

DANISH EXPERIENCE WITH AD PLANTS AND FUTURE DIRECTION

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INTRODUCTION

Since 1988 the centralized co-digestion plant concept was developed and implemented in Denmark. It turned out to be a considerable success, and since 1995 the technology held a prominent position in Danish energy policy and green-house gas mitigation strategy. This is because the technology addresses not only energy production, but also a number of environmental issues such as fertilizer utilization and odor control.

The development was initiated by implementation of an ambitious government technology development effort, and was also a result of the fact that the technology emerged at a time and a place, which generally provided a favorable environment for the development. Over time, several set-backs have also occurred, however, the ambitions are still remarkably high. The government Green-Growth-Plan from 2009 targets 50% of the manure production should be utilized for biogas production by 2020.

WHAT WAS SUCCESSFUL IN ENCOURAGING AD ADOPTION IN DENMARK, AND WHAT WERE THE RESULTS?

From 1988 to 1998 twenty (20) centralized biogas plants were established in Denmark and remain in operation today. More than 500 farmers are involved, 1 million metric tons of manure and 0.3 million tons of organic waste are treated on a yearly basis. Energy production from the centralized plants amount to approx. 2 PJ and 60 on farm plants account for another 1 PJ, which means it still covers just a minor share of national energy consumption, which amounts to 900 PJ. The development was stimulated by an ambitious government initiated technology development effort, and also by a range of “*push & pulls*” not always introduced to support this specific development, but on the other hand turned out to favor it.

The development is linked closely to the implementation of the first so-called “fresh-water-action-plan” in 1987. It all started with a basket of dead lobsters from the Baltic Sea. These pictures were shown in the evening news on national TV on October 8, 1986. As it turned out later, it was carefully coordinated with a massive campaign initiated by the nature conservation society. Nevertheless it created a tremendous debate, political action was demanded, which ended up in the mentioned fresh-water-action-plan, which actually later had two successors. But nutrient leaches from industry, households and agriculture were held responsible for the poor quality of the Baltic Sea waters in general and the destiny of the lobsters in specific. So, wastewater treatment should now be widely implemented, and livestock farmers faced restrictions in their handling and application of livestock manure.

First, they required 6-9 months storage capacity for manure, in order to secure that manure was only spread in times where nutrients could be obtained by crops. Secondly, the amounts of manure applied per hectare was restricted. For dairy farmers it was set in the range between 1.7 – 2.3 so-called animal units (Examples; 1 unit was for one Holstein dairy cow, for pig producers it was 1.7 animal units, and 1 one unit was three sows and their piglets). This regulation, which is normally referred to as the “harmony rules” secures a certain balance (harmony) between livestock production and the amount of land controlled by each individual farm. Third, minimum nitrate utilization ratios on manure were introduced and nitrate quotas were assigned to each crop, which basically restricts the amount of chemical fertilizer used in crop production.

No wonder farmers strongly opposed these regulations at the time, as they were consequently subject to significantly increased production costs. So when the Danish Biogas Action Program was launched in 1988, many farmers recognized the centralized biogas plant concept as a multifunctional technology which might help or ease farmers’ compliance with the new restrictions. This is due to the fact that biogas companies might make the investments in the necessary storage tanks, which enable farmers to rent the required capacity. If carefully planned, the tanks were placed in positions optimal for the end-use of the manure as a fertilizer. This would in fact, from the farmer’s point of view save money from manure storage, transport, and spreading. Another important aspect is the fact that surplus manure is easily distributed from one farm with a surplus to another farm with a deficit, as it is transported in trucks owned by the biogas company. The redistribution reduces the land required for manure spreading for the livestock producer. Thus, the restrictions on manure handling and utilization formed a kind of regulatory push that initiated farmer’s interest in centralized biogas plants.

The Danish Biogas Action Program was a government initiative from 1988. The aim of the program was to investigate, whether centralized biogas plants could be economically viable if all agricultural, energy, and environmental aspects were taken into account. The program provided investment grants for a number of plants, a monitoring program and funding for identified research and development tasks. Undoubtedly farmer’s interest concentrated on the 40% investment grants obtainable for the first plants from 1988 to 1992. Later the grant ratio was reduced to 20%.

During the Danish Biogas Action Program the understanding of the centralized plant concept as an integrated energy production, waste treatment and green-house gas reduction facility emerged. And there is no doubt that the Program was crucial to the Danish development for a number of reasons (Raven and Hjort-Gregersen, 2005). First, because a bottom-up strategy was applied and interaction between farmers, operators and researchers was stimulated in order to integrate gained experience. Second, the first program was succeeded by new programs for more than a decade, which secured the continuity of the activities maintaining the documentation of experience and keeping it available for new players in the field. Third, the technology developed in a time and a country, in which many regulations, initiatives, and other preconditions actually favored the development and implementation of the centralized biogas plant concept.

Legislative vs. economic incentives

There is no doubt that the first Fresh Water Action Plan turned on farmers' interest in the AD Technology, and it was the main incentive. The optional investment grants were recognized as a kind of co-responsibility from society, which helped convincing farmers that their plants might be economically successful. In addition, the market for produced biogas was provided by purchase obligations for electricity. When produced from biogas or other renewables, energy prices were (and are) subsidized. In the beginning they were just exempted from energy tax. Heat from biogas still is, but electricity from biogas production has since 1992 been sold at fixed, subsidized price. For several years it was about 11 cents/kWh, but since 2008 the price has been 14 cents/kWh. Whether this level is sufficient or not mainly depends on what biomass sources are available for biogas production and this is where the waste enters the scene. Since the early 1990's landfilling of organic waste was prohibited. Instead it should be either recycled or incinerated (for heat and power production). Incineration is more costly than recycling due to taxation, which made application to biogas plants both an economic and convenient way for food processing industries to dispose their organic waste.

In Denmark biogas has so far only been utilized for combined heat and power production. District heating systems are very widespread in towns and cities. Many of these were fuelled by natural gas and the transition into biogas was easy, though, sometimes mandatory through central energy planning by the Danish Energy Authority. So more or less voluntarily the district heating companies buy the biogas or the heat from the biogas plants, and the power companies buy the electricity production. Thermal heat is sold in a price range from 50 – 100 US\$ per MWh. Electricity is sold at a fixed price, which for the time being is 14 cents per kWh. Traditionally energy production and supply in Denmark has been based on a non-profit principle. For some years now that has been changing, but not for district heating companies and companies supplying fuels to district heating companies. The principle is maintained to protect heat consumers in towns or cities from uncontrollable heating costs, but for the biogas plants the system implies that basically they may only produce modest profits. If they do, they will have to agree on reduced biogas or heat prices next year. Now that does not make sense from a business point of view. Not unless you remember, that farmers' main interest was to apply the technology in order to ease their compliance with new environmental restrictions and reduce their costs to do so. So, from the beginning, they accepted not to be able to withdraw profits from the biogas plant company.

However, this is about to change. Now farmers tend to insist on considering biogas production as a new branch of business, and they look enviously to the German border, where some farmers actually make a living on biogas production. But in the historical perspective, the economic incentives were not the most important drivers for farmers' adoption of AD technology in Denmark. On the other hand, the provision of a market and economic preconditions that enabled viable biogas production was indeed important.

Lessons learned from 20 years of community digestion

One major lesson was that the monitoring program during the Biogas development program from 1988 - 2002 provided an eminent learning system especially for plant operators and owners. Gained experience was effectively communicated, and the activities proved crucial to the gradually improved technical performance of the plants, which was, not surprisingly, accompanied by improved economic performance as well. In addition, if special problems needed further attention, they were identified as special research tasks and addressed.

Another lesson is that the above mentioned incentives for food processing industry to direct their waste streams to biogas plants turned out to be the major key to both technical and economic success of AD technology in Denmark. It is much easier to achieve process stability and high biogas production when waste supplies are in ample quantities. And if that is the case, the risk of economic failure is limited. But in year 2000 – 2001 round 50 new on-farm plants were established and put into operation. At first, the constructors supplied the necessary waste, but after a while they left, which made demand and competition about most attractive waste resources increase dramatically, and treatment fees turned into costs from a plant perspective. Lack of good waste has been a problem for some time now, and plants and developers are searching for other types of concentrated input. Thus, a high level of certainty for sufficient biomass supplies from the start is recommended. In fact, lack of waste is an important reason why only very few new plants were established during the last decade.

Furthermore, it turned out that the farmers' involvement seems to be crucial for the success of the plant. In Denmark very often farmers own their service companies like dairies, slaughter-houses and feed-stuff supply companies as co-operative companies. Thus, it seemed natural to organize many of the centralized biogas plants as co-operative companies, which gave farmers full control, as well as responsibility. In theory this provides the incentives for farmers to supply good quality manure to the plant, which becomes increasingly important as waste resources become more and more scarce.

Application of biogas for combined heat and power production in local district heating systems left many biogas plants with only one customer, which is not always an optimal situation. The situation lead to a number of disagreements, and many plants look forward to the optional distribution of biogas via the natural gas grid in near future.

On the technical front, the continuously stirred reactor is the prevailing digester type in Denmark, at least at the centralized plants. It is made of steel and in most cases with a slowly rotating top-mounted stirrer. Several tanks of this kind have been built at sizes of 5000 m³, and an 8000 m³ tank is in planning. However, in these cases they need several stirrers, and more experience to be gained from that. Also concepts were developed in which advanced manure separation technology was integrated after the digester, but so far without much success.

Most of the larger plants operate at thermophilic temperature, 53-55°C.

One major technical breakthrough was the upcoming of a bio-scrubber for biogas cleaning. In a separate tank biogas is desulfurized in a bacteriological process using

atmospheric air. Earlier, the quality of biogas was a major challenge for CHP engines, which led to significant maintenance costs. Biogas quality is no longer considered as a problem.

Optimization of influent dry matter

In Denmark dry matter content in manure is relatively low as shown in Table 1. That in fact, represents a substantial challenge for biogas production as biogas is not produced from water but from organic matter.

Table 1. Dry matter content in different slurry types. Average figures from 3 centralized biogas plants.

Slurry from	Sows	Fattening pigs	Dairy cows
Dry matter content, %	2.5	4.5	7.5

Source: Information from Linkogas, Ribe Biogas and Lemvig Biogas

The reasons for this situation are numerous, but the consequences for plant economy are significant. The methane production per ton of as fed material is shown in Table 2. In some cases even the energy content cannot cover the transport costs.

Table 2. Methane production potential in pig slurry at different levels of dry matter content.

Dry matter content, %	2	4	6	8	10
CH ₄ potential, m ³ /ton	5	10	15	19	24

Source: Own calculations

The figures show dramatically increasing methane production potential by increasing dry matter content in pig slurry, which of course will directly affect the economic potential by digesting it. As a matter of fact, there are very good reasons for attempting to optimize or increase the dry matter content. But how can that be done?

First of all, no builders of animal houses ever made any considerations about the fact that manure could finally be utilized for energy production. So in production systems water consumption is designed for the needs of the livestock production, sanitation and inexpensive disposal, which means that optional optimizations are relatively easily identified.

In Dairy production, for example, it is known that some milking robots consume 6 m³ of fresh water per cow annually just for cleaning. If led to the slurry system, it increases the amount of slurry by approximately 25%.

In pig production large amounts of water is used for cleaning. If directed into the slurry system the dry matter content may be compromised. But certain system designs allow slurry to be taken out before cleaning, and water to be led to separate storage facilities after cleaning, but before pigs re-occupy the house.

In many cases, rain water from roofs and outside areas is led to the slurry system, because it was considered an inexpensive way to dispose it. This water may be led to separate storage tanks or in the future into small nearby willow groves.

Manure separation has been subject to considerable interest among farmers in recent years, because if slurry is separated and the fiber fraction is exported from the farm, the land requirements of the previously mentioned harmony rules are eased. Consequently, farmers who wish to expand their livestock production need to control less land if their slurry is separated, and the fiber fraction for example is exported to a biogas plant. Thus, the system represents a mutual win-win situation for farmers and biogas plants. However, different separation technologies have different characteristics

Table 3. Separation efficiency. Efficiency defined as the relative share of the component found in the fiber fraction.

Separation efficiency %	Screw-press	Decanting centrifuge	Band-pass filter with polymers
Volume	3-5	5-21	15
Total solids	17-32	45-63	89
Organic solids	7-15	50-80	86
Total N	5-9	11-28	40
Phosphorous	7-15	52-80	89
Biogas production potential, m ³ CH ₄ /ton	36-64	40-90	56-80

Also in-house separation systems may become more widespread in the future. So-called source-separation systems, which separate urine and feces fractions have been developed, but are not yet widespread as they are typically more costly.

In European countries and especially in Germany a considerable enlargement with plants using energy crops has taken place. This kind of development requires a high subsidy level to cover production costs of the energy crops, which so far is not the case in Denmark, and the use of energy crops is limited. It is not that farmers are not interested in producing and selling energy crops to biogas plants, but this activity is not encouraged by the subsidy system. It is a government opinion that energy crops should not substitute food production in agriculture. Instead they encourage digestion of concentrated manure fractions like deep litter, poultry manure and manure fibers. The government also other favors digestion of surplus biomass materials like straw, tops from carrots and potatoes, waste from vegetable or fruit production, and even grass from uncultivated grass-lands. Methane yields for some of these biomass sources are provided in Table 3. Currently special attention is paid to these biomass types, as these are seen as an option to collect and recycle nitrogen from extensive grass-lands on to cultivated agricultural areas.

Table 4. Methane production potential from concentrated manure types, crops and residues from agriculture, Nm³ CH₄ per ton as fed

	DM (%)	OM (%)	CH ₄ potential (m ³ /ton)
Deep litter from dairy	30	24	48
Fiber fraction from pig manure	28	22	54
Poultry manure	48	38	108
Sugar beets	20	18	65
Corn silage	30	28	100
Green grass silage	30	27	59
Grass/hay from extensive lands	80	64	160

Source: Own calculations

A comparison between Table 2 and Table 3 reveals significant differences in the per ton methane production potential. That means that the biomass types in Table 3 may be supplied to slurry based biogas plants in order to increase average dry matter content, and thereby to increase biogas production. But it has to be taken into consideration that it takes costs at different levels either to grow or procure them, and some existing plants may need additional equipment to handle the higher DM content. Furthermore some of the most lignified biomass types like straw may require pre-treatment to achieve higher digestibility.

Danish “Green-Growth” Plan

In 2009 the Danish Government launched the so-called “Green-Growth” Plan. It can be seen as recognition of the importance of agriculture for Danish society in a time where agriculture in general is not that popular. And also a recognition that in the future agriculture still has a role to play as a new-job facilitator and a food producer in growth, as long as the development is green.

The Green-Growth Plan has two headlines:

1. An Environment and Nature Plan for Denmark
2. A Strategy for a Green Agriculture and Food Industry in Growth

The Environment and Nature Plan picks up the line from the previous initiatives and introduces new regulations to improve quality of water systems to: reduce impacts from pesticides on humans and animals, reduce green-house gas emissions, improve bio-diversity, increase access to nature for the public, and to improve monitoring of nature. In case of restrictions certain compensation can be obtained.

The Strategy for a Green Agriculture and Food Industry contains a removal of some and a simplification of other regulations that previously restricted individual farms to grow larger in size. These initiatives should help improving the competitiveness in livestock production. The plan also encourages farmers to become suppliers of green

energy. It contains the ambition that 50% of livestock manure should be utilized for biogas production by 2020. In order to accomplish this target a new investment grant scheme was established. In addition, negotiations on restructuring the subsidy scheme have been going on for a long time. (They are not yet concluded, but in November the government signaled an increase in electricity prices from 14 – 18 cents per KWH). Also, the strategy tends to encourage perennial energy crops like willow groves.

Future direction for Danish centralized biogas plants

The existing plants were designed mainly for digesting liquid manure and certain amounts of organic waste. In recent years this strategy has become far more problematic due to the competition of the waste. In fact they face significant challenges, technically as well as mentally, in the transition towards application of more concentrated biomass types. New plants, of course, are from the beginning equipped with necessary facilities for mixing and feeding of concentrated biomass types. Also in the future, biogas plants may demand higher quality of manure supplies from farmers, especially with focus on dry matter contents in pig slurry. Some farmers may have to introduce separation technology if they want to supply manure to a biogas plant.

For more than 20 years Denmark was a producer of natural gas from the North Sea. At an early stage a widely branched natural gas grid was established and most major cities are connected. The natural gas is used for local combined heat and power production. In the first place, it formed a brilliant opportunity for biogas plants as they could simply substitute the natural gas at the local CHP facilities. However, as mentioned, having only one customer was not always an ideal situation. But now the natural gas resources are diminishing and production already declining. Natural gas distribution companies turned out to be more than interested in purchasing biogas, upgrading and distributing it via the natural gas grid. From there it can be used for CHP production, heating purposes, industrial use, and especially as vehicle fuel. Recent rising in oil prices have made fuel prices so high that we are close to a situation, where biogas is competitive. Thus, with little or no subsidies, biogas is likely to be distributed via the natural gas grid and substitute gasoline or diesel as a vehicle fuel. Biogas will be produced in the western, rural areas, where the livestock production takes place, and applied into cars and busses in major cities.

Finally, we see a development where large slaughterhouses and dairy companies involve in large biogas projects for marketing reasons, as they can then brand themselves with a greener profile.

REFERENCES/FURTHER READING

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