

LIVESTOCK MANURE TO ENERGY

Status, Technologies and
Innovation in Denmark

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The Danish situation with a livestock density among the highest in the world, combined with being surrounded by vulnerable nature such as the Baltic Sea, has promoted a situation with considerable competence when it comes to innovative technologies for handling of livestock manure in an environmentally safe way. The growing awareness of resource depletion and climate challenges has furthermore clarified the huge potentials for reducing greenhouse gas emissions from the livestock manure via exploiting its energy content. Already today, around one fifth of all Danish pig and dairy farmers are involved in livestock manure based biogas production, most of them via farmer cooperative owned industrial size biogas plants.

This pamphlet aims to provide a general overview of Danish state-of-the-art technologies and competences in the supply chain from livestock manure to energy, and explain some major contextual policies, legislation and framework conditions. It also holds a quick reference guide to the related technology suppliers and other companies and institutions with competences in the supply chain. The pamphlet is intended for anybody with interest in innovative ways to handle current challenges to reduce the environmental and climatic impacts of livestock farming, while in the same time increase the renewable energy production and the demand for animal products from a growing population.

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Role of livestock manure in Danish policies

► **Firm policies and rigid legislation has promoted the development of advanced technological solutions for handling of livestock manure in Denmark, initially to reduce its harmful environmental impacts, and now additionally to exploit its potentials for climate friendly energy.**

Speaking about biomass in Denmark, livestock manure is always considered an important resource. Agriculture plays a significant role in Denmark's economy and is characterised by a high livestock production that for instance makes Denmark the world's number one exporter of pork. The amount of livestock manure being produced in Denmark is about 35 million ton per year, equal to 6 tonnes per each of Denmark's slightly less than 6 million inhabitants!

Terminology

Livestock manure is organic material consisting primarily of a more or less homogenous mix of feces and urine from livestock, including bedding material, and secondarily of other material that would be discarded as waste from a livestock production such as fodder residues, silage effluents and process water.

The most important sub-groups of livestock manure are

- Slurry
- Deep bedding/litter
- Liquid manure
- Solid manure

Livestock manure terms are popular, not solicited by any legislation. More details about livestock manure terms can be found at www.agro-technology-atlas.eu/manures.aspx, as well as examples of analyses.

In Denmark, about 80% of the manure is produced as slurry in mainly pig and dairy cattle farms. Deep bedding comes from all types of livestock units and is the dominating manure type in chicken production. Liquid and solid manure is mainly from old animal houses with drained, solid floors – today, called source separated manure.

ENVIRONMENTAL POLICIES

Until beginning of the 1980s, livestock manure alone was considered a natural crop fertiliser that along with pressure for high crop productivity and cheap energy prices lost ground to the use of mineral fertilisers in the 1960s and 1970s. In

1985, however, the Danish government launched the so-called NPO plan due to increasing problems with the water quality. The NPO plan set demands to harmony between the farmed area and the number of livestock, as well as to the minimum capacity for storage of livestock manure on farms. Since then still tighter regulations from both the EU and Denmark have triggered a technological development, with the effect that, today, the huge amount of nitrogen (N) and phosphorus (P) in livestock manure is utilised with almost the same efficiency as that of mineral fertilisers, alleviating the environment for N and P loads, and farmers for costs for purchase of fertilisers.

Today, the environmental considerations are taken even further: it is not only a question of saving the environment for pollution, but also a question of resource efficiency, here under concerns for depleting resources of phosphorus and fossil fuels. The EU has developed a road map to a resource efficient Europe as part of its 2020 strategy, aiming at bio-based societies. The Danish Minister of Environment has followed up by establishing a National Resource Plan, launched in autumn 2012.

CLIMATE POLICIES

In Denmark as well as internationally, the recognition of global warming and its harmful effects has led to the determination of measures to reduce the impacts. The United Nations' Kyoto Protocol committed Denmark to a CO₂ reduction of no less than 21% in the period from 1990 to 2012 while the average of EU countries is 8% reduction. Already in 2010, Denmark's CO₂ reduction had reached 23% via efficient measures, such as EU's emission trading scheme that makes it more profitable to switch to biomass-based energy production.

EU'S 20-20-20 TARGET

The EU has by adoption of its climate and energy package in December 2008 already laid track to the EU after 2012 - also in relation to quota trad-



Danish legislation demands livestock farms to have a capacity to store slurry for a minimum of 9 months, calculated according official default values for manure production. Safe and sufficient storage of livestock manure is a pre-condition for good manure management – it preserves the livestock manure quality, and for slurry it enables the use as crop fertiliser in the springtime when the plants need the nutrients. The photo shows Agri-Tanken made in pre-fabricated concrete elements with lake stones surface.

ing. The goal is an overall reduction of greenhouse gas emissions in the EU of at least 20% below 1990-levels and an increased share of renewables in energy consumption by 20% by 2020, 20% higher energy efficiency, and 10% renewables in transport by 2020.

Again, Denmark has via its National Renewable Energy Action Plan made a stronger commitment of 30% CO₂ reduction, considering the multiple positive effects of this: increased employment, less dependency and less spending of foreign currency on imported energy resources, and not least the possibility of a combined achievement of waste handling and environmental goals.

CO₂ NEUTRAL ENERGY

EU's Climate and energy package (in specific Directive 2009/28/EU on renewable energy) determines that energy produced on basis of biomass, which like livestock manure is categorized as wastes in EU regulations, is CO₂ neutral.

In addition, when livestock manure is used for energy production the atmosphere is saved for the methane and nitrous oxide that are released when animal manure decomposes and would

have subsequently been released into the atmosphere; these gases have respectively 21 and 310 times more global warming potential than CO₂. Furthermore, when the energy production happens via anaerobic digestion, the bio-availability of the nitrogen is increased and can save further on use of petrochemical-based fertilisers. Qualified ISO 14064 auditors of carbon credit projects therefore fully accept that livestock manure energy projects generates much larger emission reductions than other biomass-based energy projects.

The high CO₂ emission reduction effect makes livestock manure based energy projects among the most cost-efficient. Researchers at Aarhus University have suggested the price for obtaining such CO₂ emission reductions to be comparable with the market price, which on the spot market in the EU is around 10-12 €/tonnes CO₂.

BIO-SECURITY ASPECTS

EU's hygiene package from 2003 determines that safety of food depends on all steps in the supply chain from field to table, i.e. that every farm is part of the food supply chain. Food safety deals with contamination of food with microbes, chemicals

and foreign bodies. For livestock farms, ensuring a high food quality is about dealing with the prevention of contamination of produce as milk with livestock manure.

In Denmark, a Hygiene Business Code (National guidelines) was developed in cooperation between farmers' organisations and the veterinary and other authorities, and a number of private quality certification schemes have additionally been established. The high focus on food safety and hygiene has increased the requirements to manure handling and processing technologies so that it does not leak and is easy to clean.

FUTURE HANDLING OF LIVESTOCK MANURE

However, pathogens and chemical residues in livestock manure also have the potential to contaminate waters when spread on the fields for fertilising and in this way endangering human and animal health. In fact, EU's Animal By-products Regulation clarifies that livestock manure is so-called "Category 2 waste" and use of it for fer-

tilisation of fields can only happen provided that the competent authorities do not consider this a health hazard.

Livestock production units are becoming increasingly large and in Denmark an average dairy cattle farm has 140 dairy cows + young stock and an average pig farm 2,750 pigs. The requirements of EU's Industrial Emission Directive for environmental approval of intensive pig and poultry farms has been expanded to cover all livestock farms in Denmark, except for the very small hobby farms. A bottleneck for the environmental approval is often the hearing of the neighbours who typically are worried about the smell from the production and the manure spreading activities. A condition for an environmental approval is often that the farm invests in technologies to reduce the smell from the production, first of all via air cleaning technology in the stables.

As a way to combat the abovementioned challenges that relate to livestock manure - environ-



Injection of slurry requires more energy and the working width is generally smaller than when band laying systems are used. Here the working width is increased to 12 metre by use of a trailed injection boom, and an additional front mounted slurry tank expands the capacity of the slurry tanker and improves the power transmission from the tractor. Photo: Harsø

ment, renewable energy, bio-security, smell, resource efficiency, fewer and larger livestock units – the former Danish Government launched the Green Growth Plan in 2009. This policy strategy suggests that in 2020 up to 50% of the livestock manure shall be treated for energy purposes (before being spread as fertiliser on fields) and ultimately all of it. The technologies for processing would comprise anaerobic digestion, gasification, pyrolysis and combustion, including different pre and post treatments. The current government supports this part of the Plan, and some politicians go further and suggest that the spreading of raw, untreated manure on fields shall be banned, thus indicating how future policies might be.

2020 ENERGY AGREEMENT

Early 2012, the Danish government made an energy agreement. The agreement, which reach out to 2020, consolidates the general political encouragement to produce biogas from livestock manure:

- The investment support, which is based on recognition of the positive environmental effects of manure-based biogas production, is increased to 30%. Technically the support is only guaranteed in 2012 and future years' sup-

port would depend on the prioritisation of funds in the rural development program for Denmark from 2013.

- The subsidisation of the production is increased to 15.3 €/GJ and much differentiated compared to the earlier subsidy, which only was given to the electricity production: the new subsidy favours directly the use of the biogas for transport purposes and for heating. The subsidy is regulated with the market price for natural gas to ensure the competitiveness.

By August 2012, the energy agreement has not been fully implemented in Danish legislation, which can be obtained from the Danish Energy Agency (www.ens.dk). However, the Danish Minister for Climate, Energy and Building, Martin Lidegaard, has declared that subsidies would not be available to new biogas plants relying on maize silage as one of the main substrates.



Technologies for handling of livestock manure

► In Denmark, better manure management, first of all, safe storage of the manure and application of manure to crops at the right time as part of a fertiliser plan based on fertiliser norms, as well as use of innovative technologies for air cleaning and field spreading have made it possible to reduce the consumption of N in mineral fertiliser with approx. 50% during the last 25 years. This saves Danish farmers an expense of approx. 100 € per ha, alone for N fertiliser!

Whether the livestock manure is used for energy production or not, the goal is always that to produce as high quality manure as possible in the given production system, and to maintain the good quality by the way it is handled!

In general, high quality in manure means as high concentration as possible. This is especially the case when manure is used for energy production which is based on the content of organic matter.

The organic matter in livestock manure is to some extent dependent on the feed ration, including the salt and sugar content of the feed, the phosphorus and protein norms and the use of benzoic acid and/or phytase in pig feeding. However, in a given livestock production unit, the livestock manure type and quality produced is to a large extent given by the building design and the technologies used for handling the manure.

Slurry

Subgroup of livestock manure. Slurry is usually a mix of feces and urine from livestock, bedding material with small structure like sawdust or chopped straw, washing water, water spill, etc. and originating from stables with whole or partly slotted floors.

Normally, slurry has a dry matter content of 2-10% when brought to the fields for fertilizing. Typically about 70% of the dry matter is organic matter.

The variation in dry matter content is much related with the technologies that are used for handling the slurry in all steps, from it is excreted from the animals till its nutrients are made available for field crops.

HANDLING MANURE IN HOUSES

In Denmark, there is an increasing interest in us-

ing technologies that preserve the good manure quality between excretion and until it reaches the manure storage. This deals first of all with preventing ammonia evaporation, by which up to half of the nitrogen in the manure could be lost with the ventilation air, representing a big economic loss for the farmer. Ammonia is polluting the air and thus endangering human and animal health and being harmful for the environment. Another important aspect is the avoidance of water dilution through excess use of water by cleaning and water spill.

Value of plant nutrients

Plant nutrients are in general mentioned as N, P and K, while also S and Mg are typically considered in fertilizing of crops.

Indicative prices of plant nutrients, calculated on basis of current market prices for mineral fertilizers are:

- N: € 1.5 per kg
- P: € 4.0 per kg
- K: € 1.3 per kg
- S: € 0.8 per kg
- Mg: € 0.6 per kg

The amount of plant nutrients in the annual manure from a dairy cow is typically 127 kg N (of which 76 kg NH₄-N), 21 kg P, 116 kg K, 1 kg S and 9 kg Mg. If for instance 25% of the ammonium N (NH₄-N) is lost in the houses via evaporation in a herd with 100 dairy cows, this would then represent an economic loss of € 2,850 per year (1,900 kg NH₄-N).

SLURRY COOLING

Ammonia evaporation is negatively correlated with the temperature. Cooling the slurry in the slurry channels with an effect of 24 W/m², the slurry channel has been verified to give 31% re-

duced ammonia evaporation. The effect on evaporation depends on the housing system and the cooling effect.

Slurry cooling is established by embedment of plastic (PEL) tubing at the bottom of slurry or manure channels in the stables. The hoses are typically laid with a distance of 35-40 cm. In stables with slurry systems, the cooling hoses are alternatively laid directly on top of the channel bottom. The cooling tubes are connected to a heat pump. Liquid cooling is most relevant in pig herds in which the recovered heat can be used for heating purposes, which typically involves herds with sows and piglets.



Photo: KH Norøtherm

Tubes for slurry cooling laid out for being moulded into the slurry channel floors in a pig house to be built.

IN-HOUSE ACIDIFICATION

In-house acidification of slurry means that slurry constantly is mixed with sulphuric acid and recirculated in the slurry channels inside the animal houses. The recirculation and addition of acid ensure that the pH in the slurry is kept at a level of

Ammonia and ammonium

Ammonia (NH₃) and ammonium (NH₄⁺) is not the same. The chemical equation that drives the relationship between ammonia and ammonium is:



NH₃ (ammonia) is on gaseous form and therefore likely to evaporate.

Untreated slurry has normally a pH of 6.5 – 7, and at this pH, 50-85% of the N is on ammonium form. The equilibrium is moved to the right of the equation with increasing acidification. Equilibrium is reached at pH 5.8, and when the pH is lowered further to 5.5, there are almost no ammonia left in the slurry.

5.5 which typically requires addition of 4-7 litres of sulphuric acid per ton slurry.

The in-house slurry acidification has been verified to reduce ammonia evaporation by 70% in cattle houses and 60% in pig houses.

An additional effect is 60% reduced ammonia evaporation during field application, equal to an increase in the bio-availability of the nitrogen in the slurry of about 20%; this is the reason why Danish legislation allows field application of acidified slurry by use of trailing hoses, rather than the more expensive application of non-acidified slurry by injection.

Livestock farmers also appreciate the big investment savings on slurry tank covers that they can achieve by in-house slurry acidification.

Yet an argument for farmers is the larger fertilising effect of acidified slurry which per ton typically contains 1 kg N and 2 kg S more than usual. This is especially economically important for Danish crop farmers due to the nitrogen quota system they are subject to, normally restricting them to use 10% less N than economically optimal.



Photo: Infarm

In-house acidification system.

The pH of acidified slurry is only lowered to 5.5 which can be compared to that of rain water. Therefore, no corroding effects are seen on concrete or equipment in contact with the acidified slurry.

Sulphuric acid is a strong acid and it is important to prevent accidents. The system shown on the picture above includes e.g. an acid tank with double walls and an emergency shower.

A disadvantage of acidified slurry is that it cannot be used for anaerobic digestion later on due to

the inhibiting effect of low pH on the methanogenesis. Thus, acidified slurry alone can be used for anaerobic digestion if it is co-digested with other material that brings up the pH.

AIR CLEANING

The incentive to develop systems for cleaning air in livestock houses derives from the agricultural sector being under great national and international pressure to reduce its environmental load. For animal production this involves requirements for a reduction of ammonia emissions, other nitrogen compounds, etc. This also applies to odours from livestock houses. Producers are facing an increasing number of limitations when they wish to establish new livestock housing systems or extend them. These limitations often occur as protests against the odour load.

Chemical air cleaning has been proven to remove 90% of the ammonia emissions from animal houses while biological air cleaning technologies remove >70% of the ammonia emissions and in the same time reduce the smell by 40-75%.

Air cleaners can be applied on closed housing systems with controlled ventilation. Such systems are normally used for pig and poultry production but not used on normal dairy farms. It means that in most cases air cleaners cannot be used to reduce emissions from cattle housing systems.



Photo: Skov

Biological air cleaning system being installed as part of the ventilation system in a pig house.

Air cleaning is also used at industrial size biogas plants in order to reduce the smell from the slurry reception pit and from other biogas production facilities.

CLEANING OF STABLES

Design of the stables, especially of the floors, has much influence on the ammonia evaporation from the stables. It is generally important to se-

cure that the floors are as clean and dry as possible, and that the manure is removed as often as possible.



Photo: LJM

Wire dragged scraper used on a solid, drained floor in a dairy cow unit.

Scraping solid drained floors in dairy cow stables by use of wire dragged scrapers, or scraping slotted floors by a robot scraper, has been proven to reduce the ammonia emissions by 25%.

In pig houses the most conventional way of cleaning is by use of wire dragged scrapers in shallow channels under slotted floors or via pull-plug cleaning.

A special V-formed slurry channel is also installed in some stables under the slotted floors, making the surface very small whereby the ammonia evaporation is reduced. The V-formed slurry channels can further be equipped with water flushing and with underpressure ventilation in connection with air cleaning, by which ammonia emissions and nuisances are minimal.

TECHNOLOGIES FOR MANURE STORAGE

Solid manure and deep litter is stored on concrete manure pads with drains and either supporting walls or a rim of at least 2 metres concrete to avoid leaking and seepage.

Slurry is normally stored in tanks.

SLURRY STORAGE AND COVERING

In Denmark, round tanks made of prefabricated concrete elements are conventionally used for slurry storage. It is recognized to be the cheapest solution, considering the durability of such tanks, and also a safe way to store the slurry.

New slurry tanks on pig and mink farms, established less than 300 meters from the neighbours'

house, must be provided with a cover in the form of floating cloth, tent cover or the like. The installation of a fixed cover can be omitted if a natural crust is established on top of the manure and regularly monitored.



Photo: Agro-Top

Slurry tank mounted with tent cover.

It is required to install automatic alarms on slurry tanks located within 100 meters from streams, water-carrying ditches and lakes larger than 100 square meters and on slurry tanks located on sloping terrain (over 6°) toward streams or lakes. The alarms send a text message to the responsible manager if the level of slurry in the tank drops unexpectedly. Depending on the tank's location and the surrounding terrain, it may be required that the alarm is supplemented with a physical barrier around the tank, for instance a concrete wall or a ditch in the soil. These rules will prevent accidental spills and contamination of streams and lakes with manure.



Photo: Skovgaard's Beholderkontrol

Photovoltaic driven alarm on a slurry tank.

In Denmark, a so-called "10-year slurry storage control" secures that the quality of manure storages is monitored.

TRANSPORT AND FIELD APPLICATION

Most Danish farms have a good harmony be-

tween their number of livestock and farmed area. Typically Danish farms would be able to dispose of their livestock manure as fertilizer on fields within 3-5 km from the livestock unit where it is produced. However, livestock production without owned land is legal.

Since 2001 and 2002 it has been illegal to spread liquid manure by use of irrigation canons and by broad spreading, respectively, due to health and environmental considerations. Most slurry is presently spread by use of slurry tankers with band laying system in the spring time where the crop needs the plant nutrients.



Photo: AP Gyllevogne

Most slurry is spread on growing winter crops in the springtime by use of large slurry tankers mounted with band laying system.

The slurry spreading equipment is, as indicated by the above picture, large and expensive which is why most transport and spreading is carried out by machine pools which effectively can utilise the equipment in the short spreading period.

Injection has to be used on bare fields and on grasslands, as well as in some nature sensitive areas.



Photo: SAMSON

Growing livestock unit sizes result in more transport of slurry before spreading. Therefore, it is more profitable to use trucks to bring the slurry to the fields, possibly combined with temporary storage in containers and self loading slurry tankers.

Danish legislation has made it possible to spread slurry by use of band laying systems in case the slurry is acidified. One possibility is acidification during spreading; a system that has gained considerable success even on commercial conditions due to its ability to reduce ammonia evaporation during spreading with 50% for cattle slurry and 40% for pig slurry, thus ensuring that more N is available for the crop.



Photo: BioCover

Slurry tanker with band laying system equipped with acidification system.

An alternative to injection on fodder grass areas is to use tank acidification, i.e. mixing of the slurry with sulphuric acid in connection with the homogenising of the slurry just before spreading.



Photo: Hansø

Acidification in the slurry storage is done in connection with agitating just before field application.

ENVIRONMENTAL TECHNOLOGY VERIFICATION

Many of the abovementioned technologies are drawn up on the so-called technology list, kept by Danish Environmental Protection Agency. The technology list presents eco-efficient technologies which the Danish authorities may demand to be installed as a condition for environmental permission of livestock farms.

Only technologies that have undergone an acknowledged test, undertaken by relevant research institutes, are included in the list and considered Best Available Techniques in Denmark. The tests verify the environmental efficiency of the technologies.

Thus, a large part of Danish manure handling technology is marketed with validated and impartial descriptions and documentation of effects and operational costs etc. This is important for confidence to the producers; a survey has revealed that only 11% of buyers trust the technology providers' own information.

There are different test and verification systems:

VERA is an abbreviation of Verification of Environmental Technologies for Agricultural Production. Technologies are tested according to specific test protocols. The test results are recognised by authorities in Denmark, Germany and the Netherlands.



DANETV (Danish Environmental Technology Verification) is a test brand held by a consortium of five acknowledged technological institutes. DANETV's tests are recognised internationally and globally.



WIN-WIN TECHNOLOGIES

The below figure shows that Danish farmers have been able to reduce the consumption of N-fertilisers with approx. 50% during the last 25 years, while the amount of N removed with the crop and the amount of N in livestock manure-based fertiliser to a great extent is unchanged. The innovative technologies for handling, storing and spreading of livestock manure are largely to credit for this development.

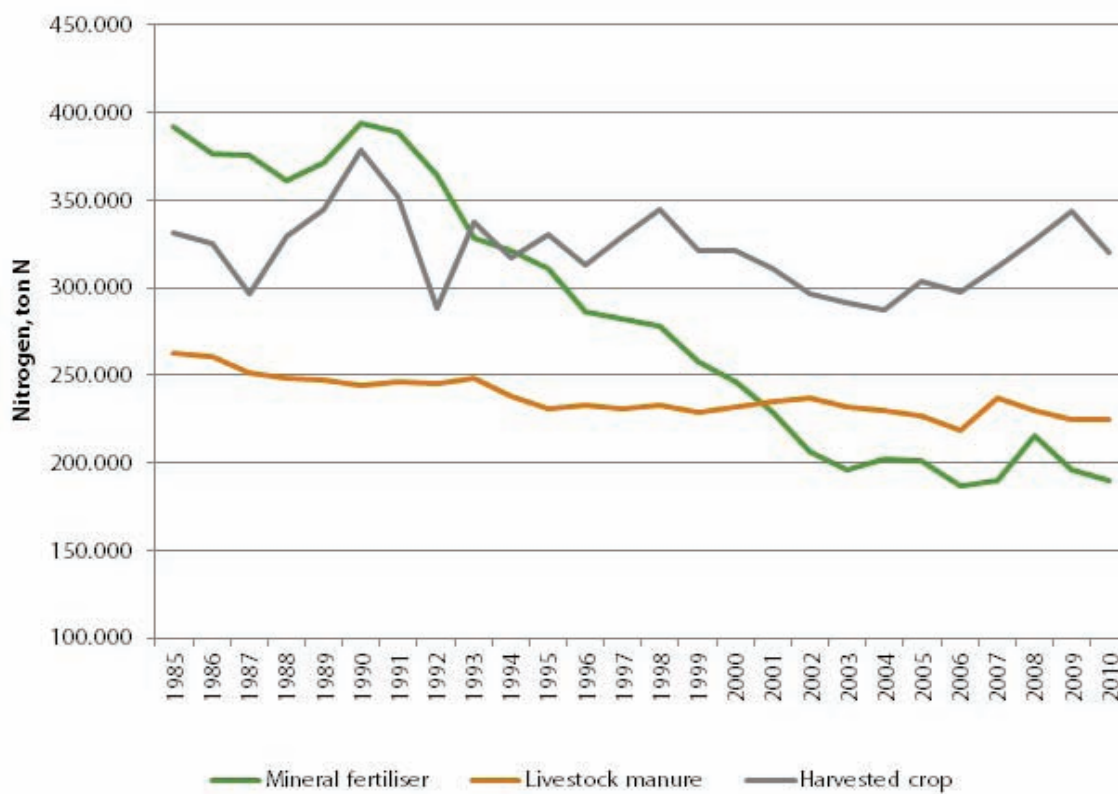


Figure 1: In Denmark, better manure management, first of all, storage of the manure and application of manure to the crops at the right time as part of a fertiliser plan based on fertiliser norms, as well as use of the other technologies mentioned above, have made it possible to reduce the consumption of N in mineral fertiliser with approx. 50% during the last 25 years. This saves Danish farmers an expense of approx. 100 € per ha, alone for N fertiliser! Figure provided by Leif Knudsen, Knowledge Centre for Agriculture.

Energy production from livestock manure

▶ **Already today, approx. 10% of the Danish livestock manure is utilised for energy production. The figure shows that Denmark is amongst leading countries in this respects and that there is a vast, yet unutilised potential.**

During the last 10 years, energy production from livestock manure has become interesting due to its combined benefits for the livestock farms and the society, although the actual energy value in itself is insufficient to ensure economical feasibility.

The value of manure for energy purposes is mainly dependent on its content of organic matter, crude ash and water.

ENERGY FROM WET MANURE PRODUCTS

In general, all types of raw livestock manure would be relevant for anaerobic digestion, as well as some processed form of raw manure, especially separation solids.

Especially in connection with biogas production it is normal to calculate with Volatile Solids (VS) which is "The quantity of solids in a sample which is lost by ignition of the dry solids at 600 C". As a rule of thumb, and unless specific analyses exists, the VS content of livestock manure can be considered to be 75% of the dry matter (DM) content.

The biogas production per m³ slurry from pigs and cattle is about 290, respectively 210 m³ per ton VS. Cattle slurry on the other hand contains more VS than pig slurry.

However, in practice there are large differences in the actual productivity of biogas plants due to differences in

- technological configuration, including pre-treatment technologies;
- quality of individual substrates and of the entire mixture of substrates; and
- management quality.

ENERGY DENSITY OF SOLID MANURE PRODUCTS

Normally, only manure products with less than 60% water are able to burn. An exception from that is horse manure which is able to burn even with a content of 70% water and give a positive,

although small, net energy production.

The following table shows the energy density for different fuels.

Table 1: Energy density of different fuels.

Fuel	Specific energy, MJ/kg
Methane (1.2 kg/Nm ³)*	55.6
Natural gas (0.83 kg/Nm ³)	53.6
Gasoline	46.4
Biodiesel	42.2
Dried manure/manure pellets with 11% water	14.9
Broiler manure with 36% water	10.0
Sitting hen manure with 24% water	6.9
Horse manure with 70% water	3.5

*Biogas contains about 65% methane (varies from 50 – 70%), so the energy density of biogas would be around 27.8 MJ per kilo.

Therefore, combustion and other ways of thermal exploration of the energy in manure is only relevant for deep litter qualities with a low water content and for dried manure. However, due to the humid climate, the energy prices and technical challenges, it is normally not profitable to dry manure in Denmark.

FOCUS ON CONSERVATION OF NUTRIENTS

In Denmark, manure based energy production has so far been focused on anaerobic digestion where nutrients are conserved. Today, almost 10% of the Danish livestock manure production is processed on a biogas plant, and about 20% of Danish pig and dairy farmers are involved in biogas production.



DIGESTER 1 -
955m³

Example of technology for mixing of the digester tank, based on a beam of re-circulated digestate and biogas.
Photo: Landia

Biogas production

▷ **Danish biogas technology is internationally renowned for its suitability to process livestock manure-dominated substrate mixtures, ensure a high net energy productivity where the heat from the electricity production is utilised, and being scalable and suitable for both farm-scale plants and industrial size plants.**

Biogas production, or anaerobic treatment, is a series of biological processes in which microorganisms break down organic molecules in absence of oxygen, resulting in the production of a mixture of gases, named biogas, mainly composed of methane and carbon dioxide.

Danish agricultural biogas production is characterised by

- being based on a minimum of 75% livestock manure as substrate (including stomach content from slaughterhouses);
- taking place on farm scale plants as well as on industrial size biogas plants; and
- having a high utilisation of the produced biogas via heat and electricity.

PLANNING OF THE PRODUCTION

A biogas plant is complicated in its technological setup and operations which require knowledge of disciplines such as engineering, biology, chemistry, trade, agriculture, and logistics, just to mention a few.

Typically, the establishment of a biogas plant requires several approvals, for instance an environmental approval and a building approval. Also, there are normally several agreements that have to be secured before the investment, for instance agreements on supply of the production of biogas, heat and/or electricity.



Photo: Henning Lyngsø Foged

Planning of biogas production is vital for the economic success and the process is often taking several years. Here PlanAction and the owner discuss the feasibility for improving an existing biogas plant.

There is no “one solution fits all” situation for biogas production; each plant is unique with its own specific situation, for instance about the types and amounts of available substrates.

Consulting companies can be involved in different ways and some of the most important services they can provide are feasibility studies, applications for environmental approvals, preparation of tender material, supervision of building/installation and commissioning of the plant.

ORGANISATION

Agricultural biogas plants are organised as farm-scale or industrial scale biogas production.

INDUSTRIAL SCALE BIOGAS PLANTS

Industrial scale biogas plants are characterised by being large, in Denmark averagely treating more than 100,000 tonnes livestock manure and other substrates per year. They are often being organised as a farmer owned cooperative, and in some cases they are owned by other stakeholders such as energy companies. Such plants often treat the manure from 40-100 farms, and sometimes more, and have employees to operate the plant.

Industrial scale biogas plants in Denmark

There are currently 20 industrial size agricultural biogas plants in Denmark with capacities varying from 50,000 to 500,000 ton substrate per year. The plants treat manure from about 1,600 livestock farms.

The advantage of the industrial scale biogas plants is that they can utilise the economy of scale which makes them able to invest in more efficient technology. It is an important factor for farmers who get their manure treated, that they do not need to bind own capital in the plants, except from a deposit, and that the plants also function as regional centres for re-distribution of



Thorsø Biogas is an industrial scale biogas plant treating around 120,000 ton substrate per year, of which approx. 65% livestock manure that is delivered from 60 farms nearby, 35% stomach content, sludge and other organic wastes from food processing at a dairy and a slaughterhouse, and a little waste water treatment sludge. The anaerobic digestion happens at thermophile temperature. Around 30% of the digestate is re-distributed to crop farmers, while the rest goes back to the supplying livestock farmers. The gas is via a pipeline to the nearby Thorsø village used for climate friendly district heating.

Photo: Burmeister & Wain Scandinavian Contractor A/S

the anaerobic digested manure, the digestate.

FARM-SCALE BIOGAS PLANTS

Farm scale biogas plants are characterised by only receiving manure from one livestock farm and being a legal and economic part of that farm.

Farm-scale biogas plants are especially attractive for large livestock farms which are able to utilise some economy of scale due to their size and, by means of the plant, can promise neighbours less nuisances from the production.

Advantages of farm-scale biogas plants are:

- The decision process is easier and faster, also about the establishment of the plant.
- The farm can produce its own heat which can be an advantage for pig farms in particular.

Farm scale biogas plants in Denmark

There are currently 57 farm scale biogas plants in Denmark with an average capacity of approx. 25,000 tons of substrate per year.

TECHNOLOGICAL CONFIGURATION

Several companies in Denmark have specialised in production of components for biogas plants. Some of the main components, whose design and function are crucial for the productivity and economy of the biogas plants, are the digester tanks, and the mixers for the digester tanks.

DIGESTER TANKS

An important feature of digester tanks is their ability to keep a stable inside temperature, independent of the temperature outside, and to make the heat requirement as small as possible. Insulation material is relatively cheap and should never be too thin; 20-30 cm insulation is recommended for thermophile and 15-20 cm for mesophile production.

Heat exchangers are profitable at biogas plants with a high alternative value of the heat and especially for the thermophile biogas plants.

In many cases, it is decided that two serially connected digester tanks, a primary and a secondary digester should be built in order to capture an extra 10-15% biogas production.

Mixing of the content of the digester tanks is



Photo: Assentoft Silo A/S

The digester tank is the hearth of the biogas plant and the best option for manure-based biogas production is cylindrically formed tanks made from steel. In this case, a primary and a secondary digester tank are being built. Between the inner and outer steel plates is 20 cm rock-wool for insulation.

important for giving the methane producing microbes the best conditions and also to make it possible for the biogas to be released from the digestate. The electricity consumption on a biogas plant is often around 10% of the produced electricity at the plant's combined heat and power (CHP) unit, and the largest share of this is used for stirring the digester tanks. Energy efficient stirring is therefore one of the success criteria for profitable biogas production. Mixing is often done with submerged propeller mixers.

Mixing of digester tanks with livestock manure based digestate is done with a minimum of use of energy when the tanks are cylindrically formed and a height that is larger than the diameter of the tanks.

LIVESTOCK MANURE SEPARATION

Slurry separation into liquid and solid fractions is often a stand-alone technology. However, many manure separators are installed in connection to biogas production, either before or/and after the digestion.



Photo: Henning Lyngsø Foged

Mobile separator which rotates between 6 pig farms every fortnight, ensuring that fresh separation solids with high biogas yield are supplied to the biogas plant and the separation liquids with high fertiliser value remain on the farms.



Farm-scale biogas plant. The photo shows the digester tank, containers and various equipment and installations for gas cleaning and management of the plant, the secondary digester tank, and a covered storage tank for digestate. Photo: Xergi

OTHER TECHNOLOGIES

The turn-key suppliers of biogas plants would often contract industrial suppliers or local companies for standard components of the biogas plants, such as the reception pits, valves, pipes and pumps, the Screen Capture And Data Analysis (SCADA) unit, the flare, the gas buffer store, the biogas cleaner etc.

Specialised components found on some biogas plants are for instance

- Biomixers that are useful for loosening material with large particle size, such as deep bedding;
- Macerators that chop substrates with large particle size and high lignocellulosic content, such as deep bedding, into small pieces, whereby its digestibility is increased, and it is avoided that the material creates a floating layer in the digester tank
- Hygiene units that can pressure sterilise substrate which is category 2 waste, such as slaughterhouse waste, according EU's animal by-products regulation.

LOGISTICS

Transport of livestock manure and digestate between livestock farms and the biogas plant is an important activity at industrial size biogas plants. It is important that the used trucks have a high capacity in order to minimize the transport, and in order to reduce nuisances and risk of disease spreading, they should be easy to clean between every transport and they should not spill during transport and loading/unloading.



Photo: VM Farm

Truck tanker for transport of slurry and digestate between farms and regional biogas plants.

RESEARCH

Denmark has several universities and research institutes which conduct research in biogas production. The main goal of the research is to find methods to increase the profitability of manure-

based biogas production in a sustainable way, for instance through advanced pre-treatment technologies, use of additives and enzymes, optimisation of the feed mix, and biogas potential of new substrates and other wastes to supplement livestock manure, for instance straw.



Photo: Flemming Nielsen, Story2Media

Morsø Bioenergy is an industrial scale biogas plant which is based on digestion of separation solids that is produced from 375,000 ton slurry annually with a mobile separator on the livestock farms, thus saving 95% of the transport costs by only transporting the separation solids to the plant and not the liquids. The plant also separates the digestate and market the separation solids to garden owners and the like, thus not returning it to the livestock farms.



The research biogas plant at Aarhus University has digesters in sizes from 125 litres to 1,600 m³ which can be configured in many ways with pre-treatment technologies and after-treatment of the digestate, thus being a unique place for performing research. Photo: Flemming Nielsen, Story2Media.

Use of biogas

► **Most Danish biogas plants convert the biogas to electricity via a biogas engine, and the framework conditions stimulate the highest possible energy efficiency which includes the use of excess heat, often in the local district heating. Upgrading of biogas to natural gas quality becomes more interesting due to changed policies, and the Danish natural gas grid can be used for transport and storage of the gas.**

Biogas is mainly used for three purposes: conversion to electricity, production of heat, and use in the transport sector after upgrading to natural gas quality.

CONVERSION TO ELECTRICITY

The conversion to electricity via a biogas generator requires that the biogas is desulphurised, i.e. that its content of hydrogen sulphide (H_2S) is reduced to a minimum. The H_2S would otherwise convert into sulphuric acid during combustion, leading to severe corrosion of the engine and a considerable reduction in its operational life. The cleaning is often done as a biological process, based on sulphur oxidizing bacteria. Biogas based on livestock manure has a content of H_2S of around 3,000 ppm and the concentration has to be reduced to maximum 200 ppm before combustion of the gas in a motor.



Photo: BiogasClean

Installations for biogas cleaning at Maabjerg Bioenergy which produce around 18.4 million m^3 biogas per year from approx. 500,000 tons livestock manure. The biological scrubbing takes place in the three tanks in front while the container is for the process technical unit for steering of the process.

Conversion of the biogas to electricity is often a preferred solution if the subsidies for biogas production are linked to electricity production. However, the conversion efficiency of biogas generators is only in the level of 35-40% (larger motors are more efficient than small ones).

The excess heat in the flue gas is captured with an exhaust heat exchanger. Typically, the biogas plant uses 15% (mesophile) to 25% (thermophile) of the energy in the produced biogas for heating up the biomass in the digester tanks.

PRODUCTION OF HEAT

The net excess heat from a biogas plant that produces electricity represents about 35-45% of the energy content of the produced biogas, and in the form of warm water this heat can be used directly for heating. For farm-scale biogas plants the heating is used in the living house or in the stables while industrial size biogas plants would sell the heat to local district heating plants.

Some biogas plants, however, combust all the biogas for heating purposes. Rather than transporting the warm water to the nearest district heating system, it is often more better to transport the biogas to the boiler house of the district heating plant, financially speaking.



Photo: Hollensen Energy

10 MW gas boiler.

USE IN THE TRANSPORT SECTOR

Another principal use of the biogas is in the transport sector, i.e. to upgrade it to natural gas quality, which is a requirement if the vehicles are

to use the biogas as a fuel, or if it is meant to be injected into natural gas grids.

The upgrading process is basically a separation of the biogas' content of 55-70% methane (CH_4) from its unwanted content of 30-45% carbon dioxide (CO_2), plus a small content of ammonia (NH_3), hydrogen sulphide (H_2S) and hydrogen (H_2). The process raises the biogas' methane content to about 98% according to applicable standards while it is energy adjusted by use of a little propane and compressed to at least 200 bar.



Figur 2: The backbone of Denmark's natural gas grid consists of 860 km national gas pipes, a gas store and 46 regulation stations. The grid is connected to regional and local gas pipes.

Different technologies exist for upgrading of biogas to natural gas quality, most developed are Pressure Swing Adsorption (PSA), membrane technology, physical absorption (including water scrubbing) and chemical absorption (including amine washing).



Photo: Ammonogas

Upgrading of biogas to natural gas quality is mainly a question of separating methane from CO_2 and other unwanted gases. Here it is done in columns in a process based on amine absorption.

Use of digestate

► For digestate it is extra important to use technologies that prevent ammonia evaporation, i.e. by storing it in covered slurry tanks and spreading it with injection or a band laying system, possibly combined with acidification.

Digestate from livestock-manure based biogas plants should be handled like slurry or other liquid manure, provided it is secured that used co-substrates legally could be used for fertilising of crops, even without the anaerobic digestion.

In the EU, anaerobic digestion does not change the legal definition of livestock manure; it is also in processed form defined as waste and the feasible methods for its disposal is to use it as fertiliser for crops.

The main differences between raw slurry and digestate are shown in the following table:

Table 2: Typical chemical characteristics of untreated slurry and digestate.

	Dry matter, %	pH	N-total, kg/ton	NH4-N, kg/ton
Cattle slurry	6.0	6.5	5.0	2.8
Pig slurry	4.0	7.0	5.0	3.8
Digestate	2.8	7.5	5.0	4.0

The fact that digestate has a higher pH and also contains a larger share of the nitrogen on a mineralised form, makes the risk for ammonia evaporation higher.



It is extra important that digestate is stored and handled with technologies to prevent ammonia evaporation. Photo: Agrocover

So, for digestate it is extra important to use technologies that prevent ammonia evaporation, i.e. by storing it in covered slurry tanks and spreading it with injection or a band laying system, possibly combined with acidification.

LESS SMELL AND HIGHER FERTILISER VALUE

Despite the higher risk for ammonia evaporation, digestate has a much less intense odour than untreated slurry. The reason for this is the lower viscosity of digestate, which together with a

smaller and more homogeneous particle size makes it percolate faster into the soil. Since neighbours' main concern about livestock production farms are related to odour, this factor is therefore often of importance for farmers' decision to invest in biogas production.

Due to the increased amount of $\text{NH}_4\text{-N}$, a farm that fertilises with digestate can often get the same fertilising effect with 10-20% smaller dose.



Other technologies

▷ **Danish companies offer boilers of varying sizes up to industrial size for combustion of solid livestock manure types like deep litter from chicken production. Technologies for gasification and pyrolysis of livestock manure types seem to be theoretical possibilities for the future.**

Technologies for thermo-chemical production of energy from livestock manure comprise direct combustion, co-firing, gasification and pyrolysis.

COMBUSTION

Direct combustion refers to the burning of biomass directly in a furnace to produce heat and electricity. Steam produced from heat of combustion powers a turbine that turns on a generator to produce electricity. Manure as a fuel has the potential to be burned directly if the manure water content is less than 60%. However, because its ash content (the inorganic residue such as soil or other inorganic material that remains after combustion) is higher than other biomass (e.g. wood and straw) or fossil fuels (e.g. coal), direct combustion of manure is rarely efficient.

Because of the quality variability and high water content of animal manure, it is often desirable to mix it with other less variable and more dry fuels for combustion. One means of doing this is co-firing which refers to mixing biomass and fossil fuels in conventional power plants. Significant reductions in emissions from sulfur dioxide (SO₂), an air pollutant released when coal is burned, are achieved with co-firing systems in power plants that use coal as input fuel.

Co-firing of manure with coal may also reduce emissions from coal of nitrogen oxide (NO_x), which contributes to air pollution. This depends on whether the manure is injected at the proper location, such as the secondary combustion chamber, where it serves as supplemental or



Photo: KEM

Industrial size boiler for combustion of chicken deep litter.

reburn fuel and as an organic source of urea and ammonia (NH_3). Upon co-firing manure and coal, NH_3 is released from manure and combines with NO_x to produce harmless N_2 and water. On the other hand, co-firing of manure with coal has the negative effect of hampering phosphorous recycling in the agriculture.

Combustion of manure is not taking place in Denmark at commercial basis. This is partly due to some technical challenges but the main reason is that manure is categorized as waste, according to EU legislation. It means that certain taxes have to be paid when manure is combusted and this reduces the profitability of this activity. In addition, manure combustion plants should meet the same requirements as for waste incineration plants in terms of online monitoring of flue gas emissions etc.

GASIFICATION

Gasification is the process by which carbonaceous fuel (any fossil or biomass fuel consisting of or containing carbon) is converted to a useable gaseous product without complete combustion of the fuel.

The process occurs in an oxygen deficient (partial oxidation) environment at high temperatures. The resulting fuel is a producer gas (a synthesis gas or syngas) that consists primarily of varying ratios of hydrogen and carbon monoxide (CO).

Syngas can be further processed into other fuels or products by chemical conversion or burned to heat a conventional boiler. Also, it can replace natural gas in a gas turbine.

PYROLYSIS

Pyrolysis is a thermo-chemical conversion process whereby biomass is heated at high temperatures in the complete absence of an oxidant (oxygen).


Products from this process include combustible gas, liquid condensates and charcoal. The liquid portion is called pyrolysis oil which can be burned to generate electrical power. It can also be used as a chemical additive to produce plastics and other bio-products.

However, neither technologies for gasification nor pyrolysis of livestock manure types are commercially used at present, but are under certain conditions, they would be interesting possibilities for the future.

Members of the Innovation Network for Biomass with competences within “Livestock manure to energy”

Logo	Contact	Description	Production	Logistics	Pretreatment	Conversion	Energy Utilisation	Research, Consultancy, Trade Association etc.
	BioGasclean A/S Hvidkærvej 41 DK-5250 Odensen SV Tel: +45 6617 2177 www.biogasclean.com	Manufactures and markets biological biogas desulphurisation plants. The biogas is cleaned for hydrogen sulphide (H ₂ S) so it can be combusted in high efficient gas engines and used for combined heat and power production.	•					
	AP Gyllevogne Østermøllevej 42 DK-7900 Nykøbing Mors Tel: +45 9772 1261 www.ap-gyllevogne.dk	Manufacturing and development of slurry tankers, slurry trailers and ground equipment. Dribble bar and slurry injector systems.	•					
	Haarslev Industries Bogensevej 85 DK-5471 Søndersø Tel: +45 6383 1100 www.haarslev.com	Haarslev Industries is a process technology company, providing powerful solutions for the benefit of the global environment. We supply complete systems and equipment for the processing of animal by-products, sewage sludge, bio fuels and by-products from food and beverage production.	•					
	Lind Jensens Maskinfabrik A/S Kroghusvej 7, Højmark DK-6940 Lem St. Tel. + 45 9734 3200 www.ljm.dk	LJM A/S has 50 years of experience and extensive knowhow regarding production and marketing of a wide range of products, including: submersible pumps, dry mounted pumps, various mixers and manure handling systems.	•					
	NISSEN energi teknik A/S Byvej 25 DK-8654 Bryrup Tel: +45 75756500 www.nissenenergiteknik.dk	NISSEN energi teknik A/S is one of Denmark's leading sales and service companies within the decentralized energy industry. We design, manufacture, supply and install power plants based on natural- and biogas engines and gas- and oil burners from Dutch Zantingh BV.	•					
	Perstrup Beton Industri A/S Kringelen 4-6 DK-8560 kolind Tel: +45 8774 8500 www.perstrup.dk	Perstrup Beton Industri A/S produce concrete elements for agriculture and industry.	•					
	REHAU A/S Industrivej 51A DK-4000 Roskilde Tel. +45 4677 3700 www.rehau.dk	REHAU produces RAUVITHERM pre-insulated pipes for the biomass industry and RAUBIO fermenter heating system for fermentation plants.	•					
	VM Tarm A/S Tværvej 25 DK-6880 Tarm Tel: +45 9737 1644 www.vmtarm.dk	VM Tarm A/S is Scandinavia's largest producer of liquid manure tankers in stainless steel. With more than 15 years experience within transport of manure, we develop high quality liquid manure tankers.	•					
	Swea Produktion A/S Vestervang 14 DK-6000 Kolding Tel: +45 7556 8333 www.swea.dk	Production: Manure transporters, separators for slurry, biowaste and more.	•					
	AgroTop A/S Birkesøvej 19, Gammelstrup DK-7850 Stoholm Tel: +45 9754 1733 www.agrotop.dk	AgroTop A/S has over 20 years of experience in providing and installing slurry tank covers all over Europe.	•					

Logo	Contact	Description	Production	Logistics	Pretreatment	Conversion	Energy Utilisation	Research, Consultancy, Trade Association etc.
	Grontmij A/S Granskoven 8 DK-2600 Glostrup Tel: +45 4348 6060 www.grontmij.dk	Grontmij is the third largest engineering consultancy in Europe with nearly 9,000 professionals. At the heart of our business is the sustainability by design principle - a leading value proposition for our customers.	•					
	Infarm A/S Systemvej 6 DK-9200 Aalborg SV Tel: +45 9632 6800 www.infarm.dk	Produces, develops and sells acidification systems for reducing ammonia emissions from pigs and cattle stables. Selling separators and slurry tank alarms for pig and cattle manure.	•					
	BWSC A/S Gydevang 35 DK-3450 Allerød Tel: +45 4814 0022 www.bwsc.dk	BWSC offers centralized farmer based biogas plants for production of energy out of biomass by an anaerobic digestion process.	•		•	•	•	
	Lundsby Bioenergi A/S Nørrevangen 18 DK-9631 Gedsted Tel: +45 9649 4300 www.lundsby.dk	Produces both manual boilers and fully automatic combustion plants for most types of solid fuels (biofuel), including automatic plants from 10-6500 kW for straw, wood chips, wood shavings, sawdust, pellets, coal, grain and husks.	•		•	•	•	
	TechRas Miljø ApS Gjessøparken 17 DK-8600 Silkeborg Tel: +45 8684 8840 www.techras.dk	Provides total "plug and play" separation systems with decanters or screw press for separation of manure.	•		•	•	•	
	Baltic Renewable Denmark Rådhusvej 13 DK-2920 Charlottenlund Tel: +45 4182 4696 www.BalticRenewable.com	Develops and manufactures complete manure based biogas systems for co-generation of electricity and heat: ½ to 2 MWeI.	•		•	•	•	
	Bigadan A/S Vroldvej 168 DK- 8660 Skanderborg Tel: +45 8657 9090 www.bigadan.dk	Turnkey design, supply and operation of large scale biogas facilities; based on 30 years of international biogas experience.	•		•	•	•	
	Nordic BioEnergy ApS Jelshoejvaenget 11 DK-8270 Hoejbjerg, Aarhus Tel: +45 2386 8886 www.nordicbioenergy.dk	Planning, design, building and operation of biogas plants. Producer and designer of pretreatment for food waste, grass, straw etc. Producer and designer of slurry- and digestate separation.	•		•	•	•	•
	AL-2 Agro A/S Kogsvej 62 DK-6780 Skaerbaek Tel: +45 3169 6501 www.al-2.com	Manufactures customized turnkey separation systems, built in container / mobile both mechanical and chemical-mechanical systems, focus on phosphors and biogas potential, and on the simplicity and reliability in the systems.	•		•	•		•
	GEA Westfalia Separator A/S DK Nørskovvej 1b DK-8660 Skanderborg Tel: +45 4030 0266 www.gea-westfalia.dk	GEA Westfalia Separator DK is leader in technical solutions and knowledge of mechanical separation of liquid manure and digestate.	•		•		•	•

Logo	Contact	Description	Production	Logistics	Pretreatment	Conversion	Energy Utilisation	Research, Consultancy, Trade Association etc.
	Svanholm.com Marienbergvej 132, 1. DK-4760 Vordingborg Tel: +45 7026 5811 www.svanholm.com	Sells and supports analyzers and sensors for fermentation and for concentration monitoring of gasses for research and production.	•			•		•
	AEM ENGINEERING Hyrdeengen 37 DK-2625 Vallensbæk Tel: +45 2480 9024 www.aem-engineering.dk	High efficiency GOSMER Biogas plants. Very low own consumption. High efficient low-power separation process. More than 30 years of experience. Power Plants using all kinds of combustible gases.	•			•	•	
	3P Technology Sletten 47 B DK-7500 Holstebro Tel: +45 9610 9110 www.3ptechnology.com	3P Technology develops and designs PLC and SCADA software for the process and machine industries. Today 3P Technology has the most up-to-date technology software within automation of process and machine systems.	•			•	•	•
	MHJ Agroteknik Baldersvej 7 DK-8850 Bjerringbro Tel: +45 8668 1922 www.mhj.dk	Developing, manufacturing and supplying individual solutions for poultry, pig and dairy farming as well as industry related to farming. Our core areas are ventilation, air cleaning and transportation / feed systems. Our focus is to optimize both on environment and production economics for the investor / end-user.	•				•	
	Jørgen Hyldgård Staldservice A/S Nørgårdsvej 18 DK-7500 Holstebro Tel: +45 9742 8189 www.jhstaldservice.dk	Develops, produces and market manure treatment plants, both sulfuric acid treatment and biogas.	•				•	•
	AP Company A/S Lundvej 24 DK-8700 Horsens Tel: +45 7568 2522 www.apcompany.eu	Providing high quality mechanisation packages and counselling regarding business plans, authorities processing, and financing.	•					•
	Gråkjær A/S Lundvej 24 DK-8700 Horsens Tel: +45 9613 5555 www.graakjaer.dk	We handle the entire process in the establishment of your livestock production. Involving issues such as planning, environmental assessment, cost analysis, financing, and product development as well as dealing with the authorities and the actual construction of the building.	•					•
	SAMSON AGRO A/S Vestermarksvej 25 DK-8800 Viborg Tel: +45 8750 9300 www.samson-agro.com	SAMSON AGRO A/S has more than 65 years of experience in developing and manufacturing agricultural machinery and equipment for distributing manure. The product line includes slurry tankers, tools, computer equipment, manure spreaders, and mixers for slurry tanks.	•	•				
	A-Consult Agro A/S Fabriksvej 8, V. Lyby DK-7800 Skive Tel: +45 9687 5800 www.aconsult.dk	Supplies precast concrete tanks for use in agriculture, the water industry and for biogas plants.	•	•			•	
	ASSENTOFT SILO A/S Silovej 1, Assentoft DK-8960 Randers SØ Tel: +45 8649 4566 www.assentoftsilos.dk	Designs, produces and erects biogas reactor and storage tanks, made from bolted steel plates, insulated, if required. Sizes from 500 m3 to 7,000 m3. We provide active coaching and help in designing your complete system.	•	•				•
	Green Center Videncenter Råhavegård Maribovej 9 DK-4960 Holeby Tel: +45 5460 7000 www.greencenter.dk	Green Center is a business and research center working together with agriculture, agribusiness and eco-technology industries. Green Center is part of the Knowledge Center "Råhavegård" and is located in the Zealand Region.	•	•			•	•

Logo	Contact	Description	Production	Logistics	Pretreatment	Conversion	Energy Utilisation	Research, Consultancy, Trade Association etc.
	Harsø Maskiner A/S Fåborgvej 5 DK-6818 Årre Tel: +45 7519 5333 www.harso.dk	Development and production of manure management equipment such as: acidification tanks, slurry tankers, slurry pumps etc.	•	•	•			
	AgroTech A/S Agro Food Park 15 DK-8200 Århus N Tel: +45 8743 8400 www.agrotech.dk	Gives advice and develops projects in all aspects of manure handling from production to energy production and back to the agriculture.	•	•	•		•	•
	STARING A/S Staringvej 9-11 DK-9700 Brønderslev Tel: +45 98821622 www.staring.dk	Staring is supplier of a 100% mechanical operated manure separating plants that works without use of polymers and any additives. With a high efficient screw press combined with a 32 micron screen this system is super efficient. Staring also supply a wide range of submersible manure agitators and pumps, slurry pumps with guide rail system. Gen sets, mixers etc.	•	•	•	•		
	Xergi A/S Hermesvej 1 DK-9530 Støvring Tel: +45 9935 1600 www.xergi.com	Contractor and O&M operator of turnkey biogas plants. More than 25 years of experience with design, engineering, procurement, construction management, commissioning and operational services.	•	•	•	•	•	
	AMMONGAS A/S Ejby Mosevej 5 DK-2600 Glostrup Tel: +45 4363 6300 www.ammongas.dk	Biogas upgrading with high efficiency to 99% pure methane with 1 ppm H ₂ S. The green process uses little electricity and emits < 0.1% CH ₄ .	•	•	•	•	•	
	RENEW ENERGY A/S Kullinggade 31 DK-5700 Svendborg Tel: +45 6222 0001 www.renewenergy.dk	Engineering services company providing focused consulting in sustainable bioenergy production. Draws on more than 20 years' experience within anaerobic digestion and biorefinery solutions. Provides technologies for biogas plants, biogas/separation plants and biorefinery plants integrated with ethanol plants, distilleries and other industrial plants.	•	•	•	•	•	•
	Landia Industrivej 2 DK-6940 Lem St. Tel: +45 9734 1244 www.landiaworld.com	Landia is a world-leading manufacturer of: Heavy-Duty Chopper Pumps, Submersible Mixers, Jet-Aerators and advanced process units. Landia was founded in 1933, giving the company almost 80 years of experience in manufacturing high quality pumping & mixing equipment.	•	•	•	•	•	•
	Gøma Viborg Petersmindevej 6 DK-8800 Viborg Tel: +45 8661 0377 www.goma.dk	A specialist shop selling and repairing various manure handling equipment.		•				
	Thyregod A/S / Kimadan Borgergade 46 DK-7323 Give Tel: +45 7573 4099 www.thyregod.com	Production of various slurry handling equipment such as: slurry pumps, mixers, drag hose systems, slurry wagons, etc.		•				
	Gjøl Vakuum-Anlæg A/S Drøvten 44, Gjøl DK-9440 Aabybro Tel: +45 9827 7300 www.gva.dk	GVA Gruppen project, product, install, and maintain slurry plants for both pigs and mink.		•	•			

Logo	Contact	Description	Production	Logistics	Pretreatment	Conversion	Energy Utilisation	Research, Consultancy, Trade Association etc.
	BioCover A/S Veerst Skovvej 6 DK-6600 Vejen Tel: +45 2963 4936 www.biocover.dk	Development and sale of SyreN technology - system for acidification of slurry (sustainable application of slurry – reduction in eutrophication and odour).		•	•			
	Danish Technological Institute Kongsvang Alle 27 DK-8000 Aarhus C Tel: +45 7220 1000 www.dti.dk	Development and documentation of technologies through research, test and verification i.e. separation, pretreatment and optimization of biogas production. Emission abatement, sensor technology etc.		•	•	•	•	•
	PlanAction Klamsagervej 32 DK-8230 Aabyhøj Tel: +45 4030 1420 www.planaction.dk	Consultancy in development, planning, implementation and operation of biogas plants including financial and environmental assessments, technical setup, organization and finance. Planning and implantation of use of biogas for energy as well as for utilization of the digestate.		•	•	•	•	•
	Norconsult Danmark A/S Lautruphøj 1-3 DK-2750 Ballerup Tel: +45 2810 3799 www.norconsult.dk	Consulting services on setting up biogas plants (sludge, manure, source separated household waste and other types of organic waste), energy production, biogas upgrading, use of fertilizers. The recycling of nutrients - organic fertilizers - controlled struvite precipitation - ammonia stripping. Impact assessments for agricultural applications.		•	•	•	•	•
	VengSystem A/S, Nautrup Moellevej 22, DK-7870 Roslev Tel: +45 9759 2072 www.vengsystem.com	Odour filters.		•		•		
	Ceno Top Mølbjergvej 6 DK-6340 Kruså Tel: +45 2612 7987 www.ceno-top.dk	Ceno Top sales biogas storage tanks in Scandinavia. World leading storage systems with long service life, maintenance free set-up, permanently gas-tight, high operational reliability, suitable for heavy wind and snow loads.		•		•	•	
	HedeDanmark A/S Klostermarken 12 DK-8800 Viborg Tel: +45 8728 1000 www.hededanmark.dk	Handling and utilization of biomass and waste from biogasplants. Delivery of organic residues (other than manure) to biogas production.		•				•
	C.F. Nielsen Sølbjergvej 19 DK-9574 Bælum Tel: +45 9833 7400 www.cfnielsen.com	C.F. Nielsen A/S was established in 1889 and is today the world leading manufacturer of mechanical briquetting presses. We supply briquetting solutions to industrial and private consumers all over the world- with installations for wood waste and other biomass products on all 5 continents.			•			
	Agrometer A/S Fælledvej 10 DK-7200 Grindsted Tel: +45 7672 1300 www.agrometer.dk	Production of mechanical screw presses for separation of slurry into liquid and dry matter.			•			
	BBK Airclean A/S Linnerupvej 5 Hjortsvang DK-7160 Tørring Tel: +45 7567 6066 www.bbk.dk	BBK Bioairclean markets, projects, produces, and maintains biofilter solutions for odour removal. The main fields of activity are animal rendering plants, sewage treatment plants, composting facilities, fish processing industry, and biogas plants, but other types of organic industries may also benefit from BBK filters.			•			

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	Kemira Water Denmark A/S G-Vej 3 DK-2300 Copenhagen Tel: +45 3313 6711 www.kemira.dk	We offer chemical products and customer-driven solutions to the food, feed, pharmaceutical and chemical industries. Utilizing our application expertise, our customers can benefit through improved profitability and enhanced product quality.			•			
	Millag Søndervang 29 DK-6780 Skærbæk Tel: +45 8861 2600 www.millag.dk	Millag deliver slurry lagoons according to individual specifications and with or without alarm system and covering.			•			
	Opicon A/S Birkmosevej 1 DK-6950 Ringkøbing Tel: +45 7020 2509 www.opicon.dk	Opicon A/S manufactures and sells sand washers for the extraction of sand from slurry. The sand can be reused after the washing process.			•			
	PBJ Miljø A/S Ørnevej 22, Bremdal DK-7600 Struer Tel: +45 9616 6066 www.pbjmiljoe.dk	PBJ Miljø produces and specializes in geomembranes, specialty wells, and PE plates.			•			
	Skovgaards Beholderkontrol ApS Petuniavej 226 DK-7800 Skive Tel: +45 4095 3930 www.agrocover.dk	Distribution and mounting of slurry tanks, covers, and maintenance.			•			
	Varde Køleservice ApS Nordre Boulevard 96B DK-6800 Varde Tel: +45 7522 1117 www.vardekoleservice.dk	Varde Køleservice project, install, and service plants for manure cooling. The cooling of manure reduces the ammonia evaporation.			•			
	Vitfoss Ulsnæs 34 6300 Gråsten Tel: +45 3368 5600 www.vitfoss.dk	Provides a product for slurry handling. It can be used in slurry tanks/lagoons, slurry channels/containers, preliminary tanks and biogas plants.			•		•	
	Rotor A/S Industrivej 8 DK-6800 Varde Tel: +45 7522 1000 www.rotor.dk	Specializes in natural ventilation, mechanical ventilation, biological air cleaning, and odor and ammonia reduction.			•	•		
	DTU - Technical University of Denmark Frederiksborgvej 399 DK-4000 Roskilde Tel: +45 2132 6955 www.risoe.dtu.dk	Research and consultancy related to the production of biofuels from agricultural residues: conversion technologies, biomass pretreatment, sustainability assessments, small scale biogas concepts, GHG emissions from manure handling.			•	•		•
	Hexa-Cover ApS Vilhelmsborgvej 5 DK-7700 Thisted Tel: +45 9617 7800 www.hexa-cover.com	Hexa-Cover® Floating Cover is perfect on almost any form of fluid surface. Hexa-Cover® Floating Cover is the ideal solution for eliminating such things as: Emissions, Odors, Evaporation, Organic growths, UV effect, Heat loss.			•	•	•	
	KEM A/S Haandvaerkervej 4 DK-6880 Tarm Tel: +45 9737 2100 www.kem.dk	KEM A/S is engineering biomass fired steam boilers used for power generation and/or district heating, utilizing the energy from; poultry litter, straw, husks, wood, olive etc. KEM A/S manufactures cranes, fuel feeding systems, grates and ash handling.			•	•	•	•

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	Combigas ApS Tinghøjvej 13 DK-6893 Hemmet Tel: +45 9680 8068 www.combigas.dk	ComBigas is a supplier of ready to use biogas plants. This includes preparing of the feasibility study, analysis, calculations and obtaining of the various permits.			•	•	•	•
	Aalborg University Department of Energy Technology Pontoppidanstræde 101 DK-9220 Aalborg Tel: +45 2166 2511 www.et.aau.dk	Biomass resource studies, Recycling Nutrients to farmland. Biomass pretreatment technologies Biogas plant development. Bio-oil production test facilities. Biomass boiler test facilities etc.			•	•	•	•
	Hollensen Energy A/S Finsensvej 3 DK-7430 Ikast Tel: +45 9714 2022 www.hollensen.dk	Develops and supplies equipment for the production of heat and electricity. Components and turnkey solutions for gas and oil-fired boiler plants, gas-fired motor plants and biomass-fired boiler plants.				•		
	Kaas Staalbyg A/S Hjulmagervej 12-16 DK-9490 Pandrup Tel: +45 9618 3232 www.kaasstaalbyg.dk	Production of bearing steel constructions for several types of buildings, also in the agricultural sector. We also produce straw furnaces for KF Halmfyr.				•		
	P & I Engineering ApS Grenevej 9 DK-7190 Billund Tel: +45 7535 3572 www.pi-eng.dk	A consultative engineering company focused on developing biotech processing plants.				•		•
	HMN Naturgas I/S Vognmagervej 14 8800 Viborg Tel: +45 8727 8727 www.naturgas.dk	Distribution of natural gas in the middle and northern part of Jutland and Copenhagen, Denmark.				•	•	
	Novozymes A/S Krogshøjvej 36 DK-2880 Bagsvaerd Tel: +45 4446 0000 www.novozymes.com	Novozymes develops and produces hydrolytic enzymes for bioenergy.				•	•	
	Aage Siig Consulting Frisvadsvej 52 DK-6800 Varde Tel: +45 7522 0631	Expert in biogas plant operation and maintenance.				•	•	•
	Pon Power Øresundsvej 9 DK-6715 Esbjerg N Tel: +45 7614 6400 www.pon-cat.com	Pon Power is the Scandinavian dealer of Caterpillar diesel and gas genset, ranging from 400-9.700 kW. All Caterpillar gas-genset are compatible with natural gas and bio gas. We offer 24-hour service from authorized technicians and original Caterpillar spare parts. ISO 9001 and ISO 14001.					•	
	Frichs A/S Sverigesvej 16 DK-8700 Horsens Tel: +45 7564 7244 www.frichs.dk	Produces complete biomass fueled gasification and CHP systems for electricity and heat production.					•	
	KH nordtherm A/S Rømersvej 30 DK-7430 Ikast Tel: +45 9715 4600 www.khnordtherm.dk	KH Nordtherm is Denmark's largest supplier of heat recycling solutions for agriculture for example within slurry cooling and heating solutions for animal housing systems.					•	•

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	Danish Gas Technology Centre Dr. Neergaards Vej 5 B DK-2970 Hørsholm Tel: +45 20169600 www.dgc.dk	DGC do consulting related to utilization, transport, metering and combustion of gas as well as chemical analysis of green gasses. Furthermore, DGC is Notified body and do CE-approvals of gas appliances.					•	•
	2.0 LCA Consultants Skibbrogade 5,1 DK-9000 Aalborg Tel: +45 3332 2822 www.lca-net.com	Specialized in environmental assessment (Life Cycle Assessment and Mass Flow Analysis) of bio-mass, manure and bioenergy, including modelling of emissions from crop cultivation, feed production, animal production, manure and combustion processes.					•	•
	ON/OFF Management ApS Gravene 2 DK-8800 Viborg Tel: +45 2943 4348 www.onoffmanagement.dk	Consulting and development of biomass and waste to energy project. More than 25 years of experience form projects worldwide.					•	•
	Blue Planet Innovation Agro Food Park 15 DK-8200 Aarhus N Tel +45 8740 5000 www.blueplanetinnovation.com	Blue Planet Innovation focuses on new solutions within sustainable energy with specific focus on bioenergy. Based on the resources of agriculture and new possible business models and concepts regarding the development of bioenergy.						•
	GasCon Vejsøvej 23 DK- 8600 Silkeborg Tel: +45 2171 5216 /+45 8680 1953 www.gascon.dk	GasCon has extensive experience in design and construction of large scale biogas plants. We work as consultants from the first ideas, through feasibility analysis, tender, contract and building phase, and ensure the plant is operating to specifications.						•
	Sauer Roldskov Law Firm Soeren Frichs Vej 42 A DK-8230 Aabyhoej Tel: +45 7070 2928 www.sauerroldskov.com	Sauer Roldskov is a specialized law firm providing legal advice within the renewable sector, including the sector of biomass and bio products, in Denmark and internationally.						•
	Organic Denmark Silkeborgvej 260 DK-8230 Aabyhøj Tel: +45 8732 2700 www.okologi.dk/biogas	Organic Denmark offers advice for investment and operation of biogas plants in joint operation with organic food production. Including applications for grants for investment in biogas plants.						•
	KU-life - Plant & Environmental Sciences University of Copenhagen Thorvaldsensvej 40 DK-1871 Frederiksberg C Tel: +45 3533 3470 www.agreco.life.ku.dk	Research on manure for energy through AD, gasification or pyrolysis, with special focus on manure energy and nutrient characterisation methods, nutrient recovery from digestate, ash and chars, application to land, emissions of NH3 and GHG, solids composting.						•
	NIRAS Åboulevarden 80 Post box 615, DK-8100 Aarhus Tel: +45 8732 3232 www.niras.com	NIRAS has for the last 30 years worked with large joint biogas plants based on co-digestion of manure, sewage sludge and other organic feed stocks. Feasibility studies, design, consultant, operation advice, biogas utilization and/or upgrading.						•
	Rambøll A/S Hannemanns Allé 53 DK-2300 Copenhagen S Tel: +45 5161 1000 www.ramboll.com	Rambøll offers a full range of services for Anaerobic Digestion, biogas upgrade, gas to grid and vehicle fuel projects - including all stages from planning and project development, to design, implementation and operation and maintenance.						•
	Business Biogas Bjarnehøjvej 16 DK-3390 Hundested Tel. +45 2040 7050 www.businessbiogas.dk	Consultants in building and running of biogas plants, especially in the cross field of financing, overall economics and stabile production of biogas on sound commercial basis.						•

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 Landskab & Planlægning	CHRISTIAN ACHERMANN Pasteursvej 24, 4. sal DK-1799 København Tel: +45 2980 7793 www.christian-achermann.dk	Landscape Architects dedicated to make engineering, logistics and economics of infrastructure and energy plants go hand in hand with aesthetics and landscape experiences. Consultancy within master planning, landscape analysis, visualization and EIA.						•
 ConTerra Agricultural Engineering	ConTerra ApS Niels Pedersens Allé 2 DK-8830 Tjele Tel: +45 8999 2540 www.conterra.dk	ConTerra develops solutions for legal authorities, companies and interest groups, working with environmental aspects related to agricultural activities.						•
	Danske Svineproducenter Karetmagervej 9 7000 Fredericia Tel: +45 7025 8070 www.danskesvineproducenter.dk	A political organization working on improving the conditions and the political framework to the benefit of Danish pig producers.						•
	KonsultKompagniet Bjarnehøjvej 16 DK-3390 Hundested Tel: +45 2040 7050 www.konsultkompagniet.dk	Consultants in building and running of biogas plants, especially in the cross field of financing, overall economics and stable production of biogas on sound commercial basis.						•
	Market Select ApS Gammel Nybyvej 24, Troense, Tåsinge DK-5700 Svendborg Tel: +45 8680 0390 www.marketselect.dk	Market Select identifies, selects and arranges contact to new potential partners, whether customers, suppliers, sub-suppliers, distributors, agents, wholesalers, manufacturing partners and more. Market Select advises on export development, sourcing, assists with export measures and investigative work as Export Manager-for-hire. Market Select is your sparring partner for strategy development and education.						•
	Nordic Folkecenter for Renewable Energy Kammersgaardsvej 16, Sdr. Ydby DK-7760 Hurup, Thy Tel: +45 9795 6600 www.folkecenter.dk	Nordic Folkecenter provides research and information about renewable energy (including biomass) and energy savings.						•
	PlanEnergi Jyllandsgade 1 DK-9520 Skørping Tel: +45 9682 0400 www.planenergi.dk	Consultancy assistance regarding renewable energy e.g. biogas plants, planning, design, layout, process calculations, feasibility study, Environmental Impact Assessment, implementation and monitoring.						•
	Aarhus University Dept. of Engineering Blichers Alle 20 Foulum DK-8830 Tjele Tel: +45 8715 6000 www.eng.au.dk	Research with focus on odour, ammonia and greenhouse gases from livestock production systems and on the development of sustainable technologies for processing livestock manure. We have focus on logistics and operational management. Main activities involves pretreatment technologies and production of biogas in a full scale digester.						•
	Westcome A/S Vegavej 8, Soften DK-8382 Hinnerup Tel: +45 8672 1422 www.westcome.com	The consultancy company works in the wastewater and agricultural branch, where wastewater cleaning, sludge handling and treatment, industrial wastewater conditioning and animal manure anaerobic digestion are the main fields of work.						•
	STRUKTURforsyningen ApS Granvej 5 DK-4652 Hårlev Tel: +45 2686 2000 www.strukturforsyningen.dk	Management consultancy in the utility sector including biofuel and biogas.						•

