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Future biomasses for biogas

Denmark has a large unexploited energy potential in the shape of animal manure representing between 20 and 30 PJ. The manure can be exploited at biogas plants, but in order for this to be profitable for the plants, the manure needs to be combined with other types of biomass, such as organic waste and energy crops.

By Henrik B. Møller

It is a well-known fact that it is very difficult to establish profitable biogas plants that convert animal manure alone. So far, the finances of the plants have been based on the fact that they have had the opportunity to add easily convertible organic waste. The main part of the traditional waste resources, however, is already being used, so it is necessary to find new ways to ensure that more biogas plants will be built in future.

The Danish Institute of Agricultural Sciences is currently researching the possibilities of increasing the gas yield and finding alternative biomasses. In the spring of 2004, the first pilot reactor was installed at the liquid manure laboratory at Research Centre Bygholm. Since then, the small reactor has welcomed three more colleagues, of which the last one was installed towards the end of 2004. The reactors, which have all been built at the University of Southern Denmark in Odense, offer unique possibilities to carry out very realistic tests in a full-scale plant.

Each of the small reactors contains 120 litres of biomass, and each of them has a small pretank, in which the biomass is mixed. The content of the reactors can be measured with built-in load cells and heated very precisely from 15 to 70° C. The gas produced in the individual reactors is measurable with a margin of only one per cent. All routines are controlled by means of a PC, and programming and commissioning has taken place at Bygholm. ▶

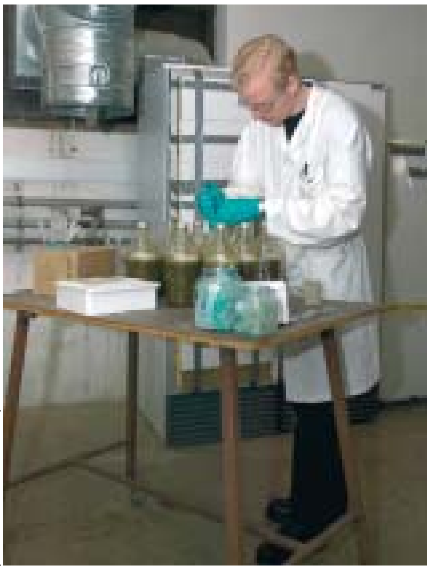

photo: torben skøtt/biopress

Student Verner Holm carries out tests where enzymes are added to increase the gas production.

Alternative biomass

So far, biogas plants have been able to charge fees for receiving some of the waste, while on the other hand they have had to pay for high-value products. In the future, where biomass will increasingly consist of energy crops and crop residues, the plants will have to pay the costs of growing and transport at the least. In that connection, it is important to know the exact gas yield and possible inhibiting effects of the various crops. When these parameters are known, the most advantageous biomass or combination of biomasses can be chosen.

Lately, the Danish Institute of Agricultural Sciences has carried out digestion tests of maize, grass, grain, wheat straw and barley straw. Furthermore, a series of pre-treatment tests has been carried out in the shape of pressure-cooking and chemical treatment, and tests are also carried out with added enzymes.

Energy crops

It can be difficult to predict which energy crops are most optimal from a growing, environmental and financial point of view. Grass and maize are often mentioned as the most obvious choices because of their high yields. Furthermore, grass has a number of derived effects, e.g. reduced pesticide consumption and reduced leaching of nutrients compared to grains.

The Danish Institute of Agricultural Sciences has carried out tests with maize from two localities and grass and grass-clover from two localities. The results appear from figure 1, which among other things, show that most of the crops yield more than 350 litres of methane/kg organic dry matter. In the tests, the easily convertible grass was above the level of maize, while the hardly convertible grass provided a lower yield than the maize.

photo: torben skøtt/biopress

Henrik B. Møller pours liquid manure into the pretank of one of the four test reactors in the liquid manure labora-

Straw

In specialist literature, the methane yield varies from 150 litres/kg organic dry matter to 370 litres/kg organic dry matter. A complete conversion of straw yields approx. 432 litres/kg organic dry matter, and the conversion rate in connection with traditional digestion thus varies from 35 to 85 per cent.

For gas yields in the lower end of the scale, it is not profitable to use straw at biogas plants. With a market price of e.g. DKK 0,40/kg straw, it costs approx. DKK 3 to produce 1 m^3

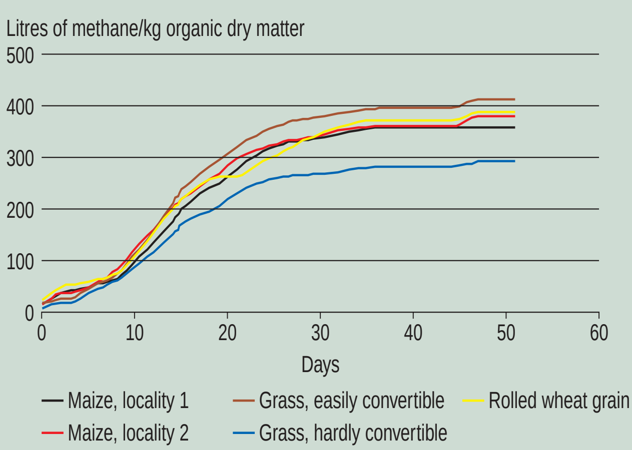

Figure 1. The methane yield of various energy crops in connection with batch digestion for 40 days.

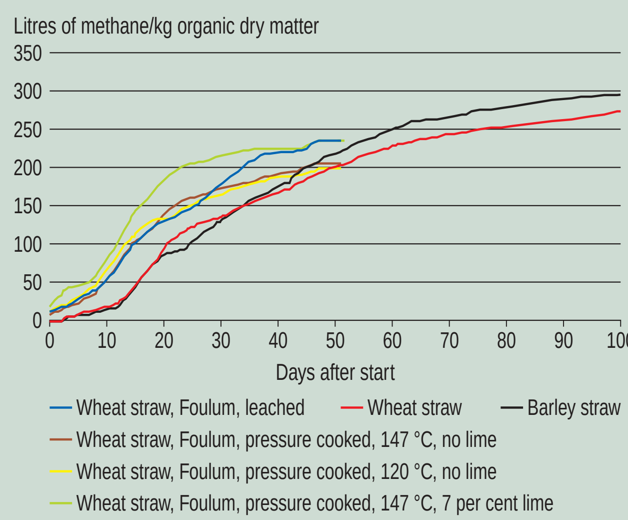

Figure 2. The methane yield of various straw types and pre-treatment options.

methane, which is not financially feasible.

If the yield can be increased to 250 litres/kg organic dry matter or more, straw, however, becomes an interesting biomass to add at liquid manure-based biogas plants, provided that a satisfactory solution of how to handle the straw can be found.

At the moment, the Danish Institute of Agricultural Sciences is carrying out a series of tests to illustrate the biogas potential of straw and the possibilities of increasing the conversion rate. The results of the digestion of barley straw and wheat straw appear from figure 2, which, among other things, shows that barley straw produces a higher yield than wheat straw.

Straw is known as a biomass which is relatively hard to convert, but a sufficiently long retention time will entail good conversion even without pre-treatment. At biogas plants with very long retention times and gas reception in so-called after-storage tanks, it will thus be realistic to obtain a methane yield of 250 litres/kg organic dry matter.

Pre-treatment

In connection with the digestion tests, a series of pre-treatment methods has been studied with a view to increasing the gas yield. These are comminution and milling, pressure-cooking without or in combination with lime and leaching. Furthermore, tests are carried out where the fibre fraction is retained in the reactor and the digestion process continued.


photo: torben skøtt/biopress

Laboratory technician Gitte Hastrup Andersen carries out a test where energy crops are degassed.

All pre-treatment methods entail a significantly faster conversion. The preliminary results imply that leaching and the combination of pressure cooking and lime are the most efficient methods to decrease the conversion time.

As soon as possible, new tests will be carried out which will illustrate the influence of pre-treatment on the conversion time. For plants with long retention times in after-storage tanks with gas reception, pre-treatment based on the current results will hardly be advantageous, though.

Profitability

The profitability of adding biomass at biogas plants mostly depends on the value of the methane at the particular plant and the costs of producing the amount of biomass to be added.

The value of methane is typically around DKK 2.50-3.50/m^3. The costs of producing 1 m3 methane from various raw materials are shown in figure 3.

The difference between the costs of producing 1 m^3 methane and the proceeds that the plant can obtain from selling the gas has to cover the expenses of handling, operation and payment of interest of the equipment that is required to handle the crops. This applies to existing plants, where the costs can be considered from a marginal perspective.

If, however, a new plant is to be established, where the energy crops have to contribute to the profitability of the plant, it is another matter. In such cases, the costs of producing 1 m^3 methane must be lower in order for the plant to be profitable.

Seen from a marginal perspective, it is possible to cover the operation costs

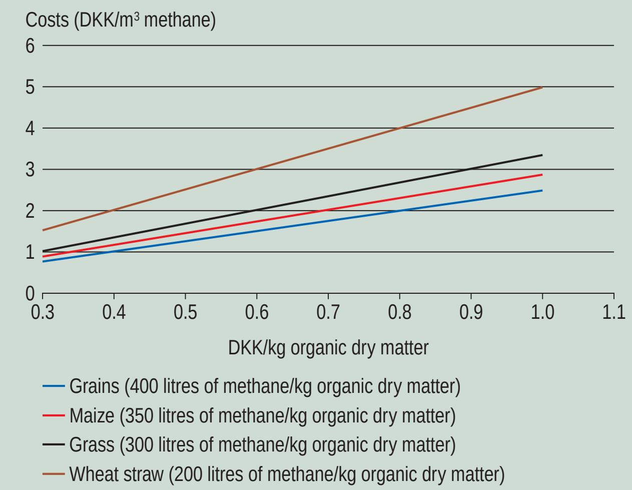

Figure 3. The costs of producing 1 m^3 methane dependent on the price of buying/producing various types of biomass.

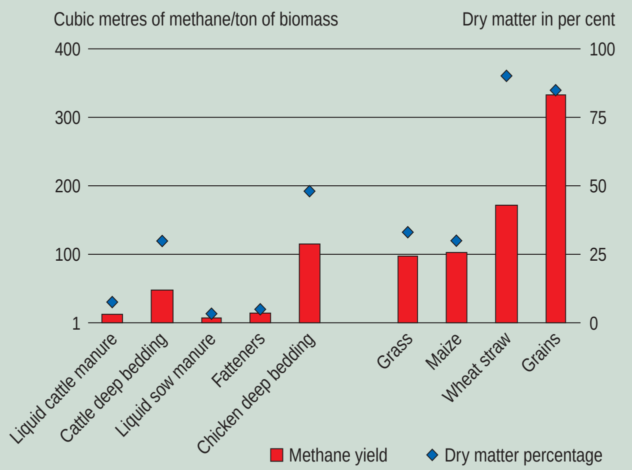

Figure 4. Typical yield levels and dry matter percentages for various types of animal manure and energy crops.

photo: torben skøtt/biopress

Biogas plant at Grøngas near Hjørring. Apart from liquid manure, the plant adds various forms of energy crops such as maize and grass.

of a plant if the value of one m^3 methane is DKK 3, and the raw material costs do not exceed DKK 1.50-2.00/m^3 methane.

In comparison, the raw material price of liquid manure is DKK 1.40-1.70/m^3 methane at a dry matter content of respectively 6 and 4 per cent. The liquid manure can of course be collected free of charge, but as the average transport costs are approx. DKK 20/ton, the raw material price is close to the price of energy crops.

If a raw material price of DKK 2/m3 methane is acceptable, it is possible to pay DKK 0.70/kg organic dry matter of maize which corresponds to approx. DKK 0.83/feed unit. For grains, it is possible to pay approx. DKK 0.80/kg organic dry matter.

For straw, a price of approx. DKK 0,40/kg, which is the current market price, will only become profitable if a cost of DKK 2/m^3 methane becomes acceptable. If a pre-treatment process in the shape of leaching or pressure cooking can be carried out for less than DKK 100/ton, the profitability will be improved provided that the yield is improved with more than 20 per cent. For plants with long retention times in after-storage tanks with gas reception, pre-treatment is, however, unlikely to be profitable.

Gas yield/ton biomass

In practice, however, the price and the methane yield per kg organic dry matter are not the only decisive factors. The gas yield per ton is also of a certain importance. All other things being equal, a high yield per ton gives a higher net yield as a smaller amount of biomass has to be handled and heated, and less reactor volume is needed. Therefore, it may prove sensible to pay a higher price for biomass with a high gas potential/ton than for less concentrated types of biomass.

On the other hand, there is a limit to the amount of biomass with a high dry matter content that one biogas plant can process. In a fully agitated reactor, the dry matter content of the biomass should not exceed approx. 10 per cent. In practice, that means that the amount of straw that can be added at a liquid manure-based biogas plant is limited to approx. 5-10 per cent of the total amount of biomass.

Figure 4 shows some typical yield levels and dry matter percentages for various types of animal manure and energy crops.

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Ærø gets Denmark's first ethanol plant

Ærø's Renewable Energy Organisation has recently made a contract with BIOSCAN for the construction of a biogas plant at a price of DKK 26 million and an ethanol plant at a price of DKK 12 million. Furthermore, Ærø's Renewable Energy Organisation has given BIOSCAN an option on the other necessary investments in connection with the establishment of the plant, including gas pipes and a combined heat and power plant at a total price of DKK 20 million.

The integrated biogas/ethanol plant is the first of its type in the EU, and for that reason the EU subsidises the project with approx. 35 per cent of the costs of construction. The plant will e.g. experiment with various raw materials for the production of ethanol, including deep bedding, solid manure and energy crops. Subsequently, the residual products from the process will be used as raw materials at the biogas plant, which entails an improved energy economy compared to traditional ethanol production.

- The idea is to use what cannot be used for ethanol production for biogas. That way, the raw material costs can be distributed between the two plants, says Poul Ejnar Rasmussen from BIOSCAN.

Producing ethanol on the basis of sugary crops is simple, but the price of the crops is problematic. On the other hand, converting cellulosic biomass, such as deep bedding and waste, to ethanol is expensive and complicated, although the raw materials are free.

The difficult part is to find a cheap method to "open" the cellulosic raw materials in order to create a cheap sugary substance. On Ærø, the plan is to pre-treat the waste by means of steam (steam explosion) and then use enzymes to break down the cellulose. That way, a sugary substance will be produced, which can be fermented to produce ethanol. *TS*

The politicians' decision to allow combustion of the fibre fraction from biogas plants can give the industry a needed lift. This may mean that plans to build the world's largest biogas plant near Holstebro can now be implemented. The picture is from the Maabjerg plant near Holstebro, where fibre fraction combustion tests have been performed.

photo: torben skøtt/biopress

Focus on research opens up for new possibilities

Biomass has been put on the political agenda, and through research and cooperation, this may give the industry a needed push forward.

By Troels Witter

Concepts such as ammonia evaporation, nitrate leaching, bioenergy and combustion of fibre fractions have emerged in the political debate, which opens up for new possibilities to strengthen the research efforts in these areas and thus give the industry a needed lift.

So says senior research associate Sven G. Sommer from the Danish Institute of Agricultural Sciences. He is also the head of the Knowledge Centre of Manure and Biomass Treatment Technology.

- The Action Plan for the Aquatic Environment III as well as the Rural Development Programme emphasize better exploitation of nutrients, reduced environmental strain from the agricultural sector and alternative energy sources. This opens a possibility for the industry, through strengthened research and cooperation, to help develop the knowledge and technology that can help push the industry forward and thus strengthen the Danish position on the market for biomass technology, says Sven G. Sommer.

Closer dialogue

He stresses that broad cooperation is a prerequisite for a successful mission.

- The research programmes attach great importance to researching total entities and to the fact that the business sector participates in the research. Denmark boasts a time-honoured tradition for research in this sector, but we have not always been good at cooperating and sharing the knowledge we have gathered.

- In order for us to take advantage of the current attention to the subject, we as researchers must enter into a closer dialogue with each other and with the business sector, the authorities, the consultants, the farmers and the biogas producers. I hope that the Knowledge Centre of Manure and Biomass Treatment Technology will continue to experience the same wide support that it has enjoyed since it opened in January and at the subsequent events, as this is the kind of forum that can help coordinate and control the development, he says.

The competences are there

Sven G. Sommer believes that the Danish sector has the competences it takes to break through internationally in terms of technical and theoretic knowledge and experience gathered though a sequence of years at the existing biogas plants and separation plants. But apart from that, he is pleased that the industry is shows promise thanks to some ambitious projects - e.g. the coming biogas plant near Måbjerg and large projects on Ærø and Bornholm. The Danish Institute of Agricultural Sciences itself intends to invest almost DKK 30 million from the sale of some research facilities in a test plant for biogas and liquid manure separation, and Sven G. Sommer believes that these projects show that the trade is ready for development and new thinking.

- Furthermore, there are projects such as the Technical University of Denmark and Elsam's attempts to produce ethanol. All in all, I believe the future will offer interesting visions and possibilities that we must help each other take advantage of, concludes Sven G. Sommer.

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The biogas plant in Blåbjerg has had periodic problems ensuring a stable gas production. In the autumn of 2004 the process ground to a halt - probably because too much fish waste had been fed into the reactor.

photo: torben skøtt/biopress

When the reactor dies

Practically all biogas plants experience periods during which the gas production becomes unstable and at worst completely stops. Dead reactors, as the phenomenon is called, cost the biogas plants a considerable amount of money every year, but now researchers have tried

By Torben Skøtt

At the Institute of Environment and Resources at the Technical University of Denmark, a group of researchers have set a target to obtain more knowledge of how the biogas process can be optimised and how to avoid that the process becomes unstable. The latter is not least interesting to the many plant managers at the biogas plants around the country, who suddenly experience that their production of gas is falling for no apparent reason.

For many years, we have known that the accumulation of organic acids in biomass - the so-called VFA level - increases the risk of the process getting out of balance. A continuous monitoring of the VFA level has therefore been used as a method to ensure an even and stable gas production.

During the past few years, however, it has been discovered that some plants operate with relatively high VFA levels without experiencing noticeable problems. On the other hand, there are other plants that operate with very low VFA levels, though they have not done anything to achieve these. Finally, there are examples of plants that have been rebuilt after which changes in their VFA levels have been recorded, in spite of the fact that the same types of biomass were used.

Analyses from 18 plants

The uncertainty of how the VFA level influences the practical operation of the biogas plants has made the researchers at the Technical University of Denmark analyse a series of biomass samples from 18 common biogas facilities from April 2002 to August 2003. Subsequently, the analyses were compared with the operational problems that the biogas plants had reported to the Danish Energy Authority.

In outline, the 18 biogas plants are similar. They are operated either as thermophilic or mesophilic plants with a main stage and possibly a hygienisation or a post-digestion stage and a storage for degassed biomass.

As it appears from table 1, the capacities of the plants vary greatly. The three largest plants thus treat 34 per cent of the total amount of biomass while the three smallest plants only treat approx. 4 per cent of the total amount.

Problematic waste

The study demonstrates that most plants have a general VFA level of 1-2 grams/litre biomass with a few fluctuations up to 3-4 grams/litre of biomass.

There are, however, several marked exceptions. For instance, Blåbjerg had a fairly high and varying VFA level until November 2002, when it suddenly fell. This happened at a point where the plant stopped adding mucosa, which is a waste product from the production of insulin. Mucosa contains a lot of protein, and it also has a considerable content of nitrogen, which was probably the reason for the increased VFA level.

Further information

The report "Kortlægning og dokumentation af procesforhold på danske biogasanlæg" (Mapping and documentation of process conditions at Danish biogas plants) has been prepared by the Institute of Environment & Resources at the Technical University of Denmark.

Rena Angelidaki was responsible for the project, while Majbrit Stavn Jensen acted as the overall resource person. Anette Hejnfelt was the editor of the report, and furthermore several students participated in the project.

The report may be downloaded from BiogasForum Öresund's homepage: www.biogasforum.dk.

After the study, there was a stop-down at the plant in the autumn of 2004. Though there are no samples for this period, this supports the theory that large amounts of fish waste can be a risk factor, because the breakdown was connected with a large delivery of "pump water" from unloading of fish caught to be processed industrially, which entailed a halving of the gas production. Subsequently, the process was further overloaded as employees tried to restart the process by emptying out one third of the reactor content and replacing it with liquid cattle manure mixed with 50 per cent water.

Another example is Vaarst-Fjellerad, which had periods with VFA levels up to 6 grams/litre biomass. Here the reason turned out to be that large amounts of fish waste, periodically up to 20 per cent of the total amount of biomass, had been added. When the amount of fish waste was reduced, the VFA level fell proportionally.

In Hashøj, there were periods with considerable fluctuations in the VFA level. The typical reason was high loads combined with the fact that the biomass had a high ammonium content.

In the spring of 2003, Snertinge registered an increased VFA level. The increase occurred in a period where the operation strategy was changed, which probably caused "disturbances" in the biological process.

Problematic liquid mink manure

Apart from analyses of biomass from the 18 common plants, for a short period in the autumn of 2002, the researchers received samples from a farm plant in Farsø. At that time, the plant was being commissioned, and obtaining a stable process caused enormous difficulties.

The plant received considerable amounts of liquid mink manure, which is known to have a high ammonium content. The samples showed an extremely high VFA level of around 15 grams/litre biomass. As the supply of biomass was stopped at one point, and material from the reactor was re-cultured, the VFA level fell to around 5 grams/litre. As the supply of liquid mink manure was later resumed, the VFA level increased again.

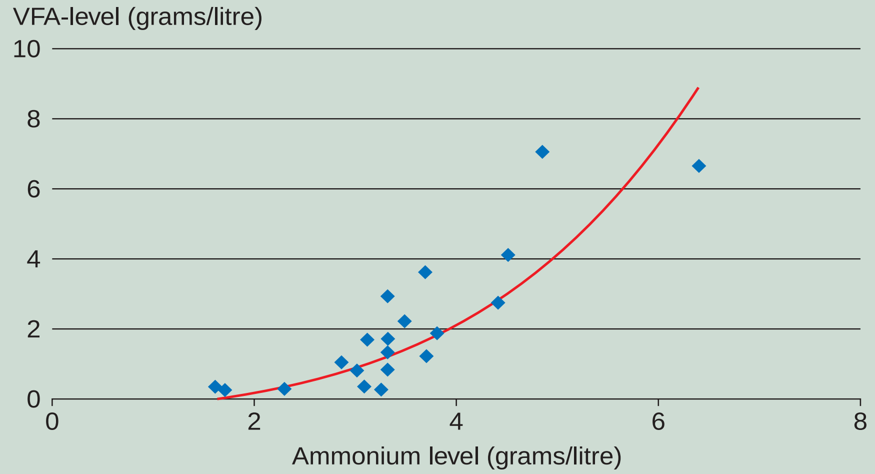

Figure 1. The connection between the ammonium content of the biomass and the VFA level.

Figure 1 shows the average VFA levels for the individual plants compared to the average ammonium content of the biomass. As appears from the figure, the average VFA level increases considerably when the ammonium content exceeds approx. 4 grams/litre biomass.

The ammonium content of the biomass is thus an important factor to ensure a low VFA level and thus a stable process. In thermophilic plants the ammonium content should be less than 4 grams/litre biomass, while mesophilic plants can handle somewhat higher levels.

Plant	Biomass m^3/Year	Reactor m^3
Revninge	13,000	3,000
Vegger	22,000	1,400
V. Hjermitslev	22,000	1,500
Filskov	30,000	850
Blåhøj	34,000	1,320
Snertinge	46,000	2,700
Sinding-Ørre	50,000	2,250
Århus (hushold.)	55,000	1,700
Hashøj	57,000	3,000
Fangel	58,000	3,850
Vaarst Fjellerad	60,000	2,000
Nysted	82,000	5,000
Århus (gylle)	85,000	7,200
Studsgård	116,000	6,000
Thorsø	116,000	4,600
Blåbjerg	120,000	5,000
Ribe	162,000	5,000
Lemvig	165,000	7,000
Lintrup	172,000	7,200

Table 1. Overview of the plants that have participated in the study.

Conclusion

It is difficult to state a specific VFA level as an unambiguous limit between stable and unstable operation. This has to do with the fact that the various plant have their own "normal" levels. A relative change in the VFA level can thus be a better indication of an imbalance than a specific value.

A VFA level of 1-2 grams/litre biomass indicates a stable process. How much it takes for the process to stop down completely is hard to say, but levels up to 10 grams/litre biomass have been registered without causing actual stop-downs.

It is often difficult to point out one specific reason for a drop in the gas production, as this often has to do with an interplay between several unfortunate factors. Foaming in the reactor tank and a high ammonium content, however, increase the risk of the process becoming unstable. And the same is true for mucosa and certain types of fish waste. Finally, unstable operation can create imbalance in the biological process, e.g. variations in the reactor temperature, variations in the in-feed and agitation or a sudden exposure of the reactor to a high load. ■

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Gasification of animal manure

photo: danish fluid bed technology

The fibre fractions from biogas plants can be used to good advantage as fuel in gasification plants - just like straw and wood.

The biogas industry senses the dawn of better things after the politicians' decision to allow combustion of the fibre fractions from biogas plants. But it may be better to use the fractions at gasification plants. This is the attitude of Peder Stoholm, managing director of Danish Fluid Bed Technology, who has just carried out a series of promising tests with gasification of pig manure.

The tests have been carried out in a so-called circulating fluid bed gasifier, as mentioned in the last issue of Bioenergy Research. The gasifier is particularly suitable for difficult fuels such as straw, manure and waste. In the beginning of the year, a series of successful tests were carried out with "the world's worst straw", as Peder Stoholm expresses it, and recently the success has been repeated with dried pig manure.

A total of 25 tons of dehydrated liquid pig manure were converted to a combustible gas over a period of 50 hours. The process was stable, and during the last 20 hours the gasifier was set to 110 per cent load, which caused no problems whatsoever.

The gas is very tarry and cannot be used to operate engines just like that, but it is suitable for district heating plants and power plants. When asked about the advantages of gasification compared to direct combustion in a boiler, Peder Stoholm says:

- You cannot burn manure in a boiler without enormous problems with deposits. The combustion chamber will quickly be lined with phosphorous deposits. Chicken manure is worst, but pig manure also contains large amounts of phosphor that will be deposited in the boiler.

The tests that Peder Stoholm has carried out with the fluid bed gasifier did not bring about deposits. The phosphor content is concentrated in the ash, which can subsequently be separated and recycled as fertilizer. *TS*