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PREFACE

This report is primarily based on the work of the Danish biogas task force, which was established as a result of the Energy Agreement of 22 March 2012. The purpose of the task force is to examine and support concrete biogas projects in order to facilitate the projected biogas development up to 2020.

The focus of the task force was on the practical integration of the new biogas production in energy system, including the utilization of gas, the necessary infrastructure and contractual relationships. The aim was to ensure effective and appropriate integration of biogas in the Danish energy supply, which was consistent with the policy objectives, both in regards to current challenges for specific biogas plants and the role of biogas flexible renewable energy form on longer term.

The task force's final report was published in 2014.

1 STATUS FOR BIOGAS DEPLOYMENT

Denmark's energy policy took shape after the oil crises of the 1970s. When oil prices accelerated in 1973, Denmark was among the OECD countries that were most dependent on oil, with more than 90% of all energy supply being imported oil. Consequently, Denmark launched an active energy policy to ensure the security of supply, and to enable Denmark to reduce its dependency on imported oil.

Denmark chose early on to prioritise energy savings and a diversified energy supply that concentrate on increased use of renewable energy. A broad array of energy policy initiatives were launched, including a focus on combined electricity and heat production, municipal heat planning, and on establishing a more or less nationwide natural gas grid. Furthermore, Denmark significantly improved the efficiency of the building mass, and launched support for renewable energy, research and development of new environmentally friendly energy technologies as well as ambitious use of green taxes.

Through a persistent and active energy policy, Denmark has drastically shifted the energy system towards greater efficiency and a focus on renewable energy. Despite the notable results, there is still a long way to go before Denmark will be entirely independent of fossil fuels (DEA, 2010).

The utilisation of biogas has a part to play in the transformation of the energy system, a part that although currently modest, continuously becomes more important as the use of fossil fuels decrease.

1.1 HISTORICAL DEVELOPMENT

Denmark has produced biogas for energy purposes for many years, firstly in sewage purification plants, and later – in the 1970s – in biogas plants in connection with agricultural plants and from landfill sites. From the mid-1980s, it has been a political priority to increase the exploitation of biogas, especially from livestock manure.

In 1986, the Government established the Coordination Committee for Biogas originating primarily from livestock manure (in liquid form known as slurry). In 1987, the Committee published its first action plan for joint biogas plants[1], which was implemented during the following years. During this period, the development was characterised by a number of biogas project failures, especially in the beginning of the 1980s, and partly also during the 1990s. However, through the 1990s, a substantial production increase took place. Since then, there has been a moderate production increase of slightly above four PJ per year.

[1] 'Joint biogas plants' receive manure from many farms, cattle farms, pig farms as well as typical organic waste and/or energy crop. This means that there is a redistribution of nutrients, from farms that have too much to farms that can use more.

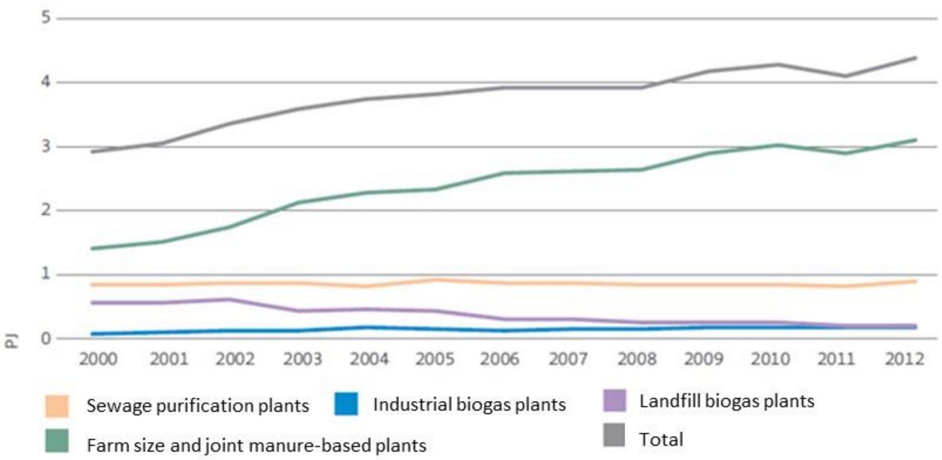

FIGURE 1: THE DANISH BIOGAS PRODUCTION FROM 2000 TO 2012.

1.2 CURRENT STATUS

As of 2012, roughly 7%., or approx. 2.5 million tons, of the Danish livestock manure is used for biogas. Apart from manure, organic industrial waste, food waste, sewage sludge and energy crops are degassed in biogas plants. In total, 4.3 PJ of biogas was produced, hereof 3.1 PJ from a mixture of manure, organic waste and other biomasses in the manure-based plants. The production takes place in 21 joint manure-based plants, 46 farm-sized biogas plants, 57 sewage purification plants, 5 industrial biogas plants and 25 landfill biogas plants. Many of the existing plants were established prior to 2000. From 2000 to 2012, a few joint biogas plants and several farm-sized biogas plants were established.

Most of the biogas produced is used to generate electricity in gas engines, or for the production of electricity and heat in combined heat and power plants (CHP). There is a well developed transmission and distribution network for natural gas in Denmark. At present, a small fraction of biogas production is upgraded to natural gas quality and injected into the natural gas network.

The Danish Energy Agency (DEA) has assessed the total biogas potential in Denmark to be a little more than 40 PJ. When other possible utilisations of the same biomass resource are taken into account along with technological development, the potential in 2020 is estimated at just below 50 PJ (DEA, 2014).

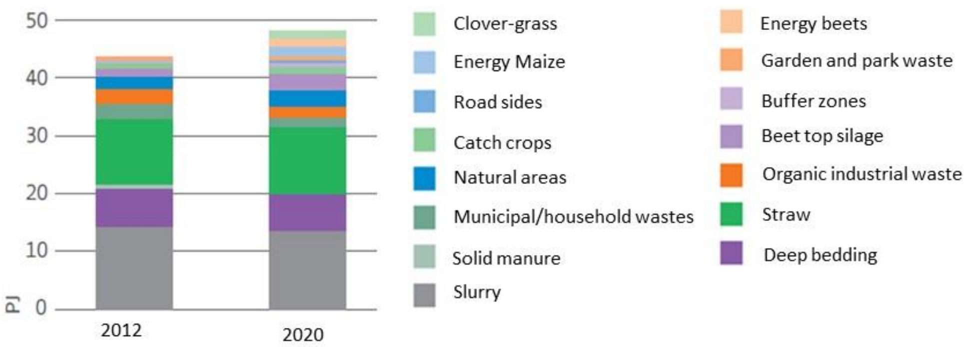

FIGURE 2: BIOMASS RESOURCES IN 2012 AND 2020 (DEA, 2014).

1.3 Expected biogas expansion

With the current framework conditions, biogas production is projected to more than double by 2020, from 4.3PJ to around 10PJ. However, the assessment is uncertain. Final investment decisions have only been made regarding a limited number of projects, corresponding to a production expansion of roughly 1.5PJ. On the other hand, plans exist for a number of biogas plants, and if these plans are realised production could be increased to around 15-16PJ.

An important driver of this expansion is the energy agreement's increased operating support for the use of biogas for electricity generation and upgrading. Another driver has been the investment support scheme, which was established in 2009 as a part of Denmark's Green Growth Strategy (Biogas Taskforce, 2014).

The expected expansion of biogas production in Denmark is shown in the figure below.

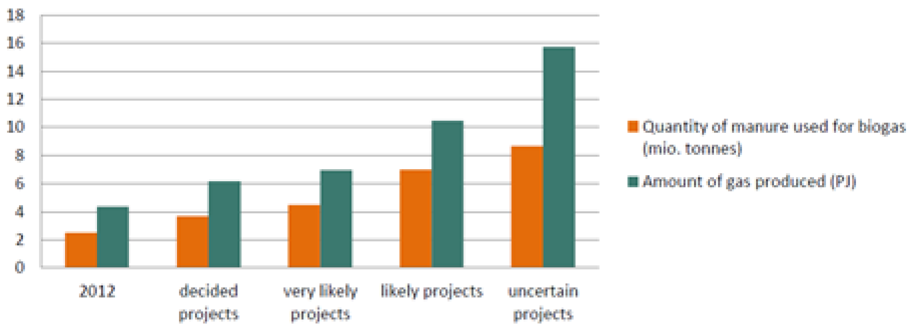

FIGURE 3: EXPECTED EXPANSION OF BIOGASPRODUCTION IN DENMARK 2012-2020 (BIOGAS TASKFORCE, 2014)

2 Targets for biogas deployment

Three political initiatives and agreements constitute the framework for biogas deployment in Denmark: The "Green Growth" initiative from 2009, "Our Future Energy" from 2011, as well as the broad political energy agreement from 2012.

2.1 Green Growth 2009

The”Green Growth” initiative, which formed the basis for a political agreement concluded in June 2009, includes the objective that 50% of the livestock manure is to be used for green energy in 2020. This objective would require a significant acceleration of the current development in biogas deployment. The Danish Ministry of Climate and Energy estimated in 2010 that to reached this objective, an increase of biogas production of approx. 15 PJ/year to a total of approx. 20 PJ/year in 2020 would be required (Ministry of Climate and Energy, 2010).

2.2 Our Future Energy 2011

In the proposal from the government prior to the energy negotiations ”Our Future Energy” from November 2011, Denmark set an objective that its energy consumption in 2050 should be supplied solely by renewable energy. Furthermore, the proposal also contains targets representing milestones for the development that should assure progress until 2050.

2020: Half of electricity consumption is to be supplied by wind power. Compared to 1990, this would reduce greenhouse gas emissions by 35%.

2030: Coal is to be phased out of Danish power plants. Oil boilers for space heating are also to be phased out.

2035: Electricity and heat supply is to be covered 100% by renewable energy.

2050: The entire energy supply – electricity, heating, industry and transport – will be sourced from renewable energy.

Furthermore, Our Future Energy also aims at utilising half of the livestock manure for production of biogas by 2020.

2.3 The Energy Agreement 2012

The Energy Agreement of March 2012 details an ambitious strengthening of biogas development by including it as an integral part of achieving the overall target of 35% of renewable energy in Denmark by 2020. The Energy Agreement improved the economic conditions for biogas production, and among other things, stated that biogas should be utilised to a larger extent outside of the combined heat and power sectors than it is today. With the Energy Agreement, a new subsidy model, and new support systems for the production and use of biogas were adopted.

3 Reasons for utilising biogas

There are many advantages related to utilising biogas in Denmark. The two most important drivers of biogas utilisation in Denmark have been the transformation of the energy system towards more renewable energy, and agricultural waste management. Over the years, secondary reasons such as the climate change agenda, job creation in remote rural areas, and export of knowhow have furthered deployment efforts.

3.1 Transformation of the energy system

Biogas is a flexible energy carrier, suitable for many different applications. One of the simplest applications of biogas is direct use for cooking, but biogas can become an important element in the flexible renewable energy system of the future. Biogas is upgradable and can be stored in the central gas storage facilities and thereby used as flexible fuel for electricity production in the absence of wind. The gas can also be made useful for high temperature heating in industry, or utilised in the transport sector.

Total available biomass resources for use in energy supply are limited. This applies both at the national and global levels. Biogas plants are capable of utilising wet biomass resources in an environmentally sustainable manner. Therefore, these plants can contribute to utilising part of the limited biomass resources in an appropriate manner.

Furthermore, developing and implementing renewable energy technologies such as biogas from anaerobic digestion, based on national and regional biomass resources, will increase security of national energy supply, and diminish dependency on imported fuels (Seadi, Rutz, Prassl, Köttner, & Finsterwalder, 2010).

3.2 Waste management

Denmark is an agricultural country with a very large livestock production compared to its size. This implies an extensive production of organic manure to be handled and disposed of in an environmentally appropriate way. Today, this disposal, mainly of slurry (a mixture of animals' urine and faeces and wash water from the cowsheds and milking rooms), consists of collecting manure in containers and later applying it as fertilizer to the fields (Biogas Secretariat, 2011). An advantage of biogas production is the ability to transform organic wastes from industry, agriculture and households into a valuable resource, by using it as substrate for anaerobic digestion (Seadi, Rutz, Prassl, Köttner, & Finsterwalder, 2010).

In the course of biogas production, a number of the organic components in livestock manure that cause strong odour are degraded resulting in a significant reduction of odour nuisance. Studies have shown that odour nuisance from newly applied degassed livestock manure have been reduced by 50-75% when compared to untreated manure. On the other hand, the addition of certain types of industrial waste in biogas plants can cause increased odour nuisances compared with the use of livestock manure alone.

3.3 CLIMATE IMPACT

When livestock manure is degassed during production of biogas, the emissions of methane (CH_4) and nitrous oxide (N_2O) are reduced when the livestock manure is applied to the fields. Moreover, the biogas production contributes to a reduction of the emissions of carbon dioxide (CO_2) as alternative fuel sources are replaced. The magnitude of the reduction itself depends on the nature of the replaced fuel. The production makes it possible to handle wet waste fractions and to recycle nutrients that would be lost through combustion, e.g. phosphorous, which could become a limited resource. Therefore, the degassed manure can replace fertilizers and thus reduce climate implications (DEA, 2014).

3.4 JOB CREATION IN REMOTE RURAL AREAS

Production of biogas from anaerobic digestion requires a workforce for the production, collection and transport of anaerobic digestion feedstock, manufacture of technical equipment, construction, operation and maintenance of biogas plants. This means that the development of a national biogas sector contributes to the establishment of new enterprises, some with significant economic potential, increases the income in rural areas, and creates new jobs – especially in remote rural areas (Seadi, Rutz, Prassl, Köttner, & Finsterwalder, 2010).

3.5 EXPORT OF KNOWHOW

Lastly, the production of biogas represents a still developing renewable energy technology, which at present is only sporadically being developed. At the international level, Denmark is at the forefront with regard to biogas development. This because Denmark has focused on practical development and expansion of biogas, while Denmark's agriculture and energy infrastructure form a good basis for biogas production. As a result, as European and international focus on biogas production increases, the Danish biogas industry is well positioned to increase exports (DEA, 2014).

4 BIOGAS IN THE ENERGY SYSTEM

The natural gas network represents a well–developed infrastructure in Denmark and natural gas accounts for approx. 20% of the country's energy consumption. Furthermore, a number of gas companies are planning to introduce the use of natural gas within the transport sector. As biogas and natural gas fundamentally have the same applications, and due to the current price and tax structures, biogas may often replace natural gas.

Today, the purification of biogas (sulphur removal) in the majority of plants takes place via a simple bacterial process. In the event that the biogas is to be added to the natural gas network, a further purification will take place, and the CO_2 is removed in a so-called "upgrading plant". After upgrading, the gas is almost entirely composed of methanol. The upgraded gas has a higher heating value, although not as high as the heating value of natural gas from the Danish part of the North Sea. The upgraded gas is referred to as 'biomethane' or 'bio natural gas' if added to the natural gas net.

Regardless which entity is the buyer of biogas, the necessary infrastructure must be established. This could be low pressure gas pipes to transport biogas from the plant to a heating plant, enterprise or upgrading plant, or compressors and natural gas pipes, when biogas is transferred to the natural gas network.

4.1 Electricity and heat production

Until now, biogas has primarily been used for combined heat and power (CHP) production. The electricity has been sold to the electricity market, and the heat to the district heating suppliers, or (as is the case of many farm-sized biogas plants) utilised for the heating of farmhouses and stables within the farms. The production of heat and power in decentralized CHP plants is normally carried out by burning the biogas directly (i.e. without upgrading) in an engine that produces electricity and provides heat for district heating.

4.2 Industry

Within industry, biogas is utilised in industrial processes (typically for burning or smelting), within an engine producing electricity and heat, which is subsequently used by the enterprise, or in a boiler for pure heat production. In most cases, biogas can replace natural gas directly, however, in certain industrial applications, an upgrading of the biogas, completely or partially, to natural gas quality will be required.

4.3 Transport

Biogas can be used for transport purposes. This implies that the gas, completely or partially, is upgraded to natural gas quality. The application can take place directly if the upgraded biogas is added to a gas station where cars be refuelled. The upgraded biogas can also be added to the natural gas network that brings the gas to the natural gas stations.

4.4 Upgrading

Feeding into the natural gas network requires the removal of CO_2 from the biogas. This is carried out in upgrading plants. Due the new subsidy structure in the energy agreement, the transfer of biogas to the natural gas network has just started (see Chapter 5). At the moment, two upgrading plants have been established in Denmark.

4.5 Downgrading

In some city gas networks it is possible to use biogas directly (after purification) because the natural gas that still accounts for the major part of the gas supply has been 'downgraded' (through a 1:1 mixture with air) so that it has a heating value equivalent to old fashioned city gas. In 2013, the energy company HOFOR initiated the use of biogas in the city gas network of Copenhagen.

4.6 UPGRADING OR DIRECT USE OF BIOGAS

Most biogas plants have a more or less constant gas production over the year, because this yields the lowest generation costs. The constant production provides challenges in terms of integrating biogas in the energy system because it also requires consumers with a more or less constant consumption. This challenge will grow as and more fluctuating renewable energy needs to be integrated in heat and power systems and as the production of biogas increases.

When consumers with constant demand are lacking three other options exists:

1) Adjustment of the biogas production according to demand.
2) Local storage of the biogas
3) Upgrading the biogas and injecting it into the natural gas system (as described in section 4.4)

If biogas production only exceeds demand occasionally and at a low level an economically attractive solution may also be to flare the excessive biogas in these situations.

Ad. 1. Analyses show that if a biogas plant has access to resources, which can be adjusted, it is biologically and technologically feasible to, over the course of a number of weeks, vary the production of a biogas plant by 100% or more. It is also biologically possible to adjust the production from one day to the next, and thus, to a certain degree, adjust biogas production to energy demand. However, biogas plants require a large capital investment and therefore regulation of production is associated with significant costs.

Ad. 2. Many biogas plants already have storage facilities that can handle demand variations over the day. Storage facilities, which can handle variations over several days or weeks, do however involve significant investments.

Ad. 3. Upgrading the biogas provides access to the large storage facilities in the natural gas system. However, this comes at cost of almost €4/GJ and there are energy losses related to upgrading and network injection.

Today, the majority of biogas produced in Denmark is used directly at local CHP plants that have natural gas as an alternative source. An important question that, among others, the Danish biogas task force has tried to investigate is whether this is the optimal way of using biogas in the future.

Model calculations from the biogas taskforce show that the next 10-15 years, the highest socioeconomic value is achieved when biogas is used directly in local power plants or to supply process energy in industries. Further, adjustment of the biogas production according to demand could play an increasing role in the years to come.

Around 2035 the energy system is expected to be increasingly dominated by wind power, and there will be a large demand for CO_2 neutral electricity production as back up for wind power. At that time, it will be necessary to store biogas for weeks and months, and as such it will become cost-effective to upgrade biogas.

In the long run, the transport sector can become a possible user of natural gas, and in this case biogas will have to be upgraded. Biogas will likely be particularly relevant for heavy transport (i.e. trucks, shipping, etc.) as it is hoped that light transport (i.e. passenger vehicles) to a large extent will be converted to electricity (Ea Energy Analyses, 2014).

5 Framework conditions for biogas

Since the 1970s, the agricultural sector in Denmark has shown a great interest in biogas. One of the reasons for this is the opportunity afforded by joint biogas plants to establish local cooperation in a better utilisation of the nutrients in manure, and furthermore, to reduce the odour nuisance when manure is applied to the fields in spring. At the same time, in the 1980s, due to concerns regarding the aquatic environment, farmers were obliged to store manure during winter. A joint biogas plant could assist in complying with the storage obligation, and farmers would be able to share investment costs.

5.1 Operating subsidies for biogas

Until 2012, a subsidy was paid for electricity produced from biogas. Furthermore, heat production from biogas is exempt from energy taxes, and thus receives an indirect subsidy. The direct subsidy for electricity production had since 2008 been fixed as a Feed In Tariff (FIT) at 10 €cent per kWh, or as a Feed In Premium at 5.4 €cent per kWh to be added to the market price of electricity. The tariff is regulated every year at 60% of the Net Price Index[2] (NPI) increase, and in 2012 this amounted to a 10.6 €cent per kWh (FIT) or feed in premium of 5.8 €cent per kWh (FIP) (€16.11/GJ).

In addition to the feed in premium, the user of biogas for electricity production receives, as mentioned earlier, an indirect subsidy in that no energy or CO_2 tax is collected. When biogas replaces natural gas or other fossil fuels the value of this indirect subsidy amounts to approx. €8/GJ heat (the savings are €8/GJ heat in form of state taxes). When the biogas is used in a gas engine with 36% electricity production and 54% heat production, the combined value of subsidies will amount to 0.36*16 + 0.54*8 = approx. €10/GJ biogas.

In addition, both natural gas and biogas are subject to a NO_x tax and methane tax.

The Energy Agreement from March 2012 improved the economic conditions for biogas and envisioned that biogas should be utilised to a greater extent outside the CHP sector. The parties agreed that the total direct and indirect subsidies for biogas used in CHP, or fed into the natural gas grid, should be fixed at €15.44/GJ in 2012, which would mean a substantial increase. It appears from the agreement that “parity in subsidies” should exist between feeding into to the natural gas grid and to CHP. The new subsidy tariff was passed by the Parliament on June 18th 2012.

[2] The net price index illustrates the same price development as the consumer price index but without indirect taxes and subsidies.

In connection with the adoption of the law, the Climate, Energy and Building Committee submitted an additional report on future sustainability criteria that must be fulfilled in order to receive subsidies. Figure 4 shows the new tariff for operational subsidies, applicable in 2012.

- €10.6/GJ in basis subsidy for combined heat and power heating (direct and indirect subsidies)
- €10.6/GJ in basis subsidy for upgrading and distribution via the natural gas grid
- €5.2/GJ in basis subsidy for industrial processes and transport

In addition:

- €3.5/GJ for all applications – scaled down with increasing price of natural gas. If the natural gas price the year before is higher than a basis price of €7.1/GJ the subsidy is reduced accordingly.
- €1.34/GJ for all applications – scaled down linear every year from 2016 to 2020 where the subsidy expires.

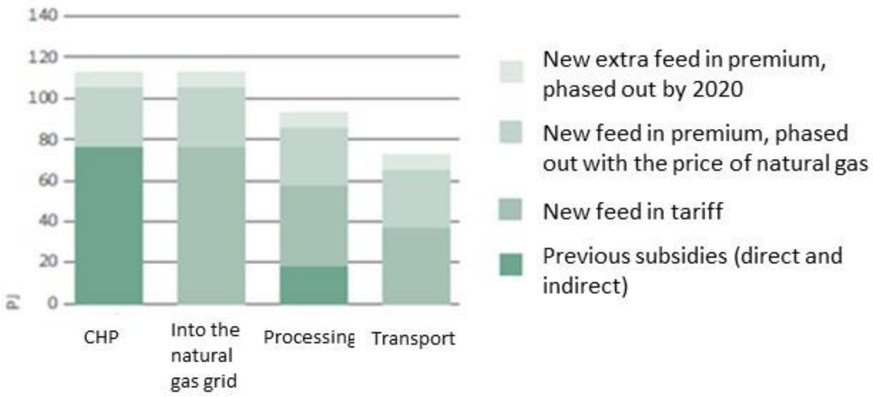

FIGURE 4: THE AMOUNTS OF SUBSIDY BASED ON THE ENERGY AGREEMENT APPLICABLE FOR 2012 REGARDING THE VARIOUS APPLICATIONS OF BIOGAS.

European Commission approved the increased operational subsidy for the use of biogas in CHP and for upgrading to the natural gas grid as state aid in November 2013. The subsidy for industrial processes, transport and other exploitation has not yet been approved, and has therefore not yet been put into effect.

6 Biogas technology choices

Several types of biogas plants are useable for treatment of different types of biomass and each type has its advantages and drawbacks. In practice, only the continuously stirred plants (CSTR – Continuously Stirred Tank Reactor) are used on Danish farm-sized biogas plant and joint biogas plants (Nielsen, 2009).

Biomass is delivered to the plant and stored in one or several pre-storage tanks, and is then a number of times daily continuously or semi continuously pumped into a sanitation tank or directly into the reactor. At most large plants, high energy efficiency is achieved through heat exchange of the fresh cool biomass with the degassed warm biomass.

When a CSTR plant is operating, a small part of the biomass will be pumped directly through the plant in a very short retention time. This means that the biological process still emits gas. For this reason, most plants are now equipped with a post-storage tank that collects the residual gas production.

In a few cases, the industry utilises so-called anaerobic filter plants e.g. Up flow Anaerobic Sludge Blanket (UASB plants), a type of plant capable of treating biomass with a low dry mater content. The advantage with this type of plant is that the retention time (the time a given biomass is present in the reactor before it is pumped out) is very short, often only a few hours or a few days, and that the reactor tank does not need to be that big.

The following sections only take a closer look at the continuously stirred plant as this plant is the most widely utilised in Denmark, both for digesting of agricultural biomass and sewage sludge. A typical biogas plant is outlined in the figure below.

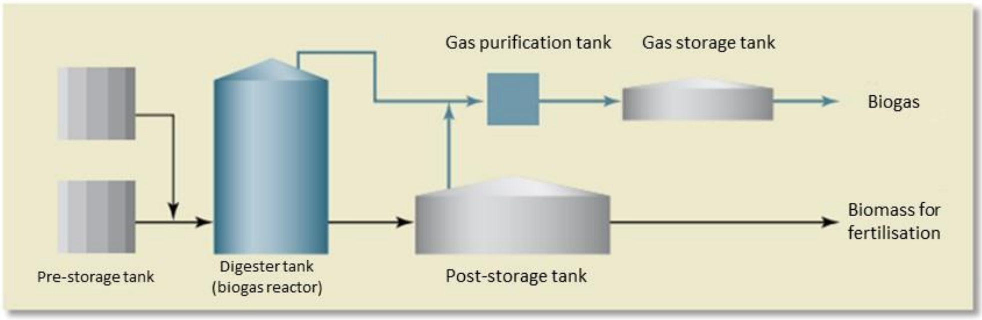

FIGURE 5: OVERVIEW SKETCH OF A BIOGAS PLANT. LIVESTOCK MANURE IS RECEIVED IN THE PRE-STORAGE TANKS OF THE PLANT, FROM WHERE IT IS PUMPED (NIELSEN, 2009).

6.1 PRE-STORAGE TANK

In the pre-storage tank, the biomass is mixed by means of a submerged stirrer to a homogenous mass. The pre-storage tank typically has a capacity large enough to allow the plant to operate during weekends without additional fresh deliveries. From the receiver tank, the biomass is pumped into the digestion tank, either directly, or more often, through heat exchangers to recycle part of the heat from the biomass that at the same time is pumped out of the tank. Some plants also operate with a mixing tank between the pre-storage tanks and the reactor tank. Considerable amounts of odorous substances are excreted from the pre-storage tanks and can be vented and degraded via various odour treatment instruments, or added to the gas engine as combustion emissions (Biogas Secretariat, 2011).

6.2 DIGESTER TANK

A digester tank, often a steel tank, is normally equipped with heating pipes and the temperature in the tank is typically maintained in either the mesophilic temperature range around 37^{o} C, or the thermophilic temperature range around 52^{o} C. With thermophilic operation, it is possible to operate with a smaller tank because the digestion is faster. On the other hand, the process can be more sensitive to biological inhibition of e.g. nitrogen or ammonia. The choice therefore depends on what type of biomass is utilised. The digestion tank is isolated to reduce the loss of heat and is equipped with a stirring system to keep the tank fully mixed. Furthermore, it is equipped with several temperature and pressure sensors to control operational temperature and filling levels. Finally, the tank is equipped with an overflow tube with contact to the storage tank to ensure that the tank cannot be overfilled. With the mesophilic operation, the biomass is on average maintained within the tank for 20 days. With thermophile operation, roughly 16 days is sufficient. After the final digestion, the biomass is pumped out again, most often through a heat exchanger, into a post-storage tank, where it is normally kept for a further 14 to 30 days (Biogas Secretariat, 2011).

6.3 Post-storage tank

The post-storage tank is meant to be a buffer before the digested biomass can be removed and finally stored in the farmer's own storage tank, or used as manure directly on agricultural land. In most cases, the storage tank is covered, primarily in order to collect additional gas production (Nielsen, 2009).

6.4 Gas purification tank

Biogas contains hydrogen sulphide that has to be removed before the gas can be used (either directly in engines or for other use). Removal of hydrogen sulphide used to be a significant problem, but is today accomplished through a simple biological process where sulphur bacteria can degrade hydrogen sulphide into pure sulphur or sulphuric acid. This sulphur, in an aqueous solution, is often also pumped into the post-storage tank and is therefore returned back to the fields and plants. After the purification, the gas contains a certain amount of aqueous vapour that is removed by cooling and condensation before the gas is subsequently stored in a gas storage to be used as fuel (Biogas Secretariat, 2011).

7 Economics of biogas

7.1 Investment and operations costs

Biogas plants are capital-intensive facilities that process large quantities of wet biomass. The resulting economic challenge is achieving a gas output large enough to cover the costs associated with the transport and handling of the biomass. This is particularly challenging for the most important biomass input, the slurry (wet manure), which has a relatively low dry matter content, and therefore a low gas yield (DEA, 2014).

The cost of producing biomass can be allocated according to the following main elements:

- Investment in the biogas plant
- Operations and maintenance
- Transportation of slurry to the plant

- Purchase of biomass (if required)

In addition, there may be additional investment and operating costs associated with the handling of difficult biomasses, such as straw and garden or park waste.

A biogas plant's investment costs cover a variety of items, ranging from the purchase of land for the plant, the various holding tanks described above, SCADA systems, buildings, and facilities for the production of process heat. As noted previously, biogas plants are capital-intensive, but in relation to the energy content of the input material processed at the facility (i.e. the slurry), they also have high operation and maintenance costs. The transport of slurry to and from the biogas plant also constitutes a significant portion of the overall cost.

The investment cost is usually based on the processing capacity of the plant, and is expressed in Euro/tonne. There can be economies of scale related to the building of larger biogas plants (i.e. joint or centralised plants) relative to building smaller plants. On the other hand, experience shows that simple, smaller, farm-sized biogas plant can sometimes be established at a lower cost. A review of realised projects revealed that for a large biogas plant with an annual processing capacity of roughly 365,000 tonnes, the total investment cost was a little over €22 million, equating to roughly €60/tonne/year.

Operating costs for biogas plants include labour costs, maintenance costs, and other diverse operational costs. Costs associated with the purchase of energy crops, as well as the transport of slurry and energy crops, are not included in operational costs.

The cost related to the transport of slurry to the biogas plant is assessed to be around €3.5/tonne. Of this, the capital costs for the trucks are estimated to constitute roughly €0.7/tonne, while the remaining €2.8/tonne is attributed to fuel, labour, and truck maintenance costs. In practice, transport costs will of course depend on the distance to the biogas plant, and will thus be higher for bigger plants that receive slurry from a larger catchment area, and lower for smaller plants with a corresponding smaller area.

The table below displays key cost figures compiled from realised projects for both small farm-sized biogas plant capable of processing up to 75,000 tonnes annually, as well as biogas plants capable of processing 200,000 - 400,000 tonnes per year.

	Farm sized facility (up to 75,000 tonnes per year)	Biogas plant (200,000 – 400,000 tonnes per year)
Total investment	€60 / tonne / year	€44 / tonne/ year
Operational costs	€3.5 / tonne	€3.5 / tonne
Slurry transport		€3.5 / tonne

TABLE 1: KEY COST FIGURES FOR BIOGAS PLANTS. PLEASE NOTE THAT THE COSTS ASSOCIATED WITH THE PURCHASE OF ENERGY CROPS, PROCESS HEAT, AND TRANSPORT OF BIOMASS IS NOT INCLUDED. EXPERIENCE HAS SHOWN THAT SIMPLE FARM-SIZED FACILITIES CAN BE ESTABLISHED AT A LOWER COST THAN INDICATED IN THE TABLE.

The total biogas production cost also depends on the biomass composition at the specific plant, because this affects the specific technologies that are required to process the biomass, for example pre-treatment facilities etc.

Thereafter comes the cost associated with the transport and handling of the biogas, which can include costs related to a low-pressure gas pipeline, low-pressure storage facilities, and potentially upgrading.

Another factor that affects the total production cost is the type of biomass utilised. The figure below displays the cost of producing biogas from various biomass inputs. The production cost when using municipal/household waste, straw organic industrial waste and energy maize are significantly lower than when production is based on livestock slurry or catch crops. The differences is primarily due to the difference in the cost of handling and pre-treatment of the biomass input, transport costs and cost of biomass itself e.g. the cost of buying energy crops vs. livestock slurry which can be collected free at the farm in exchange for the residual product of degassed biomass. The production costs do not include the cost of upgrading and injecting the biogas into the natural gas grid. As will be described in section 7.4, this would increase total costs by approx. €3.6/GJ.

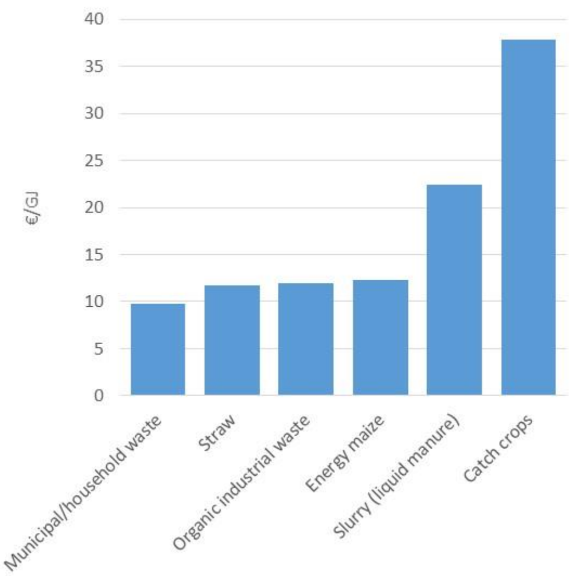

FIGURE 6: GAS PRODUCTION COSTS BASED ON VARIOUS BIOMASS INPUT.

7.2 Nutrient economics for the farmer

An important element for the overall biogas economics is the nutrient economy for the farmer that provides the manure/slurry to the biogas plant. For the farmer, this has proven to be a key motivator for building farm-sized biogas plants and/or providing slurry to larger biogas plants. This value is due to the farmer's plants being able to absorb more nutrients, and an opportunity to fertilise closer to the economic optimum[3]. The value associated with the increased utilisation of the nitrogen, which the degasing process results in, has a value of roughly €0.7/tonne manure. To this, can be added a similar value for being able to fertilize closer to the economic optimum – i.e. adding more fertilizer. Depending on the size of property and livestock, the total value of these elements can exceed hundreds of Euros per year (DEA, 2014).

As was mentioned previously, a biogas facility requires a rather significant upfront investment. Pooling of resources by investing in a joint biogas plant may therefore be an option for the many farmers who cannot, or prefer not to, invest in their own facility.

7.3 Risk factors

Some of the prerequisites for achieving a positive business case can be determined with reasonable certainty prior to commencing a project. Factors that can be determined prior to project commencement, are the construction costs, slurry availability, and to some extent, the biogas offtake. Other factors will be uncertain, based on estimates, or could change over time. For example, it should be possible to determine the operation and maintenance costs, as well as gas output rates at the time of project start. In practice however, a number of facilities have not realised anticipated gas yields, and have incurred operation and maintenances costs higher than expected. Meanwhile, the costs associated with purchasing and handling biomass resources other than slurry are uncertain, as are future prices for electricity and heat. Natural gas prices are another uncertainty factor, which affects the amount of variable subsidy received, also for facilities in areas not connected to the natural gas grid.

7.4 Upgrading facilities

In order to transfer biogas to the natural gas grid, current regulations require that the CO_2 be removed from the biogas, thus raising its calorific value.

[3] Manure from swine production often contain more phosphorus than is needed for optimal fertilizing. The opposite applies for manure from cattle and organic waste. This means that the swine producers often over fertilize significantly with phosphorous, while cattle farms often have to add extra phosphorus in the form of fertilisers. The mixture of different biomass inputs means that the farmers receive a better return product from the biogas production with regard to the content of phosphorus. Furthermore, degassing of manure into biogas means that the nitrogen in the manure can be exploited better. Thee biogas production process alters the ratio between organically bound nitrogen and nitrogen in ammonium form so that there are more of the plant-available ammonium. The fertilising effect is therefore higher of degassed manure than raw manure and loss of nitrogen in the form of leaching will be less. This change is greatest for cattle slurry and solid manure.

Depending on the facility size, a number of sources indicate that water scrubber units are the most cost-effective type of system. The following discussion will therefore refer to this type of system. Other technologies will differentiate themselves both in terms of capital, operations, and maintenance costs, but at present, it is not anticipated that any alternative system can achieve an overall lower cost than water scrubber units.

Facility investment costs can be divided into the following main components:

- The upgrading plant itself
- A system for post-treatment of the resulting gas (to remove residual methane)
- Grid connection

Grid connection to the natural gas network includes adjusting the pressure of the gas to that of the natural gas grid (40 bar at major upgrade facilities), equipment for measuring the gas quality, and odourisation. Connection costs for the service line are not included in the calculations here, as they are heavily dependent on the distance from the plant to the natural gas grid.

For the total facility components, there is a substantial economy of scale advantage for larger facilities.

An upgrading facility with an approximate size of 1,000 m^3 of biogas is estimated to have a cost of roughly €4,700/Nm^3 CH_4/h, including methane reduction and net injection, but excluding the cost of the service line (see Table 2).

Upgrading facility	
Capacity	1000 Nm^3 biogas/h
Operational capacity	591 Nm^3 CH_4/h
Upgrading facility, investment	€3,020 /Nm^3 CH_4/h
Methane reduction, investment	€335 /Nm^3 CH_4/h
Net injection, investment	€1,345 /Nm^3 CH_4/h
Total investment	€4,700 /Nm^3 CH_4/h
Electricity usage	0.38 kWh/m^3 CH_4 0.10 kWh/m^3 CH_4 compression to 40 bar
Operations and maintenance	€95 /Nm^3 CH_4/h
Methane loss	1%
Down time	2%

TABEL 1: TECHNOLOGY AND COST DATA FOR AN UPGRADING PLANT WITH A TECHNICAL CAPACITY OF 1,000 NM^3 BIOGAS/H.

The main variable operating costs consist of the power consumption for both upgrading and compression to the required net pressure. Electricity consumption for upgrading requires roughly 0.25 kWh/Nm^3 biogas, which corresponds to approximately 0.38 kWh/ Nm^3 CH_4 produced. With respect to the electricity consumption for compression, it is estimated that to compress from 7 bar (output pressure from the water scrubber units) to 40 bar (the gas net pressure), requires roughly 0.10 kWh/ Nm^3 CH_4.

In addition, are the costs associated with maintenance, wages, etc., which are approximately €95 /Nm^3 CH_4/h/year.

With the assumptions described above, an interest rate of 5%, and an economic lifetime of 10 years, the total upgrade cost can be estimated to be approximately €0.13 /Nm^3 CH_4, which corresponds to €3.6 / GJ.

8 Challenges and barriers for biogas deployment

Existing barriers related to biomass are: finding customers for the gas, operating finances and financing. Furthermore, biogas is subject to extensive energy regulation as well as environmental and agricultural regulation. Planning new plants is therefore time-consuming and challenging for both market actors and the authorities.

The financial situation for biogas plants is still uncertain, despite the increased subsidies. This is linked to the fact that some of the new subsidies are being phased out and will disappear completely after 2020 if the price of natural gas develops as expected. Upgrading and grid connection are relatively costly. Furthermore, biogas plants have difficulties obtaining a sufficiently high price when selling biogas for CHP. Consequently, they rarely achieve the full value of indirect subsidies for this use.

With regard to expanding biogas capacity, it will be difficult to find suitable biomass to supplement slurry in order to achieve adequate gas production. Deep litter and straw are considerable elements in plans for both existing and new biogas plants. This type of biomass could potentially replace energy crops and industrial waste as the basis for biogas expansion, however specific long-term operational experience and documentation regarding the economic durability of these raw materials are still lacking.

The cost of producing biogas is typically €17.5-19 per GJ, and €20.7-22.3 per GJ in upgraded form. As fuel solely for heat production, biogas is therefore not a financially competitive solution for enterprises compared with alternatives such as heat pumps, solar heating, wood chip-fired boilers and geothermal energy (Biogas Taskforce, 2014).

9 Opportunities for promoting the deployment of biogas technologies

There is an extensive planning process associated with the establishment of biogas plants, including the EIA procedure. The Biogas Unit (Biogasrejseholdet) assists municipalities with the planning phase. Service is available to municipalities within three areas: placement considerations, planning process and problem solving. The funding of the Biogas Unit has been extended, and the Unit will thus continue to support biogas deployment.

Furthermore, there are a number of potential opportunities for promoting the deployment of biogas technologies that can be initiated. As mentioned above, the financial barrier is key, and the market price of biogas is a critical parameter to ensure incentive for an ambitious expansion of biogas. Thus, focus should be on reducing costs, increasing sales opportunities, and promoting the upgrading of biogas and thus the use of biogas for flexible power generation and transport.

If the funding barrier can be reduced, this could promote biogas deployment. Options could include a fund for investment subsidies, the ability to provide government-guaranteed low-interest loans, changes in the regulation of the natural grid companies' costs, or implementation of efficiency improvements in order to reduce the operating costs. The barrier for supplying biogas into the natural gas grid would for example be reduced if a portion of the costs are paid by the grid company. Furthermore, there have been discussions concerning the conversion of indirect subsidies to direct subsidies, so that the subsidy does not depend on whether the biogas is upgraded or not.

The new subsidy framework means that natural gas companies have an interest in biogas, and they have proved willing to invest in biogas plants and upgrade facilities. This opportunity will unfold in the coming years.

10 Stakeholders

The Danish Energy Authority Amaliegade 44 DK-1256 Copenhagen Tel. +45 33 92 67 00	Offers guidance and financial support for biogas projects.
The Danish Environmental Protection Agency Strandgade 29 1401 København K Phone: +45 72 54 40 00	Administers rules on manure use in connection with biogas plants.
Biogas Association of Denmark Axelborg Axeltorv 3 DK-1609 Copenhagen Tel. +45 33 14 56 72	A trade association that aims at improv-ing the conditions of biogas plants in Denmark.
The Danish Biogas Association Vester Bjergevej 2 DK-6760 Ribe Tel. +45 75 44 50 13	An organisation for biogas plant owners in Denmark. Provides among others new biogas plants with experience from previous projects.
Bioenergy Group University of Southern Denmark Niels Bohrsvej 9 DK-6700 Esbjerg Tel. +45 65 50 10 00	The Bioenergy Group has technical and organisational knowhow within biogas production.
Department of Food and Resource Eco-nomics (IFRO) Rolighedsvej 25 DK-1958 Frederiksberg Tel. +45 35 28 68 00	Has financial expertise within biogas production.
The Danish Agricultural Advisory Centre The National Department of Crop Pro-duction Udkaersvej 15, Skejby DK-8200 Aarhus N Tel. +45 87 40 50 00	Disseminates knowledge on the nutri-ent utilisation of e.g. digested slurry.

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Denmark's energy policy took shape after the oil crises of the 1970s. When oil prices accelerated in 1973 Denmark was among the OECD countries that were most dependent on oil in its energy supply. More than 90% of all energy supply was imported oil. Consequently, Denmark launched an active energy policy to ensure the security of supply and enable Denmark to reduce its dependency on imported oil which led to one of the most ambitious biogas development programs in the world.

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