Title	**Ten years of operational experiences with the ecosan-biogas plant at a family-owned farm and restaurant in Germany**
Keywords	Ecosan, biogas, cogeneration, digested manure, fertiliser, closed-loop
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Short CV for Introduction Purposes (100 words max)	Presenter will be Heinz-Peter Mang; Mr. Mang has been working for over 25 years on projects involving biogas, waste and wastewater treatment and reuse, and ecological sanitation. Mr. Mang has advised the German Agency for Technical Cooperation (GTZ GmbH) and the Food and Agricultural Organization (FAO) on the planning, construction and monitoring of biogas plants in developing countries. He designed decentralized community wastewater treatment systems and introduced urine separation toilets in Bolivia in 1994. He has trained Bolivian, Burundian, Burkina, Cuban, Chinese and Jamaican institutions on decentralized wastewater treatment and reuse. He is currently working as a Biogas and Ecosan Expert at the Chinese Academy of Agricultural Engineering.
Photograph attached (jpg)	

INTRODUCTION

The cattle farm and restaurant "Michelbacher Hof" is located in Bessenbach, near Aschaffenburg in Northern Bavaria in Germany. It is a family-owned business that has been using sustainable ecosan principles for liquid waste management since 1994. The current activities taking place at the farm can be described as follows:

- The farm occupies 200 ha area of land, of which 170 ha is used for grazing and fruit trees, and 30 ha is used to grow fodder crops (e.g. maize and oat) for cattle and horses, and to grow field crops for the farm-owned bakery and distillery.
- The farm possesses 280 cattle and 50 horses; these live inside a barn in winter but are outside on grazing land during summer.
- The farm produces hornless cattle for meat production and breeding purposes.
- Each week one cattle is slaughtered and sold in the restaurant and the farm shop.
- The restaurant can serve about 250 guests.
- Four families (a total of 14 persons) live and work at the farm.

In 1994 the farmer was adding an on-site slaughterhouse to his business, and had three wastewater management options:

1. Build a local decentralised wastewater treatment plant for the wastewater generated from the restaurant and slaughterhouse;
2. Build a 2.5 km pipeline to the closest town sewer; or
3. Use an integrated concept where the wastewater and waste of the entire farm, households and restaurant would be beneficially reused for its fertiliser and energy value. This option is termed <u>ecosan-biogas plant</u> in this paper.

The first option was discarded because of expected relatively high operating costs, e.g. for aeration (in addition to the capital cost which was estimated to be € 100,000). The main disadvantage of the second option (apart from costs for the pipeline[1] and sewer discharge permit costs) was that the pipeline would have had to cross parcels of land owned by about 150 owners (each having small parcels of land along the way); permission for this would have been very time-consuming to obtain. The third option was finally chosen since the biogas technology appealed to the farmer and because this option would result in lower operating costs due to electricity and heat generation from the biogas.

The plant was designed and constructed by TBW-Technologie, Bau- und Wirtschaftsberatung GmbH-Frankfurt/Main, Germany (this company no longer exists) and Krieg & Fischer Ingenieure GmbH, Göttingen, Germany (with input from two of the authors). The advantages of this third option, and how it has worked out in practise for the last ten years, are described in this paper.

DESCRIPTION OF THE ECOSAN-BIOGAS PLANT

The ecosan-biogas plant was constructed in 1993 to deal with the liquid and solid organic waste from the farm houses, restaurant, cattle and horse barn, and the slaughterhouse. An overview of the main mass and energy flows at the farm is provided in Figure 1.

The ecosan-biogas plant consists of the following elements:

- "*Conventional low flush toilets*" in the restaurant and farm houses (low-flush buttons but no urine diversion); The designers determined that there would be no particular advantage for urine diversion toilets in this project since urine can be used together with the anaerobically digested waste(water) as fertiliser.

[1] A cost estimate obtained in 2004 showed the costs of pipeline construction to be € 234,000.

- One concrete 100 m^3 "*wastewater storage tank*", which also acts as a pre-mixing tank; The wastewater from the restaurant and farmhouses as well as distillery waste from the small farm distillery, horse urine (stable run-off) and horse dung is collected by gravity in this tank on the lowest point of the farm area. The amount of sewage produced is about 2.5 ML/year.
- One *collection channel* (500 m^3 usable volume): A collection channel is located under the cattle shed (see Figure 2), and acts as a liquid manure storage tank (liquid manure collects in this tank via gaps in the floor; the amount of manure produced is also about 2.5 ML/year).
- One *heated and insulated anaerobic digester* (280 m^3 volume, fully mixed): Heating to 40 - 44°C is accomplished by internal heat exchangers on the walls and the floor of the digester using "cooling" water from the biogas CHP engines.
- One *anaerobic digester for storage* of digested waste and biogas (1500 m^3 volume, not mixed, not heated, not insulated)
- Two cogeneration modules (each with one 37 kW electricity generator and each with 74 kW of heat recovery through cooling water and exhaust gas heat exchanger). Two units are needed because one unit has to be taken off-line for about 24 hours for an oil change every 400 operating hours (i.e. ca. every 16 days), and to adapt the capacity to the different summer and winter gas production flowrates[2].

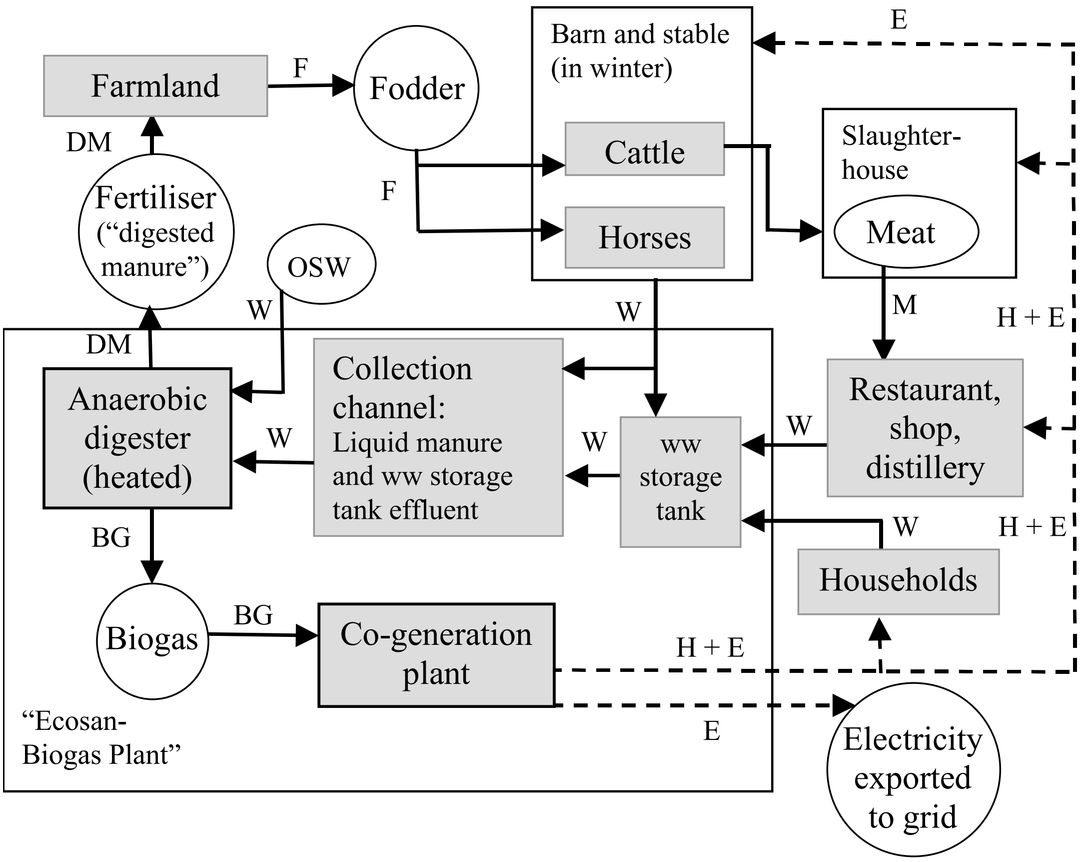

Figure 1. Simplified flow diagram for Michelbacher Hof showing main mass and energy flows (abbreviations: BG = biogas; DM = digested manure; E = electricity; F = fodder; H = heat; M = meat; OSW = various organic solid wastes; W = waste (liquid or solid); ww = wastewater)

Once per week wastewater is pumped from the wastewater storage tank to the collection channel with a submersible cutting pump to flush out and mix the content of the collection

[2] In winter, the cogeneration plant operates 24 hours per day to meet the process heat demand of the digester in particular; in summer the cogeneration plant only operates during the day.

channel. Liquid manure from the cows falls through gaps in the floor of the cattle shed into the collection channel (see Figure 2). The feed pump to the digester pumps about six times per day from the collection channel to anaerobic digester no. 1. In addition there is a feeding device to digester no. 1 for various organic solid waste such as straw and dung from the horses, solid organic waste from the restaurant and hot vegetable oil from the kitchen.

A second anaerobic digester is placed in series to digester no. 1, and also acts as a storage tank for the digested manure/wastewater/waste-mix and as a main gas holder. There are about 20 days hydraulic retention time in digester no. 1 and 3.6 months in digester no. 2. Both digesters have flexible plastic covers for biogas collection and storage (see Figure 2).

Generally a minimum of 500 m^3/day of biogas is produced in winter, while only 100 m^3/day is produced in summer (in summer there is less liquid manure production because the cattle is grazing outside). The biogas is used for electricity and heat generation in the cogeneration plant.

Figure 2. Left: Collection channel under the floor of the barn (note the gaps in the floor). Right: Digester no. 2 showing the flexible plastic cover filled with biogas

We call the system at Michelbacher Hof a “closed-loop system”, but of course there are small nutrient mass flows entering and exiting the farm. Entering flows are for example four pigs per week, vegetable oil, vegetables, bread, flour, saw dust and various food types. Exiting flows include solid meat wastes (by law these are not allowed to be digested in the anaerobic digesters), one third of the meat of one cow (leaves the system via the farm shop) and two thirds of the meat of one cow (via consumption in the restaurant).

REUSE OF ECOSAN PRODUCTS

Fertiliser

The “*digested manure*” (being the end product of digesting the mixture of liquid manure, sewage, organic solid waste, dung etc, as described before) is stored in digester no. 2 and then applied to the farm land (pastures and fodder production fields) on demand between February and November. The farmer applies the digested manure with a conventional agricultural machine (a large barrel on a truck with distribution system). If the sewage was not digested together with the animal wastes, the farmer would have to dilute the digested manure with potable water to enable this type of spreading on the fields and to achieve a homogeneous product.

Before the installation of the ecosan-biogas plant and in the first few years after the installation, the farmer had to apply commercial nitrogen fertiliser to his pastures and fields (in addition to applying normal liquid manure). Over time he has been able to eliminate this external fertiliser use for the pastures (a decreasing amount is still being used on the fodder fields), and he has observed an increasing soil fertility over the years. He attributes this to the better plant availability of nitrogen in the digested manure compared to non-digested liquid manure (due to nitrogen released from organic particulate matter during the anaerobic digestion process).

Further benefits are that the odour nuisance from this type of digested manure is much lower (practically non-existing) when it is applied to the fields, compared to non-digested liquid manure.

The amount of nitrogen produced by all the processes taking place at the farm (mostly originating from human and animal urine and excrements, and some solid waste containing nitrogen) covers nearly exactly the amount of nitrogen needed as fertiliser on the farm.

Pathogen removal is achieved during the retention time in the anaerobic digesters (although the exact degree of pathogen removal has not been measured). During the soil application, further pathogen removal is achieved. The digested manure does not come into contact with any food products that are consumed directly. Hence the risk for the public health is considered negligible and there have been no public health incidents during the last ten years of operation. The reduction of pathogens through mesophilic digestion (38°C) is already proven for municipal sewage sludge digesters which stabilise the sludge in a 20-30 day retention time. In agricultural biogas plants the retention time is longer and often the temperature is higher.

Heat and electricity
Apart from the fertiliser produced, the other important ecosan products at this site are heat and electricity, which are produced by the cogeneration plant. The heat is firstly used to heat the anaerobic digester no. 1. Further, there is a 70 m isolated district heating pipe that leads to the restaurant, slaughterhouse, the residential houses and a swimming pool. The heat generated from the cogeneration plant fulfils entirely the heat demand for hot water (note that a significant amount of hot water is required for the slaughterhouse), and it also provides 20% of the heating requirements in winter (the remainder is produced from wood-fired ovens with the wood being excess wood harvested from the land).

The electricity produced from the cogeneration plant is used to meet over half the electricity demand of the restaurant, slaughterhouse, residential houses and lighting of the barn. Any excess electricity is sold back to the general electricity grid.

COMMISSIONING AND OPERATING EXPERIENCES

The main commissioning problems were:

- The original heating system for digester no. 1 included a movable plate heat exchanger between incoming feed and outgoing digested manure (using the so-called Freese system). However, this system did not work well, due to pasted covers on the heat exchanger and was removed already in 1995, and replaced with fixed tubular heat exchangers on the wall and the bottom of the cylindrical digester.
- Straw that is added to digester no. 1 caused mixing problems (the project's target was to maximise biogas production for energy and heat production; this is the reason why the straw is being added). This problem was solved in 2003/4 when a better mixing system was installed in digester no. 1.

CAPITAL AND OPERATING COSTS

The total investment cost was € 200,000 (this includes retro-fitting work, e.g. installation of a new mixer and heat exchanger, building a shed over the digesters) in 1993. With the knowledge gained from this project, a future project of this size could be realised for approx. € 100,000, based on today's prices.

The income and savings from the biogas-ecosan plant include:

- Savings on fertiliser use estimated to be € 20,000 per year (without using any manure, the mineral fertiliser costs would be € 40,000 per year (based on € 200 per hectare); when using non-digested liquid manure, mineral fertiliser costs would be € 20,000 per year; with digested manure there are no mineral fertiliser costs). The fertiliser improvement value is estimated as € 10 per Livestock Unit per year, or € 55 per ton of N, € 56 per ton of P and € 28 per ton of K, all per year)
- The agricultural lands are continuously increasing in value (improving soil fertility).
- Annual savings resulting from on-site electricity production were € 23,400 in 2004 (based on an average tariff of 14 cent per kWh)[3].
- The annual income from selling excess electricity back to the grid (at times when production exceeds demand) was € 5,300 in 2004, based on 10.23 cent per kWh, which is paid by the electricity provider e.on for buying back electricity (same tariff independent of time of day).
- Savings resulting from not having to purchase natural gas for heating of water all year round and heating buildings in winter (these savings have not been quantified yet, but it should be noted that the cogeneration plant produces about one third of its kW output as electricity and two thirds as heat).

Expenses of the biogas-ecosan plant include:

- Oil change for generators every 400 operating hours (negligible cost);
- New cogeneration modules every 15,000 to 20,000 operating hours at a cost of about € 4,000 to 5,000; and
- Spare parts for maintenance.

CONCLUDING REMARKS

The process described in this paper is a good example of an ecologically sustainable, closed-loop system. Liquid and solid organic wastes generated at the Michelbacher Hof are used to produce fertiliser, electricity and heat. Further benefits are higher yields and no odour problems with the digested manure compared to non-digested liquid manure.

It must be noted that the legal situation for this type of closed-loop system is somewhat unclear in Germany. Some federal states where there is a lot of decentralized agriculture, for example Bavaria and Baden-Württemberg, accept this approach (but do not actually encourage it). Other federal states such as Schleswig-Holstein have laws against this type of reuse.

The conditions for the permission for such reuse systems under German federal laws are:

- Private on-site treatment of sewage with a closed-loop reuse of all by-products (water and sludge) in the own agricultural production or industry; and
- The alternative costs for a conventional connection to the closest existing public sewerage network is more expensive than € 4,000 per inhabitant, after the

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[3] Note that in addition to the electricity produced on-site, further electricity worth € 18,000 is purchased per year (average tariff of 14 cents per kWh).

investment subsidy (80% in average) which is supported by the municipality is subtracted.

Today, about 10% of the German agricultural biogas plants are co-digesting the household sewage with the animal wastes in and on their own farm. But unfortunately, the European standard for organic agriculture is not (yet) allowing this practise for certified agriculture.