Construction and operation of biogas plants with clover grass as input material

Experiences from biogas plant managers on organic farms in Germany

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Content

Introduction and general issues

For the organic farmers and biogas plant operators interviewed, the main aims of biogas production are to

- establish a system to increase nutrient input into the crop rotation and to have a more flexible source of input while preserving or improving soil fertility
- find a productive use for clover grass or other catch crops/green manure

The generation of electricity and heat – while valued as a welcome source of income and a relevant contribution to a sustainable energy supply – is seen as secondary to the nutrient issue by all biogas managers interviewed.

The following examples vary considerably in their experiences, outlook and strategies. There are, however, some issues which were raised by most or all of the biogas practitioners interviewed:

- Particularly operators with long experience in stockless organic farming see nutrient management as a significant challenge to the long-term success of the farming system.
- Stirring and the correct temperatures are vital for successful biogas production from clover grass. If unsuitable technology is used, floating layers in the fermenters and - connected with this – separation of the substrate’s phases can present considerable problems.
- Standard stirring technology is often not sufficient for clover grass as substrate. Slow-moving stirring devices such as paddle stirrers should be preferred.
- There is potential for increased biogas yields and/or easier stirring when methods of disintegration are used. So far, however, the effect of the different disintegration techniques on biogas production and their energy consumption are not always easy to determine.
- While standard technology designed for more difficult substrates may be able to handle a significant proportion of clover grass, the exclusive use of this substrate requires specialist experience.
- Gas-tight storage of digestate gets a mixed reception from plant operators. On the one hand, it can significantly reduce emissions of Methane. On the other hand, apart from being an additional investment which may not be offset by the use of the Methane, gas-tight storage may lead to higher temperatures in the substrate at the time of application. This in turn can cause high losses in ammonia and burn plant leaves. Also, digestate treatment involving aeration of digestate in

order to encourage the transformation of ammonia into organic biomass is hardly compatible with a gastight environment involving methane.

100% clover grass is possible: Miller, Schmiechen (Bioland)

Description

Hubert Miller has been running a stockless organic farm in Schmiechen / Southern Bavaria for 20 years. Miller has teamed up with four other stockless organic farmers in the region to build and operate a biogas plant running on clover grass. They could not find any reference operation running exclusively on clover grass. The plant in Schmiechen was constructed between May and December 2005. While all partners contribute investment and biomass, Miller is responsible for the operation of the plant. The plant uses biomass from about 20 organic farms.

Figure 1: Feeder and first fermenter. To the left is the covered silage storage.

Technical details

Feeder: push floor container and auger, insertion at the top of the fermenter

Digester:

- One high and slim vertical concrete digester (13 m high, 12m diameter, 1470 m³) with a central axial mixer which is suspended from the concrete ceiling. Additional circulation is provided by pumping the substrate. There is no internal heating but a heat exchanger in the pumping circuit.
- One low (6m) and wide secondary “standard” digester (1360 m³) with horizontal stirring an foil roof. No internal heating but heat exchanger in pumping circuit.
- Slurry storage: concrete slurry store, 1360 m³, uncovered

Stirring:

- Main digester: Central axial stirring (15 kW), suspended from the concrete ceiling
- Second digester: Submersible mixer (10 kW) and paddle mixer.
- Slurry storage: Submersible mixer (11 kW).

Figure 2: Example for central/axial stirring (for technical reasons not from the plant Miller). Photo: DLZ

Mechanical Substrate disintegration:

- Electrokinetic disintegration (Vogelsang, 20.000 V, 80 W) integrated in pumping circuit[1]
- Rotacut macerator between digester and secondary digester

CHP-engine: 333 kW el. , 254 kW th.

[1] Further information: http://www.lfl.bayern.de/ilt/umwelttechnik/13727/biogasendbericht.pdf

Table 1: Biomass input Miller/Schmiechen (approx.)

year	Clover grass	Other biomass
2008	20%	80% corn silage and other substrates
2009	88%	12% corn silage
2010	99%	1% kibbled rye grain
2011	80-90% (+ some manure)	10% corn silage

Experiences

In the first years of operation, the use of clover grass in the plant was a major problem. **Blocked-up pipes and broken augers** were only two of the problems the operators were confronted with. Many experiments and changes were necessary. Satisfactory production with 7.800 h at full load with 80% clover silage was reached in the third year of operation (2008).

The **central feature** of the biogas plant Miller is the **high and slim main fermenter with external heating and pumping circuit and vertical stirring with a central axial mixer**. Miller puts the capability of this system to cope with the substrates used down to several factors:

- The shape of the fermenter: The high and slim shape of the fermenter facilitates effective stirring and decreases the need for external heat input (better insulation due to better ratio of surface to volume than standard fermenters). In six years of operation, the fermenter has not had to be emptied from stones/sand. Heating is usually only necessary between November and March.

- The stirring: Vertical downward stirring allows for more effective mixing than horizontal stirring, particularly in the slim fermenter. Swimming and sinking layers are successfully avoided, the material is held in suspense. Also, problems with undigestable materials (stones, sand) accumulating in the fermenter are avoided because these don't travel to the bottom but stay in suspense and travel through the fermenter to the slurry storage. On average, clover grass silage caries a higher content than corn silage due to harvesting methods. Effective stirring leads to better mixing of the substrate and supports the upward movement of the biogas bubbles from the substrate into the gas storage (particularly relevant for substrate with high DMC).

- If problems with swimming layers occur on the plant, this is not in the main fermenter, but in the (standard shape) secondary digester. Miller stirs 1.500 m³ with 15 kW, the blades are at about 3 m from the bottom.

- The external heating: Particularly with clover grass as substrate with high DMC and high content of long fibres and particles, heating tubes installed internally can be at risk of being blocked ("mat of fibres" round the pipes), damaged or even broken off their brackets. At the Miller plant, the substrate is drawn from the fermenter (at 3 m) into pipes. These pipes travel through a heat exchanger and past the electrokinetic disintegration. The pump with

Figure 3: External heat exchangers for the substrate.

a capacity of 730 m³ per minute then pumps the substrate back into the fermenter with a downward-facing jet. This supports mixing of the substrate and avoids sinking layers.

The first **heating system** via heat exchangers did not work properly – in Millers opinion due to the high dry matter content (DMC) of the substrate. A new, simpler system was built by the local blacksmith: An 80 mm steel pipe is running inside a 110 or 120 mm pipe (red pipes in picture on the right). Substrate is pumped through the inner pipe while heating water is pumped through the outer pipe in opposite direction. This system is working well and provides sufficient heating. For a new plant, it could be refined using the experiences made thus decreasing energy use and wear on the electric substrate pumps.

The **secondary fermenter** in classic construction (6 m height, horizontal stirring) is seen as a big mistake due to problems with swimming layers. The stirring is by far less efficient than in the first fermenter and requires high energy input. The original combination of submersible mixer with a quickly rotating blender couldn't handle the substrate, so the blender was replaced by a paddle mixer with slower movements.

The Huning **feeding system** used can't be recommended. Wear and tear has been too high. After only one year auger and push floor had to be replaced. However, the feeding systems available today are much more advanced (e.g. plastic lining, other materials, higher material thickness, larger auger diamete). From the feeder, the substrate has to be transported higher up than in standard plants due to the high fermenter. Therefore, the input system uses more energy. Today, more economical systems are available .


Figure 4: Rotacut

Substrate disintegration: The **rotacut** mechanical disintegrator (picture on the right) is an absolute must with clover grass. The disintegration of the material with cutting down of particles and long fibres leads to a substrate which can be stirred more easily. This also enables the gas to exist from the substrate more easily. Miller doesn't see the rotacut to have an influence on the gas yield and sees this view supported by published experiments.

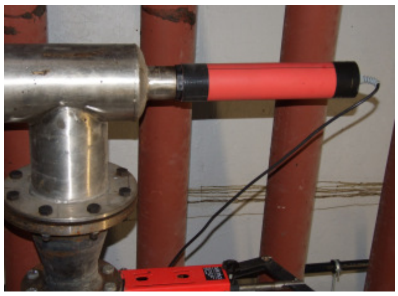
Figure 5: Elektrokinetik disintegration

The **electrokinetic disintegration** (red in picture on the right) has not lived up to its promises of a 20% increase of substrate efficiency. After six months' monitoring, a 3% increase of substrate efficiency was recorded, which was statistically not significant. While Miller would not use the system in a new plant, he has left it in operation since it reduces the energy demand for stirring the substrate by making the substrate easier to stir.[2]

The **biology** of the clover grass system is considerably less stable than a maize silage system. Even a change from one silage batch of clover grass to the other requires careful observation and possibly **blending of the silage charges** for a while. It is vital to keep a close eye on the qualities of input biomass and fermentation process.

[2] Results of a research project on electrokinetic disintegration involving an organic biogas plant: Bayerische Landesanstalt für Landwirtschaft , 2009: Optimierung der Verfahrenstechnik landwirtschaftlicher Biogasanlagen. Abschlussbericht, Freising, www.lfl.bayern.de/ilt/umwelttechnik/13727/biogasendbericht.pdf

A decisive factor with great variability and far reaching consequences for the operation is the dry matter content (DMC) of the substrate. The **DMC in the silage should be analyzed monthly**. Standard values like those published by the German KTBL should not be used since the situation on the plant may differ widely.

The optimum DMC is defined primarily by the requirements of an effective conservation process (silage) and the technological capability of the biogas plant. At the plant Miller, the DMC in the fermenter is at about 15 %.

Temperature management: The process runs at its best when substrate temperature is at 43 °C. At 42 °C, the fermentation process is working fine, but for unknown reasons an additional 2 to 3 Ampere is required for stirring. Below 40 °C, stirring becomes increasingly difficult and biogas production is slower. While the need for heating is relatively small due to insulation and shape of the fermenter, the temperature in the first fermenter may rise to about 45 °C in summer. In 2008, the biological process broke down when substrate temperature rose to 49 °C. Miller is considering the option of actively cooling the fermenter with cold water via heat exchanger. He is convinced that with clover grass, the fermentation cannot be managed as a thermophile process but has to be operated at mesophile conditions. This is due do the high protein content of the substrate and to inhibitions caused by ammonia.

What makes biogas from clover grass expensive? Miller sees three major positions where biogas plants run mainly on clover grass will have higher costs than those operation on corn silage:

- Investment: The investment is higher because more expensive technology is necessary, particularly where stirring and substrate transport is concerned.
- Harvesting cost: Clover grass with its higher water content and two or (usually) more harvests per year has higher costs for harvesting and transport. Miller considers it more or less impossible to pay farmers for the cover grass. They will however, get the fertilizer (biogas slurry) in return for the crop which makes the exchange worthwhile.
- Electricity consumption for plant operation is relatively high. Particularly the stirring and transporting of the relatively dry and viscous substrate requires a considerable amount of electricity, so the overall electricity consumption is well over 10% of electricity production.

Biogas slurry as fertilizer: Since the main reason of biogas production for Miller lies in its advantages for plant production, he is eager to preserve the nutrients contained in the slurry for soil and plant fertilization. He recommends spreading the slurry as early in the year as possible in cold weather in order to avoid nitrogen losses from the high ammonia content in the slurry. This is true for all biogas slurry but particularly for clover grass biogas slurry with its high nitrogen content. He has experienced an increase in yields, but reckons that still a considerable proportion of the nutrients is lost before and during application as fertilizer. Together with scientists and engineers he's convinced that it should be possible to fixate the nutrients in microbial biomass thereby preventing losses. He warns against applying slurry which is still warm from the digester since this may cause the ammonia to burn the plants and will also lead to high nutrient losses by evaporation.

Further information

Hubert Miller can be contacted regarding further information on organic biogas from clover grass. He is prepared to support organic farmers intending to start up biogas plants and to advise them in planning, building and operating their plant.

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Workability and variety: Wiggert, Löffingen (Bioland)

Description

Shortly after converting its farm (approx. 300 ha arable, 100 ha pasture) to organic agriculture, the family Wiggert established a biogas plant in 2006 as an addition to crop production and the suckler cows & beef (approx. 80) on the farm. With technology from Agricomp, a general contractor focusing on biogas plants for a wide range of substrates, the Wiggert family has managed to process successfully a mix of input materials with up to 50% of clover grass.

Input material: The operation is run on a mix of substrates with clover grass, grass, whole crop silage, corn silage and cattle manure contributing biomass in variable quantities (see Table 2). About 30% of the total material can be classified as originating from "energy plants", that means from plants grown primarily for the purpose of producing energy. Clover grass is not seen as "energy plant" since it is needed on the farm primarily for its contribution to soil fertility and nutrient accumulation. About 10% of the input originates from conventional crop production. This includes part of the corn silage as well as some clover grass.

Table 2: Biomass input Wiggert

Substrate	Percentage (approx..)
Clover grass / grass	30-50%
Whole crop silage (including pulses)	20-30%
Corn silage	10-20%
Cattle manure	15%

Feeder: push floor container "Vielfraß" and auger

Digesters: 3 Digesters with internal heating and stirring (height: 6 m, diameter: 18 m,18 m, 20 m), 1 slurry tank with stirring and foil cover (20 m), 1 open slurry tank

Slurry treatment: Separator between 1st and 2nd slurry tank

CHP: 530 kW el. including exhaust turbine

Retention time: approx. 130 days

Experiences

Wolfram Wiggert reports a **successful operation** of the plant more or less from the beginning. Choosing a general contractor experienced in dealing with difficult substrates has proven a worthwhile decision.

The push floor container as **feeder** has proved to have low energy consumption as well as acceptable reliability and to be suitable for the substrates used. For clover grass and other substrates rich in long fibres, the augers leading from the feeder to the digester are heavily used.

Short distances, large augers: The distance from the feeder to the entry into the digester should be as short as possible (3 m in Wiggert's case) – ideally the feeder is situated near the top of the fermenter e.g. following the relief of the ground or an artificial bank. Feed-in augers should not need to go round bends. This will reduce wear and should keep replacement costs low. The augers should have large diameters and should be made from quality steel. They will then live longer. Wiggert has needed to replace the augers about every 2-3 years.

The **first fermenter** of the plant is fairly small. Wiggert sees this as a reason why at the beginning of plant operation, it took fairly long for the microbiological process to be established. Also the need for continued use of trace elements (Schaumann) is increased according to Wiggert by the small fermenter size. "We're always running the fermenter on the verge of what's possible." The volume load of the first fermenter is approx. 8 kg/m^3 oDM x day.

However, the "intensive" running of the first fermenter may also contribute to the low **electricity consumption** of the plant (5-6 % of electricity generated) since less substrate has to be stirred. Another reason for this low consumption rate may be the high efficiency and the high number of annual operating hours of the CHP engine. This improves the relation of energy needed to energy produced, since total energy consumption depends largely on biogas production and only to a smaller extent on CHP operation.

The stirring in the second fermenter had to be improved. An additional blender and a paddle mixer were installed in the second fermenter. For a new plant, he'd use **three paddle mixers in the first fermenter and two paddle mixers in second/third fermenter.**

With a **separator**, there is no swimming layer in the 2^{nd} slurry storage. Also, the separation enables a more differentiated and flexible application of the digestate. The danger of burning plants at application of warm slurry is low because the second slurry storage is not covered thus allowing the slurry to cool off more easily.

With about **3.000 €/kW el.,** the investment was relatively low compared to other biogas plants.

What would Wiggert change if he started again?

- He would choose to **invest more where it leads to higher reliability** of operation.

- The fairly small building plot available for the plant has turned out to be less than ideal – a **larger building site** would have allowed for more economical arrangement of the components (e.g. fermenters in a group instead of a chain).
- He might invest in a **larger first fermenter.** With this he would attain a lower volume load. In the opinion of the operator, this would make the biogas process easier to control and may reduce the need for surveillance, adjustments and constant addition of enzymes.
- A **larger slury storage** would be useful to make best use of the slurry for crop production.

Wiggert sees major factors for the success of his plant in long operating hours of the CHP (more than 8.500 hours per year), a high electric efficiency of the CHP engine (dual-fuel engine in his case) and low energy consumption for the process.

Hydrolysis and Recirculation: Wittenberghof, Stahlbrode (EU organic)

Description

The Wittenberghof in Stahlbrode / Mecklenburg-Vorpommern is a farm with approx. 520 ha arable land, 130 ha grassland and 200 suckler cows. Conversion to organic agriculture was completed in 2009. On his farm, Gerald Schulz has established a 500 kW_{el} biogas plant operating mainly on organically grown leguminous and non-leguminous catch crops and animal manure. The plant has been constructed as a modified version of the so-called "Rottaler Modell" with partly anaerobic hydrolysis. Start of Biogas production was in January 2012.

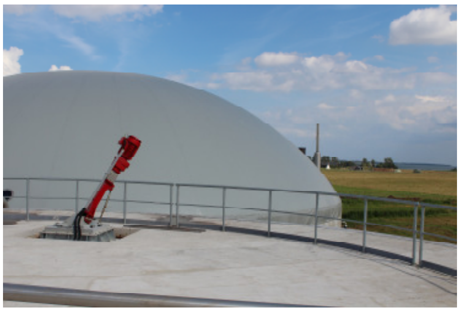

Figure 6: Fermenter with concrete roof and digestate storage with foil roof

Biomass: Ca. 45% of the biomass consists of clover grass, lupine and other catch crop silage. At the time of the consultation, the biomass input consisted of clover grass silage, oat silage, catch crops, cattle manure and poultry manure.

Table 3: Biomass input Wittenberghof

Substrate	Biomass per year
Cattle manure (organic)	4.000 t
Turkey manure (conventional at present)	2.000 t
Clover grass, grass, catch crops (rye, lupine)	3,500 – 5.000 t

Hydrolysis: 3 compartments of 300 m³ each (> 40 kg oDM/m³ x day). The hydrolysis is thermophile (> 50 °C), partly anaerobic and slightly acidic (below pH 6.5). A controlled amount of air is pumped into the substrate of the anaerobic hydrolysis compartment with a small compressor to reach an oxygen content of up to 0.5 % in the hydrolysis. Digestate is added (recirculation).

Digester: 1 Digester with 1.400 m³ and gas proof concrete ceiling (7-8 kg oDM/m³ x day, sometimes up to 10 kg)

Digestate storage: 1 storage tank with 3.400 m³ (gas proof foil cover)

CHP: 600 $kW_{el.}$

Slurry treatment: Separator after the second fermenter; dryer for separated solids of the digestate (New Ecotech).

Biomethane production: aiming at > 400 m³ CH4/t oDM (results not yet representative because of short productive period)

Thermal energy: The heat generated by the CHP engine is used for drying of the substrate. The original plan was to deliver the heat to a nearby agricultural holding, but this could not be realized since the negotiations with the potential energy user had a negative result.


Figure 7: Pumps and pipes between the fermenters

Pumping: The pumps (Vogelsang) are located centrally between fermenter and digestate storage. This decreases pumping distances. The pumping system is fit for the job and flexible enough to handle different operating conditions.

System: The biogas production system on this plant was designed by Snow Leopard Projects (www.snow-leopard-projects.com). The project engineer Walter Danner considers this system as particularly suitable for substrates in organic farming (up to 80% clover grass if the rest of the substrate is more easily digestible, e.g. maize or sugar beet). He claims a remaining gas production potential in the digestate of no more than 0.5 % and reports biogas plants with his concept to reach an average of > 400 Nl CH_4 per kg oDM. Technically, the system provides a hygienised digestate (the respective certification for Germany is under way). For economic reasons, the system is recommended for a minimum CHP capacity of 250 kW el. (continuous production).

Experiences

Planning: The planning and – particularly – the permission phase took more than one year longer than originally planned.

Building: The construction process was **badly coordinated**. In particular, the construction manager was not doing his job well. The lack of an able site manager caused severe and expensive problems in the first year of operation (see also below). Contract work sections were badly coordinated; mistakes and laxness of the craftspeople were neither controlled nor corrected. Two examples for severe mistakes:

- The concrete used was of a quality only suitable for indoor use and not resistant to the demanding conditions of a biogas plant. This caused expensive and time-consuming work for correction.
- Electric installations were carried out without closing up trunking exits against water (or substrate). This was the cause for a severe electric blackout on the plant.

Schulz urgently recommends any biogas project to place an emphasis on excellent and meticulous **supervision of the construction process** – money saved here is offset many times by just one serious mistake.

Start of production: Initial establishing of production was slow, technical mistakes during building caused severe problems. Once the process was established, it could be resumed to full productivity within only few days even after long standstill in production.

Process engineering: In April 2012 the pumping system was out of operation due to faulty construction. The fermentation processes of the substrate could no longer be controlled. This resulted in an explosion causing severe damages to the plant and a complete standstill of production for almost three months.

Crop production: Sandy soils, a lack of accessible ground water and long periods without precipitation (Baltic influence!) make clover grass as main crop a relatively unattractive choice for arable farmer Schulz. He therefore uses it mainly on the more extensive fields further away from the farm. Generally, he's using a mix of catch crops including lupines (and also clover grass) in a six year crop rotation. In order to sustain crop yields, he relies on extensive use of intercropping and catch crops between main crops, and on the import of nutrients: The use of animal manure from other farms for biogas and (in the future) the use of compost from a nearby facility as fertilizer.

In 2011, barley yielded approx. 2.2 to 2.5 t/ha. In 2012, with use of biogas substrate, the yield was at about 5 t/ha. However, due to the short period of operation and the high influence of yield differences between years, the influence on biogas production on crop yields can't be analyzed yet. Schulz has the aim of attaining cereal yields of 4-6 t/ha.

Stirring: Under normal operating conditions (ca. 12-13% DM), the stirring of the fermenter and the digestate tank is working properly. However, as soon as dry matter content increases, stirring becomes more difficult. Liquid separated digestate and water then have to be added to ensure that the material can still be stirred. With the pasty substrate, stirring and a sufficient water content are vital for the fermentation process but also to physically release existing gas bubbles from the substrate and to allow them to travel upwards and be collected from the top of the fermenter. The possibility for efficient stirring is also important in the digestate storage. Only if the entire storage tank can be mixed will phase separation and swimming and/or sinking layers be avoided. If phase separation takes place, fewer solids are taken from the tank into the separator unit and the separation will work inefficiently.

The stirring equipment installed in the fermenters is not really sufficient for all situations and more robust equipment would be chosen for a new plant. In particular, products of Armatech-FTS are considered inadequate. Also, Schulz would opt for stirring equipment with a higher power output.

Despite his problems with faulty construction, Schulz is convinced that the system he has invested in is suitable for his operation. For him, the efficient digestibility of a wide range of substrates is a priority. He considers the **possibility to use cheap substrates** which demand only harvesting and transport as a big influence on the economics of the operation.

Efficiency of digestion: For Schulz, the efficiency of the system is indicated by a remaining gas production potential in the digestate of 0.32 % after 2 days in each hydrolysis compartment (thermophile) and only 16 days in the main fermenter.

Standard system with offbeat substrate: Krumbecker Hof, Stockelsdorf (Naturland/Demeter)

Description

Organic arable farming with low stocking rates on (today) 230 ha has been a focus at the Krumbecker Hof in Stockelsdorf/Schleswig-Holstein for 21 years. On the same estate is an organic vegetable farm. While the arable farm is certified by the Naturland association, the vegetable farm is Demeter certified. In June 2010, a biogas plant started production in order to increase soil fertility and crop yields and to produce renewable energy. Farm manager Gerhard Moser mentions nutrient management and soil fertility as the most decisive factors in the decision for biogas: "The decision was to increase cattle stocking rates or to establish biogas production." In his view, biogas production is a viable alternative to cattle husbandry also from a biodynamic point of view.

General contractor: agriKomp GmbH (www.biogastechnik.de)

Input material: The operation is run on a mix of substrates with clover grass, manure and by-products from the organic milling industry contributing biomass in variable quantities (Table 4). In order to gain a bonus payment for electricity ("Güllebonus" = manure bonus), 30% of the biomass input needs to be slurry or manure. This is one reason for the use of poultry and cattle manure from other farms.

Figure 8: Byproducts from the milling industry

At present 40 % of the crop area is planted with clover grass. Since this is considerably more than needed for soil fertility, about 10 % of the total substrate may be seen as originating from "energy plants", that means from plants grown primarily for the purpose of producing energy. For the future, a reduction to about 30% clover grass on the crop area is planned (through more efficient production and increase in land area). At present, about 20% of the input originates from conventional manure.

Table 4: Biomass input Krumbeker Hof

Substrate	Percentage (approx..)
Clover grass silage	60 %
Dry poultry manure (organic), cattle manure, horse manure (organic/conventional)	30 %
Milling by-products (organic) and Horse manure	10 %
Substrate from conventional agriculture	20 % cattle manure

Feeder: push floor container "Vielfraß top" and auger

Figure 9: Feeder, first fermenter and (far right) storage tank

Digesters: Digester with internal heating and stirring (900 m³), second digester with internal heating and stirring (1800 m³), one open slurry tank with 1500 m³. The fermenter size allows a retention time of more than about 150 days and moderate organic loads of less than 4 kg oDM/m³ x day.

Stirring: Paddle system "Paddelgigant" in the main fermenter. Two submersible mixers in the second fermenter

Slurry treatment: Separator "Quetschprofi" between 2nd digester and slurry tank

CHP: 160 kW el.

Electricity consumption: Electricity needed for the operation of the plant is provided by own wind turbines when available (renewable energy, cheaper than electricity from the national grid).

Figure 10: Stirring equipment "Paddelgigant" (company photo, not on Krumbecker Hof). Photo: Agrikomp

Methane emissions: Methane emissions are analyzed regularly.

Thermal Energy: The available thermal energy not needed for the biogas process is used to provide heating and warm water for 10 households on the farm as well as farm buildings and a cereal dryer.

Experiences

Organic certification: Certification was necessary for the organic growers' associations Demeter and Naturland. While Demeter permits the use of cattle manure from conventional farming under certain circumstances, the same manure may not be used after it has passed the biogas plant. In Mosers view, the standards are incongruent in this respect caused by skepticism towards the influence of biogas on the quality of the manure. He claims the biogas plant with its fermentative processes is bringing a quality into the substrate which is relatively close to the nature of animal manure – an improvement of the situation on arable Demeter farms with low stocking densities.

Input material: The mix of input materials is demanding particularly for the stirring and pumping equipment but on the whole workable. Moser is particularly content with the use of the milling byproducts: Their methane production is similar to that of whole grain. Moreover, they don't need to be crushed or kibbled and – being rich in small, dusty particles – they mix well with the silage and improve the slip of the substrates at input into the fermenter.

Feeder: The feeding system is functional, the wear and tear (esp. on the augers) is fairly high. The auger of the substrate transport has had to be replaced already – for the replacement part, stainless steel was used.

Stirring: Moser - like other operators in this study – recommends using powerful stirring equipment for the substrates used. The stirring equipment used in his plant can normally handle the substrate. However, an increase in DM has resulted in problems with the stirring equipment, particularly in the first fermenter. The transmission of the paddle system "Paddelgigant" had to be replaced after only two years of operation. With an increase of temperature in the fermenter from 43 to 46°C in recent months, the substrate has become easier to stir, significantly reducing power requirement of the stirring equipment.

General contractor: Generally, Moser is positive about choosing a general contractor offering a complete system. The Agrikomp system is working properly, and the company is experienced in biogas production with more difficult substrates. On the other hand, he was not satisfied with some of the workmanship carried out during construction; there were severe servicing mistakes in the initial stages of production and lengthy discussions about the responsibility for damages resulting from faulty servicing. Disputes have now been settled, and for the separator which went into operation in summer 2012, Moser was again relying on an Agrikomp product.

For replacement parts, he recommends comparing original parts with spare parts from other companies. With stainless steel augers for biomass transport from the feeder to the fermenter, he found considerable price differences despite comparable or superior quality.

Start of production: At the beginning of production servicing faults caused considerable problems. As contractors filled the heat exchangers with the wrong liquid, rubber sealings dissolved. The heat exchangers were no longer working properly. In consequence, the temperature in the fermenters dropped. This caused problems with the fermentation process and higher viscosity of the substrate. The stirrers in the second fermenter were damaged because of the unusually high load.

Economics: While faulty choice of material and construction had a negative influence particularly during the first months of production, Moser sees the main advantages of biogas in a sustained increase in crop yields and in the fact that clover grass now acts as a cash crop.

Crop production: Moser reports an increase of about 30% in cereal yields. However, this experience relates to only one year's experience. At the same time, there was an increase in weed pressure which Moser sees as a result of the increase in available nutrients.

Digestate management: For better nutrient management, a separator has come into operation in summer 2012. At the time of the visit the water content of the solid product from the separator was far too high. This appears to be an exception since Moser is satisfied with the regular operation of the separator. Most of the substrate produced so far is reasonably dry and remains on a heap without apparent leaking. Moser considers constructing a waterproof surfacing for the storage of the solid digestate.

Figure 11: Solids of separated slurry

As for the liquid digestate (or unseparated digestate), Moser cautions against spreading material that is still warm from the fermentation process. This can cause excessive losses of ammonia and also burn the surface of plant leaves. In his plant with open storage tank, the temperature decreases fairly quickly.