Centralised Biogas Plants

- Integrated Energy Production, Waste Treatment and Nutrient Redistribution Facilities

Danish Institute of Agricultural and Fisheries Economics, 1999

The Hashøj plant, 135 m³ biomass per day, 17 farmers involved.

The Lemvig plant, 400 m³ biomass per day, 80 farmers involved.

The Nysted plant, 227 m³ biomass per day, 35 farmers involved.

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Centralised Biogas Plants -Integrated Energy Production, Waste Treatment and Nutrient Redistribution Facilities

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Preface

The Danish government is considerably ambitious in the fields of environmental and renewable energy policies

Strategies have been formulated in order to develop and implement sustainable technologies in energy production and waste treatment.

In 1987 an action plan on developing centralised biogas plants was initiated. A development and demonstration programme was started and supported by follow-up programmes that ensured that experience was collected and communicated to interested parties.

The first programme was implemented in 1988-91. The results were so promising that another programme was initiated in 1991 which ran to 1995, and yet another from 1995-98. It has been decided to continue the programme until the end of 2001.

The Danish Institute of Agricultural and Fisheries Economics carried out economic follow-up programmes under the above-mentioned development programmes. This report presents the achievements of this follow-up in the economic field.

The report was written by researcher Kurt Hjort-Gregersen, M.Sc. and edited in co-operation with members of the Biogas Group. This group is responsible for the Biogas Development Programme under the Danish Energy Agency.

October 1999

The Danish Institute of Agricultural and Fisheries Economics
Farm Management and Production Systems Division

Johannes Christensen, Research Director

1. Introduction

Over the last decade, considerable efforts have been invested in developing the Centralised Biogas Plant Concept in Denmark.

The interest in biogas production originated in the early seventies as a consequence of the oil crises. In the search for energy sources that could comprise an alternative to fossil fuels, biogas from animal manure emerged as one option.

Several farm-scale plants were established in the following years on an experimental basis, but most of these plants were subsequently closed down because of technical and economic problems.

In 1984, the first centralised biogas plant was established. This plant, like most of its successors, was equipped with combined heat and power production facilities, as heat was supplied to a nearby village and electricity was sold to the electricity grid

The main purpose of this and other early centralised plants appeared to be energy production. It later emerged that centralised biogas plants make a significant contribution to solving a number of environmental problems in the fields of agriculture, waste recycling and greenhouse gas reduction.

In recognition of this, the government has supported the development in different ways: an appropriate legislative framework, research and development programmes, investment grants and other subsidies.

As a result, 20 centralised biogas plants are in operation in Denmark today. In addition centralised biogas plants have achieved a prominent position in Danish energy and environmental planning.

At this moment 20 centralised biogas plants are in operation in Denmark. It appears that most of the plants are placed in the western parts of the country, which is the area with the highest livestock density.

2. The Centralised Biogas Plant Concept

At the Thorsø plant a low pressure biogas storage facility on top of a traditional slurry storage tank was introduced. The system has been copied by later plants.

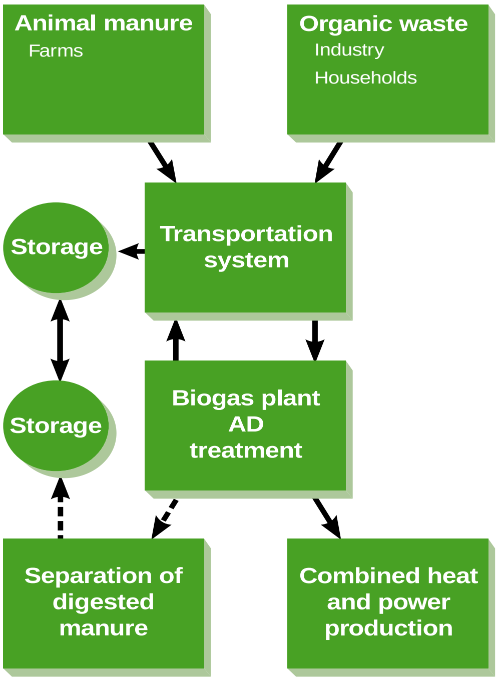
The major biomass resource for anaerobic digestion in Denmark is animal manure. Approximately 75 % of the biomass treated in Danish plants is manure. In addition, around 25 % of the biomass is waste that mainly originates from food processing industries. A few plants treat sewage sludge as a supplement to animal manure. 4 plants are capable of treating source separated household waste.

Animal manure, mostly slurry, is transported from farms to the biogas plant in vehicles owned by the biogas plant. The normal situation is that food processing industries and municipalities take care of the transportation of waste to the biogas plant.

In the biogas plant, manure and organic waste are mixed and digested in anaerobic digestion tanks for 12 - 25 days. During this period effective sanitation takes place and weeds and pathogens are killed on a satisfactory scale.

From the digestion process biogas emerges which is cleaned and normally utilised in combined heat and power production plants. Heat is usually distributed in district heating systems, and electricity sold to the power grid.

The Centralised Biogas Plant Concept.



When it leaves the digestion tanks the biomass, now called digested manure, is returned to slurry storage tanks by vehicle. Some of the slurry storage tanks are normally owned by the biogas plant. Some of them are placed near the farms while others are placed near the fields where the digested manure is to be end-used as fertiliser.

A few plants have slurry separation equipment as a post-treatment facility. Until now this equipment has not been utilised to any great extent as biogas plants have not managed to create a market for digested compost products.

However, as restrictions on manure application and demands on nutrient utilisation are likely to increase in the future, renewed attention will probably be paid to separation technologies. It is generally anticipated that further redistribution of nutrients will be required in the future. Centralised biogas plants may play a significant role in this context if they can offer an appropriate separation technology and distribution system.

A heat exchanger at the Thorsø plant for heat recovery from digested manure.

Combined heat and power production facility.

3. Why Centralised Biogas Plants ?

Agricultural interests

In Denmark, as in many other regions of the world, livestock farm size continues to increase. If not taken care of this development may lead to increased nutrient loss, which is unacceptable from an environmental point of view

In 1987 the first Fresh Water Action Plan was implemented in Denmark. The action plan restricted the application of manure and set up minimum coefficients for the utilisation of nitrogen from animal manure.

To meet these demands, farmers needed larger areas for manure spreading than they were used to, which potentially increased manure transportation costs. In addition, periods in which manure may be applied were restricted, and farmers had to establish manure storage facilities. 6-9 months' storage capacity was typically needed.

From the farmers' point of view, centralised biogas plants make it a lot easier to meet the legislative demands. The biogas company provides the storage facility investments and farmers then rent the capacity they need. Moreover, if the storage tanks are placed near the fields where the manure is end-used as a fertiliser, farmers obtain considerable cost savings from manure transportation in times of spreading. The manure is transported from the farms to the biogas plant and returned to the storage tanks. The biogas plant takes care of this transportation in its own vehicles.

Centralised biogas plants have a role to play in the efforts of environmental protection.

In addition, the anaerobic digestion process under thermophilic conditions, or in a separate sanitation step, ensures weed and pathogen kill at a satisfactory level.

Analyses showed that farmers gain considerable economic advantages from improved nutrient utilisation and cost savings when they participate in centralised biogas plants.

Transport vehicles are essential to the operation of centralised biogas plants. At the Ribe plant approx. 400 tonnes of biomass are transported in and out on a daily basis by three vehicles.

Energy interests

Biogas is a renewable energy source based on various domestic organic waste resources. Since the oil crises in the early seventies, there has been general awareness that renewable energy technologies must be developed. Dependency on fossil fuels must be reduced as future oil crises may occur and world-wide fossil fuel resources become scarce in the long run.

In Danish energy planning, various renewable energy sources should gain increasing shares of total energy consumption. Biogas from manure, organic waste, sewage sludge and landfills comprises one of these.

Environmental interests

According to international commitments to reduce air pollution and greenhouse gas emissions, Danish energy consumption must partly be converted from fossil fuels to renewable energy sources.

In addition, centralised biogas plants are well-suited for recycling various types of organic waste as long as the waste does not contain elements that may restrict the end use of digested biomass as a fertiliser. Danish environmental policy is quite ambitious with respect to the recycling of organic waste fractions.

In addition, as was true for agricultural interests, it is of major environmental interest that nutrient losses from manure application are minimised.

Finally, anaerobic treatment in a biogas plant reduces odour nuisances in times of slurry application - a side-effect welcomed by many farmers.

4. Special Danish Preconditions

The development of centralised biogas plants in Denmark, in which 20 plants were established and have operated over the last 15 years, was made possible in a framework of several special conditions. Not only have biomass resources been available, but there have also been a considerable number of legislative pushes and pulls, as well as other physical preconditions, as a consequence of general and environmental policies.

General environmental and energy targets

Government target: 20 % reduction of the 1988 CO_2 emission level by 2005

Danish Environmental Protection Agency target: 50 % of organic waste should be recycled by 2005.

Danish Energy Agency target: 1995 biogas production level should be quadrupled by 2005.

Government research and development efforts

- Energy Research Programme: grants for R & D projects.
- Renewable Energy Development Programme: grants for reviews and pilot or demonstration projects.
- Follow up programmes: experience gained is collected, analysed and communicated to farmers, plant operators, advisors, plant constructors and authorities.

Biomass resources

On a yearly basis roughly 35 - 40 million tonnes of animal manure is produced in Denmark. Consequently, manure forms a considerable resource for biogas production. The Danish centralised biogas concept was developed because manure should account for the major part of biomass treated in the plants.

As a consequence of livestock production, many food processing industries are to be found in the same areas. For food processing industries centralised biogas plants represent an appropriate waste disposal and recycling possibility as this is safe, convenient and economically advantageous.

The legislative push

- 6-9 months' slurry storage capacity required.
- Restrictions on manure application on land ('harmony rules').
- No organic waste in landfills.
- Tax on waste when incinerated but not if recycled.
- Power companies obliged to purchase electricity based on biogas at prices according to law.

Basic economic preconditions

- Government investment grants: 20 - 40 % of investment costs.
- Biogas and heat from biogas are exempted from energy tax.
- State production grant of DKK 0.27 per kWh electricity produced.
- Low interest rate, long-term (20 years) loans are provided.

The Lemvig plant is one of the largest plants in the world. It is operated at thermophilic temperatures (53-55°C) with a retention time in normal situations of approx. 16 days.

Other important issues

- Co-digestion is considered advantageous in many ways and therefore supported by veterinary and environmental authorities.
- Heat sales are possible through district heating systems which are widespread in Denmark. Heating of houses is necessary for approximately 6-8 months of the year.

5. Biomass treatment and biogas production

As previously mentioned, manure represents a great potential for biogas production in Denmark. The manure, however, is not evenly distributed throughout the country. In fact, livestock and manure production are concentrated in the western parts of Denmark. This is also where most of the centralised biogas plants are found. It has been found to be of significant importance that centralised biogas plants are placed in areas of high manure density because transportation distances may then be minimised and transportation costs reduced.

Of a total manure production in Denmark of approximately 40 million tonnes, 1 million tonnes were applied to centralised biogas plants in 1998. 51 % of this was pig manure, 44 % was cattle manure, 4 % was mixed pig and cattle manure, and 1 % was mink or poultry manure and crop residuals.

In addition, approximately 325,000 tonnes not originating directly from farms was applied to centralised biogas plants. Most of it, however, has a farm origin, but is now considered as various organic waste types. In total, organic waste accounts for approximately 24 % of the biomass treated.

In Danish centralised biogas plants manure is co-digested with various types of organic waste, which are in this way recycled. The waste application is monitored and controlled by the authorities.

	Units	V.Hjermitslev	Vegger	Davinde	Sinding-Ørre	Fangel	Revninge	Ribe	Lintrup	Lemvig	Hodsager
Year of construction	Year	1984	1985	1988	1988	1989	1989	1990	1990	1992	1993
Digester capacity	m^3	1500	800	750	2100	3200	540	4650	6900	7000	880
Process temperature(m/t)		m	t	m	t	m	m	t	m	t	m
Cattle manure	m^3	7015	13656	6728	11980	11541	5311	91164	45671	51031	10449
Pig manure	m^3	3595	0	4707	23654	32462	2206	24492	32494	67372	1619
Poultry manure	m^3					2482		917			
Mink manure	m^3				86	48		2347	33	1075	
Other manure	m^3					1971			13097		
Crop residuals	m^3										180
Total agricultural biomass	m^3	10610	13656	11435	35720	48504	7517	118920	91295	119478	12248
Organic waste from											
Intestinal contents	m^3		1150		5797	2276		19695	5567	11673	3898
Fat or flotation sludge	m^3		2613	254		3855	807	11887	591	6441	
Fodder	m^3				59				364	564	275
Fish processing	m^3	5296	1288	501				2515	17705	5012	1874
Fruit & vegetables	m^3					529	837		49		
Breweries	m^3										
Dairies	m^3				2649			5851		7917	
Sugar industry	m^3										
Bleaching earth	m^3		1447		3776						
Tanneries	m^3	340				1527					
Medical industries	m^3		96		448	956	628	3059	7321		
Other industries	m^3		99		994			51	155	256	
Sewage sludge	m^3		205						6118	5046	187
Households	m^3										
Waste total	m^3	5636	6898	755	13723	9143	2272	43058	37870	36909	6234
Biomass total	m^3	16246	20554	12190	49443	57647	9789	161978	129165	156387	18482
Biomass per day	m^3	45	56	33	135	158	27	444	354	428	51
Biogas production,1000 m^3		1492	2013	282	2348	2275	355	4762	3718	5302	656
Biogas per day	m^3	4088	5515	773	6433	6233	973	13047	10186	14526	1797
Gasyield	m^3/m^3	92	98	23	47	39	36	29	29	34	35

Table 5.1. Biomass treatment and biogas production in 1998.

m = mesophilic,
t = thermophilic,
1) running-in period included

Intestinal content comprised a total of approximately 27 % of waste application. Another 53 % is flotation sludge from food or fodder processing industry abattoirs. Plants capable of treating sewage sludge control sanitation systems that ensure pathogen kill at satisfactory levels. 6.5 % of waste application is sewage sludge. This is also true for plants capable of treating source-sorted household waste, which amount to 0.5 % of total waste application. Three centralised biogas plants treated source-sorted household waste in 1998.

Other waste applications appear from Table 5.1.

	Units	Hashøj	Thorsø	Århus	Filskov	Studsgård	Blåbjerg	Snertinge	Blåhøj	Vaarst/Fjellerad[1)]	Nysted[1)]
Year of construction	Year	1994	1994	1995	1995	1996	1996	1996	1997	1997	1998
Digester capacity	m^3	2900	4600	7500	880	6000	5000	2800	2800	2000	5000
Process temperature(m/t)		m	t	m	t	t	t	t	t	t	m
Cattle manure	m^3	7822	29432	18413	17655	13908	58650	9949	20821	8458	8841
Pig manure	m^3	17718	45232	103401	841	72567	23703	19055	2120	6350	45550
Poultry manure	m^3		1138								165
Mink manure	m^3								148		
Other manure	m^3	1957	15910	88		760	7207				
Crop residuals	m^3		29		18				194		
Total agricultural biomass	m^3	27497	91741	121902	18514	87235	89560	29004	23283	14808	54556
Organic waste from											
Intestinal contents	m^3	7639	10026	3045	5454	4880		116	159	5436	125
Fat or flotation sludge	m^3	8213	4200	1030	6052	563	5689	6210	4685	5355	408
Fodder	m^3		125	833		33		41	179	8	62
Fish processing	m^3	576	1561	0			7285	25	1792	1740	54
Fruit & vegetables	m^3			49			26	1586			137
Breweries	m^3			0				2208	177		
Dairies	m^3			5460		10515	2507			166	
Sugar industry	m^3										1819
Bleaching earth	m^3			1322		5455				359	
Tanneries	m^3			0			4509			27	
Medical industries	m^3	1264	2308	5247		1036		3118		2816	678
Other industries	m^3	965		403		889	1051				510
Sewage sludge	m^3		5052				4306	1501			
Households	m^3			54		864				582	
Waste total	m^3	18657	23272	17443	11506	24235	25373	14805	6992	16489	3793
Biomass total	m^3	46154	115013	139345	30020	111470	114933	43809	30275	31297	58349
Biomass per day	m^3	126	315	382	82	305	315	120	83	86	160
Biogas production,1000m^3		2504	3281	3860	1224	5841	3300	1694	1353	2382	1450
Biogas per day	m^3	6860	8989	10575	3353	16003	9041	4641	3707	6526	3973
Gasyield	m^3/m^3	54	29	28	41	52	29	39	45	76	25

Table 5.1 continued.

From the biomass amounts mentioned, a total of 50,1 million m^3 biogas was produced in 1998. This gives an average gas yield of approx. 37 m^3 biogas per m^3 biomass treated.

In normal situations, approx. 20 m^3 biogas is gained per m^3 slurry in Denmark. That indicates that approximately 45 % of biogas production originates from organic waste. This means that waste supplies are essential for economic success in Danish plants as long as income is primarily based on biogas production and energy sales.

6. Major Technological Steps Forward

Operational stability has improved considerably. A combination of practical experience and research has led to a situation where the know-how of AD-process operation has increased significantly among plant providers and operators. Co-digestion of manure and organic waste can be managed in order to secure process optimisation and biogas production maximisation.

-A simple, cheap and well-functioning system was developed for biogas H_2S cleaning. The system is based on atmospheric air addition in biological conversion of H_2S. Earlier H_2S caused difficulties in biogas conversion as CHP-technology is very sensitive to biogas impurities.

A vehicle at the Studsgård plant is loading digested manure before returning it to a storage tank at one of the 50 farmers involved in the plant.

-Systems have been developed, biological and technical, for the reduction of odour nuisances from biogas plants. Closed tanks are used everywhere and odour-contaminated air is transmitted to air-cleaning facilities. Today, odour nuisances from biogas facilities can be avoided by including technical or biological air treatment technology and proper management of the systems.

-Special equipment in the form of suction funnels has been developed in order to make slurry transportation more efficient and thereby minimise transportation costs.

-Low pressure biogas transmission systems have been widespread in the nineties. Operation stability has increased considerably, and biogas transmission costs have been reduced significantly.

-New types and brands of pumps and stirrers have been implemented. Consequently, operational stability has increased, and maintenance costs have been reduced.

7. Investments, financing and organisation

Some plants include a biogas plant, a wood chip burning facility and a district heating system for total energy supply of a near by village.

Table 7.1 shows the original investment costs and financing for the existing centralised biogas plants in Denmark. The upper part of the table presents the per day biomass application and biogas production in 1998 and the number of manure suppliers.

Investment costs are presented in prices of the year of investment. As plants vary considerably in size, age and technology, figures are not directly comparable.

Investment costs are divided in the biogas plant itself, under which energy transmission pipelines and combined heat and power plants, transport vehicles and slurry storage tanks are stated. In addition, some plants made investments in separation and composting equipment. Finally, other investments contain costs for straw or wood-chip burning plants, the district heating grid and pipelines for slurry pumping.

Four plants are basically different. Hodsager, Filskov, Snertinge and Blåhøj provide total integrated energy production and supply systems for the local community. Heat production at these plants is partly produced on the basis of wood chips, covering peak heat demand during the winter. Investments in these plants, and the Nysted plant, include district heating systems. The normal situation is, however, that biogas plants sell biogas or heat to a local heat distribution company that owns the district heating system, which in most cases was already there when the biogas plant was constructed.

In the lower parts of the table plant financing is presented; all plants received government investment grants. The grant share of total investment costs amounted to 20 - 40 %. The grant level has been lowered in

	Units	V.Hjermitslev	Vegger	Davinde	Sinding-Ørre	Fangel	Revninge	Ribe	Lintrup	Lemvig	Hodsager
Year of constr.	Year	1984	1985	1988	1988	1989	1989	1990	1990	1992	1993
Biomass[1]	m^3/day	45	56	33	135	158	27	444	354	428	51
Gasproduction[1]	1000 m^3	1492	2013	282	2348	2275	355	4762	3718	5302	656
Manure suppliers	-	5	7	6	35	26	2	79	62	80	6

Investments											
Biogas plant[4]	1000 Dkr	11287	12474	3870	20750	15850	11350	28950	32310	43330	6700
Vehicles	1000 Dkr	600	350	600	2500	1300	650	3700	3060	3570	500
Storage tanks[5]	1000 Dkr	-	-	-	2900	5150	-	12600	2380	8300	-
Separation fac.	1000 Dkr	-	-	-	-	2950	-	-	5800	-	-
Other investments	1000 Dkr	529[6]	552[6]	1310 7	-	-	-	-	-	-	12000[7]
Total	1000 Dkr	12416	13376	5780	26150	25250	12000	45250	43550	55200	19200

Financing											
Investment grants	1000 Dkr	4300	2856	1885	8850	10040	5400	17700	16830	14200	3900
Grants ratio	%	35	21	33	34	40	45	39	39	26	20
Indexed loans	1000 Dkr	3135	-	2860	14060	13100	5500	24750	16625	35000	12300
Mortgage loans	1000 Dkr	3402	10520	-	-	-	-	-	-	-	-
Bank loans	1000 Dkr	1579	-	1035	3240	2110	1100	-	10095	6000	3000
Own capital	1000 Dkr	-	-	-	-	-	-	2800	-	-	-
Total	1000 Dkr	12416	13376	5780	26150	25250	12000	45250	43550	55200	19200

1. Biomass application and biogas production in 1998
2. Figures of production include running-in period
3. Figures of production are as expected in normal operation
4. Biogas production unit, including pre- and post storage tanks at the plant, pipeline and CHP-plant
5. Slurry storage facilities at farms or in rural areas, exept from Sinding and in part Studsgård, where tanks are situated at the plant.
6. Vind turbines
7. Straw burning or wood-chip burning facility and district heating system
8. Pipeline for slurry pumping

Table 7.1. Investments and financing.

recent years as economic results have improved and risks thereby reduced. The remaining investment costs are primarily financed by indexed mortgage loans guaranteed by municipalities. Some of the early plants were partly financed by traditional mortgage loans but this type of loan was not applied during the nineties. Some plants obtained bank loans or loans granted by county councils.

Only one plant, the Ribe Plant, which is a limited company, controlled its own capital as part of the original plant financing

Danish centralised biogas plants are organised in different ways. Farmers started a number of plants, especially the larger ones. Consequently, today 9 plants are owned by farmers as co-operative compa-

	Units	Hashøj	Thorsø	Århus	Filskov	Studsgård	Blåbjerg	Snertinge	Blåhøj	Vaarst/Fjellerad[2]	Nysted[2]
Year of constr.	Year	1994	1994	1995	1995	1996	1996	1996	1997	1997	1998
Biomass[1]	m^3/day	126	315	382	82	305	315	120	83	86	191
Gasproduction[1]	1000 m^3	2504	3281	3860	1224	5841	3300	1694	1353	2382	1450
Manure suppliers	-	17	75	45	7	50	58	14	15	14	35
Investments											
Biogas plant[4]	1000 Dkr	18300	25600	54200	9500	46550	35400	18600	16500	30950	31700
Vehicles	1000 Dkr	1200	3500	-	700	3700	3500	1200	400	1300	1200
Storage tanks[5]	1000 Dkr	2300	-	-	1000	2850	3000	1200	400	-	1800
Separation fac.	1000 Dkr	-	-	-	-	-	-	-	-	-	-
Other investments	1000 Dkr	-	-	-	12000[7]	2600[8]	-	26800[7]	16100[7]	-	8980[7]
Total	1000 Dkr	21800	29100	54200	23200	55700	41900	47800	33400	32250	43700
Financing											
Investment grants	1000 Dkr	5100	6300	10840	2500	13900	9700	9200	6900	7700	8500
Grants ratio	%	23	22	20	11	25	23	19	21	23	19
Indexed loans	1000 Dkr	16700	22000	43360	17700	41800	32200	38600	26500	15700	35200
Mortgage loans	1000 Dkr	-	-	-	-	-	-	-	-	-	-
Bank loans	1000 Dkr	-	800	-	3000	-	-	-	-	8850	-
Own capital	1000 Dkr	-	-	-	-	-	-	-	-	-	-
Total	1000 Dkr	21800	29100	54200	23200	55700	41900	47800	33400	32250	43700

1. Biomass application and biogas production in 1998
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8. Pipeline for slurry pumping

Table 7.1 continued.

nies; 5 plants are organised as co-operatives that include heat (or gas) consumers and farmers; 3 plants are owned and operated by municipalities; 2 plants are private foundations; and 1 plant is a limited company.

8. Development of economic results and present economic situation.

During winthertime heat production is boosted by burning wood chips at the Filskov plant. The heat is distributed in a district heating system, as heating of houses is needed for 6-8 months per year in Denmark.

Over the years the economic results have gradually improved. This was particularly true in the years when organic waste application became a common practice. But the economic results have also improved due to increased operational stability. In recent years the economic results improved significantly slower than earlier. The situation has more resembled optimisation of plant operation and economic results. 1996/97 or 1997 were particularly satisfactory for most plants. However, a few plants still produce lower economic results from time to time, due to operational instability or waste scarcity.

Table 8.1 shows the development of current income which is used as a measure of economic results. It is defined as total sales, (energy sales and gate fees), minus operating costs. This is compared to a calculated break-even income, which represents the amount necessary to cover mortgage payments and reinvestments.

The table shows that plants generally were able to improve their economic results over the years. It appears that most plants have produced a current income at or above the level of the calculated break-even income in recent years.

This development expresses the fact that plant economy is stabilising at the break-even level. Even though the competition of organic waste resources has increased, many plants are still likely to find fields to optimise and thus further improve economic results.

DKK 1000	Realised								Break-even Income 1998 price level
	1991 or 1990/91	1992 or 1991/92	1993 or 1992/93	1994 or 1993/94	1995 or 1994/95	1996 or 1995/96	1997 or 1996/97	1998 or 1997/98	
V. Hjermitslev									
- Sales	1975	2451	2741	2896	2792	2697	3446	2949	
- Operating costs	1487	2121	2150	1992	1955	2114	1930	2070	
Current income	488	330	591	904	837	583	1516	879	950[1)]
Vegger									
- Sales	2069	2726	2807	3061	3143	3056	3577	3929	
- Operating costs	2200	1727	1916	1791	1918	2019	2003	2446	
Current income	-131	999	891	1270	1225	1037	1574	1482	700[1)]
Davinde									
- Sales	534	662	649	657	686	476	428	385	
- Operating costs	361	362	426	374	431	326	351	367	
Current income	173	300	223	283	255	150	77	17	270
Fangel									
- Sales	3755	4673	5103	5123	5177	4630	4620	4879	
- Operating costs	2530	3215	2681	2876	2335	2409	2341	2562	
Current income	1225	1458	2422	2247	2842	2221	2279	2317	2800[1)]
Revninge									
- Sales	930	1145	1048	1244	1135	1189	1361	1475	
- Operating costs	895	601	786	799	826	972	1067	1221	
Current income	35	544	262	445	309	217	289	254	250[1)]
Ribe									
- Sales	4378	6602	6886	7189	7910	8085	8833	9534	
- Operating costs	3906	4346	4229	4295	4680	4924	5534	5680	
Current income	472	2256	2657	2895	3230	3161	3298	3855	2600
Lintrup									
- Sales	5850	6294	6921	8162	8113	7450	8803	8824	
- Operating costs	3088	3944	4099	4541	4508	4811	4938	5367	
Current income	2762	2350	2822	3622	3605	2639	3865	3457	3600
Lemvig									
- Sales	-	2392	8886	10318	10358	10175	10939	10892	
- Operating costs	-	2074	6493	6391	5716	6327	6495	6539	
Current income	-	318	2393	3927	4642	3848	4444	4353	4200
Hodsager									
- Sales	-	-	-	1671	2325	2564	2554	2715	
- Operating costs	-	-	-	885	1219	1432	1359	1511	
Current income	-	-	-	786	1106	1132	1195	1204	1200
Hashøj									
- Sales	-	-	-	1144	2944	2978	3686	4269	
- Operating costs	-	-	-	654	1442	1637	1803	2287	
Current income	-	-	-	490	1502	1341	1882	1982	1500
Thorsø									
- Sales	-	-	-	2050	4661	5224	5722	6706	
- Operating costs	-	-	-	1747	3179	3468	3699	4212	
Current income	-	-	-	303	1482	1756	2023	2495	1800
Århus									
- Sales	-	-	-	-	-	3223	4904	6863	
- Operating costs	-	-	-	-	-	7217	7111	8723	
Current income	-	-	-	-	-	-3994	-2207	-1860	3500
Filskov				-					
- Sales	-	-	-	-	1634	3015	3234	3553	
- Operating costs	-	-	-	-	892	1621	1708	1879	
Current income	-	-	-	-	742	1394	1526	1674	1500
Sinding/Studsgård									
- Sales	-	-	-	-	-	10791	14640	15656	
- Operating costs	-	-	-	-	-	9029	11666	12329	
Current income	-	-	-	-	-	1762	2974	3327	6400
Blåbjerg									
- Sales	-	-	-	-	-	3355	6657	7901	
- Operating costs	-	-	-	-	-	1679	3566	4092	
Current income	-	-	-	-	-	1676	3090	3809	3000
Snertinge									
-Sales	-	-	-	-	-	-	4646	5377	
-Operating costs	-	-	-	-	-	-	2991	3198	
Current income	-	-	-	-	-	-	1655	2180	2850
Blåhøj									
- Sales	-	-	-	-	-	-	1685	3660	
- Operating costs	-	-	-	-	-	-	1111	1816	
Current income	-	-	-	-	-	-	574	1845	1900

Table 8.1. Development of current income

1) After obtaining respites for mortgage payments

It is remarkable that these results have been achieved as general energy prices have simultaneously decreased. This development has been compensated for by increasing the amount of biomass treated. Gas production is thereby increased.

Table 8.1 shows the development of current income.

The Vaarst - Fjellerad and Nysted plants are not included in Table 8.1 as they have not yet been in normal operation for a whole year.

The Blaabjerg Plant was constructed in 1996, equipped with two low-pressure biogas storage facilities.

Present economic situation.

In Table 8.2. the present economic situation is evaluated based on economic results presented in Table 8.1. The primary criterion for the placing of plants in the table is their ability to produce a current income that corresponds to actual mortgage payments and reinvestments. It is stressed that actual obligations are considered as some older plants obtained a respite as regards mortgage payments or were financially reconstructed. Evaluation of the present economic situation for these plants is considered after obtaining more favourable economic conditions.

Other factors are considered to a certain extent. Some plants face considerable renovation of installations and equipment and must simultaneously settle short-term loans. Finally, some plants seem to have various possibilities of adapting to changing conditions by taking action.

The Vester Hjermitslev plant is the oldest centralised biogas plant in Denmark, constructed in 1984. It is still in operation though biogas technology has developed considerably since then.

	Year of Construction	Acceptable	Balance	Under Pressure	Un-Satisfactory
Vester Hjermitslev	1984		X[1)]		
Vegger	1985	X[1)]			
Davinde	1988			X	
Fangel	1989				X[1)]
Revninge	1989		X[1)]		
Ribe	1990	X			
Lintrup	1990		X		
Lemvig	1992	X			
Hodsager	1993		X		
Hashøj	1994	X			
Thorsø	1994		X		
Århus Nord	1995				X
Filskov	1995			X	
Sinding/Studsgård	1988/1996				X
Blåbjerg	1996	X			
Snertinge	1996				X
Blåhøj	1997			X	

Table 8.2. Evaluation of present economic situation.

1) After obtaining respites for mortgage payments.

Plants are placed in the following four categories:

Acceptable:	Sufficient current income, significantly above break-even level
Balance:	Sufficient current income, at the break-even level
Under pressure	Insufficient current income, less than break-even level
Unsatisfactory	Current income significantly less than break-even level.

It appears that some of the plants obtained respites for mortgage payments. Of these, the Vester Hjermitslev and Vegger plants were not able to settle their financial obligations by their own means. They therefore obtained considerable prolongation of the pay back period and interest payment exception.

In the category, “acceptable economic situation”, there are 5 plants: Vegger, Ribe, Lemvig, Hashøj and Blåbjerg.

In the “balance economic situation” category there are another 5 plants. The Vester Hjermitslev plant was earlier in the acceptable category. In 1998 this plant experienced a decrease in biogas production caused by a lack of organic waste. This situation could unfortunately turn out to be permanent. The Revninge plant obtained a prolongation of the pay back period. In most years the Lintrup plant produced a current income at the break-even level for which reason it is placed in this category. The Hodsager plant produced a current income at the break-even level. In 1998 the Thorsø plant produced a current income well above break-even. That indicates that the Thorsø plant is moving into the “acceptable” category.

The Hodsager plant is one of the smallest centralised plants. Its treatment capacity amounts to only 40-45 m³ biomass on a daily basis. The plant also include a wood chip burning facility.

In the “under pressure category” 3 plants are to be found. The Davinde plant is a part of Davinde Energy Company that also controls a straw-burning plant. Naturally, the Board of the company is interested in economic results for the company as a whole and is not interested in optimising the biogas plant or the straw-burning plant particularly.

In 1997 and 1998 the Filskov plant produced a current income at the break-even level. However, mortgage payments will increase in the years to come and current income must be higher than the present level.

The Båhøj plant has not yet produced a current income at the break-even level

4 plants are to be found in the category of ‘not satisfactory economic situation’. The Fangel plant suffered from inappropriate construction and equipment leading to operational instability and increased operating costs. The financial situation was under pressure for several years. However, considerable renovation of installations and equipment has been carried out which provides hope of better economic results in the future.

The Sinding and Studsgård plants are owned and operated by Herning Municipal Utilities and the operation of these plants is integrated. The Sinding plant produced relatively poor economic results for a number of years. In addition, a number of reconstructions and investments were made and consequently operating credits increased. In 1994 the Studsgård plant was constructed. Now the two plants in co-operation should settle their common financial obligations. Debts are relatively high, and current income has not reached the break-even level so far.

The Århus plant also suffered from problems due to inappropriate construction. But its managers also failed to procure slurry and waste of a sufficient amount and quality to ensure satisfactory biogas production. Break-even income level has not yet been reached at this plant.

The Snertinge plant suffered from a number of problems that led to increased operating costs and lower energy sales than expected. In addition, further investments proved to be necessary. Current income at this plant has not yet reached the break-even level.

9. Derived Economic Benefits for Farmers Involved

Farmers connected to centralised biogas plants do not withdraw a profit from the biogas company. Instead they gain considerable derived economic benefits as a consequence of the operation of the plant. As previously mentioned, the main incentive for farmers to join in the cooperative solution of a number of environmental problems was caused by the legislative push. In particular, the storage tank investments required formed the main incentive for farmers to join in centralised biogas plants as they thereby gained *cost savings in slurry storage.*

However, storage tanks did not represent the only advantage gained by farmers. Some of the advantages had not been anticipated beforehand.

The organisational framework concerning the transportation system provides derived economic benefits for the farmers involved. Slurry is transported from farms to the biogas facility by vehicles owned by the company and afterwards returned to slurry storage tanks. Some of the storage tanks are placed at the farms but some are placed near the fields where the digested slurry is end-used as fertiliser. Slurry spreading is taken care of by farmers themselves and is carried out by using tractors and carriages for liquid manure spreading. In normal situations they often have to travel a considerable distance by road to reach certain fields where the slurry is to be spread. But as digested slurry is often stored in tanks near the fields, transportation distances in times of spreading are dramatically reduced in some cases. Consequently, farmers involved in centralised biogas plants gain benefits from *cost savings in slurry transportation.*

Danish centralised biogas plants all supply certain amounts of organic waste to the plants. The nutrient contents in these biomass resources represent a surplus that may be utilised by farmers who own so much

According to law, Danish farmers must control sufficiant manure storage capacity so that vinter time spreading can be avoided. Most centralised plants provide storage facilities for digested manure. In this case at the Sinding plant.

Digested manure should be considered as a fertilizer and thus as an important input resource in crop production. This is increasingly the case in Denmark. Application equipment has been optimised in order to avoid nutrient losses during manure spreading.

land that they can take more digested slurry than they supply. Some crop growers use very little manure in normal situations. However, living near a centralised biogas plant enables them to substitute chemical fertiliser if they agree to take digested slurry, which they sometimes can have without charge as it represents a surplus as far as the biogas plant is concerned.

Pig slurry and cattle slurry are mixed in a biogas plant. As a fertiliser, the slurry mix is sometimes advantageous compared to conventional slurry.

In many situations pig slurry contains a phosphorus surplus but a potassium deficit for typical crop rotation on pig farms. Conversely, cattle slurry often contains a potassium surplus but a phosphorus deficit for typical crop rotations on cattle farms. Consequently, the mixture of the two slurry types results in a digested fertiliser more suitable for crop rotation on both pig and cattle farms. Consequently, a higher proportion of nutrients is absorbed by the crops to the benefit of the environment and the economic benefit of the farmers.

As described in this section, farmers may achieve considerable *cost savings in fertiliser purchase* as members of the biogas company and as plant growers utilising digested slurry.

An analysis was carried out among 10 farmers connected to the Lintrup plant. Results showed an average economic benefit of a little less than DKK 5. per m^3 slurry supplied to the plant mainly deriving from cost savings in slurry storage and fertiliser purchase.

10. Waste Treatment Costs in Danish Centralised Biogas Plants

Four plants are capable of treating source sorted household waste. The treatment capacity of the Århus plant should in a few years reach an annual level of 17,000 tonnes household waste from the City of Århus.

In previous chapters we looked at biogas economy from a traditional business point of view. On the one hand, it is natural to do so as most Danish plants are individual companies, operating as such in a regulated market. On the other hand, no biogas plant was built solely for profit. Biogas projects were initiated because various authorities and individuals wanted integrated solutions to agricultural, energy and environmental problems. Consequently, it makes sense to measure the cost of the solutions to the problems that the centralised biogas concept is taking care of.

At the European level and world-wide, organic waste recycling is the main focus of interest for anaerobic treatment in biogas plants. The Danish centralised biogas concept is well-suited as the treatment and sanitation step in waste recycling. From the waste treatment point of view, biogas production itself is simply a valuable by-product.

However, if applied to a biogas plant, the character of the waste applied must make it appropriate for subsequent utilisation as a fertiliser. In addition, appropriate agricultural structures must be available on the local level as the digested biomass should subsequently be utilised as a fertiliser on arable land.

Organic waste applied to a biogas plant must contain no such bodies as stones or metal parts as these may crush pumps and block heat exchangers and pipelines. To ensure high standards in waste quality, source sorting of household waste, for example, must be carried out with great care and with much discipline.

If waste resources comply with the above-mentioned requirements, biogas plants are well suited for treating the waste as an element in the chain of waste recycling.

Now, what are the costs related to waste treatment in a biogas plant? Danish plants typically apply approx. 20 % of total biomass in waste be-

Table 10.1. Treatment costs and energy sales based on Danish conditions

	DKK per m^3 *total* biomass treated
Biomass transportation	
- operating costs	15
- capital costs	4
Anaerobic treatment	
- operating costs	17
- capital costs	26
Total treatment costs	62
Energy sales	51
Deficit, net treatment costs	-11

cause it increases biogas production and they obtain gate fees for the receipt of waste. Fundamentally, there is no reason why organic waste treatment costs should be any different from other biomass types, for instance slurry.

Based on Danish experience, treatment costs and energy sales are calculated and presented in Table 10.1.

The calculations in Table 10.1 are based on a fictive centralised biogas plant with a treatment capacity of 300 m^3 biomass per day. In the calculations an average biogas yield of 30 m^3 biogas per m^3 biomass treated is utilised, which is the normal situation for biogas plants with a waste ratio of approx. 20 %. The remaining biomass is slurry. The price of biogas is DKK 1.70 per m^3. A real interest rate of 5 per cent is used. Depreciation periods of 15-20 years are used for the biogas plant, 7 years for lorry chassis and 15 years for lorry cisterns.

The results in table 10.1. do not include investment grants.

It appears that net treatment costs, represented by the calculated deficit, amount to DKK 11 per m^3 biomass treated. If the gas yield or the biogas price were higher, or if investment grants were obtained, net treatment costs would be lower, and vice versa.

This means that energy sales, using the above-mentioned preconditions, do not quite cover treatment costs. However, if the plant is estab-

A brand new plant was constructed in Nysted in 1998. 35 farmers are involved in this plant which is operated at mesophilic temperatures (approx. 35°C). The biomass feedstock primarily consist of pig slurry.

	Incineration	Composting	Centralised Biogas Plant
	DKK per tonne	DKK per tonne	DKK per m^{3} 1)
Treatment costs	200-300	300-400	50-60
Waste deposit tax (1998)	210/260 2)	-	-

Table 10.2. Waste disposal costs in different technologies in Denmark.

1) Note that treatment costs are per m^3, which is almost, but not quite, equal to a per tonne unit.
2) Depending on whether it is utilised for combined heat and power production, or just for heat production.

lished primarily as a waste treatment facility, what are the waste treatment costs if plant economy is to balance ?

As the waste ratio is 20 %, net waste treatment costs are DKK 11/20*100 = DKK 55 per m^3 waste

Normally, Danish centralised plants charge DKK 50 - 100 per m^3 waste they receive at the plant. This “gate fee” level is favourable for food processing industries or other waste producing facilities. Alternatively, they face considerable costs in disposing of waste, and rules on handling, storage and waste application are becoming increasingly restrictive.

In Denmark organic waste deposition in landfills is no longer allowed. It must instead be recycled or incinerated. In the latter case, a waste deposal tax is imposed. Alternative waste deposition costs are presented in Table 10.2.

From Table 10.2 it becomes evident that waste recycling via centralised biogas plants is extremely favourable under Danish conditions. This would be the case even if there were no waste disposal tax.

11. Conclusions

The period from 1995 to 1998 was characterised by the stabilisation of operations and economy at Danish centralised biogas plants. Most plants produced steadily improving economic results but progress was not as significant as was seen earlier. Most plants increased energy sales as energy production increased due to larger biomass amounts supplied to the plants. The level of gate fees was generally maintained. Several plants optimised by collecting biogas from storage tanks at the biogas plant. Operation stability was improved and maintenance costs were under control in most places

Today most of the plants face an acceptable economic situation. But it is fair to mention that several, especially older, plants proved not to be able to settle their financial obligations by their own means. In addition, a few even relatively new plants find themselves in a difficult economic situation.

Most of the plants built in the nineties made a good start. We therefore conclude that the economic risk involved in biogas projects has been considerably reduced. However, optimal preconditions must be ensured and the quality of the project must be secured.

Economically, Danish centralised biogas plants still depend on the addition of organic waste which increases biogas production and leads to considreable gate fees. If production is solely based on livestock slurry, under existing conditions energy production is insufficient to make the project economically viable.

Danish centralised biogas plants make a valuable contribution to the solution of a range of problems concerning agricultural, environmental and energy interests. The government has considerable ambitions in the field of biogas, as biogas production should be quadrupled within a few years.

In an international context, it is relevant to regard biogas technology as a promising element in the chain of organic waste recycling. The Danish centralised biogas concept offers a total and appropriate system for treatment, sanitation, redistribution and nutrient utilisation from livestock slurry and organic waste.

In addition, Danish experience proves it to be economically advantageous.

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Over the last 15 years 20 centralised biogas plants were constructed in Denmark. This is the result of considerable government ambitions in the field of biogas.

Centralised biogas plants have proven to offer integrated solutions to a number of problems in the fields of agriculture, energy production and environmental protection.

Consequently, development of biogas technology in Denmark has been supported by a range of initiatives that encouraged the enlargement of centralised biogas plants.

The background for this development and the economic achievements are documented in this report