

BAT

IN SMALLER BIOGAS PLANTS IN THE NORDIC COUNTRIES



Nordic Council
of Ministers



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Preface

The Nordic Council of Ministers and the BAT Group under the Working group on circular economy have requested a Nordic expert team from NIRAS A/S and Vahanen Environment Oy, led by NIRAS A/S, to conduct a Nordic BAT project on smaller biogas plants in the Nordic countries.

The plants included in the project have a permitted treatment capacity larger than 30 tonnes of feedstock per day and up to the size when the plant falls into the scope of the industrial emission directive (IED 2010/75/EU), which in practice means up to 100 tonnes of feedstock per day.

The provided information can be utilized as inspiration by operators, environmental consultants and competent environmental authorities in environmental permit and supervision of the installations.

The project was started in November 2019 and finished in April 2020.

The Nordic BAT group has members from:

- The Norwegian Environment Agency
- Finnish Environment Institute
- Environment Agency of the Faroe Islands
- Environment Agency of Iceland
- Environmental and Health Protection Agency of the Åland Islands
- The Danish Environmental Protection Agency
- Swedish Environmental Protection Agency

The team of consultants included staff from NIRAS A/S in Denmark, Norway and Sweden and from Vahanen Environment Oy in Finland.

The team of consultants would like to thank the BAT group and the biogas sector we have been in contact with for good cooperation and valuable input.

1. Summary

The Nordic Council of Ministers and the BAT Group under the Working group on circular economy have requested a Nordic expert team from NIRAS A/S and Vahanen Environment Oy, led by NIRAS A/S, to conduct a Nordic BAT project on smaller biogas plants in the Nordic countries.

A biogas plant is a sustainable solution transforming organic residues, manure from farm animals and waste, into valuable products, digestate utilized as fertilizer and biogas utilized as electricity, heat or vehicle fuel. Advantages of biogas plants include that less leaching of nutrients to water environment is observed in some cases. Biogas can be stored before used and thereby complement fluctuating energy sources as wind and solar power in the energy system.

However, if a biogas plant is not well located, designed and operated, it can have negative impacts on environment and surrounding residence.

The provided information aims to help in design, operation and environmental permit and supervision of biogas plants that have positive environmental effects and minimum negative impacts on environment and local residence.

The specific objectives of the project are to:

- Describe the size and characteristics of the industry in the Nordic countries
- Describe the regulatory framework
- Describe the potential environmental impact from different types of biogas plants and utilization of the digestate and energy including emissions to air and odor, and emissions to soil, groundwater and surface water.
- Propose and describe techniques, which can be considered as BAT (best available techniques) used on biogas plants in the Nordic countries
- Describe emerging BAT techniques being developed and their impact on environment.

The plants included in the project have a permitted treatment capacity larger than 30 tonnes per day and up to the size when the plant falls into the scope of the industrial emission directive (IED 2010/75/EU), which in practice means up to 100 tonnes of feedstock per day. Therefore, the focus of the study is on smaller size of biogas plants handling different types of residues and wastes from agriculture, municipalities and industries.

The sector covers very different types and sizes of installation using different types of feedstocks and producing different types of products. The technical and economic feasibility, as well as the environmental impacts, of these plants varies greatly, being very much case-dependent. In addition, the location of the plant and local conditions have influenced the environmental permits.

Presented BAT candidates discussed in the report are:

- BAT 1: Location of biogas plant taken into consideration already in the planning stage of the plant to mitigate risks, impacts and nuisance to the environment and people
- BAT 2: Management system, including systematic and proactive approach in operation, maintenance, preparedness to unexpected situations
- BAT 3: Selection of suitable feedstock in co-digestion of different types of residues and wastes
- BAT 4: Procedures and provisions in receipt of feedstock that minimize water, air and odor emissions and risks
- BAT 5: Proper handling of channeled air emissions
- BAT 6: Proper handling of diffuse air emissions
- BAT 7: Flaring for safety reasons; best practices
- BAT 8: Possibilities in further processing and quality of digestate
- BAT 9: Quality of biogas for energy utilization
- BAT 10: BAT for monitoring of process

Emerging BAT techniques are not yet fully developed or in use in the industry, although they may be relevant as BAT candidates in the future. The last chapter discusses areas of research and development in the biogas sector.

2. List of abbreviations

BAT	Best Available Techniques
CHP	Combined Heat and Power
CO ₂	Carbon Dioxide
CH ₄	Methane
H ₂ S	Hydrogen Sulphide
NH ₃	Ammonia. Free form of ammonium nitrogen
NH ₄ ⁺	Ammonium. Ionic form of ammonium nitrogen
VFA	Volatile Fatty Acids
VS	Volatile Solids

3. Translation of selected words

In order to support the Nordic readers of this report and help biogas operators, authorities and others with interest in biogas exchanging experiences across the Nordic countries, selected words describing plant types, feedstocks and selected words from the headlines of this report that are important for the understanding are translated below.

English	Danish
Channeled air emissions	Rørførte luftemissioner
Co-digestion	Samudrødning
Digestate	Afgasset biomasse
Farm biogas plant	Gårdbiogasanlæg
Feedstock	Råmateriale, råvare
Flaring	Afbrænding i fakkelt
Joint biogas plants	Fællesanlæg
Manure	Gødning, gylle
Sewage sludge	Slam fra spildevandsrensningsanlæg

English	Finnish
Channeled air emissions	Kanavoidut ilmapäästöt
Co-digestion	Yhteiskäsittely
Digestate	Mädätysjäännös
Farm biogas plant	Maatilalaitos
Feedstock	Syöte
Flaring	Soihdutus
Joint biogas plants	Yhteiskäsittelylaitokset
Manure	Lanta
Sewage sludge	Jätevedenpuhdistamoliete

English	Faroese
Channeled air emissions	Útlát frá leiðingum
Co-digestion	Samroting / samsodning
Digestate	Sodnað / rotað tæð, lívtæð
Farm biogas plant	Biogassverk á garði / gassverk á garði
Feedstock	Rávøra, lívrundið tilfar
Flaring	Brenning av avlopsgassi
Joint biogas plants	Biogassverk í felag
Manure	Tæð, mykja
Sewage sludge	Spillivatnsevja

English	Icelandic
Channeled air emissions	Punktlosun
Co-digestion	Sammelting, blandað niðurbrot
Digestate	Melta
Farm biogas plant	Lífgasgerðarstöð frá býli
Feedstock	Dýrafóður
Flaring	Brennsla á afgangsgasa
Joint biogas plants	Sameiningarstöðvar
Manure	Mykja
Sewage sludge	Skólp

English	Norwegian
Channeled air emissions	Kanaliserde utslipp til luft
Co-digestion	Sam-nedbrytning, substratblanding
Digestate	Bioest
Farm biogas plant	Gårdsanlegg
Feedstock	Råmateriale, råstoff
Flaring	Fakling
Joint biogas plants	Sambehandlingsanlegg
Manure	Husdyrgjødsel
Sewage sludge	Avløpsslam

English	Swedish
Channeled air emissions	Kanaliserade luftutsläpp
Co-digestion	Samrötning
Digestate	Rötrest
Farm biogas plant	Gårdsanläggning
Feedstock	Råvara
Flaring	Fackling
Joint biogas plants	Sambehandlingsanläggning
Manure	Gödsel, stallgödsel
Sewage sludge	Avloppsslam

4. Introduction

4.1 Background and objective

The Nordic Council of Ministers and the BAT Group under the Working group on circular economy have requested a Nordic expert team from NIRAS A/S and Vahanen Environment Oy, led by NIRAS A/S, to conduct a Nordic BAT project on smaller biogas plants in the Nordic countries.

BAT is an abbreviation for best available techniques and is to be understood as environmentally "best", covering both "technologies" used and the way plants are designed, built, maintained and operated. "Available" is to be understood as techniques and technologies developed to a degree where they can be used in the sector on economically and technically sound conditions.

The specific objectives of the project are to:

- Describe the size and characteristics of the industry in the Nordic countries
- Describe the regulatory framework
- Assess the potential environmental impacts from treatment of different types of biomass (dry, wet), utilization of the digestate (e.g. as fertilizer) and utilization of the produced biogas (e.g. for electricity, heat or fuel)
- Describe BAT solutions regarding identified key environmental impacts at biogas plants
 - Diffuse and channeled air emissions, including greenhouse gas emissions and odor
 - Emissions to water
 - Process efficiency
 - Risk of contamination of soil, groundwater and surface water
 - Quality of end products: digestate and biogas
- Propose and describe techniques, which can be considered as BAT used on biogas plants in the Nordic countries
- Describe emerging BAT techniques being developed.

The provided information can be utilized by operators, environmental consultants and competent environmental authorities in design and environmental permit supervision of the installations.

Focus of the project is on environmental issues. Health and safety issues related to biogas process including safety of gas equipment and handling and storage of hazardous chemicals have not been discussed in this report.

4.2 Biogas plants in scope

The biogas plants included in the project have a permitted treatment capacity larger than 30 tonnes per day and up to the size when the plant falls into the scope of the industrial emission directive (IED 2010/75/EU), which in practice means up to 100 tonnes of feedstock per day.

Biogas plants treating biodegradable residues and wastes, livestock manure and sludges from agriculture, municipalities and industries are included. Landfill gas plants are not included in the scope of the work. However, some of the biogas plants in the scope of work also utilize landfill gas as one biogas stream.

4.3 Environmental opportunities and possible challenges of biogas

Biogas is renewable energy and is considered a green solution transforming organic residues and waste into valuable products as electricity, heat or fuel and organic fertilizer. Biogas can play an important role in agroecological symbiosis in gathering organic materials and distributing fertilizers and energy.

However, if a biogas plant is not well located, designed and operated, it can have negative impacts on environment and surrounding residence.

The objective of the project is to help avoiding these environmental problems and also help improving economy by avoiding problems.

The biogas plants covered of the project are very diverse, using many types of feedstocks, giving many types of outputs and uses of gas. This means that requirements suitable for one plant is not necessarily suitable for others. A case by case approach is therefor often needed.

4.4 Approach and methodology

Information on biogas plants, used techniques, and emissions were collected Nordic-wide from documents and contacts, supplemented by visits to plants. Plants of different types and sizes, using different types of feedstocks and having different ways to utilize products were contacted and visited to establish the broadest possible project coverage. Nordic industrial associations were also contacted.

In identifying the BAT candidates, a longlist of them was first developed. The shortlist of BAT candidates was then prioritized from the longlist according to the following priorities:

- BAT addressing the identified main environmental indicators
- BAT assessed to significantly reduce emission and impacts
- BAT which are economically and technically viable considering cost and advantages
- BAT primarily developed or originating in the Nordic countries

4.5 Team of consultants

The following consultants from Denmark, Finland, Sweden and Norway have contributed to the report or to the technical background:

Core team:

- Birgitte Holm Christensen, NIRAS A/S (Project Manager)
- Anne Seth Madsen, NIRAS A/S
- Esa Salminen, Vahanen Environment Oy

Support team:

- John Sternbeck, NIRAS A/S
- Linnéa Thunberg, NIRAS A/S
- Pål André Zazzera Johansen, NIRAS A/S
- Ole Møller Jensen, NIRAS A/S
- Lotte Weesgaard, NIRAS A/S
- Riikka Kantosaari, Vahanen Environment Oy

4.6 BAT Group

The BAT project has been followed and commented by the Nordic BAT Group. The members of the BAT Group are:

- Anne Kathrine Arnesen, The Norwegian Environment Agency
- Kaj Forsius, Finnish Environment Institute
- Lena Ziskason and Ingvar Fjallstein, Environment Agency of the Faroe Islands
- Einar Halldorsson, Environment Agency of Iceland
- Mikael Stjärnfelt, Environmental and Health Protection Agency of the Åland Islands
- Mette Lumbye Sørensen, Danish Environmental Protection Agency
- Elin Sieurin, Swedish Environmental Protection Agency

5. The biogas process

This chapter gives a brief introduction to the biogas process. For more thorough introduction, the reader may need to consult educational books or other material. The introduction intends to give a basis for the dialogue between authorities, operators and other interested parties.

In a biogas process, organic matter is biologically converted into biogas and digestate under absence of oxygen. Biogas can be produced from almost any organic material, for example from biomass and wastes and sludge from households, agriculture and industry. Biogas contains methane, carbon dioxide and smaller amounts of other gases and it can be used for energy purposes. The nutrient-rich digestate is the degassed organic material and can be used in land applications or fertilizer production. Since the process occurs under absence of oxygen it is also referred to as anaerobic digestion. The process has been known for more than 4000 years as a way to produce energy. It is a natural process, which occurs also in the nature.

At a biogas plant, the *feedstock* material is often *pretreated* prior to the anaerobic digestion. For only manure treating plants this is not always the case. The pretreatment can include mixing of different types of materials (co-digestion), homogenization, hygienization and mixing or dilution to the desired dry matter content of feedstock. Although also the biogas process itself destroys pathogens, depending on the feedstock (e.g. slaughterhouse waste) hygienization or pasteurization before or after anaerobic digestion may be required.

After a pretreatment, the input material is *digested* by microorganisms under anaerobic conditions. Proteins, hydrocarbons and lipids degrade in the process into volatile fatty acids and further to methane (CH_4 , 50–70%), carbon dioxide (CO_2 , 30–50%) and other gases (hydrogen (H_2), hydrogen sulphide (H_2S), ammonium compounds (NH_x) etc.) in cooperation of different types of anaerobic microorganisms. Biogas yield from different types of wastes varies a lot. Methane yield from manure can be 7–20 $\text{m}^3 \text{CH}_4/\text{t}$ wet weight (100–400 $\text{m}^3 \text{CH}_4/\text{t}$ VS) when the yield from bio-waste can be 100–150 $\text{m}^3 \text{CH}_4/\text{t}$ wet weight (500–600 $\text{m}^3 \text{CH}_4/\text{t}$ VS).

The *digestate* contains the same nutrients as the feed. Part of the nitrogen will be mineralized (transformed into ammonium, NH_4^+). The digestate is nutrient-rich biomass, which shall be stored and spread properly as described in later chapters.

After the biogas process, the volume of the digestate is roughly the same or slightly reduced as that of the feedstock. Digestate can be utilized in land applications or further processed into recycled fertilizer products.

Figure 1 gives a schematic overview of the typical biogas process.

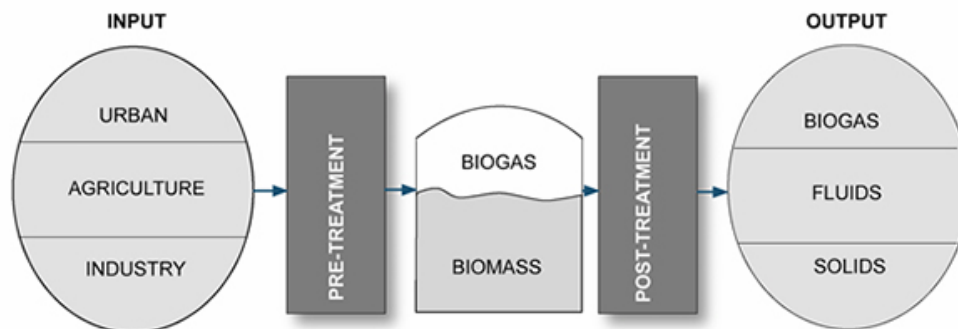


Figure 1: Schematic overview of the biogas process. The size of the inputs and outputs in the circles to the left and right does not necessarily correspond with the sizes of the real amounts in a biogas plant.

There are different technology alternatives and process modifications. In a traditional *wet digestion* process the feedstock is mixed or diluted into dry matter content of 5–15%, whereas in *dry digestion* the dry matter content can be up to 15–40% dry matter. Wet digestion is the most common plant type, since it is a very proven and robust construction. Dry or solid process does not necessarily require additional liquid in the feed, and is best suited for such feedstocks, which have high solid content. There are also other plant types, such as *upflow anaerobic sludge blanket* technology, also referred to as UASB technology, which is a type of biogas process that is used for wastewater treatment, not further discussed in this context. Biogas process can operate as a *batch* or *continuously*. Continuous operation is the more common option.

The *retention time* of the biogas process may vary greatly depending on the process conditions, feedstock materials and desired end products from 20–30 days up to 60–70 days. Generally, the longer the retention time is, the larger digester is needed, which will increase the investment cost of the installation. Too short retention time may produce an end product that is not mature and is potentially a source of odor and other air emissions such as methane.

Biogas processes typically operate either in *mesophilic* temperatures (approximately 35°C) or in *thermophilic* temperatures (approximately 55°C). Mesophilic process is generally more stable and requires less energy for heating. Advantages of thermophilic conditions include usually faster treatment time and better reduction of pathogens in the process. On the other hand, the process is more sensitive to inhibition of ammonia. Ammonia is a degradation product of proteins and other nitrogen containing materials and in high concentrations it inhibits activity of the methane producing microorganisms.

The digestion process bases on complex cooperation of different types of microorganisms. Number of factors can affect the process performance and shall be monitored for successful performance. Rapid change in raw materials or mix of raw materials, temperature or pH and long-term accumulation of intermediate products of degradation can have adverse impact on the process. In worst case, biogas production is totally inhibited, which may increase accumulation of intermediate products of degradation including volatile fatty acids, drop of pH, foaming or other consequences of potential risk of stopping the process.

The biogas process needs close monitoring, especially in the start-up, and if

conditions or feedstock are changed. *Co-digestion*, where different types of feedstocks are mixed, may improve the process performance by optimizing the content of e.g. nitrogen and Sulphur (discussed further in the following chapters).

6. The Nordic biogas industry

6.1 Biogas as part of the renewable energy sources in the Nordic countries

In the Nordic countries, renewable energy from wind power, hydropower, geothermal energy and biomass plays a significant role in the energy production.

The EU is the world leader in biogas electricity production as well as for the use as a vehicle fuel or for injection into the natural gas grid (Scarlat;Dallemand;& Fahl, 2018). Figure 2 shows the number of biogas plants in European countries.

The number of biogas plants per capita in the Nordic countries is a good European average, see Figure 3, and the number of plants is growing. In Denmark, there are more agricultural plants over others, whereas in Finland and Sweden biogas plants treating sewage sludge and mixed feedstock are dominant in treatment volumes. In Norway, biogas plants treating sewage sludge are dominant.

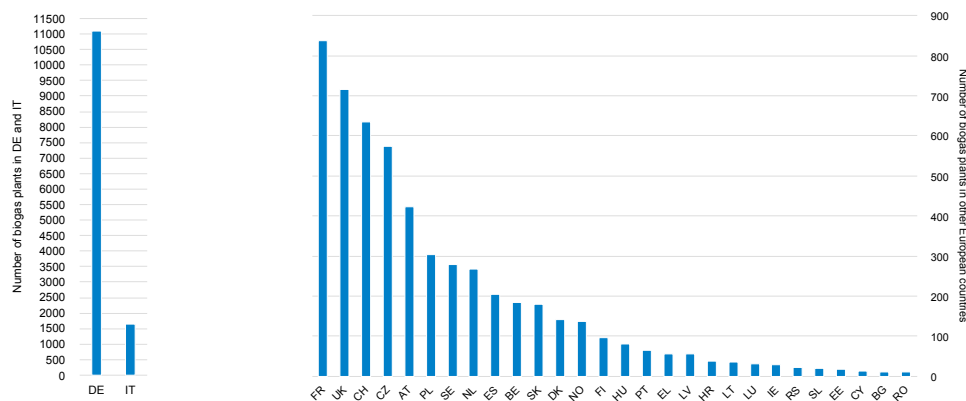


Figure 2: Number of biogas plants in European countries, arranged in descending order (European Biogas Association, 2019).

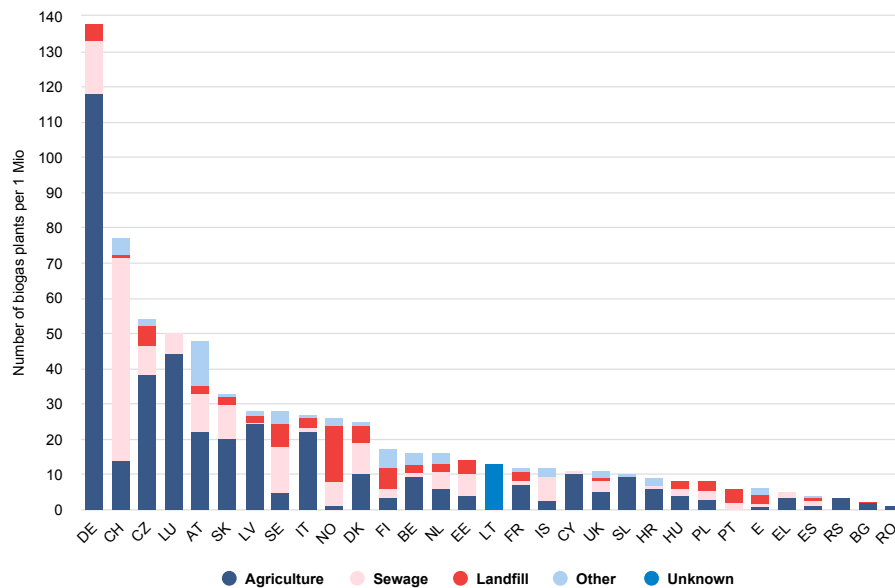


Figure 3: Number of biogas plants (total and by feedstock type) per 1 Mio capita in European countries in 2018, arranged in descending order (European Biogas Association, 2019).

6.2 Biogas industry in Denmark

The biogas industry has been growing in Denmark the past 10 years as seen in Figure 4. State subsidies helped the growth, so the biogas production reached more than 13,000 TJ in 2018.

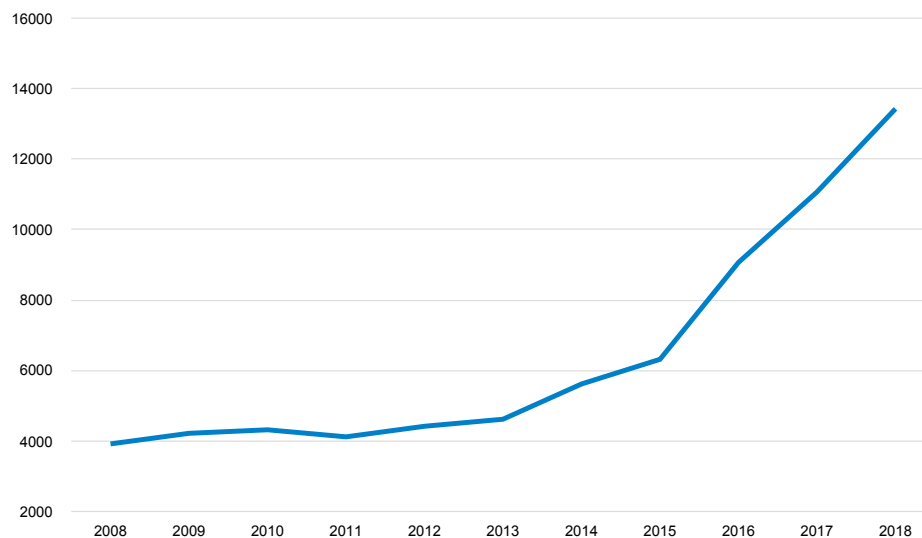


Figure 4: Biogas production in TJ in Denmark from both large and smaller-sized biogas plants, based on energy statistic for 2018 (newest yearly statistic) from the Energy Agency (Energistyrelsen), 2020.

According to (Energistyrelsen, 2019) the Danish biogas plants mainly use livestock manure from farm animals, sewage sludge and organic waste and residues as input material. More than 75% of the input biomass is animal manure in those of the biogas plants that are placed on farms or are built as joint biogas plants receiving biomass from more than one farm. The joint biogas plants are marked with dark green in Figure 5 and is the type of biogas installation with the largest growth from 1995 to 2018. Energy crops as corn and beets can be used for biogas but are not regarded to give as much advantage for the climate and the subsidies are therefore limited.

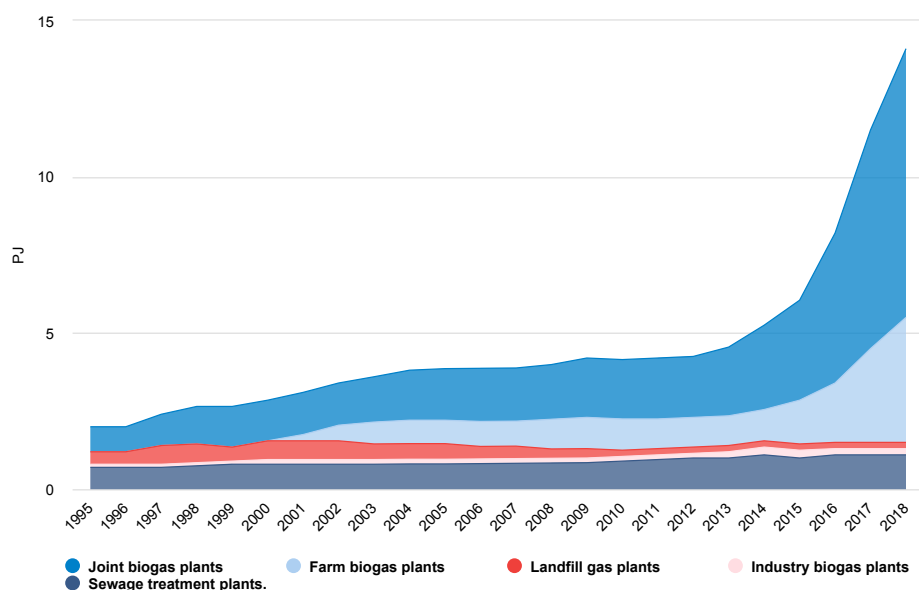


Figure 5: Types of biogas production facilities in Denmark 1995–2018 (Biogasbranchen, 2020).

The Danish Environmental Protection Agency (EPA) runs a database where the permit and inspection authorities fill in information about permitted facilities, including also biogas plants listed as list point number J 205 in the statutory order on permission (Bekendtgørelse om godkendelse af listevirksomhed, BEK nr 1534 af 9/12/2019). The plants listed as "J 205" use feedstock amounts of 30 to 100 tonnes per day and thus they are within the scope of this project. The database can be accessed by the public. A search in the database was made and the result is shown in Figure 6. There are 48 biogas plants within the scope of this project. Most biogas plants are situated in the western part of Denmark, whereas no plants are situated in the north-eastern part, near the capital of Copenhagen (København). A single biogas plant is situated on the eastern island of Bornholm.

The Energy Agency also has a list of biogas plants. The list was updated in March 2017. Of the 48 plants with permits from the list generated by the database of the Danish EPA, 26 of them can be identified as farm biogas plants by making cross reference to the list from the Energy Agency. Since the list from the Energy Agency is

from 2017, the number may have changed since then, but it gives the impression that approximately half of the plants are farm biogas plants.

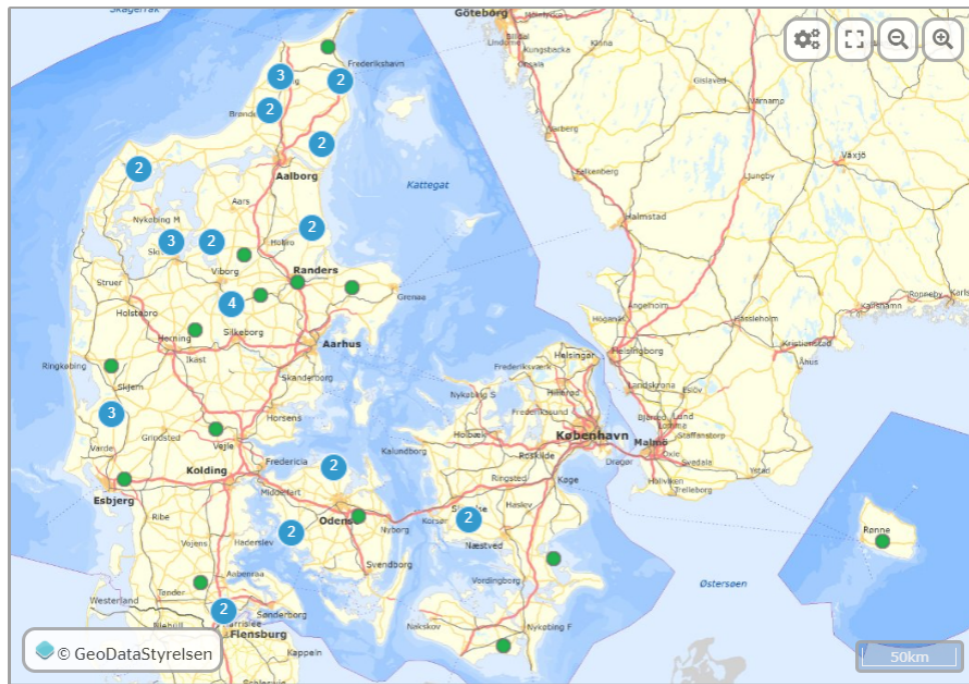


Figure 6: Danish biogas plants with environmental permit, using 30–100 tonnes of feedstock. Numbers in blue circles indicate concentration of biogas plants. Green circles indicate single biogas plants.

Besides these plants, the Energy Agency also lists 51 biogas plants situated at waste water treatment plants and 26 plants at landfills.

6.3 Biogas industry in Finland and Åland

Most of the biogas plants at municipal wastewater treatment plants in Finland were constructed in the 1980s. Most of municipal wastewater sludge produced in Finland is treated at biogas plants either at municipal wastewater treatment plants or at centralized biogas plants. Industrial plants in food and forest industry have only a few biogas plants.

The centralized biogas plant of Stormossen taken into operation in 1990 was the first biogas plant in Finland to treat mixed feed. Biogas from the Stormossen plant has been used as vehicle fuel since 2017.

The centralized biogas plant at Vehmaa was the next centralized biogas plant in operation since 2005. Most of the currently operating centralized biogas plants were put into operation in 2010s. In 2016, Gasum Oy took over seven existing biogas plants in Finland and five biogas plants in Sweden and have become the significant Nordic operator in the sector.

The first farm scale biogas plant of Kalmari in Laukaa has operated since 1998. The

farm has the first public fueling point since 2004. The farm scale plants comprise approx. one third of the number of all biogas plants in Finland, but their biogas production capacity is only approx. 3%.

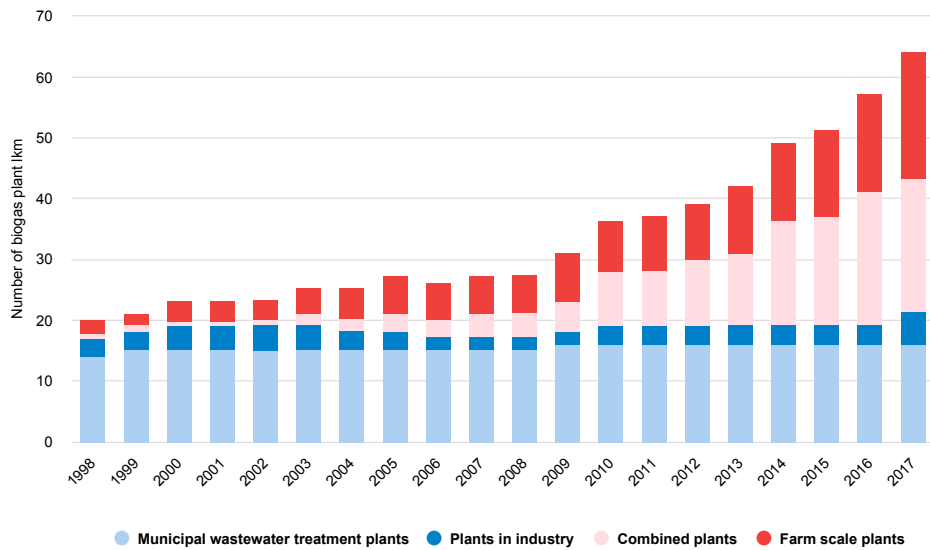


Figure 7: Number of plants in operation in Finland and Åland in 2017 (Winquist;Rikkonen;& Varho, 2018).

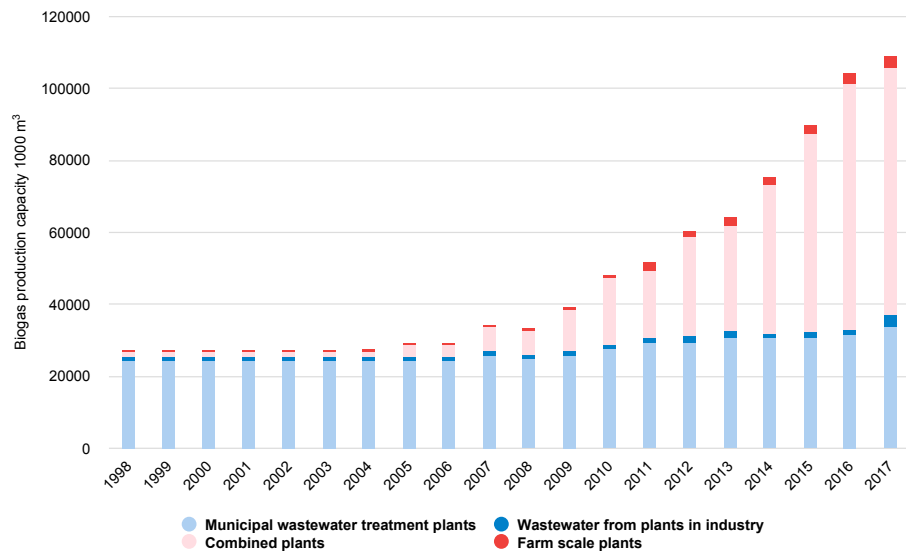


Figure 8: Biogas production capacity in Finland and Åland in 2017 (Winquist;Rikkonen & Varho, 2018).

According to the statistics information from 2017, there are approx. 61 biogas plants in Finland:

- 15 plants at municipal wastewater treatment plants
- 3 plants in industry
- 21 farm biogas plants
- 22 centralized plants treating mixed feedstocks

Approx. 15 plants of these are in the size range of 10,000–30,000 tonnes per year:

- 3 plants at municipal wastewater treatment plants
- 2 plants in industry, food manufacturing plant of Apetit Oyj, Säkylä and Stora Enso Heinola Fluting Mill
- Others treat mixed feeds

In Åland, according to the statistics information from 2017, the biogas plants of the dairy Ålandsmejeriet, Jomala (in operation since 2010) and waste water treatment plant of Mariehamn (in operation since 1979) are in the size range of 10,000–30,000 tonnes per year. In addition, the food manufacturing plant of Orkla Confectionery & Snacks Finland, Godby has a biogas plant (in operation since 1984).

Biogas is utilized at combined heat and power (CHP) plants, in heat production and as vehicle fuel. In 2017, biogas was utilized 520 GWh as heat, 178 GWh as electricity and 30 GWh as vehicle fuel. In 2017, energy production was 377 TWh in Finland and Åland, of which renewable energy comprised 136 TWh. Biogas energy (0.7 TWh) was 0.5% of renewable energy. There is a large potential, especially in agricultural biomass to increase biogas energy production in Finland and Åland.

6.4 Biogas industry in the Faroe Islands

The first biogas plant in the Faeroe Islands is currently under construction nearby Torshavn, see Figure 9. The biogas plant handles livestock manure and sewage sludge from fish production on land along with ensiled dead salmon from salmon production at sea and on land. The biogas plant is built to handle approx. 100,000 tonnes of biomass per year but has environmental permits to handle 50,000 tonnes. The biogas is used in a combined heat and power (CHP) plant, and electricity and heat are sold to the local grid. The biogas and CHP plant are owned and operated by P / F Førka, which is a subsidiary of P / F Bakkafrost. The biogas plant will start with livestock manure in ultimo February 2020 and other biomass from June 2020.



Figure 9: Færka Biogas plant nearby Tórshavn during construction (Heini Ellingsgaard, SMJ Consulting Engineers, November 2019).

6.5 Biogas industry in Iceland

A new biogas and composting plant for the Capital Area of Reykjavik will be operating by February 2020. The plant is part of a joint waste management policy by the municipalities for 2009–2020. Once the biogas and composting plant is operational, all household waste collected in SORPA's domain will be processed at the plant. Organic matter will be used for biogas production and composting, while metals and inorganic matter will be mechanically sorted for recycling.

Each year, the plant will generate 3 million Nm³ of methane gas, which can be used as vehicle fuel and 10–12,000 tonnes of soil improvers, which are useful for soil conservation. Once the biogas and composting plant is up and running, over 95% of the household waste generated in the Capital Area will be reused. (SORPA, 2020)



Figure 10: New biogas and composting plant (SORPA, 2020).

6.6 Biogas industry in Norway

According to the Norwegian waste treatment and recycling organization (Avfall Norge), there are 14 (soon 15) Norwegian biogas plants are producing in excess of 50 ton per day for commercial purposes. Additionally, there are several municipal organizations producing biogas for their own consumption.

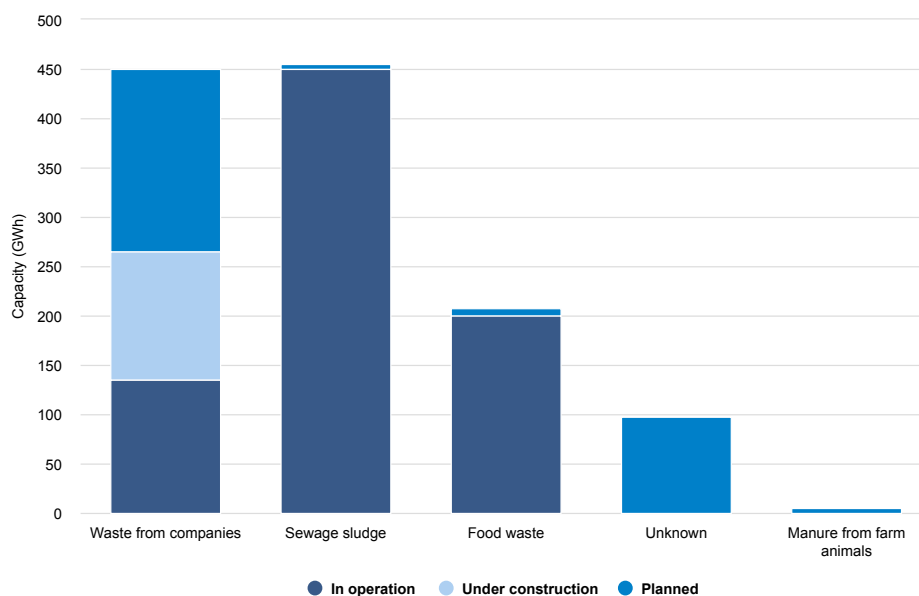


Figure 11: Norwegian biogas capacity per 2017 (Sund, 2017).

Households are source separating their food waste in several communities in Norway. That might be a reason why food waste, together with sewage sludge, are the main feedstocks for plants in operation (dark blue columns) as seen in the Figure 11.

In Norway, the transport in heavy vehicles is seen as an important market for biogas, since tanks with content weighs less than batteries with comparable energy content. A potential upcoming market is machines at construction sites, where it can be practical and cost effective to deliver liquified biogas (Sund, 2017), but today the main market is bus fleets.

6.7 Biogas industry in Sweden

The total use of biogas in Sweden was app. 3,7 TWh (13 PJ) in 2018, which was an increase of 29 percent compared with 2017. Of this, app. 2,1 TWh (8 PJ) was produced in Sweden and the import of biogas in 2018 was app. 1,6 TWh (6 PJ), mainly from Denmark.

Figure 12 shows the amount of biogas produced in different plant types in Sweden.

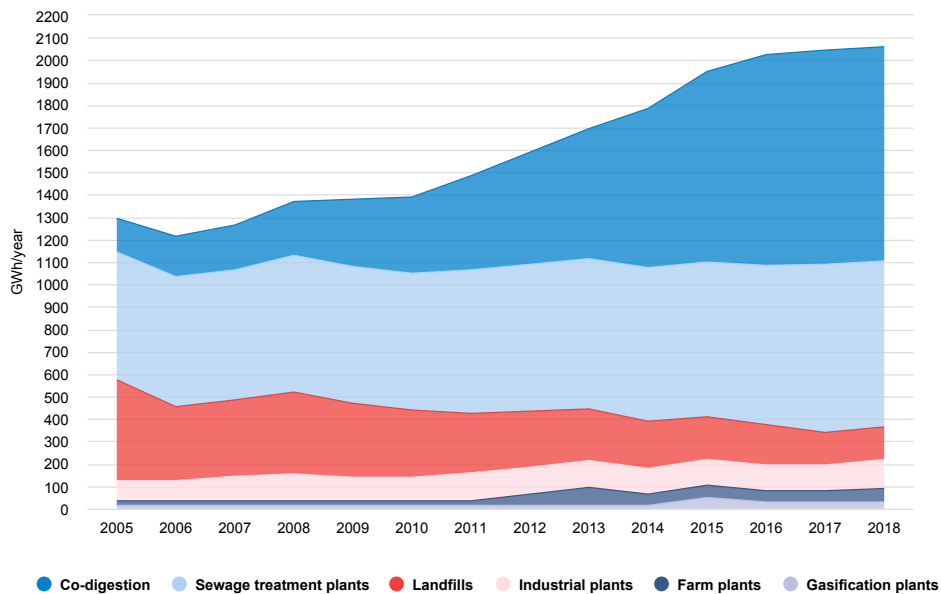


Figure 12: Biogas production per type of plant 2005 – 2018 in Sweden (Energimyndigheten/Energigas Sverige, 2020).

According to the Swedish biogas association, Energigas Sverige, 73 Swedish biogas plants handle material in the size range 30–100 ton per day. These plants are divided into four categories: farm facility plants (mainly manure), industry (only one plant handling waste from sugar beets), sewage treatment plants and co-digestion (organic waste from households, industries, slaughterhouses, manure etc.). The main category consists of the sewage treatment plants.

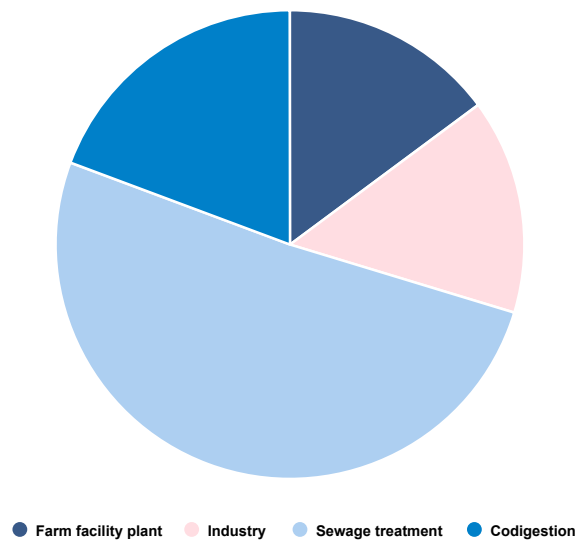


Figure 13: The four different categories of Swedish biogas plants in the size range of 30–100 ton/day.

The Swedish EPA, Naturvårdsverket, covers a database of around 200 plants subject to a permit. When the list from Energigas Sverige and the list from Naturvårdsverket were synced 28 plants remain in the size range of 30–100 ton per day, subject to a permit according to Swedish environmental law.

7. Brief regulatory overview

7.1 Regulatory overview for Denmark

The Danish Environmental Protection Agency issues environmental regulation relevant for biogas plants. Biogas plants using feedstock of 30 tonnes per day or more shall have an *environmental permit* according to the Danish statutory order on Permit of listed activities (Bekendtgørelse om godkendelse af listevirksomhed, BEK nr 1534 af 9/12/2019). The statutory order implements several EU directives such as the Industrial emissions directive and the directive on the control of major accident hazards involving dangerous substances (the "Risk directive"). The statutory order also contains national rules. Biogas plants with a capacity for raw material feedstock between 30 and 100 tonnes per day are listed as activity J 205 in annex 2 of the statutory order and will have the relevant municipality as permitting authority. If, however, the plant is covered by the risk regulation for example due to storage of larger amounts of biogas, (Bekendtgørelse om kontrol med risikoen for større uheld med farlige stoffer, BEK nr 372 af 25/04/2016) the state can be the authority.

Other relevant legislation and guidance includes:

- Statutory order on environmental impact assessment of plans and programs and specific projects (Bekendtgørelse af lov om miljøvurdering af planer og programmer og af konkrete projekter (VVM, BEK 1225 af 25/10/2018) implements the EU Directives on impact assessment from 2001, 2011 and 2014. A screening for impact assessment needs to be done before building a new biogas plant.
- A statutory order and guidance for communities on planning in areas with special interests for drinking water a number of industries that are seen as potentially threatening are listed, BEK nr 1697 af 21/12/2016 and guidance here to.
- A handbook on environment and planning (Miljøministeriet, 2008) gives guidelines on *where to place* biogas plants and recommends the distance to nearest neighbor in city area.
- Statutory order with standard requirements for the permitting of certain activities (Bekendtgørelse om standardvilkår i godkendelse af listevirksomhed. BEK nr. 1537 af 9/12/2019). Section 16 describes the *standard requirements* for biogas plants (J 205) receiving raw materials such as waste and/or manure from farm animals. The standard requirements include reception and storage of manure and other types of biomass, cleaning of vehicles used for transport of biomass, heating of biomass, anaerobic digestion, separation of digestate and storage of the separated biomasses and upgrading and storage of biogas. The environmental issues regulated include air emissions (odor, hydrogen sulfide, dust and ammonia), noise and pollution of soil and ground water or surface water. The permitting authority shall use the standard requirements as a basis for the permit but can set other requirements if the requirement is not balanced between environmental effect and economics or if it's not relevant.

Furthermore, guidances on risk, air emissions, odor and noise support the permitting

process

Regarding input of raw material and output of digestate, following is relevant:

- Statutory order on use of waste for agricultural purposes (Bekendtgørelse om anvendelse af affald til jordbrugsformål, BEK nr 1001 af 27/06/2018) sets 2 limits in its annex for waste input to biogas plants mainly using manure from farm animals. The limits are on heavy metals, LAS, PAH, NPE, DEHP and PCB7.
- The animal by-products regulation (REGULATION (EC) No 1069/2009 of the European parliament and of the council, decided 21/10/2009) is general within the EU and states the terms for prevention of spread of diseases within the processes of moving materials of animal origin not intended for human consumption. It states that treatment in biogas plants can be suitable for several of such products.
- Statutory order on Sustainable production of biogas from the Energy Agency (Bekendtgørelse om bæredygtig produktion af biogas, BEK nr 301 af 25/03/2015) states that sustainable biogas production mainly shall be based on residual and waste products. It limits the percentage of energy crops in the raw material used.
- Statutory order on environmental regulation of animal stock and on storage and use of fertilizer (Bekendtgørelse om miljøregulering af dyrehold og om opbevaring og anvendelse af gødning /BEK nr. 760 af 30/07/2019).

7.2 Regulatory overview for Finland

Environmental permits on biogas plants are based on the renewed Environmental Protection Act (527/2014) and Decree (713/2014, amended 584/2017). According to the Decree, the Regional State Administrative Agencies (AVI) in Finland license biogas plants with production capacity of 20,000 tonnes per year or more. Municipality is the permitting authority for smaller installations.

Often, professional handling of waste triggers needs of environmental permit of biogas plant, whereas for smaller plants cases may vary. Also, large scale animal farming needs an environmental permit and if only biomass waste of own farm is treated, the permit can be integrated in the environmental permit of the farm.

The Centers for Economic Development, Transport and the Environment (ELY Centers) supervise adherence to the environmental and water permits granted by AVI. Municipalities supervise the environmental permits they grant.

The Finnish Safety and Chemicals Agency (Tukes) licenses and supervises the safety of products, services and industrial activities in Finland. Several acts and decrees regulate e.g. safety of gas equipment and handling and storage of hazardous chemicals.

The Finnish food safety authority grants authorization for biogas plants for the fertilizer use of digestate. Furthermore, fertilizer products placed in markets in Finland must be included either in the national type designation list of fertilizer products or, in the case of EC fertilizers, in the list of types of EC fertilizers designations specified in Annex I to EC Regulation 2003/2003.

National Fertilizer must meet the requirements set out in Finnish Fertilizer Act (539/2006), which ensures that all fertilizer products placed on the market in Finland are safe, of good quality, and suitable for plant production. The Decree of the Ministry of

Agriculture and Forestry on Fertilizer Products (24/2011) regulates the requirements for the type designation list and the requirements for quality, marking, packaging, transport, storage, usage and other requirements as well as the raw materials used in fertilizer products. Use of sewage sludge in agriculture is regulated by Government Decree 282/1994.

In addition, several laws, decrees and standards are applicable for constructing a biogas plant as well as for raw materials and products, depending on the nature of materials treated, produced and plant operations.

Environmental impact assessment (EIA) is required according to the Law 252/2017 and Decree 277/2017 for plants with production capacity of 35,000 tonnes per year or more and therefore generally not applicable for smaller biogas plants.

The animal by-products regulation is general within the EU and states the terms for prevention of spread of diseases within the processes of moving materials of animal origin.

7.3 Regulatory overview for Faroe Islands

The Faroe Islands have an independent position in the Kingdom of Denmark and are not members of the EU or EEA. The Faroe Islands therefore have their own laws in most areas. Industrial plants are regulated in accordance with Chapter 5 of the Environmental Protection Act of 1988.

7.4 Regulatory overview for Iceland

Act no. 7/1998 on hygienic and pollution control outlines the environmental legislation on industrial activities in Iceland. For small and medium size biogas plants the municipality will be the permitting authority. Larger plants of IED size will have the Environment Agency of Iceland as permitting authority.

7.5 Regulatory overview for Norway

New biogas plants must apply for a permit according to the Pollution Control Act (forurensningsloven) from the County Governor (Fylkesmannen).

For biogas production from sewage sludge, the biogas plant may be considered an integrated part of the waste water treatment facility, and thus incorporated into its permits.

New biogas plants may be asked for a screening according to regulation on environmental impact assessment of plans and programs and specific projects (Forskrift om konsekvensutredninger).

The Norwegian fertilizer regulation (Forskrift om gjødselvarer mv. av organisk opphav) sets out quality requirements for fertilizer products from organic raw materials. § 10 defines "quality classes" for fertilizers, with their associated limits for metal content and §25 sets requirements for use of fertilizer products containing sewage sludge.

The animal by-products regulation of EU is implemented in national regulation in Norway. It states the terms for prevention of spread of diseases within the processes of moving materials of animal origin.

If the biogas plant stores large amounts of biogas, the regulation on control of major accident hazards involving dangerous substances may be relevant (Forskrift om tiltak for å forebygge og begrense konsekvensene av storulykker i virksomheter der farlige kjemikalier forekommer (storulykkeforskriften)).

7.6 Regulatory overview for Sweden

In Sweden there are different types of requirements, depending on the size and type of plant and this is regulated in a specific ordinance on environmental permit, Miljöprövningsförordningen (2013:251). Some types of plants are subject to permits which are applied for at either one of the 12 "Miljöprövningsdelegationerna" in Sweden or at one of the five land and environmental courts, depending on the size and/or the environmental impact of the plant. However, none of the plants within this study are of the size that needs a permit from the court. Some of the plants within the size range of 30–100 ton per day do not need a permit, but instead they must be notified to the supervisory authority.

For biogas production from sewage sludge, the biogas plant may be considered as an integrated part of the waste water treatment facility and thus incorporated into its permits.

The plants with a permit need to report their environmental issues each year to the supervisory authority ("Tillsynsmyndigheten"). The reports are in accordance with the terms in the permits.

Other required laws and regulations of importance include:

- The law that serves the workers right ("Arbetsmiljölagen SFS 1977:1160"). This law is general at all workplaces in Sweden. A plan for the working environment has to be made out.
- Regulation on environmental impact assessment of plans and programs and specific projects ("Miljöbedömningsförordning 2017:966").
- The animal by-products regulation is general within the EU and states the terms for prevention of spread of diseases within the processes of moving materials of animal origin. You have to hand in an application to the Swedish agricultural agency ("Jordbruksverket"), describing the process thoroughly.
- In the same process of applying to the local municipality for an allowance of construction ("bygglov"), you also have to hand in an application concerning the handling of flammable and explosive goods within the biogas plant. This according to the law of flammable and explosive goods ("Lag (2010:1011) om brandfarliga och explosiva varor").
- The law of protection against accidents ("Lag (2003:778) om skydd mot olyckor") states that you should have a plan for emergencies within your company, which is of high importance within bigger plants. You should also work with preventative actions.
- If you handle large amounts of chemicals within the plant or if the amount of stored biogas is large, you are probably concerned by the Seveso regulations

stating that you should prevent and limit the impact of serious chemical accidents ("Lag (1999:381) om åtgärder för att förebygga och begränsa följderna av allvarliga kemikalieolyckor").

7.7 Regulatory overview for Åland Islands

Åland has its own provincial laws in a number of important areas based on its autonomous position. The environmental licensing for industrial plants is outlined in the Provincial law on environmental protection (ÅFS 2008:124, ändrad ÅFS 2015:14) and decree (ÅFS 2008:130, ändrad ÅFS 2015:15). The permitting authority is the environmental and health protection agency of Åland (ÅMHM).

Often professional handling of waste triggers needs of environmental permit of biogas plant, whereas for smaller plants cases may vary. Also, large scale of animal farming needs an environmental permit and if only animal waste of own farm is treated, the permit can be integrated in the environmental permit of the farm.

Waste management is regulated in Åland by the Landskapslag (2018:83) om tillämpning av rikets avfallslag and Landskapsförordning (2018:90) om avfall.

Ålands Landskapsregering (ÅLR) licenses and supervises the safety of products, services and industrial activities.

8. Environmental impacts from biogas production

8.1 Process efficiency

The efficiency of the process is an environmental impact regarding resource efficiency and circular economy. A high efficiency means high yield in form of a large output of valuable biogas from the input of feedstock and/or good quality digestate. Efficiency of the biogas plant mainly correlates how well the process functions. If the process functions well and there are no process disturbances, energy efficiency is good and digestate is of good quality, and vice versa.

8.2 Emissions to air including odor

Potential air emissions from biogas plant processes include:

- Methane (CH_4), which is a strong greenhouse gas and also a potential health and safety risk
- Ammonia (NH_3), which can lead to excessive levels of nutrients in the environment and is also odorous
- Other odor compounds, including dihydrogen Sulphide (H_2S), other Sulphur compounds, as well as volatile fatty acids (VFA), which are intermediate products of anaerobic degradation.

A biogas process is a closed process. However, potential sources of air emissions are reception of feedstock, digestate storage, leaks and disturbances of the process. Looking at the stages before the biogas process, emissions to air occur from stables with farm animals. After the biogas process also, the spreading of digestate on land can lead to air emissions, however typically lower than if the feedstock was spread directly on land without going through a biogas process.

Minimization of leakage of methane is important. Studies based on measurements showed losses of 4,2% of the produced biogas before repair of leakages and 0,8% after (Danish Energy Agency, 2016)

Also, traffic to and from the plant causes air emissions.

8.3 Contamination of soil and water

Risk of contamination of soil and water can be seen in relation to rain water from reception of feed, vehicle wash and storage areas since these waters potentially contain organic matter and nutrients and may require treatment. If it's not adequately collected, treated and spread it may pose a risk of contamination of soil, groundwater and surface water.

Digestate utilization has the environmental advantage that it reduces the use of mineral fertilizer. However, it can pose potential risk of contamination of soil, groundwater and surface water (nutrients and hazardous substances), if used inappropriately. In EU / Nordic countries, legislation gives rather strict regulations on what type of material, how much and how it can be spread in soil. There are limits for heavy metals, pathogens as well as maximum application of nutrients per land area as described in the section, Brief regulatory overview.

If digestate is dewatered to separate solid phase from liquid phase and the liquid phase cannot be returned to the process or utilized in agriculture, such as in plants for sewage sludge, it needs treatment. This wastewater has high organic matter and nutrients, especially NH_4 content.

8.4 Noise

Traffic as well as vehicles, pumps, fans, gas compression and possible pretreatment e.g. shredding produce noise. Noise can be reduced by regular maintenance of fans, motors, etc. using noise shields where possible, enclosure of units, using silencers and slow rotating fans. This is general aspects in most industries and not included in the description of BAT techniques in the next chapter.

8.5 Variations in environmental impacts

Environmental impacts of biogas plant can vary greatly at different plants for several reasons:

- Location of the plant. In particular odor may cause problems if there are adjacent residential houses. Almost every plant causes odor sometimes.
- Environmental impacts of biogas plant need to be carefully assessed, in particular if the site is ecologically sensitive. Location of biogas plant on important groundwater area is not recommended and may not be in accordance with regulation or guidance. If rainwater or wastewater is planned to be discharged in the environment, impacts on receiving water body/course and needed treatment need to be carefully assessed.
- Type of feedstock and how material is handled by far determines the environmental impacts. Different materials require different treatment and all materials are not suitable in every location and process as further discussed in the following. For example, Restrictions are set when sewage sludge is used.
- Generally, the larger the plant is, the larger the potential impacts, but not always. Larger plants can be more stable to operate. Therefore, smaller plants can be even a bigger risk of e.g. odor emissions if operation is not professional. Smaller plants may be run as part of farm operations with less resources in monitoring of the process.

BAT candidates are described within key environmental impacts and are discussed in Chapter 9.

9. BAT techniques

When identifying the techniques that can be considered as BAT, a longlist was first developed. The shortlist of was then prioritized from the longlist according to the following priorities:

- BAT addressing the identified main environmental indicators
- BAT assessed to have a significant reduction in emission and impacts
- BAT which is economically and technically viable considering the cost and advantages
- BAT which is primarily developed or originates in the Nordic countries

The sector covers very different types and sizes of installation utilizing different types of feedstock and producing different types of products. The technical and economic feasibility, as well as the environmental impacts, of the plants varies greatly, being very much case-dependent. In addition, the location of the plant and local conditions have influenced the environmental permits.

Examples of techniques that can be seen as BAT are described below. Emission and consumption are described on a general level. To illustrate how the technique is used and which challenges it solves, examples are given.

Not all techniques are suitable for all types of plants, which is described under "applicability".

In some cases, a technique leads to new environmental impacts that need to be considered before one chooses to use the technique. For instance, cleaning of gas with a scrubber leads to waste water. That is described as "cross-media effect".

Finally, economic considerations are described for each technique.

9.1 BAT for location of biogas plant

9.1.1 Description of technique

Already in the stage of planning of a biogas plant, location is very important.

Most important is distance to closest residential houses and other sensitive receptors because even a well operating biogas plant may sometimes cause nuisances, odor and noise. In addition, it can be seen as BAT to consider infrastructure since biogas plants based on manure from more farms, organic household waste or different sources of biomass increase traffic, the larger the plant, the more traffic. In order to minimize transportation, the possibility to get feedstock and to utilize the digestate near the plant are also important aspects. Also, distance to nearest heat or gas market is relevant.

Ecological settings of plant location must be carefully considered and legislation and guidelines regarding localization near ground water resources or other requirements must be fulfilled.

Location of biogas plant is also a safety question because of risk of fire or explosion.

Examples:

In Denmark, a handbook on environment and planning (Miljøministeriet, 2008) is often used as guidance when a biogas plant is to be located. It includes the parameters of noise and harmless emissions such as odor – not groundwater protection, which is dealt with in other guideline. A Danish biogas plant was placed near a large slaughterhouse. Good transportation possibilities and closeness to the slaughterhouse that delivered feedstock were in focus when localization was decided.

In Sweden a biogas plant was located at a sugar factory making it possible to utilize the residues from the sugar production.

In Iceland the biogas plant under construction mentioned in chapter 6 is going to utilize organic waste from households and therefore a location near the capitol is rational.

Another example of a good location of biogas plant treating mixed feedstock is an old landfill area, where also the landfill gas is utilized at the biogas plant.

9.1.2 Emission and consumption figures

Depending on location and the nearby landscape and local weather conditions, impacts of emissions on people and environment are different but a certain distance to nearest neighbors ensures that possible emissions will be diluted and reduce the impact.

9.1.3 Applicability

Applies to all plants.

9.1.4 Cross-media effect

None identified.

9.1.5 Economics

If a location significantly increases the needed transportation distance or time for the plant, it may also increase the cost of transportation of raw materials and products.

9.2 BAT for management system

9.2.1 Description of technique

Management system is a tool operators can use to address design, construction, maintenance, operation and decommissioning issues in a systematic, demonstrable way. Operation of biogas plant in a professional, systematic and demonstrable way is very important and results in good process performance.

Management of smaller size biogas plants may have staff of just 1–2 persons in a plant to be economically viable, meaning that certified management system like ISO may be unnecessarily heavy – a smaller system may be enough as long as it contains all critical procedures and provisions.

The plant should have critical procedures and provisions in place, including the following to be further discussed in coming chapters:

- Preparedness to unexpected situations, process disturbance, spills, releases, accidents.
- Procedure to make sure that the process functions, monitoring of key parameters of process, feedstock and products.
- Assure that staff is professional and trained and understands biogas process (also backup plan if a person gets sick or leaves the company) Procedures on preventive maintenance and that the equipment is gas-proof and safe.

Often these requirements at least partly come from several legislations and are part of permits and authorization requirements, e.g. requirements of food, fire, chemical safety, and environmental authorities.

The benefits of a management system are:

- Better management of risks
- Improved documentation and facilitating of reporting to authorities
- Better records for communication with authorities
- Better basis for continuous improvements.

Examples:

Instructions important for environmental performance are part of the standard requirements in the Danish legislation. They can be seen as BAT also in small organizations and they include:

- How the staff shall act in order to avoid emission and spillage of biomass, biogas and digestate when biomass is received and when biomass, biogas, and digestate is handled.
- Procedures on control and maintenance of reactor tanks and pipes in order to secure that they are gas-proof at any time. For further details on how this can be done, see description of BAT for diffuse emissions to air.
- Procedures on control and maintenance of equipment for reducing air emissions and procedures for disturbed operation, including periods where the equipment is not working as intended.
- Procedures for control and maintenance of an eventual flare.

- Procedures for control and maintenance of equipment for biogas utilization (boiler, gas engine and gas upgrading system).
- Procedures for start-up of the biogas plant and cleaning equipment including the time duration.

9.2.2 Emission and consumption figures

Good management leads to less emissions, but it's difficult to assess the magnitude of the avoided emissions.

9.2.3 Applicability

Management system can be implemented for any professional operation, only the scale and scope need to be tailored based on purpose. Maybe the certified system is too extensive for smaller plants. However, these requirements often, at least partly, come from food, fire, chemical and safety permits and authorization requirements.

The model is continuous because a management system is a process of continual improvement in which an organization is constantly reviewing and revising the system.

9.2.4 Cross-media effect

No negative cross media effects have been identified for management systems.

9.2.5 Economics

The implementation of a management system will require some investment costs, mainly in human resources. When the system is in operation, there should be no extra costs for the plant.

A management system systematizes operations and minimizes risks and can in the best case result in cost savings.

9.3 BAT for selection of suitable feedstock for co-digestion

9.3.1 Description of technique

In co-digestion plants, different types of feedstock are mixed. If a plant has flexibility in the permit in choosing feedstock, it can utilize more waste fractions for feedstock and thus improve circular economy. In order to reduce emissions and to improve the overall environmental performance of biogas plants, it can be seen as BAT to choose suitable feedstock. Some compounds in the feedstock are inhibitive to the microorganisms in large concentrations.

Insufficient provision of nutrients and trace elements, as well as too high digestibility of the substrate, can cause inhibition and disturbances in the digestion process (Seadi A. T. et al, 2008). Proteins degrade in biogas process to ammonia, which may inhibit the methane production. Ammonia is also potential source of air emissions

and odor. Sulphur is another important nutrient for the microorganisms, whereas excess Sulphur can lead to formation of hydrogen sulfide, mercaptans and other strongly odorous compounds. Some compounds are inhibitive even in very low concentrations, for example compounds in chemicals such as disinfectants and antibiotics. Others are forming odorous compounds.

Unless a stable operation is achieved it's difficult to ensure a good overall environmental performance.

Some feedstock e.g. wastewater sludge may limit uses of the digestate.

In case of new feedstock its characteristics must be evaluated from different points of view:

- Is new feedstock suitable for the process regarding process overload, inhibition and odor emissions? This is further described in this chapter.
- Is feedstock receiving area/equipment suitable for new feedstock? Potentially odorous feedstock requires special attention. This is further described under the chapter "BAT for receipt of feedstock"
- In case of spreading of digestate on arable land: Is new feedstock suitable for land application? Some plants have two lines for different types of feedstock for different uses of the digestate.

Plant should have acceptance criteria and careful assessment of suitable feeds. Legislation on agricultural use of digestate also requires that the origin of waste is known and traceable. Noteworthy, especially certain industrial wastes can have large variation in composition.

In order to bring the concentration of toxicants down to a level suiting the microorganisms and to supply missing nutrients and a suitable moisture content when co-digesting feedstocks with varying characteristics, it can be considered as BAT to mix the feedstocks accordingly. That generally requires keeping track of where different feedstock types are stored and having information on content of nutrients, toxicants and water easily accessible for the operator who is responsible for the mixing.

It is not possible to write a general list here in this report of feedstocks that are acceptable for all biogas plants since the characteristics of even same feedstock may vary a lot and microbiology of biogas process is highly adaptive. That means it must be considered on a case by case level. However, there is general knowledge on components in the feedstock that can cause problems.

Examples:

- A challenge has been seen in a plant with a problematic waste from mucosa, a byproduct from the production of a blood-thinning drug which is high in Sulphur content. When mucosa is degraded in the biogas process the Sulphur is released to the gas as H_2S , resulting in an increasing need for gas cleaning to remove the gas to maintain a certain level of H_2S in the gas before utilization.
- Glycerin from biodiesel or other types of high fat containing biomass can challenge a biogas plant since the volatile organic dry matter content is high and can result in a content of volatile solids too high for the biogas process.

- Protein degradation produces ammonia, the unionized form of which is inhibitory to anaerobic microorganisms in high concentrations. Lipids, on the other hand, may cause problems in anaerobic digestion because of their tendency to form floating scum and accumulated long-chain fatty acids, which are intermediate products in lipids degradation.
- A local authority has written a permit for a plant that both gives a high flexibility in choosing feedstock and at the same time prevents and reduces emissions. The plant has a larger capacity than 100 tonnes of feedstock per day, but the example can still serve as inspiration for plants with capacity of 30–100 tonnes per day. Selected sections of the permit are given in Appendix 1.

9.3.2 Emission and consumption figures

Emissions by far depend on the feedstock. Some feedstocks can be much more odorous as compared to other and require different types of reception at the site and abatement of emissions.

9.3.3 Applicability

Vital for all plants of all sizes and types to consider what is optimum feed.

9.3.4 Cross-media effect

None identified.

9.3.5 Economics

Optimal feedstock is a question of economics from different viewpoints:

- Optimal feedstock produces optimal biogas. Therefore, good process performance and economics of the plant go hand in hand.
- Different feedstock materials may have different gate fee.
- Different feedstock has very different chemical composition and biogas yield due to their different degradability and composition.
- Quality of feedstock affects the quality of products and where it is suitable to be used. E.g. sewage sludge as feedstock may limit applications of the digestate in agriculture.

9.4 BAT for receipt of feedback

Receipt of feedstock can lead to diffuse emissions to air and can affect soil, groundwater and rainwater.

Generally, requirements for receipt of wastes may vary a lot at different plants, being simpler at farm biogas plants and more complex at co-digestion plants treating different types of residues and wastes.

9.4.1 Description of techniques

General techniques to prevent emissions to air

Generally, it can be seen as BAT to receive feedstock from vehicles with tank, closed container or closed box or via closed piping systems, and to receive feedstock indoor in e.g. reception hall with controlled ventilation and air cleaning or via piping, see Figure 14 .



Figure 14: Indoor receipt. Packaging is removed before biogas treatment.

Exception to this is if the feedstock is not pumpable and the authority evaluates that there is no risk of odor or dust problems at nearest neighboring or occupational health risk of dust; in those cases, feedstock may be received and stored outdoor. In case of storing outdoor it can be considered BAT to have the feedstock covered outdoor and to collect all rainwater from the area for treatment (as further described below).

Different types of waste may require separate reception ranges, e.g. if slaughterhouse wastes are treated requiring hygienization.

It's also considered as BAT to have an alarm for when the tank is full on receiving tanks; the alarm being installed so it can be registered from where the unloading occurs.

General techniques to protect soil, groundwater and rainwater

As in other industries, it's considered to be BAT to prevent spillage and leakage to soil, groundwater, rainwater and recipient water body or course.

Containers, tanks and biofilters must be made of durable and tight materials. The containers shall be resistant to impacts from the use of them, including loading,

unloading, mixing and covering. If leakages occur, they shall be repaired immediately. Containers and tanks above the ground shall be placed with a dike or in a container that can collect eventual leakage from tanks or assembling. Other tanks and containers shall have perimeter drain and manhole for inspection and sampling. Storage places and re-loading areas shall be made of impermeable material that can resist the impacts from vehicles and machines loading and unloading and from the material stored.

Water from loading, outdoor storage areas and vehicle washing areas shall generally be collected and if possible pumped into the biogas reactor after necessary pretreatment (e.g. removal of sand, possible preheating). If not possible, the water shall be otherwise treated appropriately. An example of feedstock receival area is shown in Figure 15



Figure 15: Feedstock receival with possibility to wash vehicle in the area.

[Just-in-time reception](#)

Time of storage of feedstock at the plant should be balanced; long storage time increases diffuse emission of methane and ammonia outside the digestion tank which can be a problem if the gas is not collected, and short storage time increases the risk of unstable production due to running out of feedstock. Some plants are aiming at “just-in-time” receipt by having agreements with feedstock suppliers that they deliver feedstock when it's needed by the biogas plant instead of when it's available from the supplier.

Farm scale biogas plants can have just-in-time receipt if the manure feedstock slurry is pumpable and thus can be pumped directly from the stables to the plant. Solutions in the stable that minimize the surface area of the manure can further help to minimize diffuse emission of methane and ammonia in the stable. This subject is however outside the scope of this project and the reader is advised to look elsewhere to find further information.

Anyway, the biogas plant must have enough storage capacity for feeds, also in case of process disturbances and maintenance breaks during process.

Biomixer for fibrous fractions

The feedstocks that may be delivered outdoor, are often delivered in a place with solid walls and with a sheet or tarpaulin as cover. Deep bedding of manure mixed with straw (deep litter) from farm animals is a typical example. When mobile machines are used to cut the straw of the deep bedding and load the feeding system, the cover must be removed and put back afterwards. Typically, a mobile machine will cut larger batches of fibrous fractions in a shorter time outdoor which may cause diffuse emissions of dust and odor.

In order to have a more operational handling a so-called biomixer can be used, see Figure 16. The biomixer has a storage capacity of 3 to 4 days and it pushes the biomass towards a unit that tears the fibrous fraction apart and treats smaller amounts continuously. It replaces the need of having mobile equipment doing the same job. A plant larger than 100 tonnes per day (Madsen bioenergy) has a similar installation which prevents or reduces emissions of dust and odor. The biomixer might be considered as a form for covered pretreatment or storage.

The biomixer, however, includes weighing cells connected to the control system which allows the operator to follow a given recipe for mixing feedstocks. This requires a larger investment but can save work time and reduce emissions.

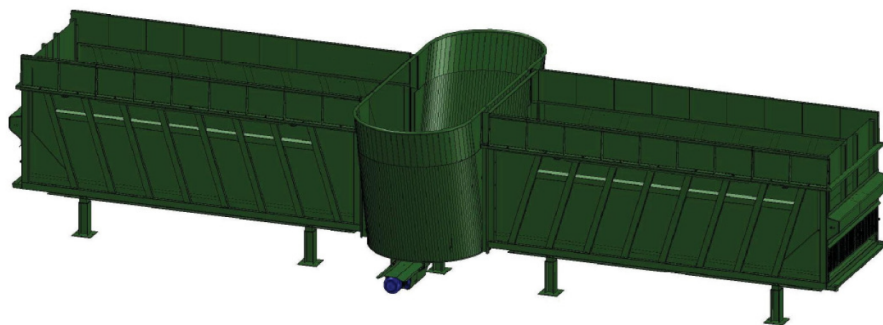


Figure 16: Example of biomixer.

Examples:

The general techniques are included in the Danish standard requirements and thereby widely used in Denmark. Just-in-time receipt is known on a few Danish plants and so is the biomixer for fibrous fractions, but is not included in the Danish standard requirements.

9.4.2 Emission and consumption figures

Emission figures are related to diffuse emissions, see chapter on that. Receiving feedstock using a biomixer will consume energy but also save fuel for tractors, front-end loaders or other machinery.

9.4.3 Applicability

The general techniques to receive feedstock are applicable to all plants, whereas some depend on the risk of diffuse odor and dust emissions. Farm scale plants can be more simple systems compared to co-digestion of different types of feedstock.

Weather conditions, such as snow and freezing, must be considered and may limit applicability of certain techniques.

Receipt "just-in-time" is applicable for farm scale plants, where the feedstock slurry is pumpable and thus can be pumped directly from the stables to the plant.

For other plants "just-in-time" is applicable if the suppliers have sufficient storage capacity and are willing to keep the feedstock stored until it's needed by the biogas plant. Applicability may also be limited for plants situated in areas with large amounts of snow that affects the traffic. Feedstocks that are only harvested few times a year may not be suitable for just-in-time receipt. It's important that just-in-time receipt doesn't lead to rapid feedstock changes since that would affect the functionality of the process.

Receiving feedstock in a biomixer is only applicable for plants using feedstocks suitable for the mixer and due to the relatively high investment costs it's only applicable for plants where the benefits are balancing the costs (proportionality).

9.4.4 Cross-media effect

No cross-media effect was identified.

9.4.5 Economics

Economics of reception systems is very much dependent on types of residues and wastes treated at the plant. Generally, farm biogas plants have more simple and low-cost systems as compared to waste treatment plants treating different types of wastes.

Just-in-time receipt requires storage capacity at the supplier who may in return demand that reflected in contract on feedstock.

Biomixer and dosage system are mostly used by larger plants and may be too expensive for some of the plants in the scope of this report.

9.5 BAT to reduce channeled air emissions

9.5.1 Description of techniques

Exhaust ventilation air from tanks and containers with biomass not digested, from receipt hall and from room for separation of digested biomass are led to an air cleaning system or to sufficiently high stack for reduction of odor emissions to a level not giving nuisance in the surroundings. Location and type of the plant shall be taken into consideration, when assessing need for monitoring of channeled air emissions. For example, a farm biogas plant may reduce odor compared to the situation if there was no biogas plant. Location at remote former landfill area is less

sensitive compared to location close to residential houses.

Techniques that can be considered as BAT to reduce such emissions to air from pipes, channels and stacks of odorous compounds such as H_2S and NH_3 are to use one or a combination of air cleaning techniques such as:

- Carbon filter

Carbon filter consists of activated carbon in a bed (often in cassettes) where the air is led through and reduces H_2S and certain other odor components by adsorption. After some time, a carbon filter gets saturated and the material must be replaced or regenerated.

- Biofilter

A biofilter consists of a bed of organic material such as tree bark, root, compost, and some inert material such as clay or polyurethane. When the emission passes through the bed, it will be biologically oxidized by naturally occurring microorganisms into carbon dioxide, water, inorganic salts and biomass. A biofilter shall be designed to fit the type(s) of emission regarding e.g. retention capacity, bulk density and porosity. A ventilation system circulates the air in the system to ensure a uniform air distribution through the bed (Commission, 2018).

- Biofilter and carbon filter can be used in a combination. An example is the so-called hybrid filter where activated carbon is coated with bioculture.
- Wet scrubbing
- Wet scrubbing with e.g. water, acid or alkaline can remove substances from the air stream to a liquid by absorption. The scrubbing liquid is sprayed into the gas and eventually smaller rings or balls are filled in the reactor in order to give the liquid a larger surface.
- If wet scrubber and biofilter is used in a combination attention should be drawn on some odorous compounds such as mercaptans and H_2S that can cause acidification of the biofilter media. Use of a water or alkaline scrubber for adjusting pH before the biofilter may be a solution. (Commission, 2018)
- Combining treatment of ventilated air with treatment of the produced biogas. (scrubber to upgrade biogas by removing H_2S and CO_2 producing end product biomethane)

Figure 17 below shows example of biofilter and wet scrubbing.



Figure 17: Biofilter (left) and wet scrubbing (right).

9.5.2 Emission and consumption figures

Cleaning of air will reduce emissions to the environment. Depending on the type of system implemented the air cleaning will result in increased consumption and cost.

A carbon filter gets saturated after some time and must be changed or regenerated. Some suppliers offer change of carbon as a service.

Biofilter consumes energy for the ventilator and require utilization of water and nutrients and depending on the supplier, a media where the bacteria can grow such as bark or expanded clay pellet and eventual energy for heating.

In a wet scrubber the absorbing liquid (e.g. acid, base, hydrogen peroxide) can often be circulated, but when the liquid is saturated, it needs to be either cleaned before being used again, or fresh liquid must be added.

9.5.3 Applicability

Composition of the emissions can influence the applicability of certain technique.

Some plants are able to fulfil emission limit values in their permits without emission reduction equipment, others with a biofilter or carbon filter alone, and others use wet scrubbing or a combination of techniques. Not all Nordic biogas plants have monitoring or limits for air emissions.

Biological air cleaning with biofilter has a long track record in Denmark and are known to work well if the H_2S content is stable. Chemical air cleaning is less sensitive to variation in temperature and is working well if the air flow is stable.

The applicability depends on the demand for the odor and emission reduction. The balance between costs and benefits and thereby the proportionality affects the

applicability of air cleaning. The demand for odor reduction both depends on the proximity to residential areas and the concentration of emission in the air.

Techniques to reduce air emissions are seldom used at smaller plants with large distance to neighbors, especially if they have a pretreatment tank leading the emission to the produced biogas.

9.5.4 Cross-media effect

The use of wet scrubber leads to waste water that must be handled properly. If scrubber uses only water, it may be possible to return it to digester.

9.5.5 Economics

All cleaning techniques impose cost for the biogas plant. The cost of air treatment with biofilter is considered cheaper than air treatment with carbon filter and chemical treatment in e.g. a wet scrubber.

9.6 BAT to reduce diffuse emissions into air

9.6.1 Description of technique

A biogas process is a closed process, but still diffuse emissions can occur. Diffuse emissions can be greenhouse gases (mainly methane), odor from ammonia (NH_3), other odorous compounds e.g. hydrogen sulphide (H_2S) and dust. Typical sources of potential diffuse air emissions are:

- Leaks from e.g. pressure relief valves, poorly sealed axels for mixers, water traps or condensate handling
- Receiving areas and prestorage
- Process disturbances and maintenance when process tanks need to be opened.
- Areas and tanks for storage of end products.
- Vehicles for transporting feedstock and end products

H_2S and other Sulphur compounds such as mercaptans as well as NH_3 cause odor already in very small concentrations. Also intermediates of anaerobic digestion are odorous, such as volatile fatty acids. Reality is that every biogas plant has some odors.

Techniques that can be seen as BAT to reduce the diffuse emissions include:

- In the design phase of the piping, minimize pipe run length, reduce the number of flanges and valves, use welded fittings and pipes, if possible, use gravity transfer rather than pumps
- When choosing equipment, choose high-integrity equipment such as valves with double packing seals, use pumps and agitators with mechanical seals instead of packing
- Prevent leakages by maintaining, servicing and avoiding corrosion of relief

- valves, sealings, water traps and other places where leakages can occur
- Avoid storing of odorous or dusty feedstock, end products and other materials in the open air and use closed tanks or buildings.
- Avoid open doors and windows in buildings where odorous materials are stored and use controlled ventilation and release the vented air through pipes and channels
- Keep all process buildings including those handling raw materials under negative pressure vented to abate diffuse emissions. Where airlock facilities are not possible, air curtain arrangements should be considered.
- Keep a protocol of complaints and note which operations were carried out, what the weather conditions were etc. in order to learn how to prevent future incidents.
- Generally, feedstock should not be stored too long from initial acceptance onsite prior to introduction into the process in order to avoid digestion before feedstock is inside the digestion tank and to avoid potential diffuse emissions from outdoor storage. Still some time for storage should be accepted, since storing for some days may help the feeding to be more continuous, helping the process stability. Hoppers and storage bins to store incoming wastes should be fitted with lids.
- Retention time should be sufficient to allow proper digestion in order to avoid diffuse emission from storage of digestate.
- Gas collection from storage tanks for feedstock and digestate can prevent diffuse emissions
- If odor can't be prevented or reduced for example at emptying of a tank for the yearly inspection, it can be BAT to consider the nuisance of the neighbors when planning the activity, and e.g. avoid doing it during vacation periods and weekends.

9.6.2 Emission and consumption figures

As mentioned earlier, studies based on measurements showed losses of 4,2% of the produced methane in biogas before reparation of leakages and 0,8% after (Danish Energy Agency, 2016). The study included nine Danish biogas plants. It found a number of leakages leading to emission of methane. Many of the identified leakages were relatively easy to repair and the benefits balanced the costs, once the plant owners were informed about the leakages. A handbook collected the experiences on tracking and repairing the leakages (Stefanek, Hansen, & Rasmussen, 2015). In total, 66 examples of leakages were identified and repaired, including leakages at connections, security valves and other leakages.



Figure 18: Examples of valves on biogas plants. The picture in the middle is an old valve not in function and leaking methane. On the picture to the right it's removed and the hole closed with a metal plat. (Stefanek, Hansen, & Rasmussen, 2015).

9.6.3 Applicability

Diffuse emissions shall be minimized by good planning and operation of the plant, whereas specific requirements for diffuse emissions monitoring or abatement shall be considered case by case depending on the type of feedstock, plant and location of the plant.

9.6.4 Cross-media effect

None identified.

9.6.5 Economics

Diffuse emissions shall be minimized by good planning and operation of the plant and are very much case by case. Leakages can be relatively easy to repair and the benefits can balance the costs.

9.7 BAT for flaring used for safety reasons

9.7.1 Description of technique

Flaring is used to burn combustible components of biogas that is not consumed or stored from the biogas operation for safety reasons or during start-ups and shut-downs. Furthermore, if methane was emitted without being burned it could not be seen as BAT since methane is a stronger greenhouse gas than CO₂.

However, since flaring is a source of pollution and leads to the burning of potentially valuable biogas, its use shall be minimized. Emissions from torch shall be minimized by optimal burning conditions.

To minimize the use, high-integrity relief valves, height, pressure, ignition system, flame detection, backup system to use in case of failure of electric power etc. should be included in a proper design of the plant and the flare.

Flare usually needs pilot flame of natural gas or other gas.

Due to safety reasons certain distances are needed from the flare to buildings etc. This is covered by gas safety regulation and not further discussed here.

9.7.2 Emission and consumption figures

The flaring prevents accidents such as fire and explosions in the case of emergency releases of biogas and thereby prevent emissions released from the fire or explosion.

The flaring itself leads to emissions of nitrogen oxides, NO_x , and carbon monoxide, CO, like other combustion processes do. (Commission, 2018) indicates emission levels for NO_x of up to app. 400 mg/Nm^3 and CO up to app. 600 mg/Nm^3 . If the biogas contains Sulphur, the flare emissions also contain Sulphur compounds as dihydrogen Sulphide, H_2S , and Sulphur dioxide, SO_2 .

The flaring prevents emissions of methane from the biogas, the efficiency being up to a 98% degradation according to (Commission, 2018), who bases the information on flares at different industrial plants in the chemical sector.

9.7.3 Applicability

Flaring is generally applicable, and so are the BAT techniques to minimize the use and prevent emissions. Smaller plants don't necessarily have flare but for example separate heat boiler as backup.

9.7.4 Cross-media effect

Flaring reduces methane emissions but increases emissions of NO_x , CO and eventually SO_2 .

9.7.5 Economics

Considering BAT in the design phase of the plant and the flare is not expected to influence economics significantly.

9.8 BAT for further processing of digestate

9.8.1 Description of technique

Use of digestate is strictly regulated in all the Nordic countries and gives the frame for utilization and further processing of the digestate. Digestate from smaller manure handling biogas plants is often utilized locally in land application directly without any further processing. On the other hand, at municipal waste water treatment plants, digested sludge is typically dewatered prior to utilization, and wastewater is returned to a wastewater treatment process.

Sometimes digestate is separated into solid and liquid phase in order to optimize concentration of nutrient in liquid and solid fraction, which may have different purposes of use.

There is increasing interest to fractionate digestate also at manure treating plants and co-digestion plants. Upgrading the digestate can have several advantages:

- Reducing water content can concentrate nutrients. It can reduce cost for storage, transport and application. Locally they may be excess of organic

fertilizing materials available.

- Adjusting nutrient content can add value to the product and minimize emissions when used in arable soil.
- Processing material can create new markets, such as replacing growing media, potting soil, peat, etc. in gardens and retail market.

Solid fraction:

If further upgrade takes place, dewatering using filter or screw press or sometimes centrifuging is often the first step to increase the solid concentration of the material or separate liquid and solid fractions. Then composting, drying or pelletizing of the solid fraction can take place – sometimes pyrolysis or incineration.

Composting can improve the characteristics of the material. The addition of structural material into the compost is usually required. Therefore, the actual volume of end product increases. Composted end product has desirable characteristics of humus, which are dark color, reduced and uniform particle size and earthy odor.

Dried or pelletized material can be stored and transported over longer distances economically.

Pyrolysis and incineration decrease volume of the end product and phosphorus remains in the material. Disadvantages of pyrolysis and incineration are high investment costs.

Liquid fraction:

If digestate is further processed by separating solid and liquid fractions, the liquid fraction derived from the posttreatment can sometimes be returned to biogas process, it can be utilized separately as fertilizer or it has to be treated as wastewater. High concentration of ammonia nitrogen can prevent return of the material to biogas process.

Various uses of the liquid effluent are applied. Most common way is to spread it on land as liquid fertilizer. When spreading, there are some recommendations that help avoiding leachate and odor and may be seen as BAT: Spread before seeding spring-sown cereals, apply evenly on the field and avoid spreading on growing seeds in warm, sunny, windy or dry weather (Dansk Landbrugsrådgivning, 2020). Techniques that can help minimizing emissions are not further discussed in this report.

Sometimes nitrogen is concentrated from liquid by different technologies, however it may not be feasible due to costs on investment and operation.

The wastewater is high in organic material (COD) and nutrients, especially nitrogen. If wastewater discharge occurs in a biogas plant treating waste, it needs to be agreed with the local wastewater treatment plant whether it has capacity to receive the wastewater. Then separate wastewater contract is made between the biogas plant and municipal wastewater treatment plant operator. Sometimes pretreatment of wastewater at a biogas plant is required before discharge to municipal treatment plant.

Sometimes wastewater is treated at a biogas plant and discharged to the environment. This requires multistep treatment of wastewater and strict monitoring

requirements and limits for wastewater discharge shall be applied. In this case it is recommended to use the monitoring requirements and limits of BAT waste treatment plants covered by IED.

9.8.2 Emission and consumption figures

Emissions and consumption figures vary a lot in different processes and for different materials.

9.8.3 Applicability

Optimal use of digestate shall be assessed case by case by demand and economics.

9.8.4 Cross-media effect

Different processes have different cross-media effects. In composting, drying and thermal treatment special precaution is needed for nitrogen emissions into air.

If digestate contains hazardous substances, they end up in some of the fractions. Drying and pelletizing consumes energy. For the crops, Phosphorus can be harder to access in the ash after pyrolysis.

9.8.5 Economics

Economics of further processing of digestate is very case dependent, depending on demand for different materials. The situation is very different for different types of materials and there are also country-specific differences.

For co-digestion plants treating waste income from digestate may be only a small part of income, however it is always important to have an environmentally and economically feasible market for all produced end products.

9.9 BAT for quality of biogas for energy utilization

9.9.1 Description of technique

Utilization of biogas for energy purposes can be seen as BAT since it can replace fossil fuels thus reducing emission of greenhouse gases. If the fossil fuel replaced is coal, several other pollutants such as emission of heavy metals from coal firing are also reduced. When the biogas is used for energy purposes its content of methane (CH_4) is transformed to carbon dioxide (CO_2). If the biomass or waste was left rotting on the ground instead of being used to produce biogas, the methane (CH_4) would have been released directly to the atmosphere without replacing any fossil fuels. Since methane is a stronger greenhouse gas than CO_2 , not only the missing substitution of fossil fuels but also the stronger greenhouse gas would have increased the climate effect.

How biogas is utilized is an economic decision of the operator and depends on physical conditions, the framework conditions, incentives, and the local market.

Biogas composition from different processes and feedstock varies, containing mainly methane (CH_4) and carbon dioxide (CO_2), and traces of hydrogen sulfide (H_2S), ammonia (NH_3), hydrogen (H_2), nitrogen (N_2), carbon monoxide (CO), oxygen (O_2). Depending on the utilization method, purification of biogas is often needed, since the unpurified biogas is corrosive due to the H_2S content and with a varying, but low calorific value due to the content of water vapor.

In general, the techniques are different when utilizing the biogas for heat or heat and power and when upgrading the gas into grid or fuel.

Several alternatives exist. A report (Eliassen & Kvist, 2015) describes techniques for

- Removal of Sulphur compounds, including H_2S :
- Adsorption with activated carbon
- Precipitation of Sulphur in the biogas reactor
- Biological Sulphur filters with addition of oxygen
- Upgrading with removal of CO_2 :
- Pressure Swing Adsorption
- Scrubbing with amine
- Scrubbing with water
- Membrane technique

The report performed measurements of Sulphur emissions from several installed techniques.

For larger plants most typically, wet scrubbing of biogas takes place. Wet scrubbing with e.g. amine removes CO_2 and H_2S and produces cleaned biogas, often called biomethane. Biomethane can be combusted to produce heat, for heat and power or injected into the national gas network. Also, for medium size biogas plants it can be pressurized, typically to 200–250 bar to make vehicle fuel.

In some cases, the separated CO_2 may be utilized for instance as CO_2 in soft drinks.

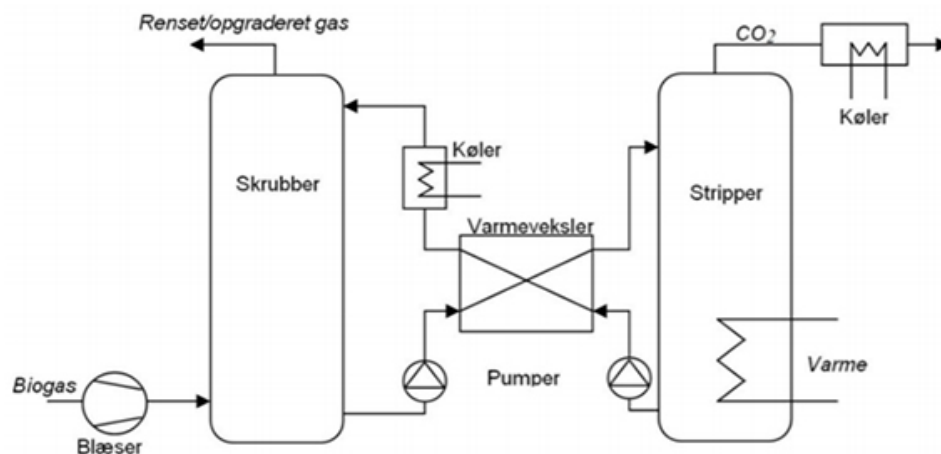


Figure 19: Diagram of amine scrubber for removing of dihydrogen Sulphide (H_2S) and carbon dioxide (CO_2). Based on (Eliassen & Kvist, 2015).

Example:

A scrubber for upgrading biogas is installed in a Danish joint biogas plant (Madsen bioenergy in Skive). In order to reach a quality suitable for the public grid, not only CO_2 and H_2S but also water steam and other impurities are removed. The scrubber uses an alkaline liquid (amine) and a regeneration step allows the liquid to be used again and again. The process needs water at 140°C which in their case is generated by a straw fired boiler. After this, the gas is compressed, dried and measured before it is delivered to the pipes from a natural gas company. At the regeneration of the used cleaning liquid, heat is used to separate CO_2 from the liquid.



Figure 20: Example of farm scale fueling station and gas storage container in Palopuro, Finland.

9.9.2 Emission and consumption figures

In the report (Eliassen & Kvist, 2015), consumptions and emissions of the investigated techniques are described.

The example process with amine scrubber upgrading biogas for the natural gas grid at Madsen bioenergy in Skive uses energy, but energy savings reduce the overall energy consumption.:

- Approximately $0,1 \text{ kWh}$ electricity is used for upgrading 1 m^3 biogas.
- Approximately 1 kWh of heat per kg removed CO_2 is needed, but after the upgrading up to 83% of the heat it can be recuperated (re-used) for heating the biogas reactors. If the recuperated heat is deducted the net heat needed for the upgrading is $0,17 \text{ kWh}$ heat. The heat recuperation was improved in cooperation between Madsen bioenergy, the supplier of the scrubber (Ammongas) and the supplier of the plant (Lundsby bioenergi). They found a solution where two heat exchangers were installed in a tank before the digester in order to utilize the heat in the only 50°C water which proved to be usable for preheating of the manure feedstock so that its temperature increases from app. 14°C to 35°C

before the manure enters the digester.

The straw fired boiler used on the Danish plant reduces the CO₂ emission from the heating required for the process. Boilers usually lead to some emissions of e.g. particles which can be reduced by proper filters and are regulated according to legislation on combustion plants. The supplier of the upgrading technique mentions that the methane loss for the technique is less than 0,04%. (Ammongas, 2020).

9.9.3 Applicability

Applicability of the different techniques for purification and upgrading biogas is described in the report (Eliassen & Kvist, 2015).

The supplier of the process at Madsen bioenergy in Skive in the example above mention that they have experience with plant sizes in the range of 300 to 3,000 m³ per hour (Ammongas, 2020). The experience of Madsen bioenergy is, that the possibility of utilizing the recuperated heat is important for the overall economy and thus the applicability. Another aspect that may limit the applicability for smaller plants is that in order to produce heated water for the process, a boiler certificate is needed for the operator.

9.9.4 Cross-media effect

The different techniques for purification and upgrading biogas consume chemicals, activated carbon and/or energy.

The process mentioned as example uses energy, but the consumed amount of energy is far less than the produced energy in the form of biomethane. Thus, the cross-media effect is not severe.

9.9.5 Economics

(Eliassen & Kvist, 2015) collected costs for the different techniques and made model calculations for use of single techniques and for combinations of techniques are shown in Figure 21.

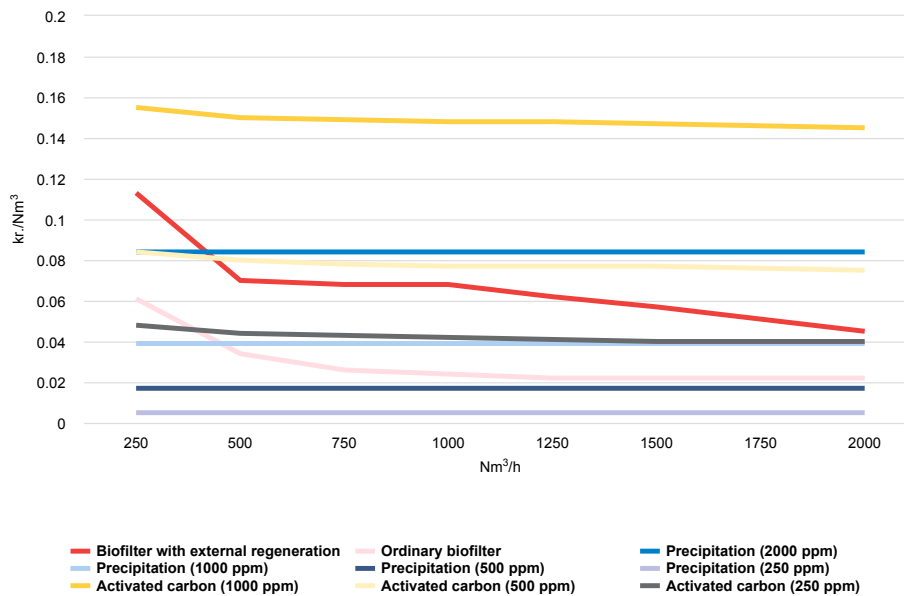


Figure 21: Model calculations of economics by the use of a single technique to purify biogas from a raw gas concentration as indicated in the brackets down to a level achievable with the technique. On the x-axis is the amount of biogas treated, on the y-axis Danish kroner per amount of biogas treated (Eliassen & Kvist, 2015).

The supplier of the process mentioned as example above has given information on the energy consumption of the process which is 9,1 Danish øre per treated m³ biogas. The liquid for the scrubber is mentioned to be "relatively cheap". The purity of the separated CO₂ is high which allows utilization of that as well (Ammongas, 2020).

9.10 BAT for monitoring of process

9.10.1 Description of technique

Monitoring of emissions will be related to requirements for emissions and is general for industrial emission and therefore not further discussed here.

As described in the introduction a biogas process bases on complex cooperation of different types of microorganisms. A number of factors can affect the process performance. The biogas process needs close monitoring especially in the start-up and if conditions or feedstock are changed.

Monitoring ensures stable operation, minimizes difficulties and provides sufficient early warning of potentially more severe difficulties with the process. Monitoring need depends a lot on type of feedstock and process.

As general rule, in daily operation, when the feedstock does not change, monitoring of biogas and methane production is often the best indicator of well-functioning process. In addition, temperature, hydraulic retention time and organic loading rate of the feedstock and liquid level of the digested shall be followed on continuous basis. In the process start up, if feedstock mixture changes, and every now and then a wider range of analysis is recommended. Further parameters to be followed may include e.g. C/N ratio, content of intermediate products of degradation including

volatile fatty acids (VFA), buffering capacity (volatile acids/alkalinity ratio), content of ammonia nitrogen and H_2S and foam levels in the digester. It is noteworthy that there are no right or wrong values for different parameters, but the values may vary highly in different processes, with different feedstock and depending on the bacterial biomass in reactor. For example, different reactors may have different temperature optimum.

9.10.2 Emission and consumption figures

By monitoring process, disturbances can be avoided and therefore it reduces emissions.

9.10.3 Applicability

Even simple manure plants need monitoring of basic parameters. More complex feedstock, more complex monitoring is needed.

9.10.4 Cross-media effect

No cross-media effects identified.

9.10.5 Economics

Monitoring needs to be adjusted, based on need. However even complex monitoring equipment is not that expensive nowadays.

Sometimes plant manufacturer offers monitoring and trouble solving services for operator which can be an economical solution.

10. Emerging techniques

Emerging techniques are BAT not yet fully developed or in use in the industry, although they may be relevant as BAT candidates in the future. Some techniques under development are mentioned in this chapter.

A technique to improve pretreatment by using an extruder for shredding grass and clover has been tested with good result on making it pumpable.

A technique to improve digestion of sludge by heating it to 150–180 °C under pressure and then lowering the pressure helps degrading the structure of the sludge and improving the digestion of the microorganisms. A pilot plant is testing the technique.

Installing screw presses in series can improve pretreatment of source-separated food waste and reduce the amount of reject (Biogasbolaget AB, 2017).

A flotation unit and a ceramic filtration unit in an anaerobic environment is meant to separate and recirculate dry matter and microorganisms internally in a biogas plant (Jürgensen, 2015).

An emerging technique for removing dihydrogen Sulphide (H_2S) and at the same time produce a fertilizer product, ammonium thiosulphate, that has the ability of reducing the transformation of ammonium (NH_4^+) to nitrate (NO_3^-) is being developed in a project started in 2018 (Topsøe, 2020).

An emerging application of biogas process is first making bioethanol by hydrolysis adding enzymes, Sulphur acid and/or steam with subsequent biogas process.

Interreg NWE funded project ALG-AD pilot combination of algal and AD technologies to reuse the excess of nutrients produced from the anaerobic digestion of food and farm waste, in order to cultivate algal biomass for animal feed and other products.

Methanization of CO_2 in the biogas to allow a higher methane content in the gas by adding H_2 (hydrogen) is also an emerging technique. The hydrogen is planned to be produced from surplus of wind and solar energy used to electrolytically separating hydrogen from water. More projects are working with the technique with different techniques for combining CO_2 and hydrogen (Hansen, 2020)

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Appendix 1

Example from a permit on requirements on choosing suitable feedstocks for mixed digestion

The example shows the outline of the requirement on feedstocks in a permit giving flexibility on choosing feedstock and at the same time preventing or reducing emissions.

Biomasses

The amount received by the plant is maximum 750,000 tonnes biomass per year.

The plant is permitted to receive and treat the following types of biomasses:

Fraction A – Manure from farm animals

Definition	Solid, semi-liquid and liquid manure, liquid from manure heap from all farm animals, including contents in stomach and intestine from slaughtered animals and processed and digested manure from farm animals and any mix of manure and digested biomass according to statutory order on commercial animal stock, silage of manure from farm animals
Expected types and amounts	Manure: 360,000 – 550,000 tonnes per year Deep bedding: 60,000 – 100,000 tonnes per year
Expected storage capacity	Tank for manure: 6,000 m ³ Deep bedding indoor receiving hall: 2,600 m ³

Fraction B – farmed biomass

Definition	Crops grown on farm land, road areas and nature areas
Expected types and amounts	Catch crops, subsequent crops and energy crops: 60,000 – 100,000 tonnes per year, hereof only a smaller share of energy crops
Expected storage capacity	2,500 m ³ (outdoor storage)

Fraction C – Waste included in statutory order on waste to land (BEK no 1001 of 27/06/2018) and not covered in by-product regulation

Definition	Waste that according to appendix 1 in statutory order (BEK 1001 of 27/06/2018) has agricultural value and can be used according to the rules in the statutory order without previous acceptance and which is not covered in by-product regulation no. 1069/2009 and repealing regulation (EC) no. 1774/2002.
Expected types and amounts	Vegetable fat/glycerin: 5,000 – 15,000 tonnes per year Residues from food industry e.g. mash, yeast cream, potato pulp, vegetable waste: 10,000 – 40,000 tonnes per year
Expected storage capacity	Fat and glycerin 200 m ³ Residuals from food industry 1,100 m ³ Part of outdoor storage of 2,500 m ³

Fraction D – Waste included in statutory order on waste to land and covered in by-product regulation on animal by-products

Definition	Waste that according to appendix 1 in statutory order (BEK 1001 of 27/06/2018) has agricultural value and can be used according to the rules in the statutory order without previous acceptance but is covered in by-product regulation no. 1069/2009 and the belonging implementing act on health rules as regards animal by-products and derived products not intended for human consumption and repealing regulation (EC) no. 1774/2002.
Expected types and amounts	Milk products from specific dairy: 30,000 – 120,000 tonnes per year. Fat of animal origin or contaminated with animal products: 5,000 – 15,000 tonnes per year. Residuals from food industry, organic food waste from food production, source separated organic waste: 50,000 – 80,000 tonnes per year.
Expected storage capacity	Milk products: 2,000 m ³ Fat/glycerin: 200 m ³ Residuals from food industry: 1,100 m ³

Before use of other feedstocks not included in fraction A – D, approval from the authority is needed.

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