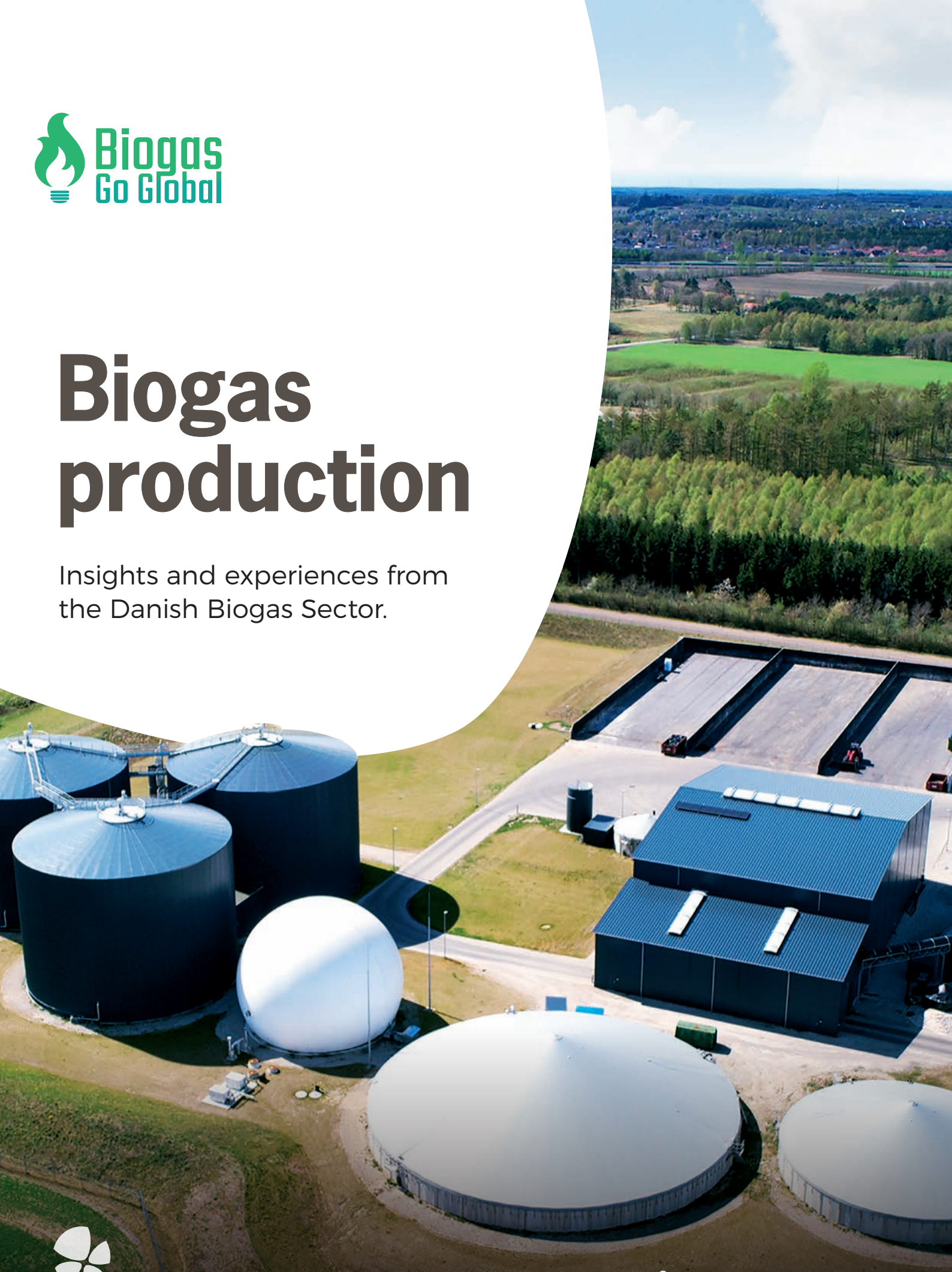
Biogas Go Global

Biogas production

Insights and experiences from the Danish Biogas Sector.



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Denmark is a world leader in biogas production.

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Denmark has a livestock density among the highest in the world.

1 Introduction

Denmark has a livestock density among the highest in the world. This, combined with being surrounded by vulnerable nature such as the Baltic Sea, has paved the way for a considerable effort in developing skills and innovative technologies for handling of livestock manure in an environmentally safe way.

The growing awareness of resource depletion and climate challenges has further clarified the huge potential for reducing greenhouse gas emissions from livestock production by utilising the energy content and fertilizer value of manure. A large number of Danish pig and dairy farmers are involved in livestock manure based biogas production, most of them via farmer cooperative owned industrial size biogas plants.

The use of slurry and muck as organic fertilizer is a much-debated issue. This is because organic fertilizer is an important source of nutrients, but can also adversely impact the environment if not handled correctly. To ensure the efficient use of the nutrients in organic fertilizer and thus a low impact on the environment, Danish companies have a constant focus on improving application techniques. Danish research institutions and universities have carried out numerous field trials to identify the best application strategies. This effort has completely changed the practice of slurry and muck application over the last 20 years. At the same time the EU and its member states have introduced regulations for the application of organic fertilizer to minimise the environmental impact with associated repercussions for application practices.

The biogas production in Denmark have increased rapidly since 2012, and it is expected that 30% of the gas in the gas grid will be renewable natural gas by 2023. More than 11 million tonnes of biomass are used to produce biogas and fertilizer on an annual basis.

This publication is for anybody with interest in innovative ways to handle the current challenge of reducing the environmental and climatic impacts of livestock farming and urban waste stream, while at the same time increasing the renewable biogas energy, and urban waste stream production and the demand for animal products for a growing population.

Denmark is a world-leading country in wind energy production and wind turbine production, but Denmark is also leading the way in biogas production.

PHOTO *Nature Energy*

2 Danish policy for the use of livestock manure

Firm government policies and legislation have promoted the development of advanced technological solutions for handling of livestock manure in Denmark.

Livestock manure has always been considered an important resource in Denmark. Agriculture plays a significant role in Denmark's economy and is characterised by large volumes of livestock production that for instance makes Denmark the world's number one exporter of pork. The quantity of livestock manure being produced in Denmark is about 35 million ton per year, equal to 6 tonnes for each of Denmark's 5.8 million inhabitants!

Environmental policies. Until beginning of the 80's livestock manure was just 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 1960'es and 1970'es. In 1985, however, the Danish Government launched the so-called NPO plan due to increasing problems with nutrient leaching and water quality. The NPO Plan set requirements to create harmony between the farmed area and the number of livestock, as well as to the minimum capacity for storage of livestock manure on farms. Still tighter regulations from both EU and the Danish government have since then triggered a technological development that has resulted in huge amounts of nitrogen (N) and phosphorus (P) in livestock manure today being utilised with almost the same efficiency as that of mineral fertilisers, alleviating the environment from N and P loads, and farmers from the costs of purchasing fertilisers.
Today, the environmental considerations go even further: It is not only a question of saving the environment from pollution, but also a question of resource efficiency and use of local resources like organic household waste, and in this instance the concerns for depleting phosphorus and fossil fuel reserves worldwide.

Climate policies. The recognition of global warming and its harmful effects, in Denmark as well as internationally, led to the introduction of policy measures to reduce its impacts. The United Nations' Kyoto Protocol committed Denmark to a CO_2 reduction since 2005.

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 fork, i.e. that every farm is part of the food supply chain. Food safety deals with contamination of food with microbes, plastic, chemicals and foreign bodies. For livestock farms, ensuring a high food quality is focused on dealing with the prevention of contamination of products such as milk contaminated with livestock manure. In Denmark, a Hygiene Business Code (National guidelines) was developed in cooperation between farmers' organisations and the veterinary and other authorities. Additionally, a number of private quality certification schemes have been established. The 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.

Market drivers for biogas in Denmark:

- Dedicated governmental support schemes
  - Investment support
  - Feed-in tariffs
- Restricted application of nitrogen and phosphorous on fields
- Ban on organic waste on landfill (1998)
- National target of minimum 50% recycling of household solid waste by 2023
- Fees for waste treatment => Co-digestion
- Follow-up programs on technical challenges
- Biogas allowed in the natural gas network
- Blending obligation for RE-transportation fuels (5,75–10%)

2.1
Danish support scheme for biogas

The Danish biogas technology has been developing for 30 years supported by different incentives and subsidy schemes. The former subsidy scheme, launched in 2012, has accelerated the development and increased the production of biogas and the amount of renewable natural gas in the natural gas grid.

Biogas production links energy production to the treatment of manure and organic waste. In Denmark manure and organic waste from industry, service-sector and households are usually co-digested in agricultural biogas plants.

When manure is used for biogas production, the emission of greenhouse gasses from handling and storage of manure is reduced. Biogas is a renewable gas that can replace fossil natural gas when upgraded. Additionally, the process produces high quality natural fertilizer as a by-product, replacing mineral fertilizers.
The production of biogas in Denmark is rapidly increasing; multiplying four times from 2012 to 2020, reaching a total annual production of around 20 PJ. Until recently, the majority of the produced biogas was used in electricity production. Today biogas is increasingly being

The production of biogas in Denmark is rapidly increasing.

Recent and expected biogas production and use in Denmark 2012-2020 (PJ).

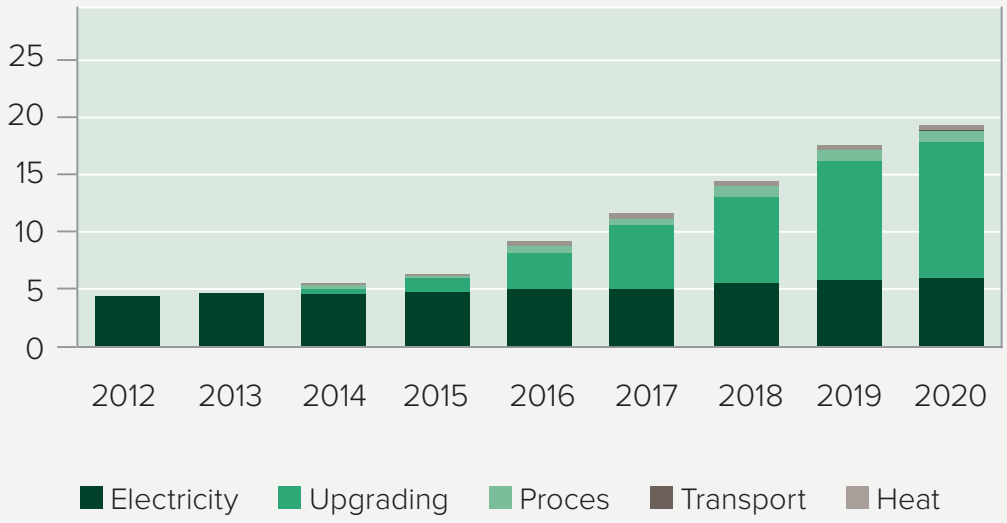


FIGURE 2.1
Recent and expected biogasproduction and use in Denmark.

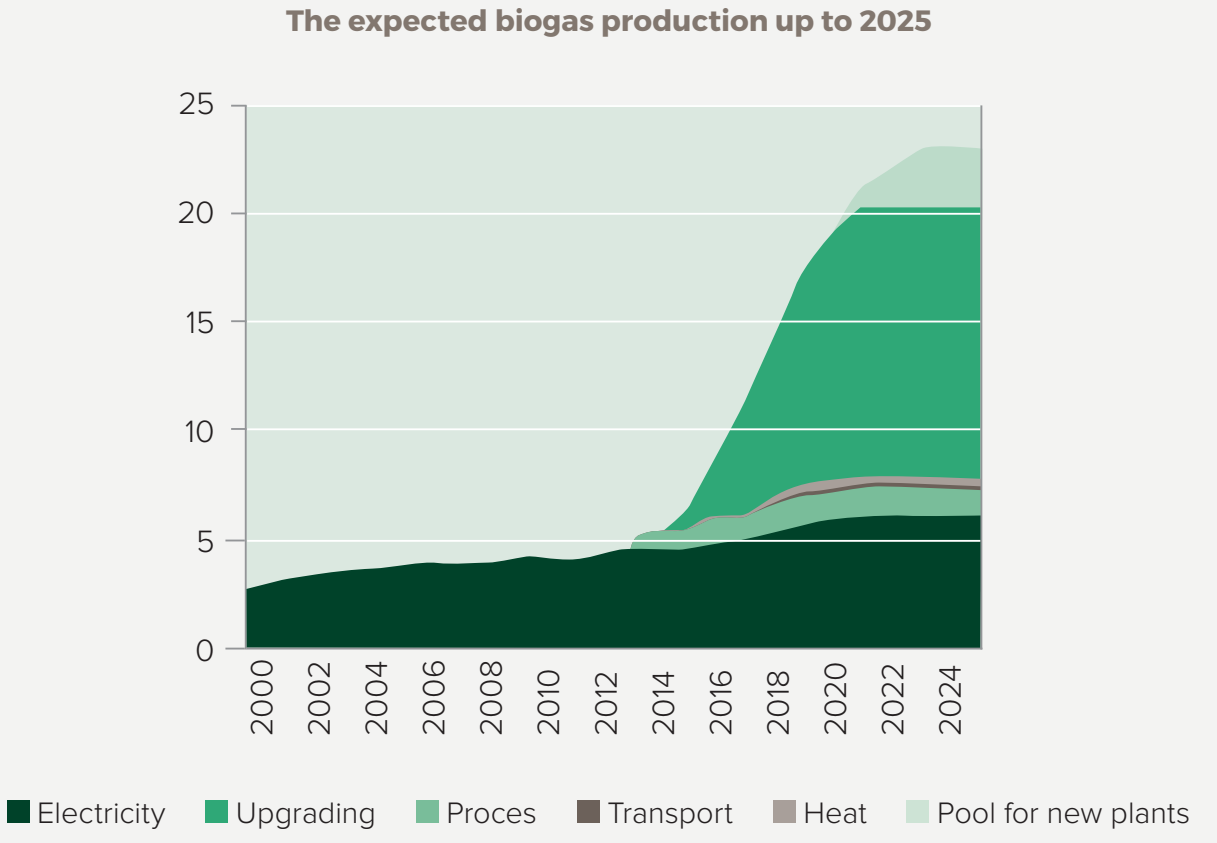


FIGURE 2.2
The expected biogas production up to 2025 calculated in PJ / year.

upgraded and injected into the natural gas grid, where it replaces fossil natural gas and is used for industry processes, transport, heat, and power. In 2018, approx. 8% of the Danish gas consumption was upgraded biogas – an EU record. It is expected that 30% of the gas in the natural gas grid will be renewable natural gas by 2030. Figure 2-1 shows the past and projected biogas production and its use in Denmark from 2012 to 2020.
In 2018, 32 biogas plants were producing 7.2 PJ (or 1993 GWh biomethane) biomethane in Denmark.

Incentives for biogas production. The current development in Danish biogas production has been achieved through a set of incentives in the environmental-, agricultural- and energy regulation, including:

- Dedicated governmental support schemes
- Taxes on consumption of fossil fuels
- Restricted application of nitrogen and phosphorous on fields
- Ban on organic waste on landfill since 1998
- Fees for waste treatment
- Dialogue and joint efforts with key stakeholders through follow-up programs and a Biogas Taskforce
- Support of research, development and demonstration of new technologies
- Limit on the use of energy crops in biogas production

Governmental support schemes. The following uses of biogas receive support as stated in the table below:

- Production of electricity
- Upgraded biogas delivered to the natural gas grid or cleaned biogas delivered to a town gas grid
- Use of biogas for process purposes in the industry
- Use of biogas as a transport fuel
- Use of biogas for heating purposes

To be eligible for subsidies biogas production cannot exceed 5% energy crops in the input feedstocks. The subsidies are given to the user of the biogas for the different purposes. This includes users of biogas for Renewable Natural Gas (RNG) production. Previously an investment support scheme existed for biogas plants, but it was terminated in 2016.

The increase in biogas production in combination with very low natural gas prices have increased the costs of the subsidy scheme significantly. The increasing support expenditures have motivated a political decision in the energy agreement (from June 2018) to stop the subsidy scheme agreed in 2012 for new plants from 2020. Instead a new scheme for RNG, including bio-methane and other green gasses such as hydrogen and methanised gas, has to be formulated and implemented. This will help to ensure the continued expansion and improved efficiency of the technology in Denmark. A portion of the funding is specifically earmarked for organic biogas production.

The focus on renewable natural gas instead of direct production of electricity from biogas is because Denmark has a high share of renewable electricity in the energy system and is approaching a situation where backup renewable electricity from other sources than wind and solar power is required.

2.2 The Danish market model for trade of renewable natural gas

The market model for renewable natural gas can roughly be said to consist of the following three elements:

- Market: Trading of the energy in the conventional gas market.
- Grid: The physical transportation of the renewable natural gas in the gas grid.
- Green Value: Virtual trading of the "green" value of the renewable natural gas.

Trading and transportation of the biogas in the conventional gas market

In order to trade biogas in the conventional gas market, the biogas producer or owner of the biogas upgrade facility must enter into an agreement with a biogas seller – or decide to register as a biogas seller at The Danish Gas Transmission Operator, Energinet.

Furthermore, it is also required that the biogas seller either enters into an agreement with a so-called shipper or registers as one. This is because the shippers are responsible for transporting the biogas to the gas market and in the grid.

When the biogas is injected and nominated into the commercial flow of the gas market, it is no longer possible to differentiate between the conventional flow of fossil-based natural gas and the renewable natural gas. This means that as soon as the biogas enters the gas grid, thus the commercial flow of the gas market, it is considered natural gas and will be traded on the same terms as conventional natural gas, thus also priced accordingly.

Virtual trading

As mentioned, it is not possible to distinguish the biogas from the other gas when it is injected into the gas grid. In order to do so, various virtual trading schemes have been set up based on market requirements and demand.

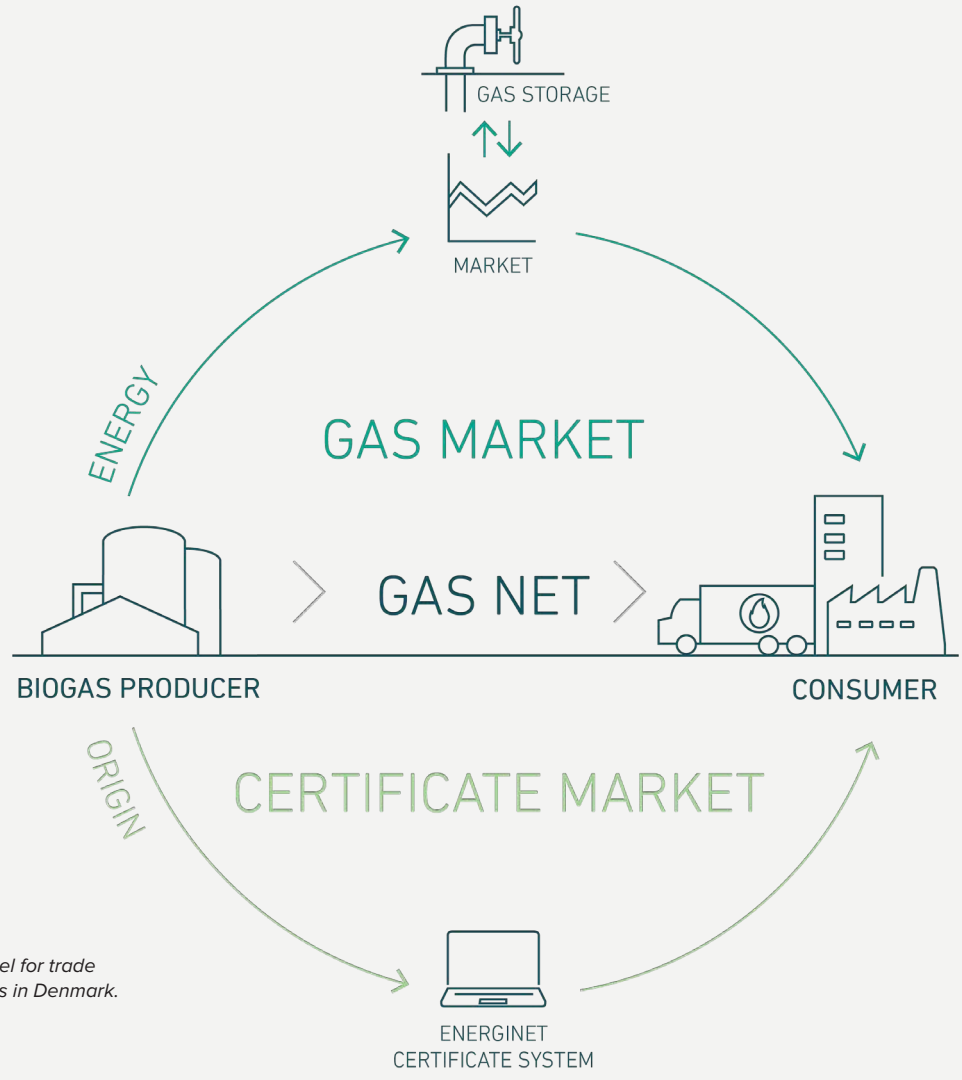


FIGURE 2.3
The market model for trade of renewable gas in Denmark.

Guarantees of Origin

In Denmark and some other European countries national Guarantees of Origin (GO) registries have voluntarily been established with the purpose of documenting the renewable attributes of the biogas supplied to the gas grid. Hence the GO scheme's function is to verify that the energy originates from renewable sources and the purchased quantity only is sold once preventing double counting.

GO are considered as a market-based instrument which can be used by private households or companies who voluntarily choose have part or all of their gas consumption covered by renewable sources. Voluntary purchases of GOs have mainly been done by companies in connection with their CSR-strategies, and to a lesser extent private households. Recently, municipalities have also started buying GOs in relation to the implementation of gas-driven busses for public transportation.

GOs are recognized under the EU emissions trading system (EU ETS). This means that companies covered by the EU ETS are allowed to disclose GOs as a means to offset CO_2 emissions in their EU ETS balance sheet.

In the EU, fuel suppliers are obligated to have a certain percentage of renewable fuel in their supply mix. Biotickets are only issued to fuel suppliers who over-deliver on their minimum share which in turn can be traded to fuel suppliers who under-deliver. It is assumed that large parts of the GO are utilized as part of the documentation subjected to this obligation.

The vast majority of EU countries have yet to establish a register for GO, and those who have, operate under different sets of rules and computer systems. As of now trades between two registries is only being done between Denmark and Germany.

In order to make cross-border transfers more transparent thus more trustworthy, all European registers have formed a pan-European association – European Renewable Gas Registry – with the objective to establish a facility with the ability to handle differences of rules as well as computer systems.

FIGURE 2.4
Organic biogas plant at the company Månsson.
PHOTO *Nature Energy*

Example: Guarantees of origin

A biogas producer upgrades the biogas to renewable natural gas quality at an upgrading facility. The upgrading facility owner is connected and delivers the renewable natural gas to the gas grid. The grid companies are responsible for the physical distribution and handling of the gas. The energy content in the renewable natural gas is traded on the gas market as conventional natural gas. The green value e.g. renewable properties and/or CO_2 reductions are traded virtually through various schemes such as guarantees of origin.

Guarantees of origin are issued to the biogas producer and traded between the Guarantees of origin Account Holders. When the end consumer purchases the guarantees of origin corresponding to the gas consumption, it is guaranteed that the consumer has made a purchase corresponding to the amount of renewable natural gas and thus the related CO_2 reduction.

It is not the biogas production itself, but the production of organic fertilizers.

2.3
Organic biogas plants

Organic farmers have a special interest in biogas plants. For them the main incentive is not the biogas production itself, but the production of organic fertilizers.

The Nature Energy Månsson plant is a large organic plant. The plant can produce up to 6 million cubic meters of of upgraded biogas (biomethane) annually. The gas is sent out to the nationwide natural gas network, which means that more than 3,600 households by now can be supplied with CO_2-neutral gas from production.

The plant mainly receives organic manure from cattle and chickens, but also conventional manure from pigs and fur. In addition, organic biomass is supplied in the form of waste from Axel Månsson's vegetable production as well as organic clover grass.

The ratio of organic to conventional biomass is closely matched, so that the residual product from gas production can be used as part of organic production in the form of natural fertilizers in agricultural cultivation

The plant consists of a number of disposal tanks, mixing tanks, and storage tanks. Trucks unload the biomass and subsequently load degassed fertilizer. All production takes place in closed systems. This means, among other things, that all tanks are closed and that loading and unloading takes place behind closed gates. The process hall and tanks have constant ventilation, which changes the air several times per hour. Before air is released to the outside, it is passed into filters that purify it by means of microorganisms and ensure that the odor is reduced as much as possible. The trucks are washed after each visit and the plant is enclosed by a wall of soil.

Nature Energy Månsson produces biogas from 150,000 tonnes of manure, organic clover grass and vegetable residues from Axel Månsson A/S.

Biogas and organic farming are very good partners. When slurry, green waste, organic clover grass and other organic waste products are treated in the biogas plant, the biomass is degassed. The remaining natural fertilizer gives higher yields in the fields, is easier to absorb for the plants and reduces, among other things leaching of nitrogen to the aquatic environment. It also has a high hygiene factor.

Organic fertilizers are a scarce resource in Denmark, and this can be a challenge when the demand for organic products is rising, but in the realm of biogas, organic farmers can become self-sufficient.

3 Biogas plant design

The Danish biogas sector has specialised in the design of biogas plants and 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 biomass pre-treatment solutions, the digester tanks, the mixers for the digester tanks and the upgrading equipment.

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 processes, and 15-20 cm for mesophile production. A stable temperature is crucial for the operation of the biogas production.

Thermophilic or mesophilic

- Thermophilic anaerobic digestion is the most widely used technology in Denmark
- With short retention times (<20 days) the thermophilic biogas yield from slowly degradable biomass like cattle manure is around 30% higher than from mesophilic.
- Thermophilic AD can be problematic with high ammonia content (>3 g NH_4-N/L) in the biomass

Temperature ranges

- Psychrophilic (10°C - 25°C)
- Mesophilic (25°C - 45°C)
- Thermophilic (50°C - 60°C)

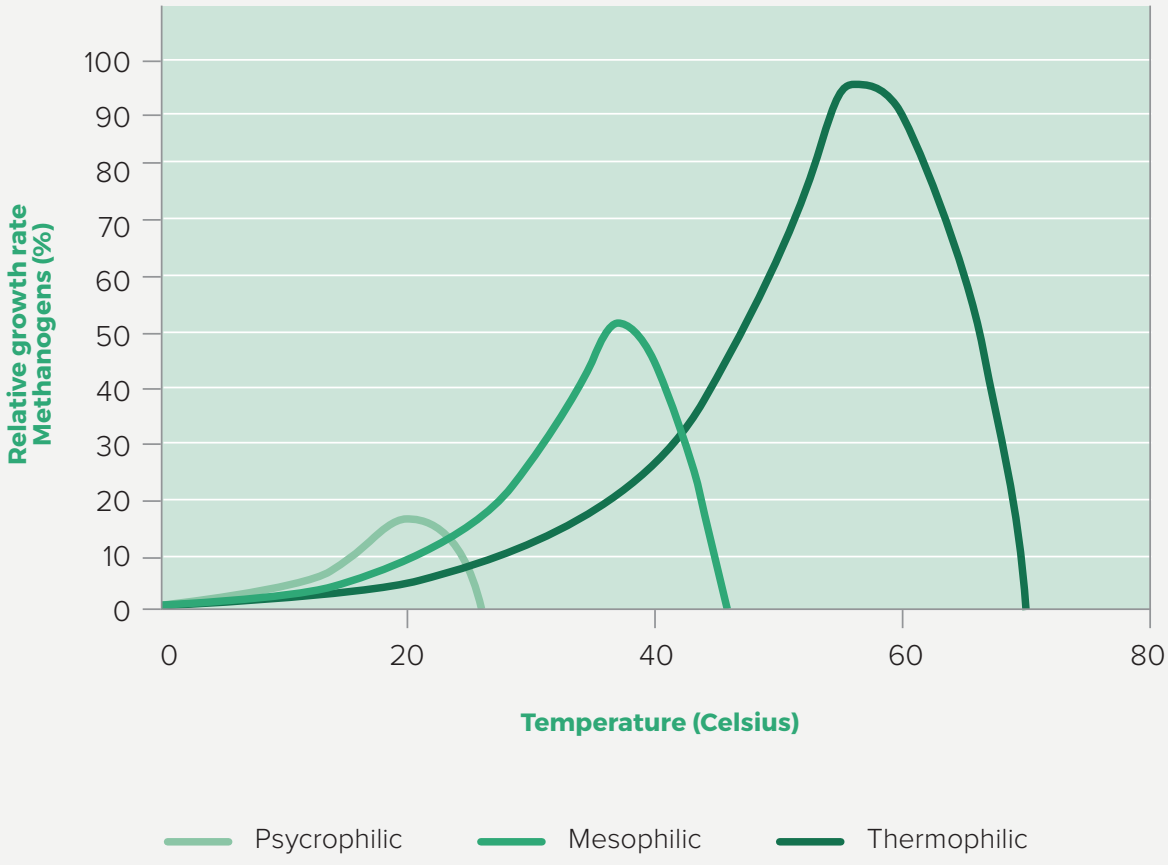


FIGURE 3.1
Conversion rates in biogas plants.

PHOTO *Nature Energy*

	Mesophilic	Thermophilic
Gas production	Less sensitive to high ammonia level and other inhibitors	Faster process and higher gas yield at a certain retention time. Sensitive to high ammonia level.
Digestate	Moderate pathogen inactivation	High degree of pathogen inactivation.
Energy input	Moderate	High unless heat exchanger is included – relevant if heat has a high value.

FIGURE 3.2
Nature Energy Korskro plant.

Flexible pre-treatment solutions offer the owner the opportunity to take in different types of biomasses, while also improving the economy of the plant by being paid to take in a variety of waste types. Heat exchangers are profitable at biogas plants with a high alternative value of the heat, and this is especially the case for the thermophile plants.

In many cases it is decided to build two serially connected digester tanks, a primary and a secondary digester, in order to produce and capture an extra 10-15% of biogas.

Mixing of the content in the digester tanks is important for giving the methane producing microbes the best conditions and to make it possible for the biogas to be released from the digestate. Mixing is often done with submerged propeller mixers. The largest share of the electricity consumption at a biogas plant is used for stirring and heating the digester tanks. Consequently, energy efficient stirring is one of the main criteria of success for profitable biogas production. Mixing of digester tanks with manure-based biomass is done with minimum energy use when the tanks are cylindrically formed, with a height that is larger than the diameter of the tanks.

Proper design ensure efficient production.

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

4 Biogas production in Denmark

Most of the biogas production in Denmark is based on large centralized continuous stirred tank reactor (CSTR) plants with co-digestion and own upgrading facilities with direct injection of the renewable natural gas into the natural gas grid.

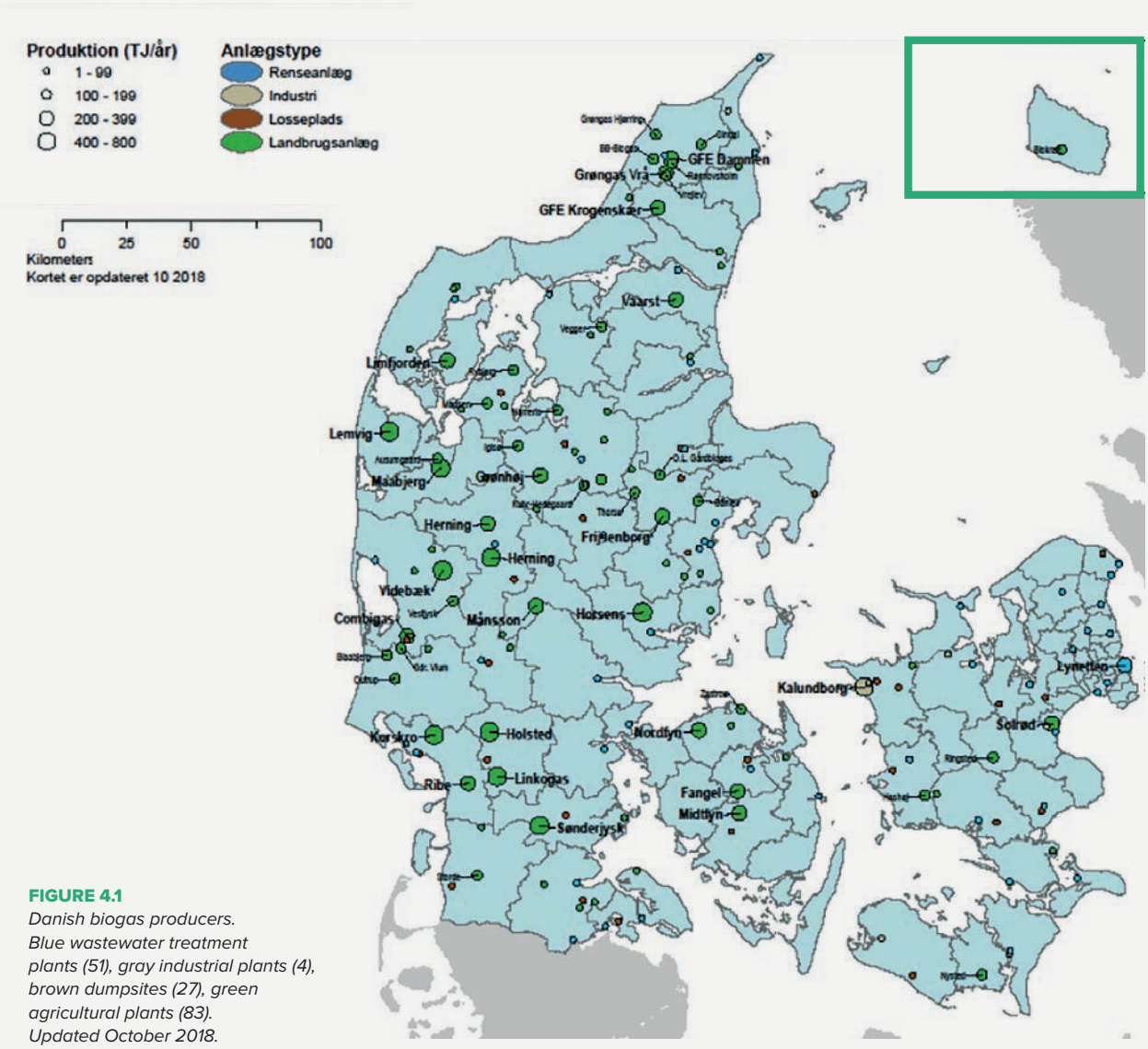


FIGURE 4.1
Danish biogas producers. Blue wastewater treatment plants (51), gray industrial plants (4), brown dumpsites (27), green agricultural plants (83). Updated October 2018.

Planning is all crucial to success.

PHOTO *Grøn Gas.*

4.1
Planning for biogas production

Planning a biogas plant and organizing stakeholders.

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.

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. The involvement of a professional consulting company is therefore crucial for the success of the biogas plant. Consulting companies can be involved in different ways. Some of the most important services they can assist with are feasibility studies, applications for environmental approvals from authorities, preparation of tender material, supervision of building/installation, and commissioning of the plant.

Many stakeholders are involved in the planning process, and in order to optimize the process it is a good idea to describe the stakeholders involved and their roles in the process.

Below is a list of stakeholders who are usually involved:

- The initiator of the project or the investor (farmer, utility, municipality)
- Financial partner(s)
- Suppliers of biomass (farmers, industries, etc.)
- Recipients of digestate (farmers, municipalities etc.)
- Buyers of the biogas (CHP plants, gas companies, industry etc.)
- Local municipal authorities
- Local stakeholders (neighbours, politicians, NGO's, local associations, etc.)
- Suppliers of technology and advisors
- Contractors

It is a good idea to visualize the organization and the activities within it, providing a general overview of people involved both within and outside of the process. The structural organization must clearly indicate who is in charge of each activity and who is involved. The following list includes some of the main activities within the planning process:

- Financing of the biogas plant
- Dialogue and approval process with the authorities
- Designing the biogas plant (site, buildings and technology)
- Dialogue and contracts with suppliers of biomass
- Dialogue and contracts with receivers of digestate
- Dialogue and contracts with buyers of the biogas
- Dialogue with local stakeholders
- Building process
- Permissions from authorities

It is recommended to have working groups for each activity as well as an overall steering committee coordinating the main aspects of the process and keeping a time schedule for making important decisions. In Denmark it is strongly recommended to involve local stakeholders in the group. Many of these activities are dependent on other activities. This makes it important to have a strong focus on coordination of the activities in order to optimize the process. The approval process is long and time consuming and it is necessary to have the right information available at the right time.

4.2
Business plan and communication

The project management of the planned biogas plant has a natural focus on its technical aspects, resulting in technical descriptions and drawings addressing the suppliers and the contractors. To supplement this, it is a good idea to have materials addressing the other stakeholders.

A stakeholder analysis may reveal the need for different information provided for the different groups of stakeholders. Financial partners have an interest in the business case and calculations behind it. Suppliers of biomass and receivers of digestate have an interest in economy, logistics and the quality of the digestate. etc. The authorities have an interest in the benefits concerning the climate and renewable energy, as well as an interest in the consequences for the local community and the environment in general. The local politicians, neighbours and stakeholders have an interest in the local perspectives on possible outcomes and consequences; this material could include information on jobs, locally produced energy, cheaper energy prices, consequences for traffic and smell, and visual effects in the local area.

The following list represents different information that can benefit the communication within the project and about the project:

- A business plan addressing investors and financial partners.
- An informal publication outlining the biogas plant and addressing investors, financial partners, local politicians, neighbours, local stakeholders (e.g. reference plants).
- Professional information concerning the biogas plant describing input, output, choice of technology, economy etc. addressing the suppliers of biomass and the receivers of digestate.
- Professional information describing the technology, production and gas quantity of the biogas plant addressed to buyers of the biogas.
- Approval material according to legislation procedures addressing the authorities.
- Technical descriptions and drawings addressing the contractors and suppliers of technology.

The prepared information could all include descriptions, drawings, visualizations etc. which can be used for all of the different publications addressing different stakeholders.

The aim is to tailor specific information to match the needs of each individual type of stakeholder; this provides each with the most relevant information possible and gives a good overview. This transparency proves that the organisation cares about all aspects of the biogas plant.

4.3
Available biomass

The potential biogas yield per m^3 slurry from pigs and cattle is limited why it makes good economic sense to suggest co-digestion with biomasses with a higher energy content.

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 the entire mixture of substrates; and
- Management of the plant.

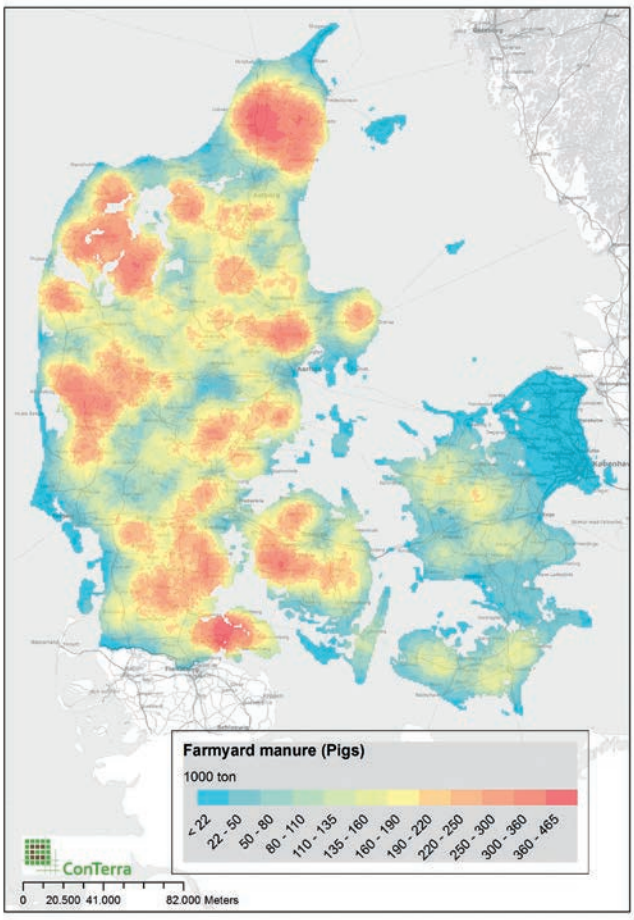


FIGURE 4.2
Distribution of manure from pig production I Denmark.
PHOTO *Conterra.*

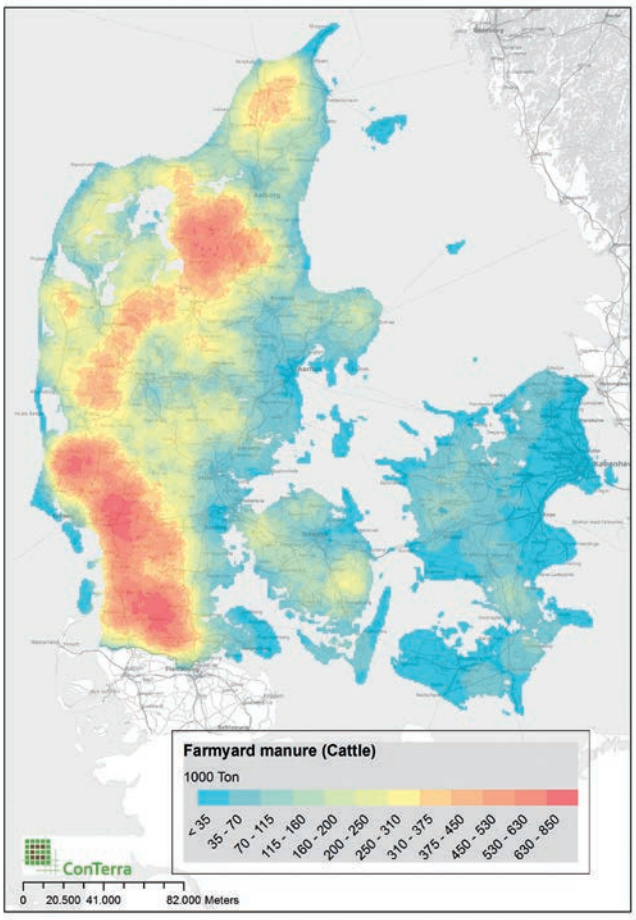


FIGURE 4.3
Distribution of manure from cattle production in Denmark.
PHOTO *Conterra.*

The animal production in Denmark is concentrated mainly in the western part of Denmark.

Among advantages of co-digestion of slurry and organic industrial wastes:

- Enhanced gas production. Higher biogas yield per m^3 feedstock when organic waste rich in energy is digested with slurry.
- Stable digestion process. Co-digestion with slurry makes digestion of waste stable.
- Advantage of scale. Centralized plants receive wastes from many different industries which is more manageable than many individual digesters. This also enables new revenue from the received waste streams.
- Nutrients utilization and recycling. The farmers take responsibility for the end-use of the product as fertilizer. A cheap and environmentally sustainable waste recycling system.

4.3.1 Manure

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

Livestock manure is organic material consisting primarily of a more or less homogenous mix of faeces and urine from livestock, includ-

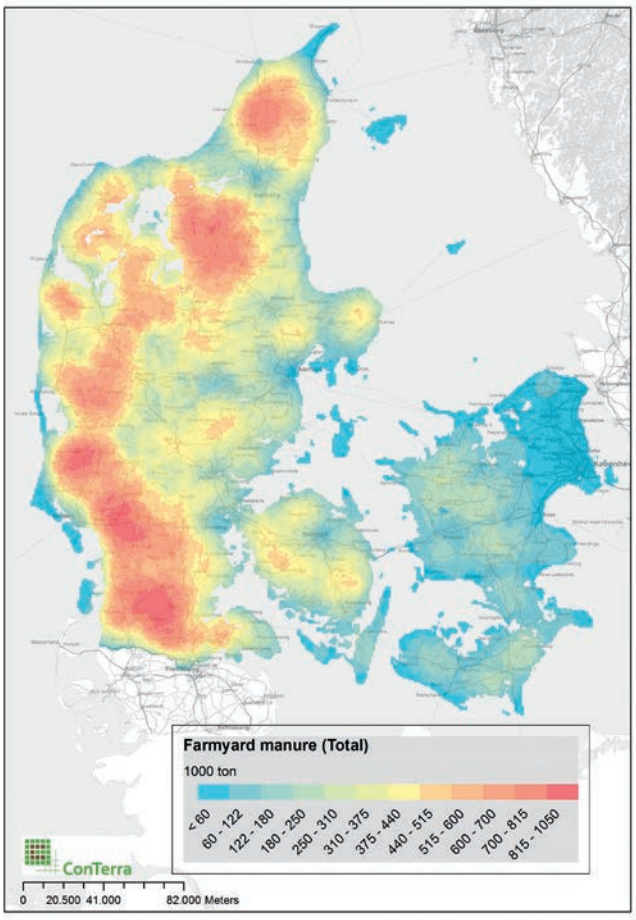


FIGURE 4.4
Distribution of the total manure production in Denmark.
PHOTO *Conterra.*

ing 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. Danish legislation demands livestock farms to have a capacity to store slurry for a minimum of 9 months, calculated according to official default values for manure production. Safe and ample storage of livestock manure is a pre-condition for good manure management – it preserves the manure quality, and for slurry it enables the use as crop fertiliser in the springtime when the plants need the nutrients.

Energy production from livestock manure. Already today about 20% of the Danish livestock manure is already utilised for energy production. This figure shows that Denmark is one of the leading countries in the world in this area, but also that there is a vast, yet unutilized potential.

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

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

In connection with biogas production it is common practice to calculate with Volatile Solids (VS). As a rule of thumb, and unless specific analyses exist, the VS content of livestock manure can be considered to be 75% of the dry matter (DM) content.

Manure handling

This section is an introduction to the most common terms and practises used concerning organic fertilizer. The guide gives inspiration for how slurry, deep litter and degassed biomass can be used to give the highest nutrient use efficiency and lowest environmental impact. Better manure management has made it possible to reduce the consumption of N in mineral fertilizer by about 50% over the last 25 years in Denmark. The key to this reduction is safe storage and correct timing of the application of it to the crops as part of a fertilizer plan based on fertilizer norms, as well as using innovative technologies for air cleaning and field spreading. This saves Danish farmers for a lot of expenses.

Madsens biogas with bioreactors, upgrading and storage facilities for biomass.

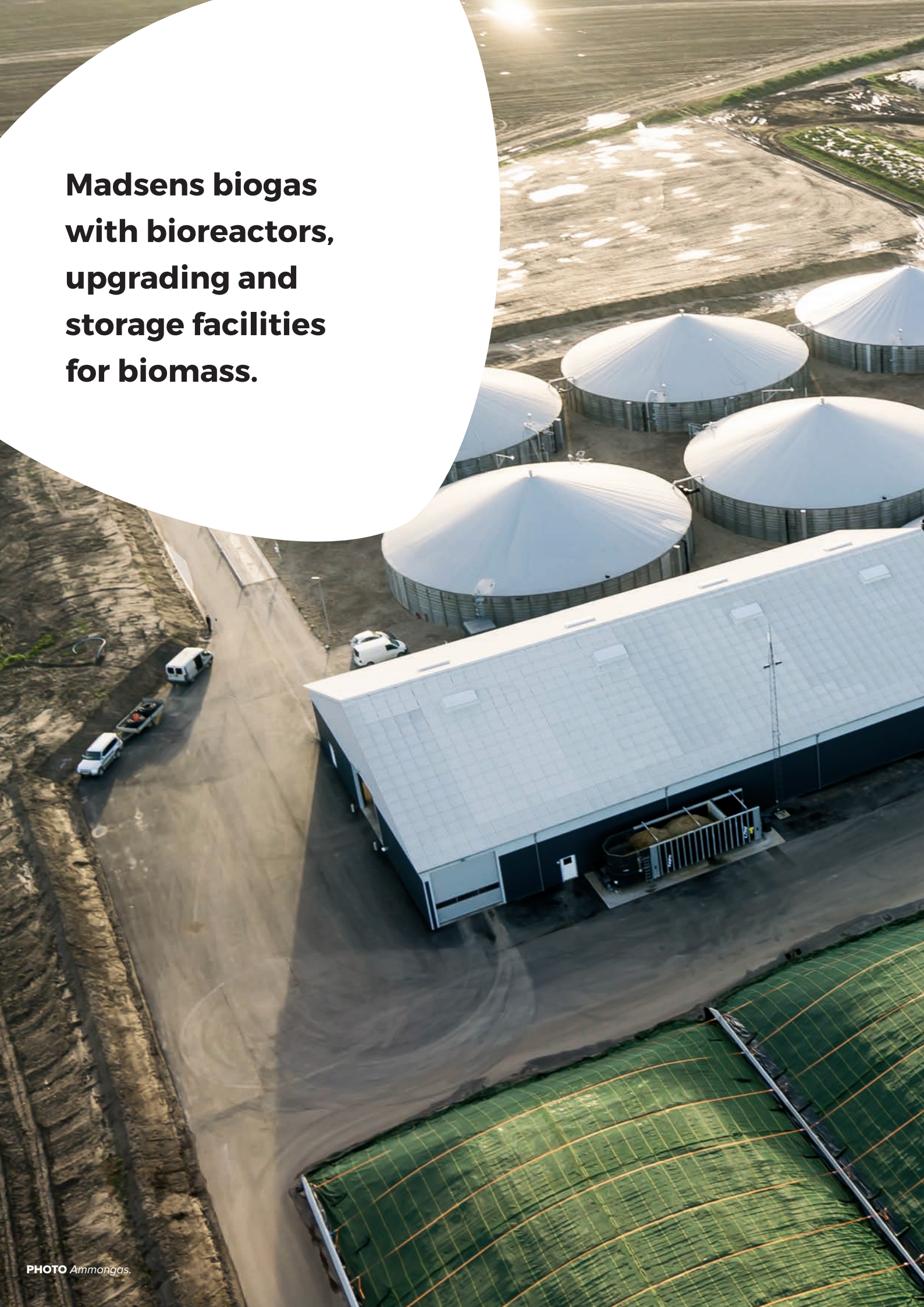


PHOTO *Ammongas.*

Whether the livestock manure is used for energy production or not, the goal always is that the manure is produced with as high quality as possible in the given production system, and that the good quality is preserved by the way it is handled.

High quality of manure generally means as high concentration as possible. This is especially true when manure is used for energy production in the form of biogas, which is based on the organic matter content.

The organic matter in the 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, the livestock manure type and quality that is produced in a given livestock production unit, is to a large extent determined by the building design and the technologies used for handling the manure.

In Denmark, there is an interest in use of technologies that can preserve the good manure quality from excretion and until it reaches the storage. This is mainly about preventing ammonia evaporation, whereby upwards of half of the nitrogen in the manure could be lost with the ventilation air, representing a big economic loss for the farmer. Ammonia pollutes the air and environment and thus endanger human and animal health. Another important aspect is avoiding water dilution of the manure from excess use of water for cleaning and water wastage.

Manure storage

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

Round tanks made of prefabricated concrete elements are conventionally used for slurry storage in Denmark. 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 neighbour residences, 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.

4.3.2 Residues

Residues from food production and biomass processing can be important substrates for biogas production. Virtually all organic residues in Denmark are collected and used, if not for other purposes, for biogas production.

4.3.3 Household waste

Denmark has a resource strategy with a target of 50% recycling of household waste. To achieve this, most Danish municipalities are required to source separate organic waste from households and collect it in a separate fraction, which can subsequently be recycled.

In order to use the source-separated household waste, it has been necessary to develop technology to process the biomass into a pulp that can be used in biogas plants. One of these technologies is the ECOGI plant from the company Gemidan.

The processed feedstock produces an pure substrate for conversion to biogas by local AD plants. Process flexibility and substrate purity were key performance objectives in the development of ECOGI. The pre-treatment technology was independently performance tested and has proven to be very effective in processing highly contaminated feedstocks which include plastic, glass and metals. Substrate purity has been independently verified at 99.96% free from non-organic physical contamination. By preventing plastic pollution of farmland and helping to conserve water this technology state-of-the-art in an environmentally friendly circular economy.

The biopulp produced is used to generate energy (biogas) and digestate, a nutrient rich fertilizer for use on farmland. To make the process more sustainable water is reused at each stage of the process. Rainwater is collected to reduce the amount of fresh water needed for processing food waste by 25,000 cubic meters of each year. For food waste this completes the Circular Economy.

FIGURE 4.7
The facility supports the circular economy by processing all types (domestic, commercial and industrial) of source separated organic waste – food waste. This robust, efficient and reliable process ensures the removal of non-organic impurities like plastic bags, metal cans, plastic bottles and other packaging from the food waste to create a very pure biopulp. **PHOTO** *Gemidan.*

FIGURE 4.6
The ECOGI centralised food waste pre-treatment facility in Frederikshavn, Denmark. The facility is owned and operated by the Gemidan waste management group. The facility has a processing capacity of over 50,000 tonnes. Feedstocks include source separated food waste from households, industry and businesses in the area. **PHOTO** *Gemidan.*

Food waste is considered a key ressource for biogas and fertilizer production in Denmark.

FIGURE 4.8
The pre-treatment facility in Frederikshavn, Denmark. **PHOTO** *Gemidan.*

FIGURE 4.9
Finished biopulp ready for the digester.

PHOTO *Food & Bio Cluster Denmark.*

4.4
Wastewater treatment plants

Wastewater treatment plants (WWT plants) are in the midst of a paradigm shift, where resource utilization and resource efficiency have become as important parameters as environmental protection. The treatment of wastewater is energy intensive. Meanwhile, the wastewater itself contains large amounts of energy and nutrients which can be utilized better than ever before due to the development of recent years.

Several wastewater treatment plants have shown that they can become net energy producers. This means that these plants produce more energy than they consume. They focus on utilizing the maximum possible organic carbon (COD) for biogas/electricity/heat production while at the same time reducing energy consumption by optimizing operations.

A number of Danish wastewater treatment plants have anaerobic treatment (biogas production) of their sludge production, partly from primary sludge and partly from biological surplus sludge.

A major difference between the biogas production at the WWT plants and the agricultural-based biogas plants is that the decayed biomass at the former is mechanically dewatered at the plants. This considerably increases the dry matter content of the biomass to be handled afterwards and reduces the cost of transport. The dewatering of the degassed sludge contributes to the internal load of WWT plants.

4.5
Energy content

In planning a new biogas plant and in connection with the ongoing operation, it is necessary to have thorough knowledge of the biogas potential of the available biomasses. The most widely used biomasses such as manure and sewage sludge have a limited energy content, so it may be necessary to supplement the feedstock to the biogas plant with biomasses with a significantly higher energy content in order to achieve a profitable operation.

In addition, the composition of the biomass for feeding must ensure that all the necessary nutrients are present in sufficient quantities.

Inhibitory concentrations of various substances in the bioreactor, such as ammonia, must also be prevented. Typical biogas potentials in different biomasses are given in the fact box below.

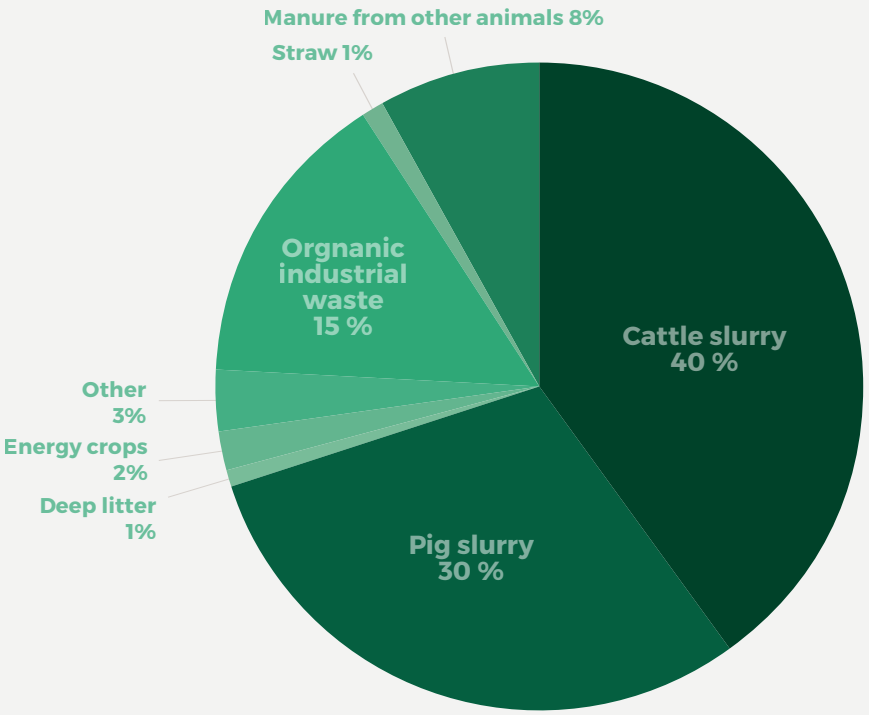


FIGURE 4.10
The expected biogas production up to Average mix of feedstocks in agricultural biogas plants 2025

Organic material	Process	Yield, ml biogas/g	ml CH_4/g	CH_4 %
Cellulosis	$(C_6H_{10}O_5)n + n\ H_2O$ -- $3nCH_4 + 3nCO_2$	830	415	50,0
Protein	$2C_5H_7NO_2 + 8H_2O$ -- $5CH_4 + 3CO_2 + 2(NH_4)(HCO_3)$	793	504	63,6
Fat	$C_{57}H_{104}O_6 + 28H_2O$ -- $40CH_4 + 17CO_2$	1444	1014	70,2

4.6
Mass balance

The nutrient content of digestate from biogas plants depends entirely on the biomass that is fed into the plant. A calculation of the nutrient mass balance is always made in connection with the planning of a biogas production.

Co-digestion is important because:
- It must be ensured that there is enough available biomass
- Nutrient composition is ensured
- Biogas potential is optimized
- The biogas process is stabilized
- Nutrients are recycled and reused

Logistics. Transport of livestock manure and digestate forth and back between livestock farms and the biogas plant is an important activity at industrial size biogas plants. It is important that the trucks in use have a high capacity in order to minimize the transport, and that they are easy to clean between every transport in order to reduce traffic and noise nuisances and risk of disease spreading. Finally, they cannot spill during transport or in connection to loading and unloading.

4.7
Organization

Agricultural biogas plants are organised as farm-scale or industrial scale biogas production. Industrial scale biogas plants are characterised by being large; averagely treating more than 100,000 tonnes livestock manure and other substrates in Denmark per year. They are often organised as farmer-owned cooperatives, or in some cases, by other stakeholders such as energy companies. Such plants usually treat the manure from 40-100 farms, and sometimes more, and have several employees operating the plant. The main 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 the farmers, who have their manure treated, that they do not need to bind own capital in the plants apart from a deposit, and that the plants also function as regional centres for re-distribution of the anaerobic digested manure, the digestate.

Farm scale biogas plants are characterised by only receiving manure from few livestock farm and being a legal and economic part of a farm. Farm-scale biogas plants are especially attractive for large livestock farms, who, due to their size, can utilise some economy of scale, and who with the plant can promise neighbours less nuisances from the production than without it.

Advantages of farm-scale biogas plants are that:
- The decision process is easier and quicker, also about establishing of the plant
- The farm can produce its own heat, which particularly is an advantage for pig farms
- Transportation is minimized

4.8
Case Månsson - A green and organic biogas partnership

Nature Energy, one of the world's largest biogas manufacturers, joined forces with the major organic farmer Axel Månsson in 2017. Together, they are transforming waste into green gas. The biogas plant will be expanded and will be ready to produce enough biogas to heat around 12,000 houses with green and CO_2-neutral gas.

In Denmark, biogas is considered a crucial element in the transition towards a more sustainable society. In reports by both the Danish Council on Climate Change and the Danish Climate Partnerships, biogas is highlighted as a key driver in Denmark's green transition. The partnerships represent the Danish business community, while the Council is an independent organ of experts. The recommendations from both organs are considered vital for Denmark's future climate politics.

Together with wind and solar energy, biogas is the third fundamental element in achieving the goal of a greener future. With this in mind, Nature Energy and Axel Månsson established a fully organic biogas plant together in 2017.

In 2019, the two companies decided to expand the plant as more farmers showed interest in becoming suppliers and contributing to the biogas production. In addition to the expansion, a separate conventional line has been added in order to increase the treatment of conventional manure and food waste in the area by 170,000 tons, thus producing more green gas and creating new green jobs locally.

A total of 38 farmers are supplying manure to the plant. The total production will be 17 million Nm^3 of methane when the expansion is fully operational. This corresponds to the energy supply of approx. 12,000 households with CO_2-neutral biogas.
In order to avoid mixing organic and conventional bio-fertiliser, the organic line and the conventional line is operating separately.

FIGURE 4.11
Månsson biogas plant. **PHOTO** *Nature Energy.*

Biogas is a great example of circular economy

The organic biogas plant is mainly treating organic materials such as manure from dairy farmers, manure from egg layers, clover, and vegetable waste from Axel Månsson's production among others.

After the expansion, the plant will be treating 255,000 tons of biomass annually which is transformed into green gas, and subsequently bio-fertilizer is offered to the organic farmers.

Nature Energy is analysing the nutrients in order to assist the farmers in planning their fertilizing of the fields and to ensure that they comply with both the nitrogen and phosphorous regulations.
In addition, the biogas plant is re-distributing nutrients in order to optimise the use of the bio-fertilizer and reduce the need for buying either organic fertilizer or mineral fertilizer.

The slurry is picked up by Nature Energy's own trucks within an average distance of 15-20 km. When the truck has picked up the slurry at a given farm, the company delivers liquid digestate at the same time. In this way, biogas is great example of circular economy.

About Axel Månsson

- Axel Månsson has been producing vegetables and eggs for more than 40 years and is one of Denmark's largest vegetable producers farming 1,100 hectares.
- Half of the production is organic. Furthermore, the company produces 45 million organic eggs from 140,000 hens annually.

About Nature Energy

- Nature Energy is one of the world's largest producers of biogas, which, among other things, converts manure and society's waste products into bio-fertiliser and green and climate-friendly gas. This means reducing climate-damaging gases from agriculture while also reducing the need for fossil natural gas.
- From 2021 Nature Energy will convert over 4,700,000 tonnes of manure and other biomasses annually into valuable bio-fertilizer, and at the same time produce around 170 million Nm^3 of methane yearly. This is enough to heat to cover 120,000 households with CO_2-neutral energy. Nature Energy currently has 10 plants in Denmark and are operating two plants abroad.

FIGURE 4.12
Biogas upgrading plant installed at Nature Energy's facility Månsson. A biogas plant which is fed with organic material from the local agriculture. **PHOTO** *Nature Energy.*

5 The use of biogas

Biogas has been produced and used in Denmark for years. Traditionally, biogas has been used for electricity and heat production in Combined Heat and Power plants (CHP) and the majority of older plants are equipped with CHP.

In connection with a support scheme implemented in 2012, it became possible to upgrade biogas to biomethane and inject it into the national gas network. Consequently, most of the biogas produced in Denmark is upgraded to biomethane and sold via the gas network. The gas distribution system is widely branched and can be accessed almost anywhere in the country.

In 2019, the Danish parliament agreed on an ambitious climate target of 70% CO_2 reduction by 2030 compared to the level in 1990. This will require massive investments in energy savings and electrification. With the green transition, energy production is getting more and more out of step with consumption. The need for electricity does not always coincidence with times of high electricity production from wind and solar, and the opposite is occasionally the case where electricity generation is significantly higher than consumption.

Denmark is very much in need of an ability to absorb surplus electricity, but also of having a considerable reserve capacity for situations when energy consumption is high, but solar and wind do not provide it.

The existing gas grid is by far the largest Danish energy storage facility. The gas grid can store an energy amount equal to one third of Denmark's annual electricity consumption. The many district heating systems in Denmark can also absorb electricity but, unlike the gas grid, cannot function as storage that can send power back to the electricity grid.

Biogas is a valuable product with many applications.

Biogas production can stabilize the electricity grid as production from wind and solar fluctuates.

Biogas in the gas grid helps take the top of the enormous pressure on the electricity grid that comes with a higher share of renewable energy, while at the same time reducing the cost for consumers. During the cold months, gas boilers can secure that the heat supply is at a reasonable price and relieve the electricity grid.

Biogas can be used for industry and transport. Biogas is needed in areas where electrification is not expected to be an option for many years to come. Heavy transport and heavy process industries to name a few.

Biogas plants and the gas network help reduce the climate impact of food production and can at the same time supply green energy for solutions where electricity and green electricity are not affected. The gas grid is Denmark's largest green energy storage facility, which can help stabilize the power grid and cause electricity generation to play at the same rate as consumption.

5.1 Biogas loss

In 2016, the Biogas Industry Association launched a voluntary measurement program for methane loss in collaboration with the Danish Energy Agency. The biogas industry's voluntary meta-loss measurement program documents that the loss from Danish biogas plants is approaching the target of 1%.

The background was the previous pilot projects that had shown that there was a potential loss, but that methods are now available to find leaks and quantify the loss, and not least that it is possible to minimize the loss of methane. This is beneficial to the operating economy and not least an important tool for optimizing the effect of biogas plants as climate change agents.

The voluntary measurement program consists of three key elements: 1. Self-monitoring program, 2. Leak detection and 3. Quantification of the methane loss.

The Danish authorities are continuing to work on the problem and a permanent mandatory scheme for monitoring methane emissions from biogas plants is expected.

5.2 Danish gas quality standards

The gas quality of biomethane must be the same as conventional natural gas and must at all times comply with the Danish gas regulation and the Quality Specifications.

Both the production and chemical composition of green gasses differ significantly from traditional natural gas. The supply of green gases to the natural gas network in Denmark still somewhat new and has until recently not been of a magnitude effecting the interoperability of the gas network. However, with an increasing injection the question arises how to define the right balance that ensures safe operation, but does not put up requirements so strict that they hinder injection of biomethane due to higher cleansing costs.

Furthermore, as gas is traded across borders differences of gas quality specification can become a challenge. In Europe gas quality specification is regulated at national level, though varies based on the country in question. In terms of injection of biomethane into the grid, this can have an effect on the competitive environment as biogas producers in countries with less strict gas quality specifications will have lower cleansing costs. Maybe more importantly, it can hinder the physical trading of gas between gas systems.

5.3 Upgrading

Biogas produced by anaerobic digestion is often used in gas turbines to produce electricity. In order to increase the value of the gas and to enable utilization of the gas in other applications, it can be advantageous to upgrade the biogas. In this way, the carbon dioxide as well as various impurities are removed and biomethane is produced. As mentioned, biomethane is similar to natural gas and can be used in similar applications, e.g. fed into the natural gas grid, or as vehicle fuel.

Currently, there are three options for using biogas in an efficient way:

- Conversion into energy in a combined heat and power plant (CHP plant)
- Feed into the natural gas grid
- Vehicle fuel

In all cases, the crude biogas must undergo a cleaning step before application. At the biogas plant the removal of hydrogen sulfide (H_2S) is performed to a certain extent. For biogas utilized in gas grids or for vehicle fuel, the gas must be cleaned and upgraded in a gas upgrading unit first. In this unit the gas is cleaned from carbon dioxide CO_2, H_2S, water vapor and ammonia.

Several different biogas upgrading techniques are on the market today. Some of them make use of the fact that carbon dioxide and methane have different solubility in different solvents. By choosing a solvent which has a high solubility for carbon dioxide, but lets methane pass through unchanged, the carbon dioxide can be separated from

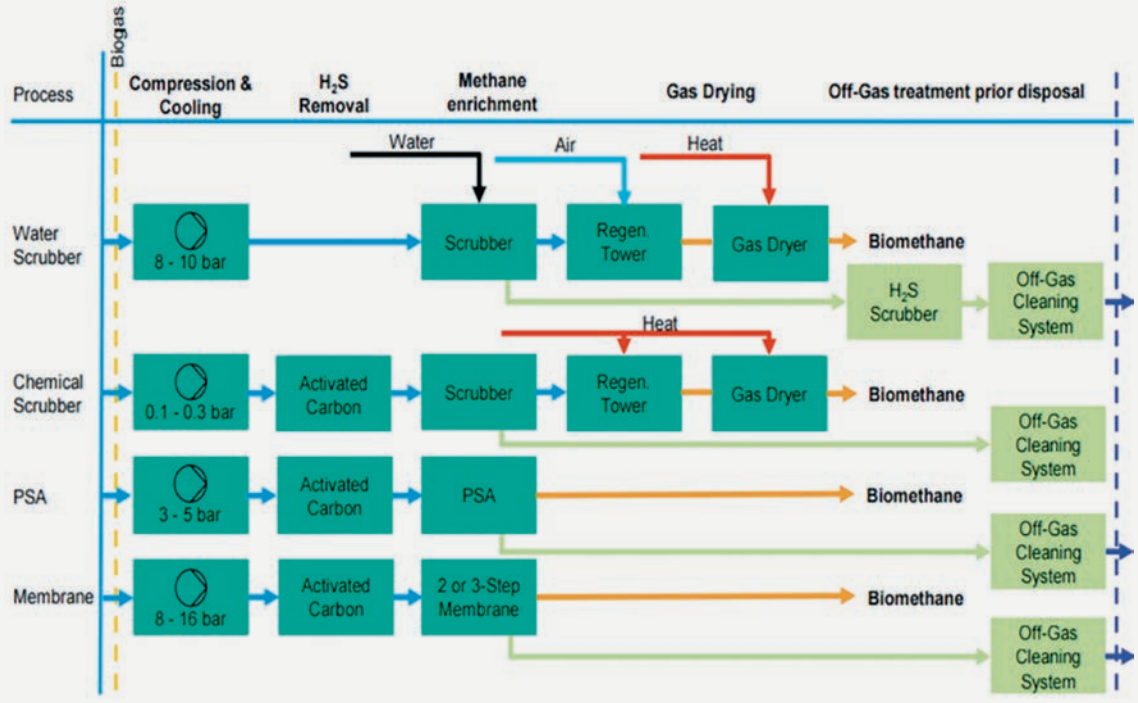


FIGURE 5.1
Different types of gas upgrading technologies (DGC = Danish Gas Technology Centre).

the methane in biogas efficiently. Common solvents used for biogas upgrading are water, amines as well as organic solvents such as Genosorb. The difference in adsorption behavior of carbon dioxide and methane on a surface at different pressures is used in pressure swing adsorption (PSA), which can be used to effectively separate carbon dioxide from methane. Another common biogas upgrading technique uses the fact that carbon dioxide is more likely to pass through a semi-permeable barrier, e.g. a membrane, than methane. By letting biogas pass through such a membrane, the carbon dioxide can thus be removed from the gas, leaving concentrated methane in the product stream. Finally, the difference in boiling point between methane and carbon dioxide can be used to separate the gases in cryogenic distillation.

Biogas produced from various substrates such as agricultural residues, biological waste or sewage sludge contains low concentrations of unwanted substances, e.g. impurities, such as H_2S, siloxanes, ammonia, oxygen and volatile organic carbons (VOC). H_2S is separated from the methane in most biogas upgrading techniques. How efficient this removal is and thus whether it is enough to meet product gas requirements differs between the different techniques. Scrubbers use absorption in water, amines or organic solvent usually remove most of the H_2S, while polishing filters are needed for membrane upgrading and PSA. When separated from the methane gas, H_2S, however, ends up in a CO_2 rich side stream such as stripper air, where it usually needs to be removed due to environmental legislation. (Source: Energiforsk 2016).

The basic concept of biogas upgrading is to concentrate the CH_4 in the raw biogas stream (~60%) by separating CO_2 (~40 %) and other minor gases (H_2S, H_2O, H_2, N_2, O_2 and VOC) from the inlet gas. This process can be carried out by applying different kinds of separation technologies which utilize the different chemical and physical behaviour of these gases. Accordingly, these technologies can also be grouped depending on which type of chemo-physical mechanisms they mainly utilize for the separation.

Upgraded biogas has high quality.

Available upgrading technologies:

1. Pressure swing absorption
2. Water scrupping
3. Amine scrupping
4. Organic physical scrupping
5. Membrane separation
6. Cryogenic upgrading

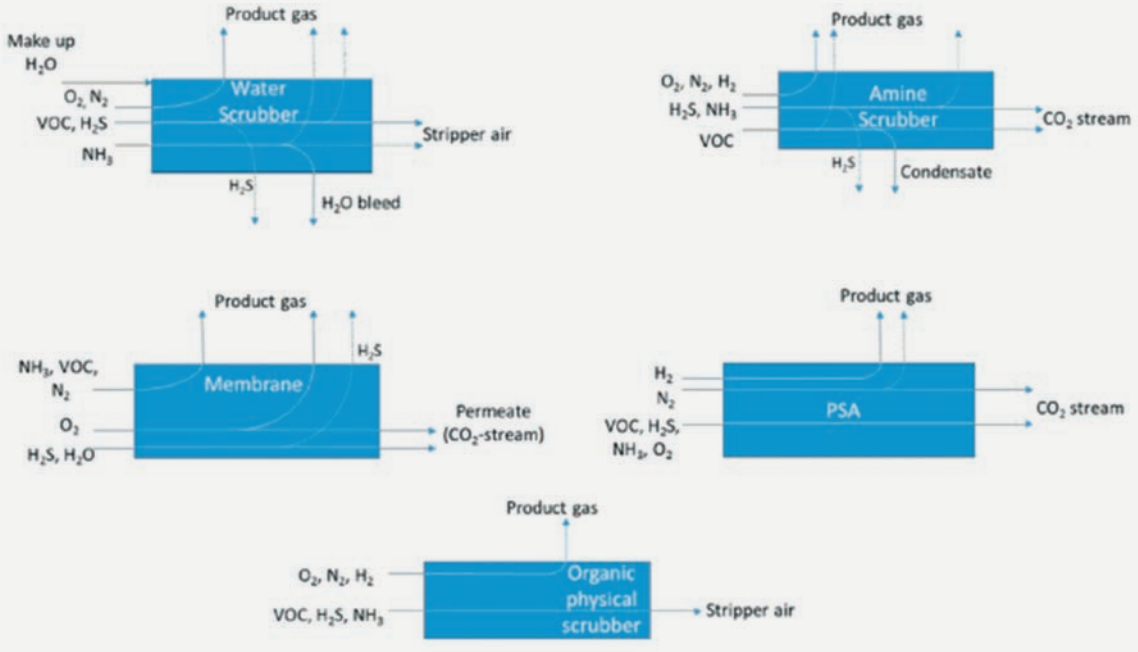


FIGURE 5.2
Path of impurities in biogas through different biogas upgrading processes. Eneriforsk 2016.

Biogas upgrading plants from the Danish company AMMONGAS is now producing 9 PJ biomethane/year (¾ of the total Danish production 2020). Reducing the emission of fossil CO_2 in Denmark by 500,000 tonnes/year.

The amine based Ammongas upgrading is remarkable by having a high efficiency in separating CO_2 from the biomethane, resulting in a very low methane slippage of just 0.04%. Further, because of the high CO_2 separation efficiency, the upgraded gas can be used for liquefaction.

The upgrading units are quite robust, as they can process raw biogas without any pre-treatment. The energy consumption is very low with an electricity consumption of less than 0.12 kWh/m^3 raw biogas and a net. heat demand of approx. 0.2 kWh/m^3 biogas (total figures for both the upgrading and the desulphurization process combined). The upgrading plants have a high availability, averaging on 98.5% including scheduled maintenance, and since there is no pre-treatment, there is no risk of fouling the gas with added oxygen and nitrogen.

The majority of the new biogas plants in Denmark use amine scrupping technologies for upgrading the biogas to natural gas grid quality.

FIGURE 5.3
Upgrading tower from the company Ammongas at Madsens bioenergy. Delivering upgraded biomethane to the Danish gas grid with an average availability of more than 99 %. The plant is powered by a combined straw and woodchips biomass boiler and in turn the recovered heat from the upgrading plant is used to power the entire biogas plant.

PHOTO *Ammongas.*

FIGURE 5.4
Biogascleaner QSR desulphurization plant at Nature Energy Maansson in Brande, Denmark. **PHOTO** *Biogasclean.*

FIGURE 5.5
Biogascleaner QSR desulphurization plant to NGF Nature Energy Korskro in Denmark. **PHOTO** *Biogasclean.*

5.3.1 Desulphurization

In most Danish upgrading projects the combination of Amine up-grading is used along with the Biogascleaner QSR desulphurization system from the Danish company Biogasclean A/S. The Biogas-cleaner QSR desulphurization system is installed downstream an Amine up-grading unit for cleaning the CO_2 flow. This combination of technologies has significant competitive advantages with lowest possible OPEX and the lowest possible methane loss, with reference to figures mentioned above. From January 2017 to January 2020 Biogasclean A/S has been chosen for 16 Danish upgrading projects producing biomethane to the gas grid. Besides those upgrading projects, the systems from Biogasclean A/S deliver clean gas to more than 580 MW gas engines worldwide.

The Biogascleaner QSR is installed downstream the Amine up-grading unit and reduces the concentrated H_2S in the CO_2 flow from approx. 7,500 ppm H_2S down to max. 50 ppm.

The Nature Energy Korskro plant produces approx. 22 million cubic meters biomethane to the public gas grid pr. year.

The Biogascleaner QSR is installed downstream the Amine up-grading unit and reduces the concentrated H_2S in the CO_2 flow from approx. 8,000 ppm H_2S down to max. 50 ppm.
The cleaned CO_2 is further treated and utilized in the food industry.

FIGURE 5.6
Storage tank installation for ironchloride.
PHOTO *Kemira.*

Control of sulfur is essential for the operation of biogas plants and gas quality.

5.4
Chemical precipitation of sulfur

A biogas plant is normally operated with a dry solid content (DS) of 3-15% in the wet substrate. The DS is in most cases degraded by about 50% and the outlet, the digestate from the digester, normally has a DS content of 2-7%. The organic load as DS is normally 2-5 kg DS per m^3 digester volume and per day.

Simultaneously with methane production, hydrogen sulfide is formed. Depending on the type of substrate, the hydrogen sulfide production varies. The biogas from manure plants can have hydrogen sulfide levels up to 2000-8000 ppm whereas biogas from household waste plants have typically 600-800 ppm. Iron salts are used to remove the toxic hydrogen sulfide and is dosed into the digester or into the substrate receiving tanks when needed. Depending on the substrate the iron need for the reduction of the hydrogen sulfide levels varies.

Depending on the type of substrate, additives like trace elements might be needed.

For energy crops, agricultural residuals and non-agricultural substrates, there is a need for trace element supplementation due to its low content in the substrates. If trace elements are not supplemented to the digester the microbiological process will be limited. The limitations in the process will cause problems to increase the organic load, to have a stable process and will also cause problems with high volatile fatty acids (VFA) levels in the digester/reactor. It will create huge problems to have a well-balanced microbiological process in the digester/reactor and cause a decreased of biogas yield due to a low degradation of the VFA and longer fatty acids. Those will not be degraded to a desirable extent to methane and carbon dioxide. But instead will be converted to methane gas in the treated digestate and will be released to the atmosphere, a so-called methane slip. The consequence will be a reduced overall outcome and profitability of the plant, but also an environmental issue since methane gas is a very potent greenhouse gas and hence shouldn't be released to the atmosphere. VFA levels should not exceed 1500 mg/l in the digester.

Depending on the energy content in the substrates, the biogas yield can vary a lot. Typically, manure from pig farming has a biogas yield of 200 m^3 methane per ton volatile solids (VS), whereas a substrate from food and restaurants disposal has a gas yield of 660 m^3 methane per ton VS.

FIGURE 5.7
Storagetank installation as a container solution. **PHOTO** *Kemira.*

5.4.1
Iron as macro-nutrient

Iron is the key component in anaerobic digestion involved in all bacterial processes.

For biogas generation, different products are used for reducing the hydrogen sulfide concentration. The reduction of hydrogen sulfide also protects the plant equipment, the gas handling system and gas upgrading systems from corrosion. If the upgraded biomethane is targeted for use as vehicle fuel, in public gas grids or as a general energy source, the hydrogen sulfide levels need to be reduced, in general, below 100 ppm in the gas phase.

Iron containing products are mainly used for the control of hydrogen sulfide in biogas systems. The added iron Fe reacts with the sulfide ion S_2- and forms iron sulfide which is a solid component that leaves the system with the solid digestate. Iron products are added directly to the digester or before the digester. Commercial iron products are available in different forms as liquid or solid.

5.4.2
Trace elements are micro-nutrients

The microorganisms in the anaerobic digesters/reactor environment utilize enzymes and coenzymes for the degradation of cellulose, starch, proteins, fat, sugars, fatty acids by the metabolism and convert the intermediate compounds into the main end products methane and carbon dioxide.

The need for trace elements in an anaerobic degradation are related to the natural content of trace elements. Substrates coming from living creatures as municipal wastewater sludge and manure from livestock production generally do not have any need for addition of trace elements as the trace elements already are at sufficient levels in the substrate. But if the organic load is increased over 4 [kg VS / (m^3·d)], there will be a need for trace element supplementation to keep up the methane CH_4 yield and not reduce the output of the biogas plant.

Substrates coming from energy crops, agricultural residues, industrial organic residues, household waste, biowaste, and industrial wastewater are normally very low in trace elements so there is a high need of additional trace elements during an anaerobic degradation process. Otherwise the functioning of the microorganisms to transfer carbohydrates, protein and fat to biogas will be disturbed.

5.4.3
Chemistry supporting the anaerobic process

As mentioned above, chemistry is needed for a well operating biogas plant. In the BDP (Kemira Biogas Digestion Products) portfolio there are pure iron products specifically for biogas plants and industrial anaerobic wastewater treatment plants. The portfolio also consists of special iron salts containing trace elements of different types and concentration. The BDP selection of a BDP product is based on the substrate, the design, or the anaerobic digestion process and the load of the process.

The purpose of adding iron products is, of course, to reduce the amount of hydrogen sulfide in the produced biogas, preventing devices and equipment from corrosion, and to provide a biogas that is accepted in gas engines, gas grids and or as a vehicle fuel. The trace elements containing BDP products are used for increased biogas production and biogas yield. The organic loading rate can be increased and the VFA levels in the digester/reactor will be reduced along with foaming problems. By a higher reduction of the VFA acids and the longer fatty acids in the digesters/reactors, acids are transferred over to methane and carbon dioxide at a higher level.

The methane slip is also reduced and the negative impact on the environment is mitigated.

Generally speaking this addition creates an increased plant capacity with no need for investments. This gives a higher economic output of the plant in terms of increased biogas yield and biogas production. In the degradation pathways iron is a macronutrient and the key component in anaerobic digestion involved in all bacterial processes. It precipitates sulfide S_2- and inhibits the toxic effect of hydrogen sulfide H_2S.

The composition of the organic matter has a significant influence on the formation of biogas and the amount of methane produced.

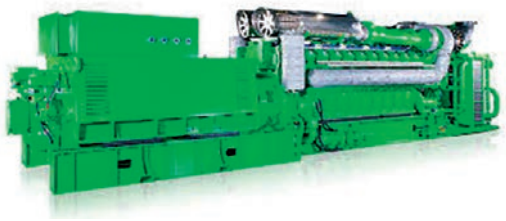


FIGURE 5.8
Gas engine and generator for biogas plants provided by Jenbacher.
PHOTO *Jenbacher.*

5.5
Combined power and heat production (CHP)

Combined heat and power plants – CHP, the use of engine generator plants for production of electricity and heat has been applied to Danish biogas plants for decades.

By using biogas in a gas engine, a power generation can be achieved which corresponds to 35-40% of the energy content of the biogas, while the rest of the energy comes out as heat from partly as hot flue gas and partly as hot water. This means that approx. 60% of the energy content of the biogas comes out as heat, and in order to make a profitable business it is necessary to sell the heat at a sensible price for other purposes. CHP plants in Denmark have the challenge that it can be difficult to sell the heat at a proper price during the hot part of the year.

5.6
Transport and logistics

Transport and logistics in connection with the operation of biogas plants constitute a significant part of the cost of operation. It is of the utmost importance for the economy to manage this well.

The biogas production at the wastewater-based plants and on the industrial plants differs from the agricultural-based plants, since most of the biomass for these usually can be fed by pumping. For the agricultural-based plants, almost all biomass is supplied by truck transport. Specially designed trucks transport the liquid biomass as manure to the plants and discharge of the digestate after decay. Planning the logistics of biomass collection and delivery of the digestate to agricultural farms is an extremely important task.

The logistics of biomass supply are of crucial importance to the economy.

FIGURE 5.9
Truck specially designed for manure transport.
PHOTO *Food & Bio Cluster Denmark.*

Power-2-X

- **Hydrogen.** Can be used directly for heat and electricity production (e.g. CHP plants), in the transport sector (e.g. fuel cells) and as a chemical raw material (e.g. at a refinery). A minor injection to the natural gas network may also be possible. The hydrogen is produced by electrolysis of water, which is a common, first process step for producing the following P2X products.

- **Synthetic methane.** Can be fed directly into the natural gas network and used for the same purpose as natural gas. Production requires a CO_2 source. The process is often referred to as Power-to-Gas (P2G).

- **Synthetic liquid fuels.** For example, methanol, gasoline, kerosene (jet fuel), diesel and gas oil. Can be used for the same purposes as the corresponding fossil oil products. Production requires a CO_2 source. The process is sometimes referred to as Power-to-Liquids (PtL).

- **Ammonia.** Basic ingredient in fertilizers. Ammonia can also be used as an energy carrier for hydrogen or directly as fuel. Production does not require a CO_2 source, but only nitrogen / nitrogen directly from the air. Since the introduction of CO_2 reduction targets for international shipping in 2018, a great deal of momentum has come from major players to develop electrolysis-based ammonia as a CO_2-free propellant for shipping.

5.7
Power2X

The conversion to 100% renewable energy over the next decades is a big and complex task in Denmark. Long-term energy system analyses have for many years indicated that electrolysis could become a central element in the conversion of the entire energy system, but it is estimated that it will probably not have significant influence until after 2030.

Power2X (P2X) is the conversion of renewable electricity production via electrolysis to hydrogen and further refining to e.g. gaseous and liquid fuels. Processes that are expected to become a central and necessary element in a cost-effective conversion to a clean and renewable energy supply.

Many analyses indicate that a massive electrification of the various energy systems through a so-called sectoral connection is central to the development of the Danish energy system. Room heating can be delivered energy efficiently with electric heat pumps, and electricity is often the most energy efficient and clean energy source for the transport sector. Electricity generation from wind and solar is today a cheap way to produce renewable energy. With the significant fall in prices in recent years, renewable electricity generation from wind and solar is gaining momentum globally and the share of electricity generation from wind and solar is today considerable.

FIGURE 5.10
Conversion of CO_2 and H^+ to methane at Aarhus University test facilities.
PHOTO *Food & Bio Cluster Denmark.*

Analyses show that approx. 40-60% of energy consumption in 2050 cannot be converted to direct electricity consumption. This energy consumption must be covered by other fuels. A great need for liquid and gaseous fuels for large parts of shipping, aircraft and heavy transport, industry, backup electricity generation, etc. is still expected. This makes Power2X productions interesting, also those based on biogas as a starting point.

FIGURE 5.11
Haldor Topsøe's pilot plant at Aarhus University for the conversion of CO_2 and H to methane.
PHOTO *Food & Bio Cluster Denmark.*

6 The use of digestate

6.1 Fertilizer value and recycling

The majority of livestock feed consists of plants and the plants contain a variety of nutrients. Some of these nutrients are converted by the animals into milk, meat or eggs, but the rest pass through the animals and end up as slurry or muck. When this is spread to crops, the circle is complete and the crops supplied with virtually all the nutrients they need. However, to partly compensate for the removal of nutrients in the animal products, there is often a need to supplement with a certain amount of inorganic fertilizer from household or industrial wastes.

Recycling nutrients, substituting industrially produced mineral fertilizer, becomes increasingly important because of the depletion of the global natural reserves of phosphorous. Digestate from biogas plants is an excellent plant fertilizer, rich in nutrients and organic matter, and with more accessible nutrients than raw manure. In Denmark and Europe both raw manure/slurry and digestate from biogas plants are used directly as fertilizer for crops without any further processing.

Replacement of mineral fertilizer with digestate requires that the digestate can be handled and used in an efficient and safe way.

Danish regulation

In Denmark the Ministry of Environment and Food is responsible for the regulation of the use of manure as fertilizer and for implementing relevant EU legislation.

The most important regulation is:

- A statutory order regulating manure management from livestock production.
- A statutory order regulating the use of fertilizers by agriculture and on plant cover.
- A statutory order regulating the use of organic waste as fertilizer on farmland.
- The use of residues from animals, e.g. slaughterhouses, is regulated by Danish Veterinary and Food administration.

Important elements in this regulation are:

- Livestock manure is allowed to be used untreated on agricultural land. The same applies for content of the digestive tract, milk and milk-based products.
- Manure and slurry must be stored in tight and covered storage tanks.
- Nutrients in manure and slurry must be used as fertilizers on crop land. The only alternative is incineration on approved incineration plants.
- There are limits to the quantities of N and P per hectare that can legally be applied to agricultural land.
- If a farm has more manure than can be legally applied on its own land, there must be a written agreement that the excess manure is allocated to another farm, a biogas plant or an incineration plant.
- Application of liquid fertilizer or degassed biomass must take place with certain technologies in order to avoid odor and emissions.
- Application of liquid fertilizer or degassed biomass must take place just before and in the growing season in order to use the nutrients efficiently and avoid leaching.
- Certain types of organic waste, like household waste, can be applied to farmland without permission, while other types need permission. For both apply limits for heavy metals, environmentally harmful substances and physical impurities like plastic. A third party controls the limits.
- Organic waste must undergo specified hygienically justified treatments before land application: stabilization, controlled composting or controlled sterilization depending on type.
- Animal by-products have to comply with EU regulations. This regulation bans the use of risky animal by-products for feed. High risk material, such as animals died from certain diseases, must be burned. Lower risk materials can be used for biogas, but sometimes only after pressure sterilization. In order to handle such material the biogas plant has to have an approved sterilization unit.

	Dry Matter %	Total Nitrogen kg/tonne	Ammonium Nitrogen kg/tonne	Phosphorus kg/tonne	Kalium kg/tonne
Slurry from cows	8	4,9	3,0	0,8	4,4
Slurry from finisher pigs	6	5,0	3,5	1,2	2,6
Slurry from sows	4	3,8	2,6	0,9	1,9
Muck (solid)	20	6,0	1,5	1,6	2,5
Urine	3	5,0	4,5	0,2	8,0
Deep litter	30	10,0	2,0	1,5	10,0

FIGURE 6.1
Typical concentrations of the most important nutrients in organic fertilizer of animal origin.

6.2 Nutrient content

Organic fertilizer of animal origin consists of 70-98% water and only 2-30% nutrients and organic compounds. Solid organic fertilizer and deep litter have a high straw content and a relatively high concentration of nutrients and solids. Liquid organic fertilizer, such as slurry, has a high water content and only little straw, so the concentration of solids and nutrients is relatively low.

The largest nutrient concentrations in organic fertilizer are of the so-called macronutrients (for example, nitrogen, phosphorus, potassium, and magnesium). Other nutrients can be found in lower concentrations (for example sodium, copper, zinc, boron, and molybdenum). Most of the nutrients can be absorbed directly by the plants.

Nitrogen in organic fertilizer occurs in two forms:
- Ammonium, which is directly available to plants
- Organic nitrogen, which must be transformed in the soil before it can be absorbed by plants. Nitrate, which is an important component in an inorganic fertilizer is, however, not found in large concentrations in organic fertilizer of animal origin.

The concentrations shown in the table are those typically found in practice in Denmark. There will, however, be large variations between farms because of the differences in feeding practice, water waste, housing design, use of straw, etc., that will all influence the composition of the slurry and muck.

6.3 Value of the nutrient

The value of the slurry, muck and degassed biomass on a farm is substantial. Organic fertilizer is able to partially or completely replace inorganic fertilizer in the field. Hence there is money to be saved on inorganic fertilizer if the slurry, muck, and degassed biomass is utilised optimally. There is no pricelist for organic fertilizer of animal origin, but its value can be estimated from the value of the inorganic fertilizer it substitutes.

The table shows the total fertilizer value for different farm types and sizes. The calculated value is based on the value of the equivalent amount of phosphorus, potassium and used nitrogen in inorganic fertilizer. To realise its full value, it is important, among other things, to apply the slurry, muck and degassed biomass in the right crops at the right time and with the optimal equipment.

The amount produced is the standard annual production. In the calculation of the value, the Danish standards for average content of nutrients in the manure/slurry depend on which type of livestock, feeding, type of housing and so on, that have been used.

The utilization rate in percent is a measure of how much of the nitrogen (total-N) is used by the crop in the year of application (first-year effect). Nitrogen in inorganic fertilizer is defined to have a use efficiency of 100%. The first-year effect is mainly the result of the ammonium nitrogen content of the organic fertilizer.

Residual effect is a measure of the effect of the nitrogen in the years following the application of the slurry, muck or degassed biomass. The residual effect is mainly the result of the organic nitrogen content. The residual effect over a period of 10 years is estimated to be 7-10% from pig slurry, 10-15% from cattle slurry and 16-24% from solid organic fertilizer.

Nitrogen utilization varies widely. How much nitrogen the crop takes up varies because of the differences in how much of the slurry and muck is organically bound to indigestible plant residues and therefore not available to the plants. The highest bioavailability of nitrogen is in slurry and urine. That is why the utilization of nitrogen is higher in liquid organic fertilizer than in solid organic fertilizer.

The degree of utilization varies because some of the nitrogen is lost to the environment before it is taken up by the plants. The best utilization of nitrogen is achieved when minimising these losses. This is achieved, for example, by choosing the most appropriate application equipment and only applying fertilizer in optimal amounts at the optimal time.

It is recommended to apply most of the organic fertilizer in the spring months. Storage capacity for slurry and muck will therefore be needed for the autumn and winter months. The optimum is to have storage capacity for 8-9 months' production.

	FERTILIZER PRODUCED			
Fertilizer type	Tonne/animal	Total output, tonne	Vale per tonne, EUR	Total value, EUR
Sow slurry	9,60	8.160	4	36.680
Finishing pig slurry	0,54	5.400	6	32.227
Cattle slurry	38,00	11.460	6	71.408
Cattle slurry	38,00	19.100	6	119.013

FIGURE 6.2
The estimated fertilizer value in Denmark November 2016 for typical fertilizer types.

Fertilizer type	Crop and application method	Use efficiency % 1 st year
Pig slurry	Trailer hose to winter crop (cerel, rape)	65
Cattle slurry	Trailer hose to winter crop (cerel, rape)	45
Cattle slurry	Injected into grass	50
Cattle slurry	Trail hose to grass (acidified)	50
Liqiud org. Fert.	Trail hoseto winter crop (cereal, rape)	85
Solid org. Fert.	Broadcast to winter crop (cereal, rape)	25
Deep litter	Broadcast to winter crop (cereal, rape)	85

FIGURE 6.3
Nitrogen utilization of organic fertilizer. In growing crops, spring and summer. SEGES P/S.

Fertilizer type	Crop and application method	Use efficiency % 1 st year
Pig slurry	Injected into spring cereal or maize	75
Cattle slurry	Injected into spring cereal or maize	70
Pig slurry	Injected into winter rape	65
Liquid org. Fert.	Injected into spring cereal or maize	90
Solid org. Fert.	Ploughed in before spring cereals	40
Deep litter	Ploughed in before spring cereals	30
Deep litter	Ploughed in before maize or beets	35

FIGURE 6.4
Nitrogen utilization when applied prior to sowing.

Digestate from biogas plants is a valuable fertilizer product.

PHOTO *Samson.*


Samson

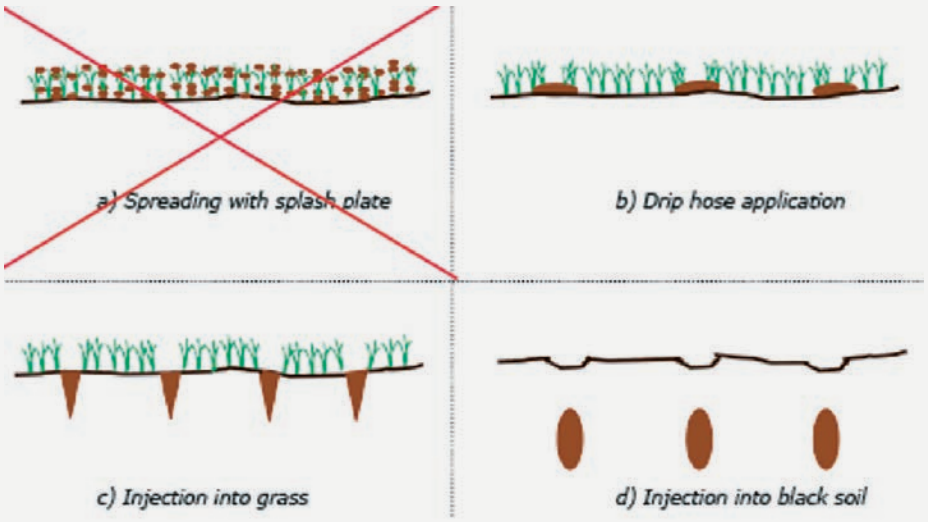


FIGURE 6.5
Position of fertilizer in crop or soil following application.

6.4
Application method and ammonia losses

Mixing is important before application. In the slurry storage tank the nutrients segregate during the storage process. Especially dry matter, phosphorus, organic nitrogen and some micronutrients will segregate and build up in high concentration in the bottom layer and the floating layer. Ammonium nitrogen and potassium do not segregate as those nutrients are water-soluble.

By mixing the slurry thoroughly prior to application you will have two advantages:

- The slurry is homogeneous and easier to pump. The tank can be emptied completely.
- The concentration of nutrients (especially phosphorus) is consistent from the first to the last load of slurry.

The digestate must be handled properly to get the optimum fertilizer effect.

Solid organic fertilizer, such as deep litter, can only be applied using a muck spreader. Ammonia losses from these types of organic fertilizers can best be reduced by ploughing in the deep litter/muck as quickly as possible following application.

Liquid organic fertilizer, on the other hand, can be applied using a number of different techniques. The nutrient utilization can be optimized by choosing the most appropriate application method for the specific crop and time of application. The figure shows appropriate methods for the application of liquid organic fertilizer.

The black line illustrates the soil surface, and the brown blobs the manure. Note that the fertilizer contact with the atmosphere is very different with the four methods. This contact is quite significant using splash plate, which has the greatest evaporation of ammonia and thus the greatest loss of nitrogen. Consequently, this method is banned in Denmark. The longer the exposure to air, the greater the loss of nitrogen from ammonia evaporation/emission. It is therefore better to use injectors, incorporators and drip hoses than splash plate spreading.

It has since 2001 and 2002 been banned to spread liquid manure by use of irrigation canons and by broad spreading, respectively, due to health and environmental considerations.

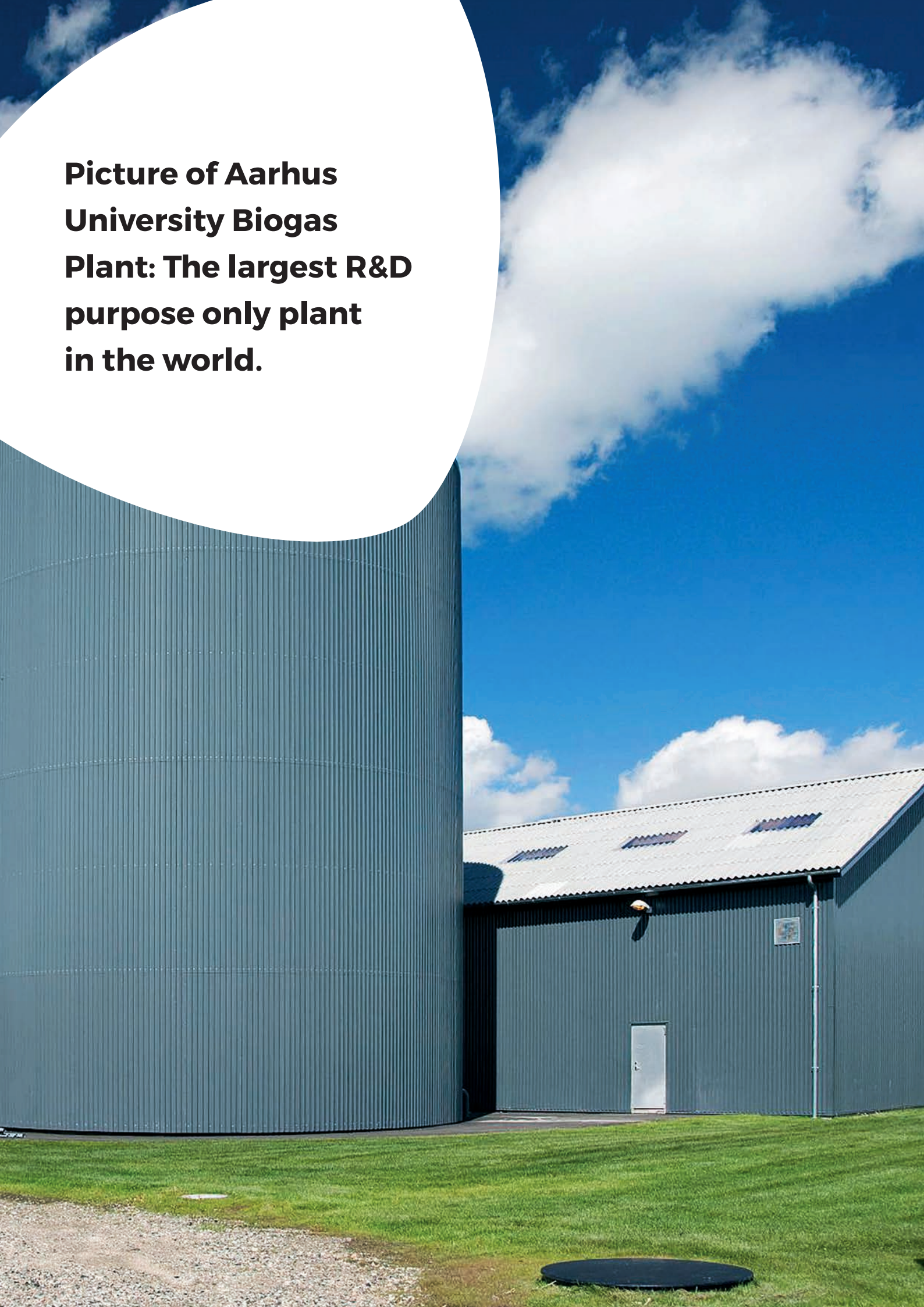
For biogas digestate it is extra important to use technologies that prevent ammonia evaporation, i.e. to store it in covered slurry tanks, and to spread it with injection or band laying system. The fact that digestate has a higher pH and as well contains a larger share of the nitrogen in a mineralised form, makes the risk for ammonia evaporation higher.

FIGURE 6.6
2 Broad spreading and sprinkling is not allowed due to very high losses of nitrogen. Torkild Birkmose, SEGES. **PHOTO** *Seges.*

FIGURE 6.7
Land application by trailing hoses. Reduction in N-emissions about 50% compared to broad spreading. **PHOTO** *GØMA.*

FIGURE 6.8
Injection in grass. Reduction in N-emission about 25% compared to trailing hose application. **PHOTO** *Samson Agro.*

FIGURE 6.9
Black soil injection. Reduction 85% of N-emission compared to trailing hose application. **PHOTO** *Samson Agro.*



Picture of Aarhus University Biogas Plant: The largest R&D purpose only plant in the world.

7 Reduce the risk of environmental problems

Among the possible environmental challenges can be mentioned:

- Ammonia evaporation
- Nitrate leaching
- Denitrification
- Phosphorus losses
- Surface runoff
- Odours

All of these risks can be reduced or eliminated by using the right technique at a suitable time.

Digestate from biogas plants have less smell and higher fertiliser value than raw manure. Despite the higher risk for ammonia evaporation, digestate smells much less than untreated slurry. This is because it has a lower viscosity, is more homogenised and has smaller particle sizes, and therefore quickly percolates into the soil among other things. As neighbours' main worries for livestock production farms concern smell, this fact is often of importance for farmers' decision to invest in biogas production.

A farm that fertilizes with digestate can, due to the increased amount of NH_4-N, often get the same fertilizing effect with 10-20% smaller dose.

7.1.1 Avoid the spread of diseases

One milliliter of slurry can contain more than one billion microorganisms. Some of these microorganisms are infectious and cause disease in animals and humans. This is why it is important to take precautions when handling slurry to minimise the spread of disease.

However, during the transport and application of slurry, degassed biomass and muck, there is a risk that disease can spread from one herd to another because the transport and application equipment can be contaminated with pathogens caused by surges, overflows and inadequate cleaning. So it is important to use equipment that does not overflow or spill during filling and that the equipment is correctly maintained and watertight so that surges during transport do not cause a problem. Frequent cleaning of the equipment will therefore also minimise the risk of spread of disease.

Generally, there is an insignificant risk of disease being transmitted to crops that are not harvested until maturity, such as cereals. This is because of the long interval between the application of slurry and crop harvest and that the infectious germs during that period are very effectively broken down by UV-radiation.

The largest risk of disease transmission is with slurry applications to grass, and special guidelines should be followed.

The Danish regulation builds on the experience that anaerobic digestion efficiently eliminates relevant pathogens in Denmark.

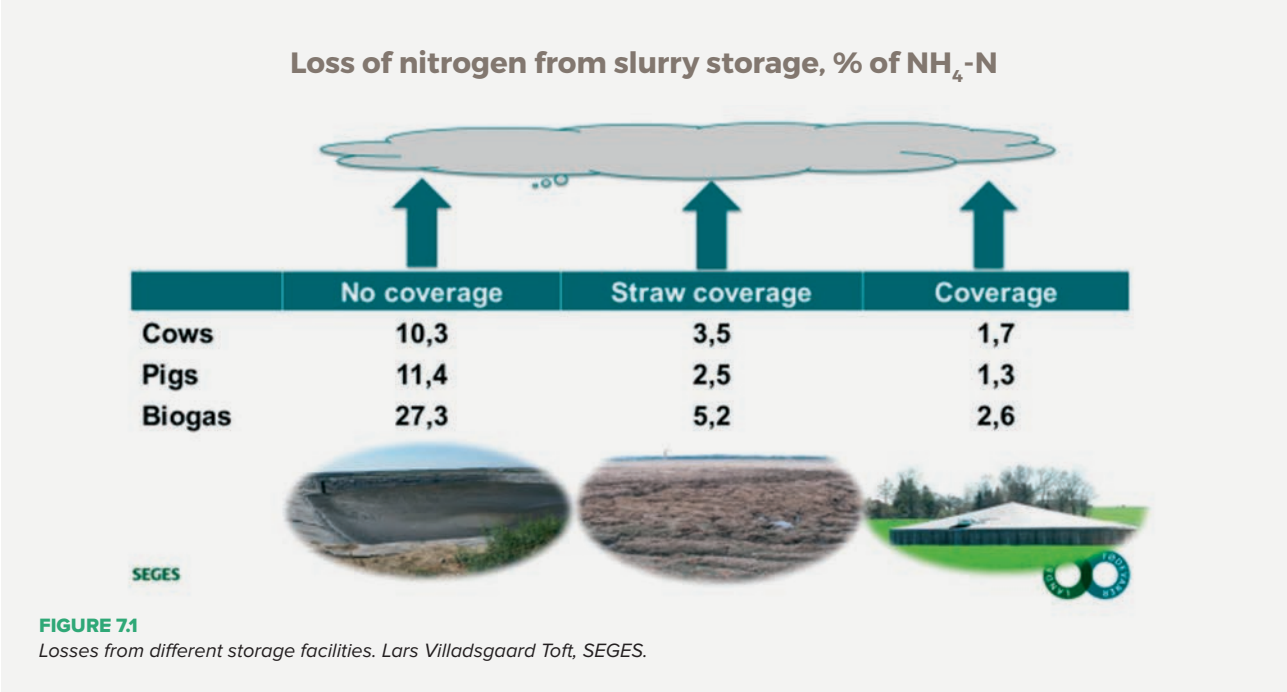


FIGURE 7.1
Losses from different storage facilities. Lars Villadsgaard Toft, SEGES.

8 Research and development

8.1 Universities

Denmark has several universities and research institutes, which perform 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.

8.1.1 Aarhus University

Aarhus University (AU) is the largest university in Denmark with about 42,500 students and 11,500 employees. The University set out its future research strategy in 2017 with the establishment of strategic research centres such as Watec – Centre for water research and CBIO – Centre for circular bioeconomy. The Department of Engineering has a strong portfolio in bio-resource technology working towards a bio-based society and a circular bio-economy. AU has continuously invested in excellent experimental facilities in the water research, biogas and biorefining sectors ranging from laboratory analytical equipment to pilot and commercial scale reactors. For instance, it operates a complete full-scale biogas plant including gas transmission line and gas engine. It also operates a biogas test plant with small and big biogas digesters. Size of digestion tank: Full-scale plant 1,200 m^3, test plant 2 x 30 m^3 and 2 x 10 m^3. There are several ongoing experiments for increasing gas production by pre-treatment and with production of high value digestate products.

AU-Foulum is heading the biogas research group at AU. The AU biogas research has a strong industrial collaboration with research in anaerobic digestion covering most areas like pre-treatment, process control, reactor design, high rate digesters, environmental impact, gas upgrading, separation and value chains for digestate, etc. Besides many years research the crew also has been working together with the industry with design of biogas installations. The existing biogas infrastructure is upgraded to state-of-the-art technology including methanization and power2x projects.

8.1.2 Aalborg University

Aalborg University (AAU) has years of experience in the field of biorefinery concepts and biogas production, anaerobic digestion, and implementation projects of bioenergy systems. Biogas is expected to play an important role in reaching the future energy policy targets of the European Union (EU). The sustainability of biogas substrates has however been critically discussed due to the increasing shares of agricultural land used for energy crop production. Mapping the biomass and biogas energy potential from a selection of potentially sustainable agricultural residues has been documented to improve in biogas yields when co-digested in biogas production. The investigated types of residual biomasses were animal manure, straw by-products from cereal production, and excess grass from

FIGURE 8.1
Test and trial facilities full scale in Foulum.
PHOTO *Food & Bio Cluster Denmark.*

rotational and permanent grasslands and meadows. The results show that sustainable alternatives to the use of maize, the dominant energy crop in use, are present in all the member states of the EU to an extent that is sufficient to ensure a continuous progressive development of the European biogas sector.

The main research activities are related to structure and function of microbial communities in engineered ecosystems, primarily related to used water treatment, biological recovery of resources (such as phosphorus) and bioenergy production. Uncultured microorganisms are investigated by various omics methods (metagenomics, metatranscriptomics, metaproteomics and metabolomics) in combination with single cell microbiology, e.g. by using microscopy and tracers. The main research focus is on organisms involved in biological P-removal, N-removal and organisms causing foaming and bulking.

Aalborg University
Center for Bioenergy and Green Engineering
Esbjerg Campus Denmark.

Aalborg University
Center for Microbial Communities
Department of Chemistry and Bioscience.

8.1.3 University of Southern Denmark

University of Southern Denmark (SDU) has a wide range of activities within research into biogas production, including in particularly the use of different types of biomass, gas potential and process optimization. Most recently a data sampling has been made to ensure trustworthy results for in total of nine biogas upgrading systems. Through a simple design process, the model simulates an individually designed biogas upgrading system. The excel model will provide knowledge about system economics, energy cost and energy flows. The model includes four traditional upgrading systems; amine scrubber, PSA, membrane, and water scrubber, and three hydrogen assisted biogas upgrading (HABU) methods; the

chemical catalyst, the in situ biological biogas upgrading and the ex situ biological biogas upgrading. Furthermore, a combined solution has been included, using a biotrickling filter and an amine scrubber.

Specialists in biomass conversion for high-value products through biochemical treatment, aerobic and anaerobic bioremediation for environmental health and bioenergy production.

- AD process and co-digestion optimisation for biogas production
- NIR, Non-destructive analysis of methane potential and recalcitrant organic matters
- Multivariate Data Analysis (Chemometrics), PLS modelling
- Wastewater and sludge treatment process technology
- Pre-treatment, pre-storage technology for biogas production
- Carbon value chain analysis
- Biorefinery and Bioeconomy

Department of Chemistry
Biological and Environmental Technology
DU Biotechnology
Campusvej 55
5230 Odense M, Denmark

8.1.4 Roskilde University

Roskilde University (RUC) is doing research on biogas because there is still a significant potential for expanding biogas production in Denmark and abroad. In addition, biogas is more than renewable energy, it also helps to create multi-page benefits for the climate, the environment and the local community:

- Reduced costs for purchasing fertilizer.
- Increased agricultural production due to increased nitrogen availability.
- Value creation of unused residual products (eg straw and industrial waste).
- Recirculation of nutrients.
- Local job creation.

Roskilde University Centre (RUC)
Universitetsvej 1
DK-4000 Roskilde, Denmark.

8.1.5 Technical University of Denmark

Technical University of Denmark (DTU) will be contributing to the development of a more profitable way of producing biogas, opening up for the production of biofuels for trucks and planes.

The Energy Technology Development and Demonstration Programme (EUDP) has granted several million DKK to the eFuel project, which aims at developing a new and robust technology for transforming CO_2 emitted from biogas plants into methane, which may become the green raw material of tomorrow in the manufacture of e.g. fossil-free aviation fuel and plastics.

The process involves retrieving CO_2 from biogas plants producing up to 40% CO_2 —today released into the atmosphere. This makes production of biogas fossil-free, and the collection of CO_2 also makes it more profitable.

The other raw material in the process is hydrogen, which is produced from water and electricity. With an increasing amount of wind power in the power grid, this technology is also one of the highly demanded ways of storing wind power.

The eFuel technology will increase the yield from biomass by more than 60%, thus making it more profitable to process the biogas into advanced biofuels for heavy goods transport and aviation.

DTU has wide expertise in the area of biofuels (biogas, biohydrogen, bioethanol) production, optimization of the anaerobic processes and development of sustainable solutions for organic waste and wastewater treatment. The Bioenergy Group at DTU Environment is working in the following areas: Biogas, biofuels, microbial electrochemistry, algae as bioresource, and biorefineries.

The DTU Bioenergy Group is working with various biorefinergy approaches where wastes and residues are converted besides energy and fuels to various bioproducts. One example of a new route of using biogas is to microbially convert methane in an aerobic process, to single cells proteins, which can be used as feed for animals. DTU has developed this route in an MUDP project (FUBAF) together with several companies and Copenhagen municipality. Another interesting product where the CO_2 from biogas is used with organics residue materials to produce biosuccinic acid, which is an interesting platform chemical used for a wide variety of final products. The concept is currently at upscaling level through an EU funded project (Neosucces).

8.2 Knowledge Institutions

In Denmark, there are a large number of companies and institutions that have competencies in design, planning, establishment and operation of biogas plants. A few of these are highlighted in this section.

8.2.1 Danish Technological Institute

The Danish Technological Institute (DTI) has more than 15 years of experience in chemical and biotechnological aspects in biogas production and biomass application. They help Danish and international companies with development, testing and verification of concepts, prototypes and commercial solutions, and utilization of nutrients from biogas plants.

In the transition to the bio-based society, the biogas plants play a central role. At the same time as organic waste and residual biomass from agriculture are utilized for green energy, the biogas plants allow recycling of nutrients and carbon back to the agricultural soil. The Danish Technological Institute has more than 10 years of experience in developing and documenting solutions for optimal utilization of the degassed biomass. They can carry out field trials to determine the fertilizer value of the degassed manure or sub-products from this.

DTI offers advice on:

- Development of technologies for separation and further treatment of degassed biomass
- New fertilizer products and soil improvers based on degassed biomass
- Applications for the fiber fraction
- Opportunities to improve fertilizer effect in degassed biomass
- Solutions for use in meeting the limit for phosphorus application on agricultural land

- Financial assessments of investments in degassed biomass technologies
- Demonstration, testing and verification of degassed slurry treatment technologies for evidence of effectiveness and operational stability of various solutions.

Technological Institute
Bio- and Environmental technology
Agro Food Park 13
8200 Aarhus N, Denmark

8.2.2 Biogas Denmark

The association for the biogas industry is working to ensure the transition to a fossil-independent society through the conversion of livestock manure, residual products from industry and households, and other organic residues and biomass for climate-friendly renewable energy and fertilizer to ensure the future energy and food supply. The biogas industry association represents all actors with an interest in biogas, including biogas producers, plant and equipment suppliers, advisers, biomass suppliers, energy, transport, waste and agricultural sectors, knowledge institutions, etc.

The biogas industry association works to promote the production and use of biogas in Denmark and abroad.

8.2.3 SEGES

SEGES and the Danish Agricultural Advisory Board count several thousand people who perform counselling in the agricultural area, including the fertilizer area.

SEGES also advises in the biogas field and has a long-standing reference list covering biogas farms, biogas joint plants, industrial biogas purification plants and anaerobic digestion tanks in wastewater treatment plants.

SEGES' consulting services include:
- System design, equipping and control concepts for biogas plants
- Mass and energy balance calculations, including benchmarking of plants
- Operational optimization of existing plants, including biological process optimization, machinery and control-related conditions
- Audit related to biomass certification and biogas production
- Special conditions related to organic biomass and biogas production
- Dimensioning and design of sanitation systems including heat exchangers for slurry and sludge fitting into heating and biogas plants
- Design and optimization of sulfur treatment plants and odor cleaners.

SEGES employees have references from a number of countries around the world, including Japan, China, Taiwan, Thailand, South Africa, Bulgaria and other European countries.

In addition, SEGES performs due diligence tasks, visual and estimation tasks, etc. in connection with trade and disputes, also in connection with biogas plants. Authority treatment is carried out on tasks in Denmark in collaboration with the Danish Agricultural Advisory Council.

8.2.4 Food and Bio Cluster Denmark

Food & Bio Cluster Denmark is the national cluster for food and bioresources in Denmark. We are the collective platform for innovation and growth in the cluster – for both Danish and international companies and knowledge-based institutions. We promote increased cooperation between research and business and offer our members one-stop-shop access to networks, funding, business development, projects and facilities. We offer various consultancy services, i.e. writing applications for soft funding, organising thematic tours and business missions, writing reports on different topics within our areas of expertise, and more.

Please visit **www.foodbiocluster.dk** for more information.

9 Companies, suppliers and advisors

Danish companies have many years of experience in establishing and operating biogas production.

Danish companies can supply:
- Know how and advice
- Delivery of equipment
- Delivery of complete installations and plants
- Cooperation on planning
- Design and dimension of plants
- Cooperation on execution
- Cooperation on operations

Danish companies can provide:
- Turn Key biogas plants
- Turn Key upgrading facilities
- Turn Key pre-treatment facilities
- Gas motor installations - CHP
- Gas cooling installations
- Storage facilities

LOGO	CONTACT	DESCRIPTION	BIOMASS HANDLING & PRETREATMENT	TURN-KEY, ENGINEERING/CONSULTANCY	PLANT COMPONENTS	GAS CONDITIONING & USE	FERTILIZER USE	R & D	OTHER
A·CONSULT	A-Consult Group A/S Indkildevej 6B DK - 9210 Aalborg SØ +45 9687 5800 www.aconsult.dk	A-Consult specialise in providing solutions for the storage and handling of liquids in the Agricultural, Water, Industrial and Renewable Energy sector. Established in 1986 we have successfully installed over 8,000 tanks throughout Europe.	●	●		●	●		
AEM Engineering	AEM Engineering Hyrdeengen 37 DK - 2625 Vallensbæk +45 2480 9024 www.aem-engineering.dk	Supplier of FRICHS Gas engines and generator sets. Power plants and Generator sets for Biogas, Gasification gas and other combustible gasses. SIVACON Power and Control panels. Control and Alarm systems. Installation, Service and Repair of FRICHS engines and other major brands.		●	●	●			
Aikan	Aikan A/S Vadsbystræde 6 DK - 2640 Hedehusene +45 4399 5020 www.aikan.dk	Aikan A/S has for 20 years delivered robust solutions for truly sustainable waste recirculation and energy production. Aikan handles solid waste from any source and purity, and includes both pre-treatment of the waste and handling of the end-user products despite low installation and running costs.	●	●			●	●	
Ammongas	Ammongas A/S Ejby Mosevej 5 DK - 2600 Glostrup +45 4363 6300 www.ammongas.dk	Ammongas A/S produces turn-key environmental plants for air- and gas purification, including biogas upgrading with amine, ammonia separation- and concentration, scrubber systems, and activated carbon filters.		●		●			
BBK bio airclean	BBK bio airclean A/S Linnerupvej 5 DK - 7160 Tørring +45 7567 6066 www.BBK.dk	BBK biofilter for odour removal. An investment in a BBK biofilter is an investment in a good relationship to neighbours and local authorities. We have been in the market since 1992, and have delivered biofilters for several facilities in Denmark, Norway, Sweden, Finland, England, Scotland, Spain and Belarus.							●
BioCover	BioCover A/S Veerst Skovvej 6 DK - 6600 Vejen +45 2963 4936 www.biocover.dk	SyreN system stabilises slurry during application. It stops emission of ammonia which increases the nitrogen utilization rate to 80 %, often adding +50 kg nitrogen pr. ha. It makes up to 40 % more phosphorus plant available while adding the correct amount of sulphur as sulphate fertilizer.					●		
BIO GASCLEAN	Biogasclean A/S Magnoliavej 10 DK- 5250 Odense SV +45 6617 2177 www.biogasclean.com	Biogasclean A/S delivers fully automated biological desulphurization systems with low operating costs, high availability, performance guarantee and with no use of chemicals. More than 270 References supplying clean gas to more than 580 MW gas engines.			●	●			
KC ProSupply BIRODAN Denmark The one-stop shop for gas equipment	Birodan A/S KC ProSupply Alsvej 21 DK - 8940 Randers SV +45 8644 8734 www.birodan.dk	BIRODAN A/S are a KC ProSupply company owned by Makeen Energy Group. We offer a broad range of gas equipment and have skilled specialist who can guide you to the right product. Honeywell Krom Schröder is just one of our high quality brands.			●	●			
BYGGERI & TEKNIK I/S	Byggeri & Teknik I/S Birk Centerpark 24 DK - 7400 Herning +45 4024 3081 www.byggeri-teknik.dk	Designing and planning agricultural buildings for household animals including the belonging slurry systems as storaging, pumping systems etc.		●			●		●
C.K.E.	C.K. Environment A/S Walgerholm 3 DK - 3500 Værløse +45 4498 9906 www.cke.dk	For 20+ years C.K. Environment A/S have offered state-of-the-art solutions for the biogas industry, including analysis of parameters such as CH_4, H_2S, CO_2, O_2, VOC and NH_4 as well as biomass sampling, WOBBE index, flow and level measuring.	●	●	●	●		●	
c-biotech	C-Biotech Fruebjergvej DK - 2100 Copenhagen +45 2882 9953	C-Biotech is a company that enables you to bring new technologies to market. We have a strong connection with the scientific community and want to bring technically and scientifically proven technologies to biogas producers in the Danish and Scandinavian biogas market, with a bridge to the European market as well.	●		●			●	

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Combigas® Complete biogas solutions	Combigas ApS Ryttervangen 11C DK - 7323 Give +45 2779 1346 www.combigas.dk	Combigas design, develop, implement and support complete biogas solutions. Our biogas technology converts organic waste into clean, sustainable energy and a valuable fertilizer.		●					
COPENHAGEN CAPACITY Invest in Greater Copenhagen	Copenhagen Capacity Nørregade 7b 3th floor DK - 1165 Copenhagen +45 4022 1436 www.copcap.com	Copenhagen Capacity helps foreign companies and investors in finding and realising business opportunities in the Greater Copenhagen region. Biogas production and usage in Denmark is strongly and increasingly encouraged by government initiatives and ambitious political climate targets, and the country's large agricultural sector with 25 million pigs makes a strong foundation for the biogas industry.	●	●	●	●	●	●	
DANISH BIOGAS CONSULTING	Danish Biogas Consulting Glarmestervej 18B DK - 8600 Silkeborg +45 8683 7483 danskbiogasraadgivning.dk	Offers consultancy services in all stages of biogas production; from planning and project development, to design, implementation, operation and maintenance. Operational services include lab analyses, biological monitoring and optimisation as well as sustainability certification.	●	●	●	●	●	●	●
Danish Energy Agency	Danish Energy Agency Carsten Niebuhrs Gade 43 DK - 1577 Copenhagen +45 3392 6700 www.ens.dk/en	The Danish Energy Agencies Bioenergy Division develops the regulatory frameworks necessary to ensure the implementation of EU Directives, and the sustainable development of the Danish biogas sector. The Agency is also responsible for developing and administering biogas subsidy schemes.							●
DANISH TECHNOLOGICAL INSTITUTE	Danish Technological Institute Kongsvang Alle 29 DK - 8000 Aarhus C +45 7220 2000 www.teknologisk.dk	DTI has more than 15 years of experience in all aspects of biogas production and utilization. We provide services to Danish and international companies regarding biomass feedstock, process optimization, feasibility studies as well as lab-scale and pilot scale test and verification.	●	●	●	●	●	●	
DANISH TECHNOLOGICAL INSTITUTE	Danish Technological Institute - AgroTech Agro Food Park 15 DK - 8200 N Skejby +45 72 20 32 95 www.dti.dk	Danish Technological Institute – AgroTech holds more than 30 years' experience in consultancy and technology development within a broad field of anaerobic digestion issues. Our customers are companies, farmers and authorities.	●		●	●	●	●	●
DVC	Dansk Ventil Center A/S Ferrarivej 14 DK - 7100 Vejle +45 7572 3300 www.dvcas.dk	Dansk Ventil Center A/S has been supplying valves to the biogas segment for many years. Our products are designed to high technical levels, but also at competitive prices due to innovative ideas and international production in large quantities.			●				
EnviDan	EnviDan A/S Vejlsøvej 23 DK - 8600 Silkeborg +45 8680 6344 www.envidan.dk	Our biogas experts have advanced and vast experience with biogas plants and have provided consultancy on biogas production in a wide range of Danish and foreign projects participating in feasibility studies, process consultancy, regulatory processing, tenders and supervision.		●					
eurofins | Agro	Eurofins Agro Testing Denmark A/S Ladelundvej 85 DK - 6600 Vejen +45 7660 4242 www.eurofins.dk/agro	Eurofins Agro Testing Denmark A/S is accredited and authorized to perform analyses within agriculture. We perform analytical tests, deliver documentation and offer tailor-made solutions to biogas plants and anyone involved with organic products for biogas, bioenergy, feed and compost.	●		●	●	●	●	
Food & Bio Cluster Denmark	Food & Bio Cluster Denmark Agro Food Park 13 DK - 8200 N Skejby +45 8999 2500 www.foodbiocluster.dk	Food & Bio Cluster Denmark is the national cluster for food and bioresources in Denmark. We are the collective platform for innovation and growth in the cluster – for both Danish and international companies and knowledge-based institutions.						●	●
Frichs Pyrolysis - recycle energy & minerals	Frichs Pyrolysis ApS Sverigesvej 14 DK - 8700 Horsens +45 4036 7165 www.frichs-pyrolysis.dk	Thermal mineralization – the method to reduce CO_2. By mineralizing dry biomass under high temperatures and oxygen-free conditions, we extract carbon from the circuit and preventing it from being CO_2. The gas has a high calorific value and can e.g. produce electricity and heat by a gas generator.	●	●		●		●	

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GEMIDAN	Gemidan Ecogi A/S Drivervej 8 DK - 6670 Holsted +45 7678 2101 www.ecogi.dk	The Ecogi technology has been developed based on years of experience in waste processing. The technology sets new standards in pulp purity especially when it comes to minimal plastic content. Ecogi is known for producing a unique substrate product that is ETV certificated for purity and quality.	●		●				
HEXA-COVER®	Hexa-Cover A/S Vilhelmsborgvej 5 DK - 7700 Thisted 45 9617 7800 www.hexa-cover.dk	The unique Hexa-Cover® is perfect on almost any form of fluid surface. Hexa-Cover® Floating Cover is used on almost all forms of basins, lagoons, reservoirs, containers, ponds and tanks Since its launch in 2004, Hexa-Cover® Floating Cover has been chosen for a vast number of installations globally, making the Hexa-Cover® Floating Cover the market leading solution.	●		●				
HYBRIDFILTER	Hybridfilter A/S Industrivej 8 DK - 8740 Brædstrup +45 8657 1700 www.hybridfilter.dk	At Hybridfilter, we develop and deliver biological filters for neutralizing hydrogen gases. Since 2012, we have extensive experience in the wastewater industry and supply about 70% of the utilities. In biogas, our deliveries started in 2016 and took off in 2018.	●		●				
Højgaards	Højgaards ApS Fabjergkirkevej 51 DK - 7620 Lemvig +45 9789 3012 www.hojgaards.dk	Højgaards produce and develop pumps, mixers and separations processes. Every component is incorporated into a process for optimal everyday use. Automation and "smart" products can help you increase your productivity. More than 50 years of experience.	●		●				
kemira	Kemira Oyj Amager Strandvej 390 DK - 2770 Kastrup +45 6991 8893 www.kemira.com	To achieve high biogas yield and low upgrading cost, it is essential to keep the levels of hydrogen sulfide low. The Kemira BDP product portfolio is the most efficient way of controlling sulfide levels in the digester.	●			●			
KINETIC BIOFUEL BOOSTING SUSTAINABILITY	Kinetic Biofuel A/S Solbjergvej 19 DK - 9574 Bælum +45 21640090 or +45 21495940 www.kineticbiofuel.com	New pre-treatment technology for agricultural residues, such as cereal straw allowing co-digestion with animal manures in biogas plants. The process is based on mechanical briquetting technology generating steam explosions enabling straw briquettes to absorb up to 7 times more after briquetting. Complete lines can be delivered from 500 kg/h and upwards.	●						
SEGES	Landbrug & Fødevarer F.m.b.A. - SEGES Agro Food Park 15 DK - 8200 Aarhus N +45 8740 5000 www.seges.dk/en	SEGES covers all aspects of farming and farm management and has extensive knowledge of the area of nutrient management and utilization. SEGES also advises in the biogas field, and has a designed and optimized the operation of many biogas farms and biogas joint plants.	●	●	●	●	●	●	●
Landia	Landia A/S Industrivej 2 DK - 6940 Lem St. +45 9734 1244 www.landia.dk	Landia delivers top quality pumping- and mixing solutions to numerous industries, including agriculture and biogas. Landia equipment is particularly known for its effectiveness in hard-to-handle liquids and service-friendliness. Read more on www.landiaworld.com	●		●				
LJM LIND JENSEN BIOGAS	Lind Jensens Maskinfabrik A/S Kroghusvej 7, Højmark DK - 6940 Lem St. +45 9734 3200 www.ljm.dk	Lind Jensen Biogas offers more than 30 years of experience in manufacturing, servicing and marketing the highest quality equipment for handling biomass and other media at a biogas plant. We strive daily to deliver the right product, of the right quality, at the right price to our customers worldwide.			●				
LSH-BIOTECH	LSH-Biotech ApS Katrineholmsalle 62 DK - 8300 Odder +45 2960 3008 www.lsh-biotech.dk	LSH-BIOTECH is a knowledge-based company with years in designing, planning and development of specialized equipment for industry, mainly within biogas technology. Our solutions are therefore based on solid understanding of the business and technical expertise.	●	●	●	●			●
Lundsby BIOGAS | Waste to energy	Lundsby Biogas A/S Hjarbækvej 65 DK - 8831 Løgstrup +45 9649 4300 www.lundsbybiogas.dk	Manage and builds turn-key biogas plants with a durable, flexible, and simple technique which is a customized solution with quality and experience. We cooperate with various suppliers of upgrade plants, so the plant delivers bionatural gas to the Natural Gas Network. We participate in considerations with power/ heating plants if there is a possibility of supplying to one.	●	●	●	●	●	●	

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nature energy	Nature Energy Biogas Ørbækvej 260 DK - 5220 Odense SØ +45 70 22 40 00 www.natureenergy.dk	Nature Energy is Denmarks leading supplier of bio-methane with 10 plants in operation producing more than 170 million m³ bio-methane per year making Nature Energy one of the world largest producers of bio-methane. The input is mainly animal manure and food waste. More plants are in the construction and final development stage.		●		●	●	●	●
NISSEN energy	NISSEN energy A/S Godthaabsvej 1 DK - 8660 Skanderborg +45 7575 6500 www.nissenenergy.com	NISSEN energy supply services and products to ensures economical, beneficial production of sustainable energy: CHP units, Gas treatment systems for biogas, Biogas upgrading units for renewable natural gas and Low NOX burners and Boiler.		●	●	●			
ON:OFF MANAGEMENT	ON/OFF Management ApS Toldboden 3, 1 sal D DK - DK-8800 Viborg +45 2943 7648 www.onoffmanagement.dk	More than 30 years of experience with biogas, nationally and internationally. Competences in the following areas: Business case and project development, Project Management, Design of biogas plants, Execution, Commissioning, Coperation and optimization		●					
PlanEnergi	PlanEnergi Jyllandsgade 1 DK - 9520 Skørping +45 9682 0400 www.planenergi.dk	PlanEnergi is a foundation providing consultancy to cliets that want to plan, implement and operate renewable energy systems. PlanEnergis consultancy services include planning, design, tendering, supervision during implementation, commissioning and optimization of operation of biogas plants	●	●	●	●	●	●	
PurFil® ApS	PurFil ApS Blaabaervej 61 DK - 5260 Odense S +45 4015 8777 www.purfil.com	PurFil® has a series of new ""non-chemical-consuming"" Separation Modules for Liquid "Waste". The PURROT® - PURUF® - PURRO® – PURNIT® – PURDRY® - PURCOMP®. Sold (like LEGO-blocks) as add-on modules, related to the needed Pre- and/or Post-separation degree at Husbandry, WWTP's and BioGas plants.	●	●	●		●		
RAMBØLL	Ramboll A/S Hannemanns Allé 53 DK - 2300 Copenhagen S +45 5161 1000 www.ramboll.com/energy	Ramboll has +30 years' experience in biogas production and has provided consulting services to most recent large-scale plants in Scandinavia. We advise biogas producers, sewage treatment and waste management companies, local/central governments, project developers, investors and banks.		●				●	
Renew energy	Renew Energy A/S Kullinggade 31 DK - 5700 Svendborg +45 6222 0001 www.renewenergy.dk	Biogas engineering services company specialized in anaerobic digestion and advanced separation solutions, with more than 30 years of experience with design, engineering, procurement, construction management, commissioning and operational services across agricultural, food and distillation sectors.	●	●	●	●	●	●	
Samson	SAMSON AGRO A/S Vestermarksvej 25 DK - 8800 Viborg +45 8750 9300 www.samson-agro.com	SAMSON AGRO is a Danish based international manufacturer of high-quality machines and equipment for the application of organic fertilizer. Our aim is to meet the demand of the global agricultural sector for solutions that optimizes nutrient utilization and applies livestock manure in an efficient and environmentally sound way.					●		
STJERNHOLM	Stjernholm A/S Birkmosevej 1 DK - 6950 Ringkøbing +45 7020 2505 www.stjernholm.dk	Stjernholm plays a central role within the market for water treatment at both public and private purification plants, in sewage systems and at waterworks throughout the country. We apply up-to-date knowledge in an active manner and we are continuously working on integrating new, useful knowledge into our solutions.	●		●				
DTU	Technical University of Denmark Bygningstorvet, Building 115 DK - 2800 Lyngby +45 4525 2525 www.dtu.dk	DTU is a technical university with the vision of developing and creating value using the natural sciences and the technical sciences to benefit society. It is ranked as the best Scandinavian university, 49th best university in Europe and 119nd best university in the world according to "Leiden Ranking 2019 - impact.						●	
unibio	NY adresse	Unibio is a leading Danish industrial biotechnology company with core competencies within fermentation using methane or concentrated biogas as feedstock. Unibio has developed an innovative and unique fermentation technology - the U-Loop® - that converts methane from any source, into a highly concentrated, organic, protein product.	●	●	●			●	

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uni link	UNI-LINK ApS Sustainable Fuels Lysabildgade 63 DK - 6470 Sydals +45 5121 0019 www.uni-link.dk	Sustainable fuel supply - UNI-LINK ApS supplies biomass from agri-waste products. Olive residues as pomace (cake) or pellets.	●						
SDU University of Southern Denmark	University of Southern Denmark Campusvej 55 DK-5230 Odense M wwww.sdu.dk/en/	SDU has a wide range of activities within the biogas system toward green transition from raw materials to biogas upgrading. Specialist in 1) advanced biomass pre-treatment technologies 2) non-destructive spectroscopic biomass analysis for rapid determination of methane potentials 3) advanced bioreactor configuration for sequential fermentation and the anaerobic digestion process, 4) carbon value chain modelling of the biogas system 5) biogas upgrading associating CO_2 capture with either direct conversion into value products. We explored design and development of new biomethanation reactors from laboratory scale to pilot trial in close collaboration with the Danish biogas industry.	●	●				●	
WESTCOME HEATEXCHANGERS	Westcome Heat Exchangers A/S Saloparken 14 DK - 8300 Odder +45 2811 9105 www.westcome.com	Westcome Heat Exchangers A/S develops and supplies counter current heat exchangers for biogas plants, wastewater treatment plants and industries where heat exchange is needed on dry matter flows. Our heat exchangers operate at very low flow speeds, which mean that the pressure drop over heat exchangers is very low, resulting in the power consumption of the sludge pumps being reduced by 70-80% compared to ordinary heat exchangers. The heat exchangers are manufactured as a fully welded product without gasket and we consider maintenance costs to be non-existent and guarantee against fouling and blocking of the heat exchangers. The heat exchangers can be supplied in the size desired in length, width and height, just as the heat exchangers can operate with different flow on the two circuits.	●		●				
WH-PlanAction	WH-PlanAction Consulting Engineers ApS Danmarksvej 8 DK - 8660 Skanderborg +45 8745 3900 www.wh-pa.dk	Independent project Consultancy for Investors and Producers of biogas. With 25 years of experience, we can offer our customers planning, design, and plant establishment, as well as startup of profitable operation of modern biogas production and delivery of improved fertilizer for farmers.	●	●	●	●	●	●	
WING CONSULT	Wing Consult A/S Holtumvej 14 DK - 7400 Herning +45 7669 8384 www.wingconsult.com	An efficient management system, which is tailored to the energy sector - especially production and trading of certified biogas - ensures safe operation, documentation and traceability. Wing Consult A/S has developed a dedicated Master Master Management System (MMS-Energy), which meets all requirements for documentation of biomass balance, production potential and sustainable production & trading of biogas according to REDCert, ISCC a.o. certification schemes. Additionally the MMS-Energy includes facilities for safe operation and maintenance etc. MMS-Energy is browserbased, and the IT platform is easily integrated with other IT-platforms like finance IT.							●
Aalborg University	Aalborg University Niels Bohrs vej 8 DK - 6700 Esbjerg +45 2166 2511 www.et.aau.dk	"AAU is a well reputated Danish University with all faculties. The ranking of Engineering programs are the 4. best in the world. We do all kinds of sustainability studies and projects of green change for the world, including large projects in Renewable Energy and Energy Efficiency and Savings. Wind, solar and Bioenergy including Biogas is among the specialities in the Renewable energy areas. Biogas - AD research and projects have been one of the focus areas the last 25 years with international projects, workshops and training programs"	●				●	●	●

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