Biogas plants

- a contribution to sustainable agriculture

DLBR®

KNOWLEDGE CENTRE
FOR AGRICULTURE

This pamphlet has been produced for Knowledge Centre for Agriculture by Torkild Birkmose, Senior Consultant, AgroTech

This version has been revised by Michael Støckler and Niels Østergaard, Knowledge Centre for Agriculture

For additional copies of the pamphlet, please order through the webshop of Knowledge Centre for Agriculture: vfl.dk/netbutik

The publication of this pamphlet is subsidised by European Agricultural Fund for Rural Development at the European Union and Ministry of Food, Agriculture and Fisheries of Denmark

December 2013

EDITORS Torkild Birkmose, Birgitte Wulff Mikaelsen
LAYOUT Marianne Kalriis
PHOTO Torkild Birkmose; Uggi Kaldan; DLF-Trifolium A/S; Jens Tønnesen, LandbrugsMedierne; Dreamstime.com

Ministry of Food, Agriculture and Fisheries of Denmark
European Agricultural Fund for Rural Development
Naturerhverv.dk
Denmark and Europe invest in rural development.

See 'European Agricultural Fund for Rural Development' (EAFRD)

Biogas plants offer **many advantages** to agriculture

Biogas production is beneficial not only to society in general but also to the individual farmer specifically. Not only because of the energy produced, but also for the following reasons:

- the farmer retrieves more nutrients from the manure
- the obnoxious smells are reduced
- the environment is protected against unnecessary CO_2
- organic waste is adequately recycled.

This pamphlet aims to present the principles of biogas production in a simple way. It focused on centralised biogas plants owned jointly by a number of farmers, as it is anticipated that such plants will have a predominant role when developing new biogas plants in the years to come. The pamflet has particular emphasis on the benefits to the farmers who deliver raw slurry to and receive digested slurry from the biogas plant.

CONTENTS

Suitable biomass for the plant

6

A cow is able to produce energy corresponding to 250-375 litres of heating oil a year.

The economy of centralised biogas plants

8

Because of the societal benefits, it is possible to secure financial support for the biogas production.

How to start

17

Start a new centralised biogas plant or become a member of an existing centralised biogas plant.

Degassing increases the fertilising effect

10

With degassed slurry, it is possible to exploit the nitrogen better than when using untreated pig slurry and cattle slurry.

Centralised biogas plants in Denmark

A centralised biogas plant receives animal manure from several farms. The largest Danish centralised plants manage several hundreds of thousand tons of slurry, waste and energy crops (in generic terms called biomass) a year, and up to 150 farmers are affiliated.

In 1984, the first centralised biogas plant was taken into use in Denmark, and since 2001, 21 plants have been in operation. Biogas is CO2 neutral energy. When burning off biogas, fossil-bound carbon is not released unlike e.g. coal, oil and natural gas. In addition, the change of the slurry during degassing leads to a reduction of emission of the greenhouse gasses, i.e. methane and nitrous oxide, from the manure during storage and after spreading. Thus, bio-gas plants have a high and cost-effective reducing influence on the climate impact.

Production of these energy types is subsidised by society. In the most recent energy action plans the Danish government has emphasized biogas production in particular. The goal of the Green Growth 2009 declaration is to apply half of the animal manure for energy purposes in 2020. The bulk of this rise is expected to originate from centralised biogas plants.

In spite of the political and financial support the development of the centralised biogas plants has been limited during the past years. A reason may be that the business economics have been too disappointing making funding of new plants difficult.

The 21 Danish centralised biogas plants manage approx. 1.6 million tons animal manure per year. This corresponds to 4-5 per cent of the total amount of animal manure in Denmark. The vast majority of the applied manure is slurry. In addition, about 400,000 tons organic waste is processed, mainly from the food industry.

In addition to centralised biogas plants, 60 farm biogas plants and a number of other plants produce biogas in waste-water treatment plants and waste disposal sites.

facts

Climate friendly

Biogas plants reduce the climate impact by:

- producing CO_2 neutral energy
- reducing emission of methane from manure storage
- reducing emission of nitrous oxide from the soil after spreading of slurry.

Map of biogas plants

How does a centralised biogas plant work?

The dry matter in animal manure consists among others of carbon. The biogas process transforms the carbon into a gas compound of methane (CH_4) and carbon dioxide (CO_2) by means of bacteria, and the reaction typically takes place in a liquid suspension. The gas, including mainly methane and CO_2, is called biogas, and it leaves the reactor as a gas, whereas the nutrients and non-digested carbon remain in the liquid biomass. Today, all centralised biogas plants receive animal manure as well as industrial organic waste. Some biogas plants also receive energy crops such as corn silage and grass silage, and a few now receive straw. Usable industrial organic waste may prove to be scarce in the future, since the best quality waste is consumed at existing plants. Thus, solid and liquid animal manure, energy crops and straw may become the normal compound in new plants.

Manure, waste and possibly energy crops are mixed in the plant pretank before the mixture is heated to a temperature at between 35-52°C. In some cases, liquid industrial waste is kept in another or even in several other pretanks. Without additional pre-processing, the mixture or the different mixtures are pumped into the anaerobic digestion tank (the reactor), in which the actual biogas production takes place. Thus, the contents in pretanks must be so fluid that it can be pumped. All through the plant the liquid mixture is transported in a closed piping system by means of pumps. In few cases, plants have equipment for dosing solid biomass directly into the reactor tank.

The biomass is kept in the reactor for 2-4 weeks or at some plants even longer, after which 30 to 50 per cent of the dry matter has been transformed into biogas. The remaining dry matter is so difficult to metabolise that it is usually uneconomical to prolong the retention time in the reactor any further.

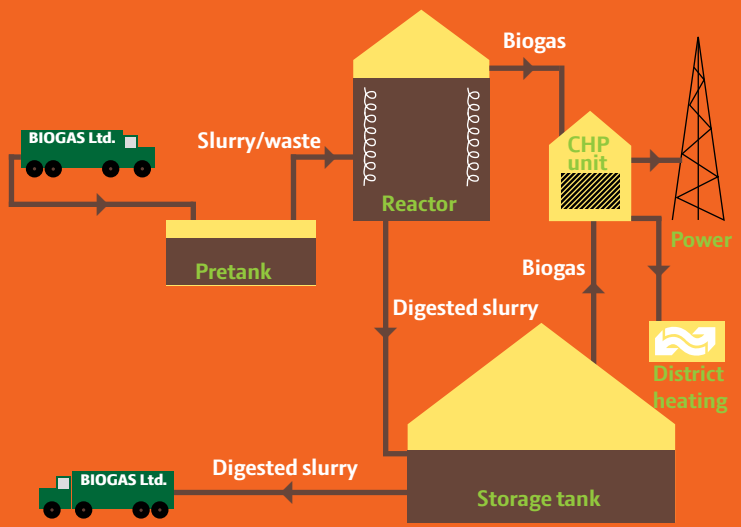
However, even after the slurry compound has left the reactor, a certain production of biogas still takes place. A considerable part of this production may be collected in a covered slurry storage tank before the slurry is returned to the farmers. This means that the biogas may be collected both from the reactor and from the slurry storage tank. The gas is usable in several different ways. The use depends on the possibilities and needs of the local area.

facts

Biogas applications

- Own combined self-supply heat and power station, in which the biogas is converted to 35-40 per cent electricity and 40-50 per cent hot water suitable for district heating. The remainder is lost as heat.
- Own gas-fired furnace, where the biogas is transformed into hot water suitable for district heating.
- Sale of gas by means of pipeline to combined heat and power stations or district heating power plants.
- Cleaning of the gas (upgrading) and sale of gas through the natural gas network.

How a typical biogas plant works



Animal manure is the most important biomass source

Danish agriculture produces approx. 35 million tons of animal manure per year. This is clearly the largest, most important and cheapest resource for the future production of biogas!

It is part of the dry matter of the manure that is converted into biogas. It is a principal rule that the higher dry matter content in slurry and waste, the more biogas is produced. Thus, e.g. chicken manure contains higher biogas potential than slurry. It is also possible to produce a high amount of biogas from separated manure fibre fractions, energy crops, straw and most types of organic waste. The major part of animal manure in Denmark, however, is slurry and, thus, slurry accounts for the highest supply rate for biogas plants.

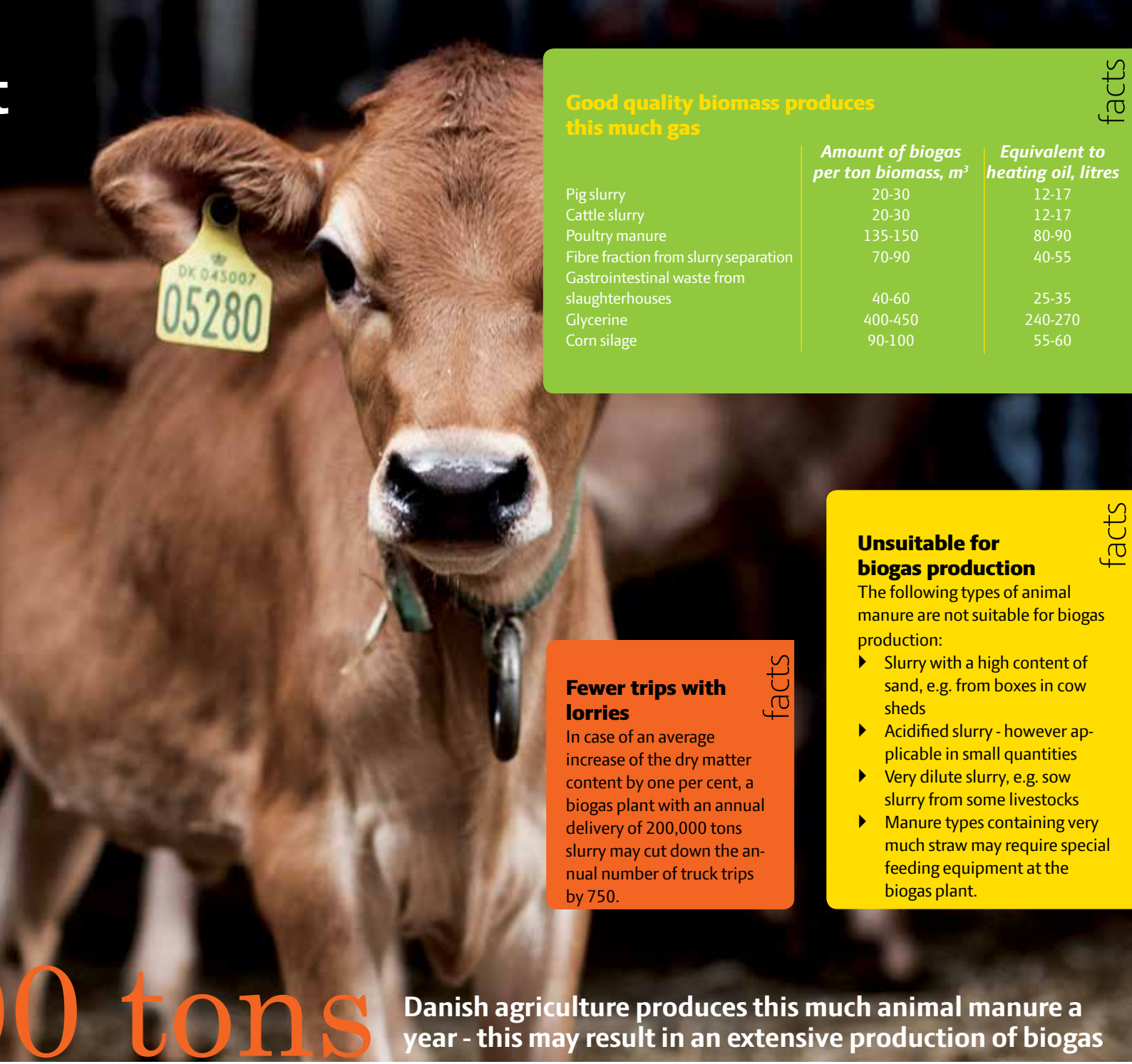
To ensure a high gas yield and low transport costs, slurry with a high dry matter percentage is desirable. Thus, the following rules for slurry to be delivered to the plant must be complied with:

- Slurry must be collected straight from the pretank
- The slurry must be as fresh as possible
- The waste of water in the stable must be reduced as much as possible
- Rainwater, washing water etc. should be channelled directly to the slurry final storage tank

Slurry with high dry matter content reduces transport costs and increases the capacity of the biogas plant, and this is certainly in the interest of farmers, as it reduces the amount of slurry to be stored and spread.

From the green fact table appears that only one ton of animal manure can produce energy equivalent to 12-17 litres of heating oil. Since a cow produces approx. 22 tons of slurry per year, the cow has a capacity to produce energy equivalent to 250-375 litres of heating oil per year - that is if all the slurry is collected and used for biogas production!

The energy mentioned in the green fact table is gross energy. This means that when calculating the actual energy production of the plant, the gross energy should be deducted from the diesel oil consumption for transporting the slurry as well as the electricity and heat consumption for the production process. Energy for transport and production process is only 15-20 per cent of the total energy production.



Good quality biomass produces this much gas

facts

	Amount of biogas per ton biomass, m³	*Equivalent to heating oil, litres*
Pig slurry	20-30	12-17
Cattle slurry	20-30	12-17
Poultry manure	135-150	80-90
Fibre fraction from slurry separation	70-90	40-55
Gastrointestinal waste from slaughterhouses	40-60	25-35
Glycerine	400-450	240-270
Corn silage	90-100	55-60

Fewer trips with lorries

facts

In case of an average increase of the dry matter content by one per cent, a biogas plant with an annual delivery of 200,000 tons slurry may cut down the annual number of truck trips by 750.

Unsuitable for biogas production

facts

The following types of animal manure are not suitable for biogas production:

- Slurry with a high content of sand, e.g. from boxes in cow sheds
- Acidified slurry - however applicable in small quantities
- Very dilute slurry, e.g. sow slurry from some livestocks
- Manure types containing very much straw may require special feeding equipment at the biogas plant.

00 tons Danish agriculture produces this much animal manure a year - this may result in an extensive production of biogas

The economy
of centralised biogas plants

Basically, revenue from gas sales is not competitive with the price of fossil fuels such as coal, oil and natural gas. However, due to the many societal advantages (e.g. reduced environmental impact and consistency in energy supply), it is possible to achieve financial support for the biogas production. Tre funding opportunities are:

- Subsidies for the construction of the biogas plant
- Improved credit facilities
- Subsidies for power production
- Duty-free heat sales.

The economy is dependent on a number of facts, including which prices to charge for gas, electricity and heating. Regardless of this, however, it is of vital importance to secure a high biogas production relative to biomass amount for the biogas plant. This means that organic waste, fibre fraction from separated slurry, deep bedding or energy crops have to be added to the slurry, and these additions often account for the biggest share of the biogas production.

facts

Learn more
about the economy of biogas plants at the biogas project website of Knowledge Centre for Agriculture. The website is currently updated with new regulations and possibilities: *landbrugsinfo.dk/biogas*

How do involved farmers benefit?

Most plants are established as limited liability cooperatives on the initiative of a group of farmers. Thus, the owners' financial risk is very limited. On the other hand, the profit is not paid directly to the cooperative members.

Farmers have primarily been interested in the indirect economic benefits and the advantages as to operation, environment, image and enhanced fertiliser efficiency, which involvement in the biogas plant entails.

Degassing changes the characteristics of the slurry

The digested mixture of slurry, organic waste and energy crops, which is produced at the biogas plant, is often called digested slurry. A few biogas plants separate the slurry after the degassing process to obtain a liquid mass fraction and a firm fibre fraction instead of digested slurry.

Digested slurry must be transported, stored and spread in the same way as slurry that has not been used for biogas production. However, there are some important differences. The distinctive features of digested slurry are that:

- it includes a mixture of several types of slurry and waste
- the organic material of the slurry (incl. certain odorants) is partly metabolized (please see page 14)
- part of the slurry's organic nitrogen has been converted into ammonium
- the pH value of slurry increases during the biogas production process.

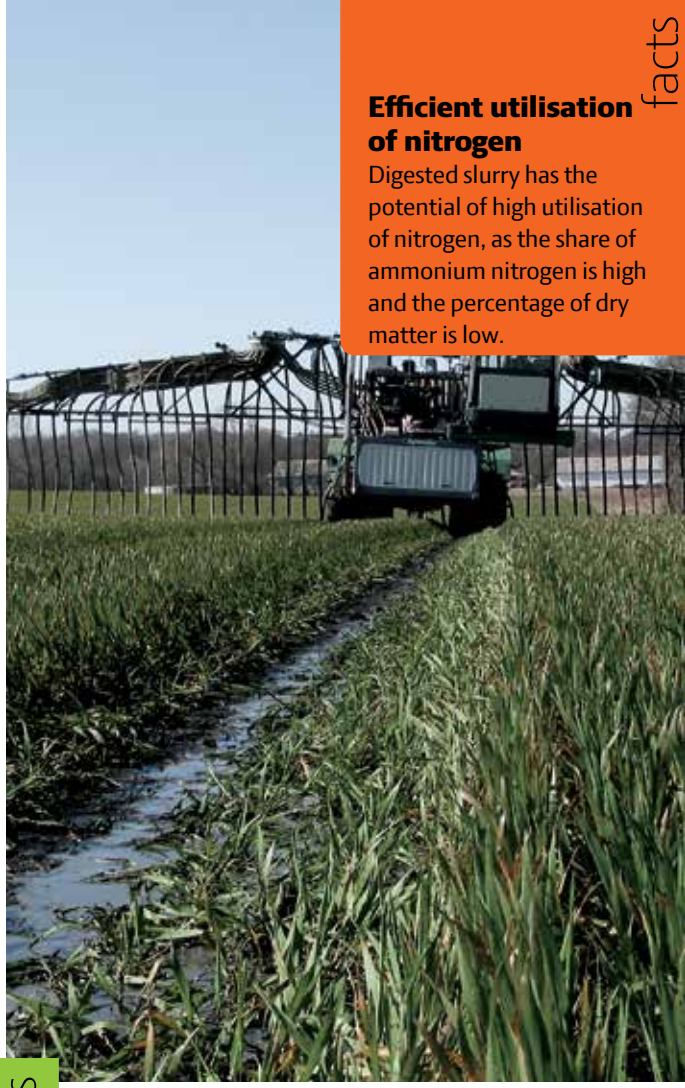
The green box below shows some typical analytic numbers for untreated slurry and for a digested compound of equal parts cattle and pig slurry. The box also shows a common analysis of the liquid fractions and the fibre fractions occurring in case the biogas plant separates the slurry at the plant.

The liquid fraction is very dilute as a big part of the dry matter ends up in the fibre fraction. The liquid fraction has an almost normal content of nitrogen and potassium, however, the phosphorus content is low.

facts

Efficient utilisation of nitrogen

Digested slurry has the potential of high utilisation of nitrogen, as the share of ammonium nitrogen is high and the percentage of dry matter is low.



Some biogas plants separate the slurry in a liquid mass fraction and a firm fibre fraction. The liquid fraction is very dilute.

facts

Typical contents in different animal fertilizers

	Dry matter pct.	*Total-N kg/t*	*NH_4+-N kg/t*	*P kg/t*	*K kg/t*	*pH factor*	*Share of NH_4+-N pct.*
Cattle slurry	6,0	5,0	3,0	0,8	3,5	6,5	60
Pig slurry	4,0	5,0	3,5	1,0	2,0	7,0	70
Digested slurry	2,8	5,0	3,8	0,9	2,8	7,5	75
Liquid fraction	1,2	4,5	3,8	0,2	2,8	7,5	85
Fibre fraction	30	8,0	3,8	8,0	2,8	7,5	50

Fertilising value increases by degassing

The physical and chemical changes of the slurry in the biogas reactor result in a changed manure effect in the field. The most significant change is the increase of the content of the plant-available ammonium nitrogen. This is an advantage, as the plants primarily utilise the ammonium nitrogen.

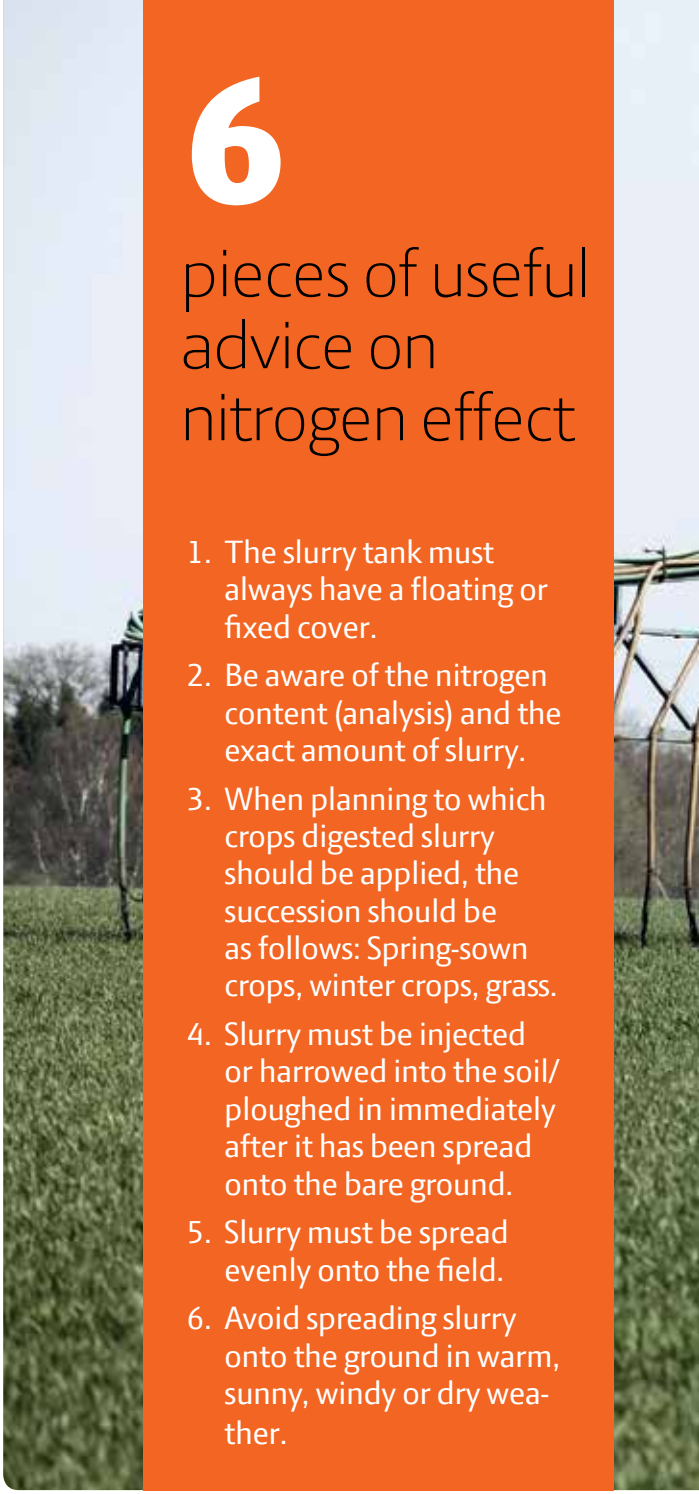
When using digested slurry, the possibilities are

- a higher crop yield, or
- a reduction of nitrogen in artificial fertilisers.

The dilute and rather fluid slurry percolates relatively fast into the ground. This contributes to reducing the ammonia evaporation risk.

For many years, Knowledge Centre for Agriculture has undertaken field trials in various types of slurry as to the utilisation of nitrogen in a.o. winter wheat. The figure shows that digested slurry is utilised better than pig slurry and significantly better than cattle slurry and that the liquid fraction from separation, however, keeps the highest value.

The ratio of phosphorus to potassium in digested slurry is often approx. 1:3 (please see table page 9). This ratio lends itself pre-eminently to a crop rotation with e.g. grain and rape, which often requires about 20 kg phosphorus and about 60 kg potassium. If, on the other hand, the crop rotation is dominated by roughage, extra fertiliser with potassium must be applied when using digested slurry, however, not when using digested cattle slurry.



6

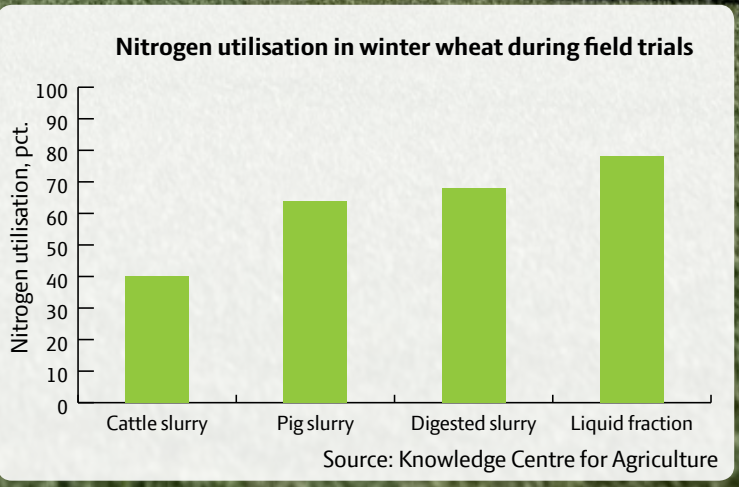
pieces of useful advice on nitrogen effect

1. The slurry tank must always have a floating or fixed cover.
2. Be aware of the nitrogen content (analysis) and the exact amount of slurry.
3. When planning to which crops digested slurry should be applied, the succession should be as follows: Spring-sown crops, winter crops, grass.
4. Slurry must be injected or harrowed into the soil/ploughed in immediately after it has been spread onto the bare ground.
5. Slurry must be spread evenly onto the field.
6. Avoid spreading slurry onto the ground in warm, sunny, windy or dry weather.

facts

Digested slurry

- As to appearance, composition and effect of nitrogen, digested slurry is largely more similar to pig slurry than to cattle slurry.
- The liquid fraction, however, resembles liquid manure more than slurry.



The environmental impact will change

Higher risk of ammonia evaporation

The degassing process results in two changes in the slurry, which means that the risk of nitrogen loss in the form of ammonia evaporation is higher than before the slurry treatment.

- Approx. half of the organic matter is decomposed. Thus, the tendency to form a floating fibre layer is reduced. Often, digested slurry does not have a natural floating layer at all.
- The rise in the pH factor increases the transformation of ammonium (NH_4) into ammonia (NH_3).

Ammonia is a volatile kind of gas and evaporates rapidly, if the digested slurry is in direct contact with the atmosphere. This weakens the fertilising value and has an impact on the environment.

According to the legislation on animal manure storage, the slurry storage tank must always be provided with a cover or a floating cover. Moreover, it is economically rational to establish an artificial floating cover, if it is not formed in a natural way.

Lower risk of nitrate leaching

The fertilising value of the manure increases during transformation of organic nitrogen into ammonium, because am-monium is more plant-available than organic nitrogen. Thus, the amount of additional fertiliser may be reduced without loss in crop yield. The risk of nitrate leaching may be reduced by reducing the amount of fertiliser.

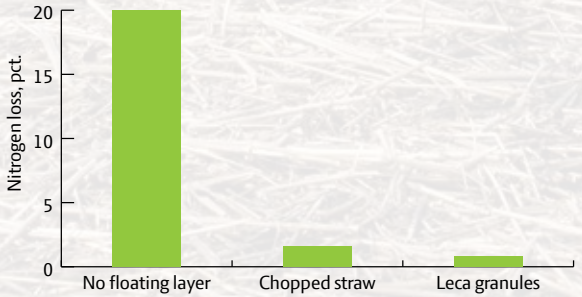
facts

The leaching of nitrate is reduced

Calculations from the Danish National Environmental Research Institute show that the leaching of nitrate decreases by 3 kg nitrogen per hectare by degassing pig slurry and reducing the need for additional fertiliser by an amount equal to the increased nitrogen efficiency of the slurry.

If the amount of fertiliser is not reduced, the effect on ni-trate leaching will, however, only be modest.

Ammonia evaporation from slurry tanks with digested slurry with or without floating layer



Source: Aarhus University

Biogas plants are also suitable for organic farmers

It may be particularly advantageous to green farmers to deliver biomass, including animal slurry, to biogas plants and use digested slurry. This way, the farmers will achieve better fertiliser efficiency and thus higher yields. It takes, however, a parallel plant to handle green biomasses as most traditional centralised biogas plants receive organic waste, which must not be a part of the green manure. Thus, green and conventional biomasses must be kept separate for the green manure to maintain its green status.

Clover from green plant growers is a good quality crop for degassing. The crop rotation on the farm is very good, the gas yield high, and after degassing the slurry is rich in nitrogen. The opportunities are multiple for different green farms (cattle farms, pig farms, poultry farms and plant growing farms) to enter cooperation on a centralised organic biogas plant.

facts

Increase yield with vegetable biomass

Generally, the nitrogen effect of vegetable biomass is relatively low, because the nitrogen in a ploughed-in vegetable biomass is not particularly plant-available, when the succeeding crop needs it. When harvesting the vegetable biomass instead and utilising it in a biogas plant, the availability of nitrogen will be increased, and the application of the digested vegetable biomass for the succeeding crop may be timed more accurately. This, too, will boost the crop yield significantly.

facts

A green production line

As the green production goes up, increasingly more centralised biogas plants show interest in establishing a green line at their plants to keep conventional and organic biomass separate.

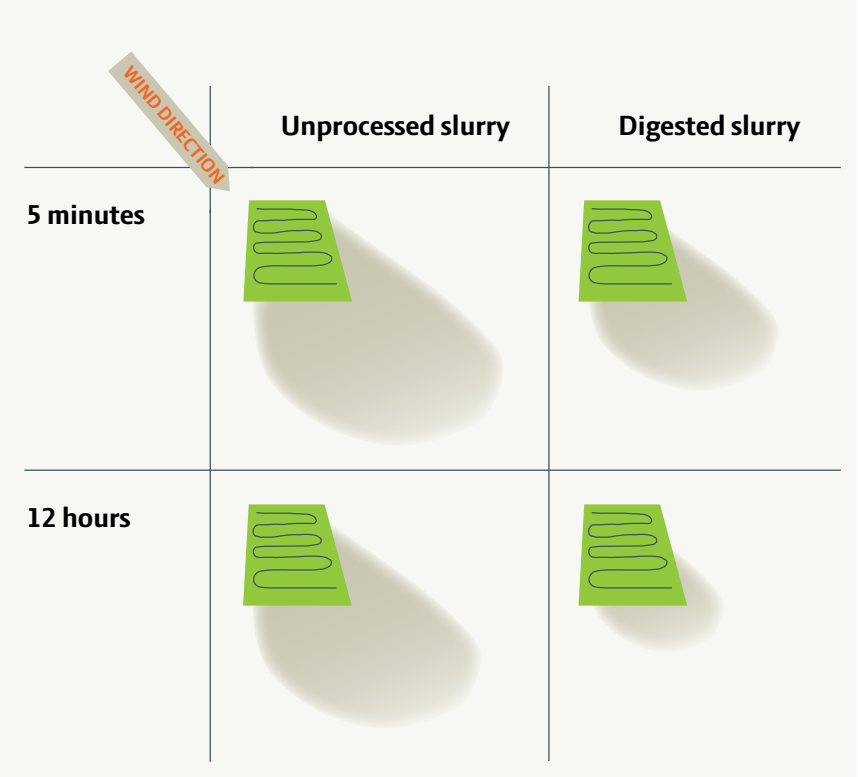
Digested slurry smells less

All countryside residents know the unpleasant and acrid smell of slurry. Especially during and after the spreading of slurry the obnoxious smell is often very strong. During degassing, many odorants are decomposed and end up in biogas or slurry.

Experiences of many farmers and neighbours of farmers show that degassing reduces obnoxious smells considerably. This is documented in scientific researches confirming that

- the amount of odorants in digested slurry is considerably lower than in unprocessed slurry, and that
- the odour nuisance from the digested slurry diminishes the longer the slurry is processed in the reactor.

Thus, the risk of neighbour complaints is far less when using digested slurry instead of untreated slurry. The farmer achieves both a larger freedom of action when spreading slurry and a better reputation in the local community, if he chooses to use digested slurry instead of untreated slurry.



The figure illustrates the spread of obnoxious smells after spreading in a field with northwesterly wind, depending on use of either untreated or degassed slurry. 12 hours after spreading of digested slurry the obnoxious smells have almost gone.

facts

Odorants turn into biogas

Slurry contains large amounts of strongly smelling, volatile acids such as butyric acid and sulphur compounds. In the biogas plant, these substances will turn into biogas and fertiliser components. This is one of the reasons for the reduction of obnoxious smells after spreading of digested animal manure, including slurry and solid biomass.

Reduced risk of infection

Most centralised biogas plants guarantee that digested slurry is sanitised. In reality, this means that the slurry should not contain any infective germs.

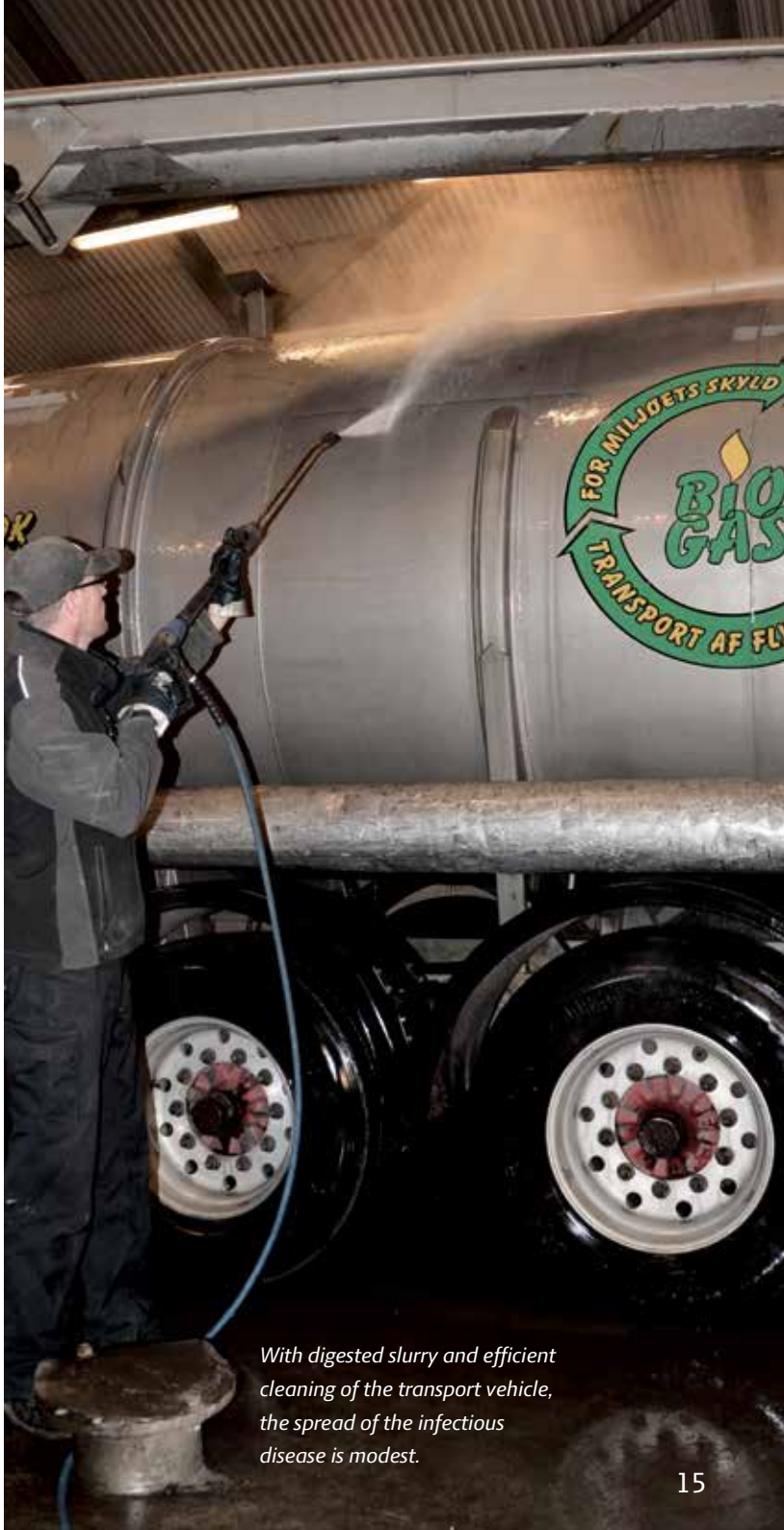
When farmers transport slurry between properties, there is always a risk that infection will spread from one farm to another. The infection may be carried with the slurry and the vehicles used for transport.

If digested slurry is used, the risk of spreading infection is very modest. Firstly because of the sanitation, and secondly because requisite cleaning of the transport vehicles is always carried out.

In order to monitor that the sanitation process is efficient enough, many centralised biogas plants carry out laboratory control of the slurry bacteria content.

facts

Sanitation
Implies that the slurry is heated to a temperature of at least 70°C for an hour or that the guaranteed retention time in the reactor (the time between pumping sequences) is at least 10 hours at a temperature of 52°C. Most centralised biogas plants observe these instructions.



With digested slurry and efficient cleaning of the transport vehicle, the spread of the infectious disease is modest.

Transport optimisation

Most farmers handling animal manure know that slurry transport expenses may be very high.

The establishment of a centralised biogas plant brings about an exceptional opportunity of achieving cost savings. The organisation and logistics of the biogas plant can also contribute to these savings.

The prerequisite of these savings is a careful coordination of the slurry transport. The usual transport procedure is that the transport vehicle arrives at the farm with a load of digested slurry, which is pumped into the storage tank. Subsequently, fresh raw slurry is loaded from the pretank, and the transport vehicle returns to the biogas plant where the raw slurry is "exchanged" with a new load of digested slurry. In this way, the transport vehicle never drives with empty tank.

Normally, the farmer himself transports slurry to the fields. However, if the transport route is long the farmer may ask the biogas plant to deliver the digested slurry at a new location. Thus, the digested slurry may be delivered to a storage tank that is built closer to his fields.

Intermediary body for the slurry surplus

The many advantages of digested slurry facilitate the sale of slurry to e.g. plant growers. Especially large plant growers prefer to buy slurry from a biogas plant rather than directly from farmers, as they can buy a big, homogenous amount of slurry, including declaration label. Mediated by the biogas plant, this reallocation is made flexible and more efficient by the establishment of a sort of intermediary body to manage slurry surplus from the biogas plant. This way, the production manager can assist livestock farmers in creating contact and contracts with plant growers and vice versa.

The farmer may ask the biogas plant to deliver the digested slurry directly at the slurry tank wherever it may be situated.

How to start

Most centralised biogas plants are established on farmers' initiative. If a group of farmers are interested in establishing a centralised biogas plant, the procedure will normally be as described below.

The initiative group will contact a consultant in the DLBR special advisory service on biogas and slurry separation (please see next page). The consultant may present the initial information on establishment and operation of a biogas plant. The consultant may also make the preliminary calculations of the finances of the planned plant and arrange a visit to a relevant centralised biogas plant. Based on these initiatives, it will be decided whether to proceed.

In the affirmative, the consultant and the initiate group in cooperation will thoroughly undertake a more technical and financial examination of the project to estimate the feasibility of the project. If feasible, the work will proceed to identify a suitable location for the plant, to acquire funding and make applications to authorities for necessary permits.

With successful results, a contract can be signed with a supplier of biogas plants and the building activities may start up. Usually, the building and implementation phases last at least a year.

Find the biogas specialist advisers of DLBR at dlbr.dk/biogas

facts

Get inspired

You may find a detailed description of the process of establishing a centralised biogas plant in the "Manual for Establishment of Biogas Plants" published by INBIOM, the Innovation Network for Biomass.

facts

New suppliers

Many existing biogas plants currently increase their capacity to associate new suppliers. Call your local biogas plant to learn more about your opportunities to join.

Useful websites

Knowledge Centre for Agriculture	vfl.dk landbrugsinfo.dk/biogas	Advisory services within all operating units of the agricultural industry. Have a special website on biogas.
DLBR Specialist advisory service for biogas and slurry separation	dlbr.dk/biogas	Advisory services on a.o. authorities consideration, establishment and operation of biogas plants.
AgroTech	agrotech.dk	Approved Technological Service Institute participating in development projects on biogas.
Danish Biogas Plant Association	biogasdk.dk	Professional body for owners of biogas plants in Denmark.
Danish Biogas Association	biogasbranchen.dk	Professional body working for the promotion of biogas plants in Denmark and abroad.
The Danish FishAgri Agency (Ministry of Food, Agriculture and Fisheries of Denmark)	naturerhverv.fvm.dk	Administers and provides grants for the establishment of biogas plants.
Danish Energy Agency	ens.dk	Responsible for energy policy issues in Denmark.

DLBR

KNOWLEDGE CENTRE
FOR AGRICULTURE

landbrugsinfo.dk/biogas