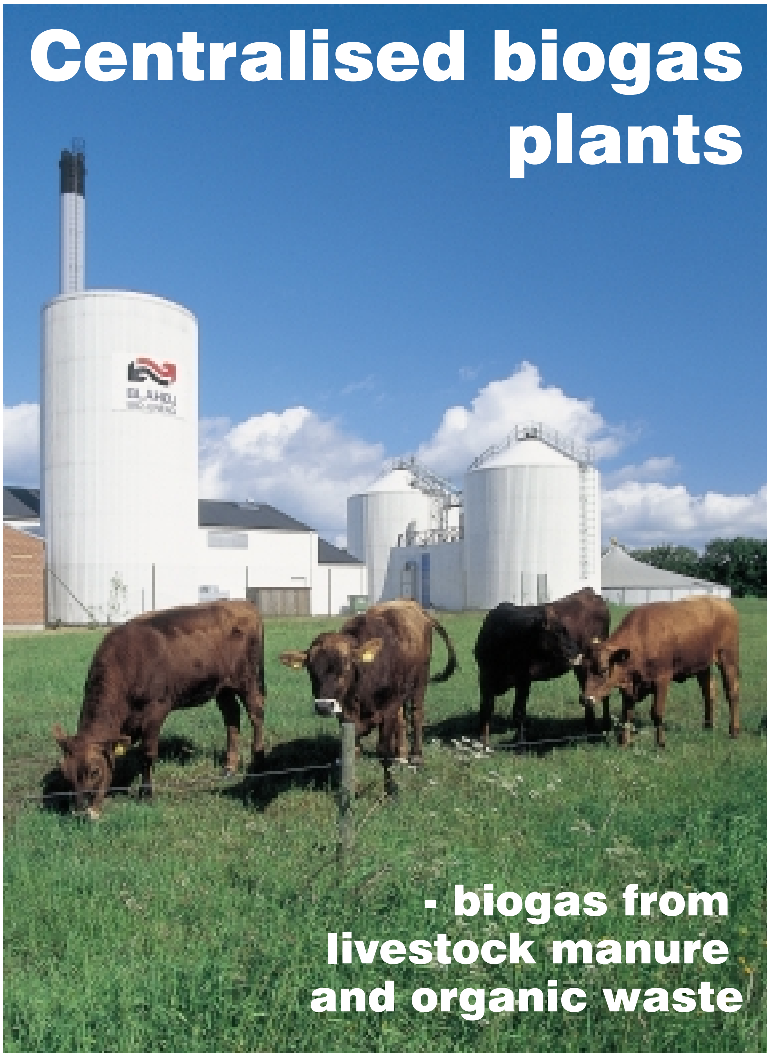
Centralised biogas plants

- biogas from livestock manure and organic waste



Centralised biogas plants are an important element of the Danish government's energy and waste handling plans. One of the main objectives is to ensure that 100,000 tonnes of household waste is reused in biogas plants by the year 2004, and that overall biogas production will multiply by eight over the next 20-30 years.

By Søren Tafdrup and Kurt Hjort-Gregersen

A centralised biogas plant is shared by several farms. The largest plants receive manure from about 80 livestock herds. The manure is transported from the farms to the centralised plant, where it is digested. Its nutrient value is determined and it is returned after gasification. Excess amounts of gasified manure is sold by nutrient value among the participating farmers. The gas is normally used at decentralised combined heat and power plants that supply district heating to urban agglomerations and sell power to the grid.

Apart from the manure the plants receive various sorts of organic waste. As the waste is to be used as a fertilizing agent in conjunction with livestock manure after digestion, it must not contain ecotoxic substances (in particular heavy metals).

The drawback of centralised plants is the costly process of transporting livestock manure. On the other hand, this process involves a well-structured redistribution of excess amounts of manure among livestock farmers and crop producers. The transport to and from the plant is carried out in tank lorries that normally hold 15-20 tonnes.

20 plants in operation

Today 20 centralised biogas plants are in operation in Denmark. Their conversion capacity ranges from 25 to 500 tonnes of biomass per day. The amount of biogas produced varies between approx. 1,000 and more than 15,000 m^3 per day.

Most centralised plants are built and owned by co-operative societies, the members being the participating manure suppliers. Some of the societies have set up common manure tanks, and this has lowered the price for the storage capacity required.

A centralised biogas plant is a renewable energy conversion plant involving a number of agricultural and environmental advantages. It is easier to distribute livestock manure by manurial value, and suitable waste from industries and households can be recirculated through the plants. The level of nutritive salt pollution can be reduced, as livestock manure and waste is converted into a homogenous product that can be used efficiently as a fertilizing agent, because its manurial value can be determined. Consequently, the amount of chemical fertilizer used can be reduced. Last but not least, the biogas produced is a CO_2-neutral fuel suitable for i.a. decentralised combined heat and power generation.

Biomass and gas production

Centralised biogas plants normally use a mixture of approx. 80 per cent manure and 20 per cent organic waste. Many different sorts of organic waste are used, including gastrointestinal substances from slaughterhouses, waste from the fishing industry, flotation sludge from various parts of the food industry, waste from tanneries, breweries, dairies, oil mills, the drug industry, etc. Furthermore, an increasing amount of municipal sewage sludge and source separated household waste is used.

So far, organic household waste has only been used in centralised plants to a very limited extent, but in the years to come we can expect significantly increased use of this type of waste.

The combined digestion of livestock manure and organic waste involves process-related as well as economic and environmental advantages.

The biological process

Technically speaking, a biogas plant is a simple process plant. Livestock manure and organic waste is mixed in one ore more pre-processing tanks. The mix is pumped into the digesting tanks (also known as reactors), where it is heated and digested anaerobically, i.e. without oxygen.

The reactors are fully stirred gastight tanks. The digestion process is ensured by a bacterial culture consisting of natural bacteria, which adapt to the individual plant over a few weeks or months. In the biological decomposition process the bacteria produce biogas and a liquid fertilizing agent.

The biogas plants apply a so-called continuous digestion process. This means that once or several times a day the biogas reactors are drained of a small amount of gasified biomass, and a corresponding amount of raw biomass is pumped in. This ensures constant supply to (loading of) the bacteria culture and stable gas production. Normally, the biomass remains in the reactors between 12 and 25 days on average - depending on the temperature.

Unlike composting systems, where the energy is released in the form of heat, practically no heat is generated in biogas plants, where the energy is released in the form of gas instead. As the conversion process is faster at higher temperatures, it is necessary to heat up the biogas plants. A small part of the gas produced is used for this purpose. 12 of the centralised biogas plants in operation use thermophilic bacteria operating at 50-55°C, whereas the other 9 plants use mesophilic bacteria operating at 30-40°C.

Most plants have gradually managed to increase the amount of gas produced significantly. This progress has mainly been achieved through increased supply of organic industrial waste - especially fatty waste types with a large content of biologically decomposable organic matter.

Furthermore, experience has shown that a considerable amount of gas is generated in the storage tanks used for the gasified manure. Therefore, gas collection from these storage tanks has now been introduced at old as well as new centralised plants. This typically increases gas production by 5-15 per cent.

The third reason for the productivity increase is that plant operation has become increasingly stable. As production interruptions are avoided, the biological process becomes increasingly stable and efficient.

Technical matters

Nowadays the plants show high reliability, but not all of them are technically perfect. At most of the plants this reliability has been

Biomass	**Total**	**Percent**
Cattle	448,495 m^3	33.2%
Pigs	529,138 m^3	39.1%
Various fertilizing agents	49,429 m^3	3.7%
Crops, misc.	421 m^3	0.0%
Slaughterhouse waste	86,936 m^3	6.4%
Organic industrial waste	214,212 m^3	15.8%
Waste water treatment plants	22,415 m^3	1.7%
Household waste	1,500 m^3	0.1%
Biomass, total	**1,352,546 m^3**	**100.0%**
Total gas production in 1998	50,092,000 m^3	
Energy production at 65% CH_4	1166 TJ	
Gas production per m^3 biomass	37 m^3	

Table 6. Amount of biomass supplied and gas production at the centralised biogas plants in 1998.

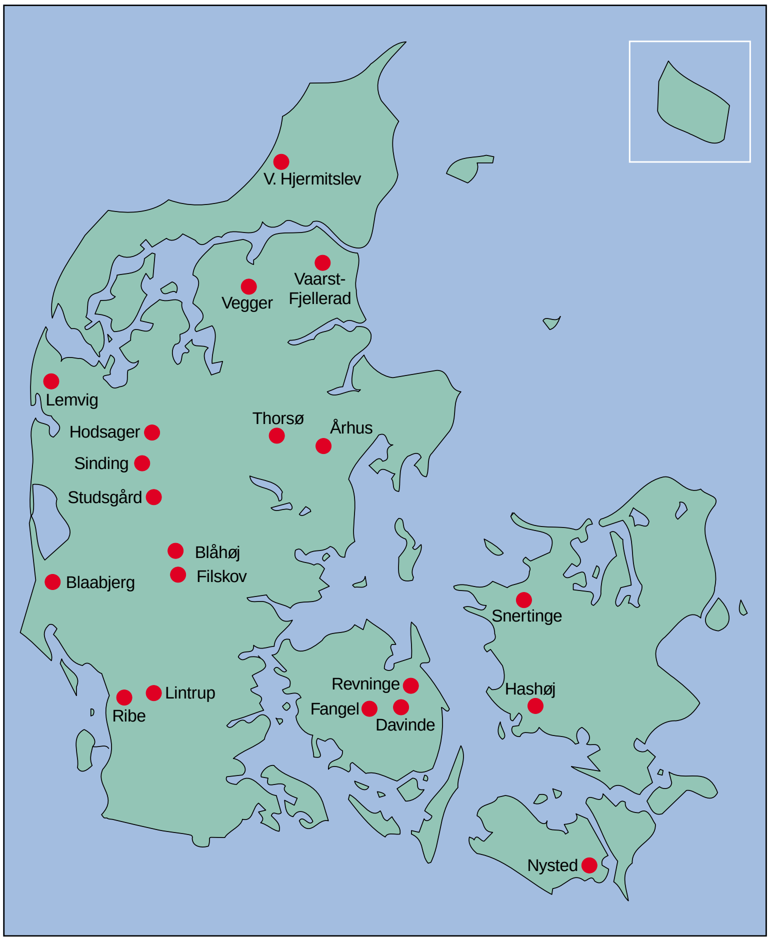


Figure 13: The location of the 20 centralised biogas plants in Denmark.

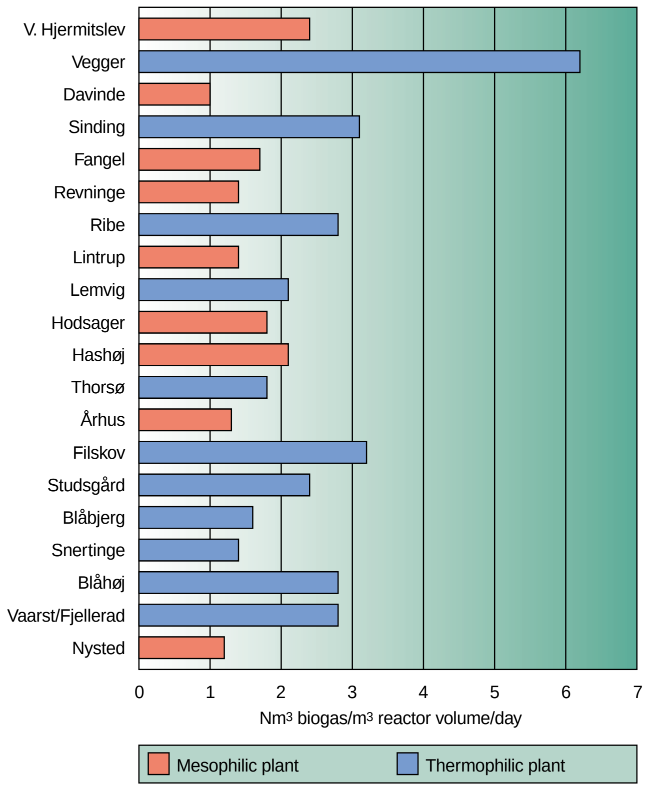


Figure 14: Gas production per reactor volume unit for mesophilic and thermophilic plants in 1998, respectively.

achieved through i.a. additional investments and reinvestments, where unsuitable components have been replaced.

Stirring was formerly carried out by means of standard propeller-type stirrers, but today a number of different stirrer types are employed, depending on where in the system they are used.

Practically all pumps used for manure pumping are helical rotor pumps. Here, several different makes and qualities have also been employed, and consequently operational reliability has been improved and operating costs have been reduced.

Half of the centralised biogas plants have heat exchangers, allowing the gasified manure to heat up the raw manure. In this way the most efficient plants can manage with a 12-14°C net heating of the manure. The heat recovery process causes deposits that have to be removed now and then by flushing with diluted acid.

Manure and other biomass substances contain a certain amount of sand. Most of it is removed after precipitation in the pre-processing tanks, but some of it is “carried” into the reactors, where it precipitates. A simple and rational way to remove the sand is by emptying the pre-processing tanks once a year or every second year and removing the sand by means of a mini-excavator.

The obnoxious smells involved in the spreading of manure can largely be overcome by gasifying it. This is one of the major advantages of biogas plants. Paradoxically, centralised plants have a reputation of causing obnoxious smells. In other words, equipment is required that effectively eliminates the smell from the biogas plant itself. This aspect of the technology has generally been underestimated. However, there are proven prevention methods involving the burning of the extracted air and the use of bark or charcoal filters.

In order to reduce the wear and tear on the engines used, the hydrogen sulphide, ammonia and particle content of the biogas must be reduced. Over the past five to six years, cleaning the gas by adding a few per cent of air has gained ground as a very efficient and relatively inexpensive cleaning method. The process makes it possible to reduce the hydrogen sulphide content from 2-3,000 ppm to a few hundred ppm, while also reducing the ammonia content.

Six plants use special equipment to separate the gasified manure and achieve a solid fibre fraction with a dry matter content of 25-45 per cent. Separation is used for i.a. the production of compost and the removal of plas-

The drawback of centralised plants is that the transportation of livestock manure is costly. On the other hand this process involves a well-structured redistribution of excess amounts of manure among livestock farmers and crop producers.

tics residue after digestion of household waste.

Economy

The economic viability of centralised biogas plants has gradually improved over the years. This has been ensured by, for instance, increasing the overall amount of biomass processed by the plants. In particular, the introduction of larger amounts of organic waste has improved the economic viability, as the plants achieve higher gas production levels and receive a higher fee for receiving the waste. In addition, the reliability has gradually improved, stabilising the operating expenses.

In recent years the increase in economic performance has been less pronounced than earlier. One of the reasons is that the price paid for the energy generated has declined in real terms through the 1990s. Such price drops necessitate increased productivity at the plants, and most of them have been able to achieve this.

Plant economy figures appear from table 7, which shows each plant's current earnings from 1990 (or from the time when the plant was set up) through 1998. The figures indicate operating receipts minus operating expenses, i.e. the amount left for payment of interest, depreciation and consolidation. The column on the far right shows a calculated minimum earnings requirement. If the plant can meet this requirement, chances are good that it will survive.

Table 7 shows that many of the plants have succeeded in making the company economy balance. Today it is possible to set up profitable plants under the right conditions. However, it must be said that many of the plants are having or have had serious financial problems.

	1991	1992	1993	1994	1995	1996	1997	1998	Minimum earnings requirement
	DKK	DKK	DKK	DKK	DKK	DKK	DKK	DKK	DKK
V.Hjermitslev	488	330	591	904	837	583	1,516	879	950[1]
Vegger	-131	999	891	1,270	1,225	1,037	1,574	1,482	700[1]
Davinde	173	300	223	283	255	150	77	17	270[2]
Fangel	1,225	1,458	2,422	2,247	2,842	2,221	2,279	2,317	2,800[2]
Revninge	35	544	262	445	309	217	289	254	250[1]
Ribe	472	2,256	2,657	2,895	3,230	3,161	3,298	3,855	2,600
Lintrup	2,762	2,350	2,822	3,622	3,605	2,639	3,865	3,457	3,600
Lemvig		318	2,393	3,927	4,642	3,848	4,444	4,353	4,200
Hodsager				786	1,106	1,132	1,195	1,207	1,200
Hashøj				490	1,502	1,341	1,882	1,982	1,500
Thorsø				303	1,482	1,756	2,023	2,495	2,100[3]
Århus						-3,994	-2,207	-1,860	3,500[4]
Filskov					742	1,394	1,526	1,674	1,500
Sinding/Studsgård						1,762	4,197	3,324	6,400
Blåbjerg						1,676	3,090	3,576	2,600
Snertinge							1,655	2,180	2,850
Blåhøj							574	1,845	1,900

1. After deferred payment of debt.
2. After debt conversion/partial respite.
3. The minimum requirement was increased after combined heat and power extension in 1997/98.
4. Original capital debt only.

Table 7. The development in the current earnings of the centralised biogas plants. The table does not include the two most recent plants at Vaarst-Fjellerad and Nysted.

What does it take?

The basic prerequisite for setting up a biogas plant is the availability of manure and organic waste in sufficient quantities as well as a group of farmers who supply manure and receive the gasified material for use in crop production. In addition, there must be a possibility of selling the biogas produced for heat or combined heat and power generation. The sale of heat requires the existence of a district heating network. Finally, there must be an organisation capable of planning, setting up and operating the plant.

It is still not possible to make centralised biogas plants economically viable, if they are based on livestock manure alone. A certain amount of waste is required. The quantity depends on the gas production potential of the waste and the fee paid for receiving it. In principle, if only the fee paid for receiving waste is high enough, it is possible to process waste that yields only a small amount of gas, but which is mainly supplied to the biogas plant in order to ensure "hygienisation" and recirculation of nutrients.

It is a great advantage for the farmers that the transportation system of the centralised biogas plant contributes to the redistribution of the livestock manure from the livestock farmers to the crop producers. Add to this that it is more straightforward to determine the nutrient value of the gasified manure than that of raw manure, and it is easier to exploit the nitrogen content. Furthermore, the pathogenic germ content is reduced considerably, and the obnoxious smells generated when returning the manure are reduced.

So far, the economic advantage of the farmers has been estimated at DKK 5-10 per m^3 manure, maybe more under certain conditions. This aspect of centralised biogas plant economy is not included in the figures in table 7.

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Successful farm biogas plants

Today the quality of Danish biogas plants is satisfactory, and steady operation has been achieved. If the farmer has the possibility of processing industrial waste at his biogas plant, it can even become a profitable business. On the other hand, it may be hard to make the plant economically viable, if only manure is available.

By Ole Elmose and Kurt Hjort-Gregersen

In Denmark approx. 20 farms have their own biogas plant, but the number of plants is expected to increase significantly in the near future. The reason for this is that today the plants are operating much better than before, and that more favourable rules have been introduced concerning the payment for the power supplied by the biogas plants to the grid.

During the first 10 years after the energy crisis in 1973 a number of farm biogas plants were set up, which unfortunately did not meet expectations, mainly due to insufficient gas production and poor technology.

The plants operating today have all been set up within the past 10 years. These technically well-run plants are all operating steadily. The gas engines are typically the weakest link, but they have also seen a positive development in recent years.

The farm plants set up tend to be increasing in size. Thus, many of the new farm plants are approximately the same size as the smallest centralised plants, and some farm plants also process manure from the neighbouring farms.

Many types

There is considerable variation among the plants as regards size and design. Several plants have horizontal steel reactors, whereas others have vertical concrete or steel reactors. A few plants use low temperature digestion at approx. 20°C, but at the majority of the plants the reactor temperature is 35-50°C.

The gas is almost exclusively used in engine/generator systems for combined heat and power generation. In 1998 the farm plants generated a total of 3.65 million kWh electrical power. This is twice as much as in 1997. The heavy increase in electrical power generation is due to a combination of new and larger plants and a higher degree of operational reliability, including continuous fish oil waste supply.

Many plants have a gas storage facility allowing so-called tariff operation, which means that electrical power generation mainly takes place when the price for electrical power is high. At several plants, the gas storage facility consists of a gastight canvas over the reactor, whereas others have a gas bag in a separate building or room.

Waste ensures profitability

In Denmark it is now possible to set up farm biogas plants that yield a satisfactory economic result. This is largely due to the fact that the Danish Energy Agency provides set-up grants and that the price paid for the power generated amounts to approx. DKK 0.60 per kWh.

The vast majority of plants receives supplies of organic waste together with the manure, which helps to increase the gas production significantly and make the plants more profitable.

It is not yet clear whether it is possible to set up profitable farm biogas plants that are supplied with livestock manure only. At several of the more recent farm plants, which were originally intended to use the farm's own manure only, it appeared that gas production levels were much lower than expected. In order to make these plants economically viable the owners have now started to increase gas production levels by adding organic waste to the biomass.

Apart from the economic advantages of the energy production process, the use of biogas plants involves certain agro- technical advantages. These include better exploitation of the nitrogen content, less obnoxious smells from manure transport and a reduction of the amount of pathogenic germs and weed germs.

Combined heat and power plants

Experience shows that it is relatively costly to keep small gas engines with an output of up to 50 kWe in operation. But today operators can conclude agreements for total service, including total repair at a price of DKK 0.12-0.15 per kWh for engines with an electrical output of 35-50 kW. This is a relatively low price for engines of this size, and it is important to know the operating expenses in advance.

In recent years several plants have had so-called dual-fuel engines installed. These are conventional diesel engines capable of operating on biogas by adding 10-15 per cent of diesel as an ignition medium. The dual-fuel engines are expected to be cheaper to operate, and their electrical efficiency is higher.

Finally, the first steps have been taken to design a 9 kW stirling engine at the Technical University of Denmark. It is intended for use in connection with for instance small farm biogas plants. Particularly low operating costs are expected, as this type of engine has very few and sturdy wearing parts. In time, a larger stirling engine of approx. 40 kW, which is being designed for wood gas purposes, is also expected to be further developed to run on biogas.

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Biogas can compete with combustion

Several centralised biogas plants - like this one at Studsgård near Herning - process organic household waste at a price of DKK 40-50 per tonne.

Centralised biogas plants can process household waste at DKK 40-50 per tonne and thus compete with the combustion plants, as regards pure organic waste.

By Søren Tafdrup

Since the late 1980s, manure-based centralised biogas plants have been developed successfully. Today the concept is based on combined digestion of livestock manure and organic industrial waste, normally in a 4:1 ratio. The 20 centralised biogas plants currently in operation reuse approx. 250,000 tonnes of organic industrial waste per year.

So far, however, biogas generation from household waste has been the source of much disappointment. The Nordsjællands Biogasanlæg biogas plant at Elsinore is the best known among several examples of this. The main problem has consisted of finding a satisfactory, simple and economically viable solution to the removal of plastics.

But now we can claim to be on the right course. Today we have successful biogas plants capable of processing source separated household waste in Herning and Grindsted. Moreover, the local authorities in Århus have made the decision to establish a source separation system and extend the local biogas plant. In Aalborg new initiatives are also being taken in co-operation with the biogas plant at Vaarst-Fjellerad.

DKK 40-50 per tonne

The fact that centralised biogas plants can now compete with the combustion plants is due to organisational, biological, technical and scale-related factors.

The organisational aspect, that the farmers take the responsibility for the final application of the gasified product in advance, is in itself of economic importance.

At large centralised biogas plants, which digest up to 500 tonnes of biomass per day, the costs are approx. DKK 40-50 per tonne, including capital costs. Therefore, the price for the processing of one tonne of "pure" organic waste can be brought to a relatively low level. For instance, it is not more problematic to handle the organic part of the household waste than e.g. solid farmyard manure.

In other words: If the waste handling utilities can "produce" biologically decomposable organic waste which contains no plastics or other foreign substances, the biogas plants can receive this waste at a relatively low price.

The main problem is that source separated household waste is generally collected in plastic bags that must be removed. The most popular solution is to eliminate most of the plastics before the digestion process and removing the rest afterwards. All in all, the price for this solution is approx. DKK 300 per tonne. Thus, the obvious development objective is to minimise the presence of plastics in the waste and preferably avoid it completely.

If you look at plant operating costs alone, there is no doubt that biogas plants can compete with combustion plants. The main uncertainty concerns the other aspects that must be considered. These include extra collection costs as well as valuation of energy produced, reuse of fertilizing agents, emissions and disposal of waste from the combustion plants.

No future for special plants

Over the past 10 years, Central and Northern Europe has seen the erection of a number of biogas plants which only process household waste. In many cases the plants have been relatively costly, both as regards investments and operation. It even applies to certain concepts that the effect can be questioned from a purely environmental point of view. The development and extension of these special plants for household waste must be expected to stop, as they are not competitive, neither from an environmental nor from an economic point of view.

In Denmark the supply of source separated household waste to biogas plants is now increasing. In 1998 the plants in Herning, Grindsted and Vaarst-Fjellerad processed approx. 3,000 tonnes in total. This figure will increase to 20-25,000 tonnes per year in the course of 2-3 years, mainly due to the extensions decided upon in Århus and Herning.

Through co-operation with the refuse collection companies, efforts will be made to implement further extensions, i.a. on the island of Zealand, in order to meet the objective in the government's waste disposal plan, Waste 21, within the next five years.

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The centralised biogas plant at Vaarst-Fjellerad processes organic household waste from Aalborg in addition to livestock manure and industrial waste.