitability and confirms the views of experts based in the region that the plant's design seemed ill-adapted to the required sisal operations, and that its substantial operating problems were due to low quality technical components.

Sisal-cum-cattle farm in Kilifi, Kenya

The biogas plant with electricity generation on a sisal-cum-cattle farm in Kilifi, Kenya is usually referred to as a positive example. It converts agricultural waste such as cow manure and sisal into biogas and produces electricity and heat as end products. The technology is practically the same as that used in Germany. The plant design seems to be well-adapted to farm operations and has been operational since September 2007. The biogas plant in Kilifi, operated by the Biogas Power Company (EA) Ltd. (http://www.biopower.co.ke/About-us.html), a joint venture of Kilifi Plantations (KE) and the German companies agriKomp GmbH and Schnell Zündstrahlmotoren AG & Co. KG, was established through a tripartite Public Private Partnership (PPP) with GTZ. According to the publications of the operating organisation, the biogas plant in Kilifi is the biggest in Kenya.

The basic technical data of the plant are as follows:

- 750 cbm digester;
- Inst. capacity: 150 kW_{el}; actual production max. 90 kW, not connected to the grid;
- 4 t substrate / day: dung from 200 cattle (40%), sisal waste (60%);
- Feedstock available for extension up to 1 MW_{el} if excess electricity could be sold to the grid at a fair tariff;
- El. Production cost: 0,16 EUR / kWh (for comparison: grid electricity 0,15-0,18 EUR / kWh).

Framework conditions:

- Frequent power cuts due to technical faults and low capacity;
- Companies have to install emergency backup power systems, mostly diesel (costs: 0,25-0,42 €/kWh);
- Kenya: High and fluctuating power costs owing to pass-through of fossil fuel costs (e.g. Kilifi: 0,1575 – 0,185 €/kWh);
- Improvement is likely owing to strong government and private sector efforts, but in the medium term, there remains the persistent risk of power cuts due to the vulnerability of hydro power to drought;
- There is currently no biogas-specific regulation in East Africa;
- Power production of biogas falls under ‘Standardised PPA‘ (TZ) or ’Feed-in Law’ (KE);
- In Kenya, biogas is covered by ’biomass’ tariffs, which are too low.

The lessons learnt in Kilifi (Franz, 2009):

- Equipment import: professional agent and close liaison with authorities for clearance of plant equipment required;
- Tariffs/grid connection: the need to liaise at a very early stage with the Energy Regulatory Authorities to allow for structured and smooth process;
- Local capacities: the need to bring qualified staff and train local staff;
- Local manufacture: local manufacturing of pipes, wiring, and civil works should be possible and reduce costs.

PSDA project, Kenya

With support of the GTZ Project PSDA, two small biogas power plants were also installed. However electricity generation could be realised only partly:

The original purpose of the plant in Keekonyokie was to deliver electricity for a refrigerating storage house. The storage house was built and the cooling compressor was purchased but the thermal insulation has not yet been installed. In the meantime, the gas generated from slaughterhouse waste is fed into a mini gas grid and supplied to 6 restaurants. The designated generator set consists of an adapted diesel engine for dual fuel use and a generator with 20kW_{el} output. The estimated cost is €0.14/kWh compared to a grid price of €0.16/kWh.

At the Abdul Sidis farm, vegetable residues are used as feedstock and the (off-grid) electricity generated by a 20 kW_{el} genset is mainly used for a water pump. Estimated costs are again around €0.14/kWh compared to diesel-generated electricity at a price of €0.36/kWh. Daily savings are estimated to reach €10.

Both plants seem to work well in technical terms.

‘Rottaler Modell’

Independent of GTZ activities, the company BME GmbH in Bavaria offers a ‘High Performance, Temperature Controlled (HPTC)’ biogas plant system known as the ‘Rottaler Modell’. According to company communications, at least 3 of these plants have been installed in Eastern Africa, 3 are under construction and 2 are in concrete planning:

- In Kenya in Mombasa (2007), Murang’a, Homabay, Bungoma (8/2009);
- Further plants are planned in Dagoretti (KE), in Kigoma, Tanzania, in Zanzibar, Uganda, Ruanda and Madagascar.

Most of these installations were carried out in cooperation with UNIDO.

- The plants of this system have a two-stage digestion system, with separate Hydrolysis and acidification methanisation;
- It has a controlled temperature of 37°C with insulation and solar heating system.

- Due to the design, even high fibrous material can be digested and a high biogas output per m³ digester volume and day is possible.
- The digester and a separate storage are made from plastic bags of a three layer material.
- Desulphurisation is achieved exclusively through the addition of a little air into the gas storage tank. Owing to the steady fermentation temperature and constant gas production and composition, this method seems to work very well.

A typical HTC plant has a 25 m³ digester bag, a 20 m³ biogas storage bag and two 4 m³ hydrolysis units, a bio filtering system for filtering the hydrolysis gas generated in the hydrolysis unit, a desulphurisation pump and a condensation trap.

The first HPTC plants in Africa apparently used diesel engines, replacing up to 80% of the diesel with biogas. In 2009, a $10kW_{el}$ generator set running only on biogas was developed by modifying a commercially available petrol generator set used on construction sites in Europe.

Most of these plants were set up near slaughterhouses to use the waste and to provide them and neighbouring buildings with electricity.

The company calculates the cost of installing the plant at around €30,000, but emphasises that profitable operation is possible even without special feed-in tariffs in remote areas where electricity generation with small diesel generators is extraordinary expensive. It calculates a payback period of 2.5 years.

However, during discussions with different biogas experts, concerns were raised regarding this expensive model. It remains to be seen whether the higher price for these sophisticated high temperature plants can be compensated for by higher and more stable production.

Feasibility studies in Kenya

The planning and construction agency AKUT Umweltschutz in Berlin carried out some feasibility and concept studies for specific biogas plant projects in the agricultural sector of Kenya. All plants were designed to use as much locally available technology and expertise for construction as possible.

The studies carried out between 2006 and 2009 came to the following general conclusions (Burkard, 2009):

- Many substrates from typical agricultural production in Kenya can be used for biogas production;
- However, the feed-in tariff for electricity that cannot be used in-house is crucial for the economical operation of biogas power plants. Most of the projects are on hold until there are appropriate feed-in tariffs available for the national grid;
- In case of exclusive in-house use of electricity, the feasibility studies show that plants can only be operated economically if there is also a profitable use for the thermal energy output of the CHPS. However, in most cases thermal energy demand is insufficient;
- Use of slurry is recommended;
- Capacity building should be provided for operators.

Key support to the development of the Kenyan biogas sector was earlier provided through GTZ's bilateral Programme for Private Sector Development in Agriculture (PSDA). GTZ has recently been commissioned to implement the 'Project Development Programme – East Africa' (PDP) on behalf of the German Ministry of Economics and Technology under the 'Renewables Made in Germany' initiative. The programme aims to build partnerships between German and East African companies in the field of renewable energy. Biogas has been identified as one of the priority areas. The PPP lessons have now been integrated into the various follow-up activities of this programme, and the information presented below has been compiled in the context of the PDP.

After the positive experience with the pilot plant in Kilifi, investors and government have expressed increasing interest and asked GTZ to make recommendations.

Study on agro-industrial biogas potential, Kenya

GTZ commissioned the DBFZ (Deutsches Biomasse Forschungs Zentrum) to undertake a study on 'Agro industrial Biogas in Kenya' (GTZ, 2010) examining the theoretical potential of 13 types of biomass from agro-industrial businesses in Kenya to municipal waste in Nairobi. The report concludes that the potential electric capacity of generated biogas is high. Biogas from all examined subsectors could cover up to 16% of the total Kenyan electricity production as of 2007/08.

Municipal solid waste, sisal and coffee production are the most promising sectors with the greatest potential. However, specific electricity production costs for small plants (50kWel) range between 0.11 and 0.29 US$/kWh. A basic feed-in tariff for small plants of about 0.20 US$/kWh was therefore proposed, but the implementation of such a prohibitively high tariff seems unrealistic. It seems probable that only bigger plants with a profitability at a lower tariff of around 0.15 US$ will be able to take advantage of this.

Based on the 'hard facts' of this study's recommendations, follow-up is currently taking place under the PDP, focusing on targeted advice and cooperation with policymakers and investors on the tariff framework.

3.2.6 Brazil

Brazil is one of the countries whose biomass energy market is the most advanced. Biofuels are produced from sugar cane and hundreds of power plants use the remaining sugar cane bagasse as fuel. Most of these plants use direct combustion and have capacities far over 1 MW.

However, a number of small and medium sized biogas power plants also exist, mostly installed in agro-industrial settings. The main purpose of these plants (using the waste of a slaughterhouse or animal production facility) is sanitation and environmental protection. The second important benefit is gas and electricity production for in-house use in the companies.

There are probably large numbers of biogas plants in farms or small industries using the gas for individual power generation, as suggested by the provision of a specific biogas motor programme by the Brazilian company Branco. It provides small motors, motor pumps and a generator set of 3.6 kW, especially for Biogas use (http://www.branco.com.br/p_lb.htm).

However, hardly any electricity provision from biogas for basic public energy needs has so far been realised. A programme for the support of alternative energy resources (PROINFA), designed to feed-in more biomass energy into the national grid, was already approved in Brazil back in 2002. However, implementation met with delays, and only big power plants with direct combustion of the biomass were able to benefit from the programme.

Feed-in Agreement in Parana

Since 2009, in the southern state of Parana (PR), 5 biogas power plants have become the very first small plants to feed their power into the public grid (Grope, 2009).

These plants, with capacities of 20 – 160 kW_el, won a tender to sell their electricity to the public energy provider Copel Distrubuicao SA in the southern Brazilian state of Parana. The feed-in tariff corresponds roughly to 0.05 EUR / kWh (Copel, 2009).

This price is not high enough to guarantee the profitable operation of biogas power plants in Brazil. It is nevertheless an important step forward, as it can help make the plants more profitable. Only the excess electricity is sold at the fixed feed-in tariff.

The GTZ Energy Programme (‘Programa Energia’), on behalf of German Federal Ministry of Economic Cooperation and Development, supports the use of renewable energy and energy efficiency in Brazil and hence also the appropriate production and use of biogas. The programme aims to improve framework conditions for the sustainable use of biogas, the analysis of experience and know-how transfer between German and Brazilian partners. In October 2009, the GTZ Energy Programme entered into a partnership with the public energy utility Eletrosul, subsidiary of Eletrobras, the national electricity provider, focusing on know-how transfer in the field of biogas. Eletrosul aims to construct biogas power plants for electricity generation in the South of Brazil.

4 Overall Appraisal

4.1 Energy Production Potential

Appropriate feedstock for electricity-generating biogas plants is available in adequate quantities in many countries. Small and medium-size biogas plants could provide a considerable contribution to national electricity generation in such countries. However, in comparison to industrialised countries, only very few small and medium sized biogas plants are used for electricity generation in Africa, Latin America and even Asia.

Electricity production from biogas can be a very efficient method for producing electricity from a renewable energy source. However, this applies only if the emerging heat from the power generator can be used in an economically and ecologically sound way. The average calorific value of biogas is about 21-23.5 MJ/m³, meaning that 1 m³ of biogas corresponds to 0.5-0.6 l diesel fuel or an energy content of about 6 kWh. However, due to conversion losses, 1m³ of biogas can be converted only to around 1.7 kWh_{el}.

Bigger biogas plants are generally more cost-efficient than smaller ones. However, electricity generation from biogas is a technology appropriate even for relatively small applications in the range of 10-100kW.

4.2 Technical Aspects

There is mature, reliable high quality technology available on the global market. The technological difficulties with which small biogas plants were confronted two decades ago have been resolved.

Different methods of desulphurisation have been successfully established and combustion motors tolerant to biogas that have proven their durability are available in the market. Sufficient know-how for planning and constructing reliable biogas power plants is also available.

Germany is one of the leading countries in terms of high quality components and know-how required for electricity-generating biogas plants. Know-how and technical components are also available in China, Thailand and other Asian countries as well as in Brazil. Electricity generation from biogas in Africa is still limited to a few pilot plants, with Kenya apparently being one of the centres of development and experience. For the construction of efficient and reliable biogas power plants, at least some technical core components must be imported from industrialised countries.

The electricity generation component of a biogas power plant does not require much more know-how and effort for maintenance than a normal generator set for fossil fuels—with a well functioning biogas fermentation process as an indispensable prerequisite.

4.3 Economic Aspects

Economically, electricity from biogas must compete with electricity generation from fossil fuels and other renewable energies such as hydro power.
Supporting factors are:

- Rising prices of fossil fuels;
- Low reliability of electricity provision from national grids with persistent risk of power cuts and vulnerability of hydro power to drought.

Inhibiting factors are:

- Relatively low prices of fossil fuels;
- Need to buy high quality components from industrialised countries;
- Unfavourable conditions for selling electricity;

- Lack of awareness, capacity and experience preventing the economic operation of infrastructure components.

The economic feasibility of a biogas plant depends on the economic value of the entire range of plant outputs. These are:

- Electricity or mechanical power;
- Biogas;
- Heat, co-generated by the combustion engine;
- The sanitation effect with COD and BOD (chemical and biological oxygen demand) reduction in the runoff of agro-industrial settings;
- Slurry used as fertiliser.

Most of the commercially run biogas power plants in developing countries are of medium size and are installed in industrial contexts, primarily using organic waste material from agro-industrial production processes such as cow, pig and chicken manure, slaughterhouse waste, or residues from sisal and coffee processing.

Assessments of economic feasibility are contradictory or inconsistent. Many press releases and information from biogas power plant producers refer to payback periods of only 1.5 – 2.5 years. In such cases, the electricity from biogas plants can be compared to the price of electricity provided through the national grid or the price of bottled LPG.

However these figures are unrealistic, except for direct thermal energy use as for cooking energy, or in very few locations with extremely expensive diesel fuel.

More realistic figures seem to be those calculated by GTZ experts in Kenya for medium and large plants (>50kW): They anticipate payback periods for plants under the DBFZ tariff scheme (~0.15 US$/kWh) of 6 years under very favourable conditions, and 9 years for unfavourable but still economically viable investments.

In spite of this theoretical profitability, recent examples from Africa show that electricity generation from biogas has not really captured the market as a ‘profitable’ technology. None of the plants described here could have been installed without international technical and financial support. This is due to the pilot status of the market and barriers such as a lack of awareness, experience, local capacity, upfront financing for project development (for own consumption projects, i.e. where there is no feed-in component) and the existence of policy barriers in cases where feed-in is required.

Many new studies come to the conclusion that biogas power plants are not commercially viable without subsidies or guaranteed high prices (~0,20US$) for the produced outputs. In Germany and other industrialised countries, only guaranteed feed-in tariffs have led to a breakthrough. Almost all well-known biogas power plants in developing countries depend on financial support from a third international party.

We have little experience to draw on concerning the possibility of using biogas power plants to cover the basic energy needs of the rural population. Most biogas power plants are connected to agro-industrial facilities and provide electricity only to very few immediate neighbours. However, calculations show that biogas could play a role in supplying isolated grids, where it represents a least cost option.

4.4 Necessary Framework Conditions

In Germany, power generation from biogas is only profitable due to grid connection and supporting feed-in tariffs. By contrast, power generation in most developing countries seems to be especially profitable in settings far away from the national grid and other energy sources, as the legal framework conditions and the lack of appropriate feed-in tariffs do not support feeding into the grid. However, there are the first signs of financial and legal support for feeding in electricity from biogas power plants in countries such as Brazil. Output-oriented support schemes (such as the German EEG) have proved to be more successful than investment-oriented financial support.

Direct subsidies and public financial contributions to installation costs have been crucial for the installation of some pilot plants. However, they have not provided incentives for proper and efficient operation. By contrast, the establishment of appropriate feed-in tariffs stimulates the construction of efficient plants and their continuous and efficient operation.

Through its projects and programmes, GTZ therefore recommends the establishment of guaranteed feed-in price schemes similar to the one in Germany.

However, besides price considerations, there remain many barriers to market penetration and development of the biogas sector:

- Lack of awareness of biogas opportunities;
- High upfront costs for potential assessments and feasibility studies;
- Lack of access to finance;
- Lack of local capacity for project design, construction, operation and maintenance;
- Legal framework conditions that complicate alternative energy production and commercialisation: for example, the right to sell electricity at local level has to be in place.

As long as the national framework conditions are not favourable, electricity generation from biogas will remain limited to a few pilot applications.

Documents and Literature

Burkard, Thilo (2009): Project cases of Biogas-plants in Kenya. Presentation for Biogas Delegation Trip, Agritechnica 2009. *Clearly presented detailed analysis of the technical and economic aspects of 5 biogas power plants in Kenya.*
http://www.gtz.de/de/themen/umwelt-infrastruktur/energie/28759.htm

COPEL DISTRIBUIÇÃO S A: VENCEDORES DA CHAMADA PÚBLICA, 2009, 2.p List of winners of a tender to sell electricity to the grid in the state of Paraná, Brazil.

ESMAP (2005) Advancing Bioenergy for Sustainable Development - Guideline for Policy-makers and Investors. Report 300/05.

Fachagentur Nachwachsende Rohstoffe e.V. (FNR) (2009): Biogas Basisdaten Deutschland – Stand: Oktober 2008. 7p. *Very short but comprehensive overview of the biogas situation in Germany.*
http://www.fnr-server.de/ftp/pdf/literatur/pdf_185-basisdaten_biogas_2009.pdf

Franz, Michael (2009): Zielmarktanalyse (ZMA). Der Markt für Biogas in Kenia. Studie des Projektentwicklungsprogramm Ostafrika im Rahmen der Exportinitiative Erneuerbare Energien des BMWi. *Description of the status in Kenya of biogas technology, available local know-how, market potential as well as legal and economic framework conditions.*
Detailed discussion of a biogas plant at a sisal plantation in Kilifi and lessons learned.
http://www.gtz.de/de/dokumente/gtz2009-de-zielmarkanalyse-biogas-kenya.pdf

Franz, Michael and Klaus v. Mitzlaff (2009): The Biogas Market in Kenya - Status Quo and Potentials. Presentation for Combined Biogas Business and Study Trip from Kenya and Tanzania, to Hannover, November 13, 2009. German Technical Cooperation (GTZ).
http://www.gtz.de/de/themen/umwelt-infrastruktur/energie/28768.htm

Grope, Johann (2009): Optimierung eines Biogasanlagenmodells unter Berücksichtigung der spezifischen Rahmenbedingungen Südbrasiliens. *Study of DBFZ on behalf of GTZ. 84 p. Describes framework conditions of biogas activities in southern Brazil and current technology. Develops proposals for optimised biogas technology.*

GTZ (2010): Agro-Industrial Biogas in Kenya – Potentials, Estimates for Tariffs, Policy and Business Recommendations. Study of Deutsches Biomasse Forschungs Zentrum (DBFZ) on behalf of GTZ, Renewable Energy Project Development Programme East Africa. 69p.
This comprehensive study documents the high potential for electricity production in Kenya from municipal solid waste and agro-industrial production, especially sisal and coffee production. About 16% of actual electricity consumption could be covered by electricity from biogas. The costs of different plant types and sizes are calculated. Grid connection and appropriate feed-in-tariffs are identified as the main prerequisites for commercial investment in this sector. The proposed basic feed-in-tariffs are within a price range similar to current levels in Germany (0.10 – 0.2 US$ /kWh el.
http://www.gtz.de/de/dokumente/gtz2009-en-biogas-assessment-kenya.pdf

GTZ-PURE (2005): Feasibility Study on Biogas from Poultry Droppings in Bangladesh, Prepared By Bangladesh Centre for Advanced Studies (BCAS) in collaboration with Energy Consulting Services (ECS), December 28, 2005. *Surveys biogas activities in Bangladesh and discusses briefly the possibilities and profitability of electricity generation in Bangladesh.*
http://www.reein.org/database/gtz/biogas_poultry_drop.htm

Mitzlaff, Klaus von (1988): Engines for Biogas. GTZ-GATE /Viehweg. 164p.
Documents early approaches of GTZ towards electricity generation from biogas. Describes the essential basics of internal combustion engines and properties of biogas as a fuel for internal combustion engines. Suggests parameters for planning a biogas engine system, with an overview of commercially available systems.

Muchel, H. and H. Zimmermann (1985): Purification of Biogas. GTZ: Aus der Arbeit von GATE, 33p. Viehweg
Documents early GTZ approaches towards electricity generation from biogas. Describes the properties and origins of hydrogen sulphide in biogas plants, its effects on the gas-utilisation equipment and methods for removing H2S from biogas.
Available at various websites, for example:
http://www.cd3wd.com/cd3wd_40/JF/JF_OTHER/SMALL/GTZ-Purification%20of%20Biogas%201985%20B.pdf

Practical Action (2009): Small-Scale Bioenergy Initiatives: Brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa. Final report, prepared for PISCES and FAO by Practical Action Consulting. Jan. 2009. 135p.

Raninger, Bernhard (2009): Biomass-Waste Management - a contribution to a Low CO2-Circular Economy and an Environmental Sound Urban & Rural Development. Presentation to International Symposium on ‘City Group Development Model’, Changsha, Hunan, China, Dec. 3 to Dec. 4, 2009.

Tomowsky, Arno (2006): GTZ Biogas-experience in Africa. Presentation held at international Workshop on the Biogas Sanitation Initiative for Africa’. Amsterdam, Oct. 2006. Unpublished.
A brief summary of lessons learned by GTZ over more than 20 years of biogas activity in Africa.

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH
HERA – Poverty-oriented Basic Energy Services
Dag-Hammarskjöld-Weg 1-5
65760 Eschborn
T +49 6196 79 6322
F +49 6196 79 80 6322
E hera@gtz.de
I www.gtz.de/hera