ANAEROBIC TREATMENT OF THE ORGANIC FRACTION OF MUNICIPAL SOLID WASTE IN DENMARK

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ABSTRACT

This report is based on several years of co-operation of our research groups with Danish biogas plants. Throughout the years, there has been a fruitful exchange of know-how and experiences in lab-scale on the one hand and large-scale on the other, leading to a better understanding of the principles of the anaerobic digestion process and to an optimization of its large-scale implementation. In order to get an overview over the current situation concerning the treatment of the organic fraction of municipal solid waste (OFMSW) in Denmark, interviews were carried out with operators of the biogas plants where OFMSW is treated and municipality staff responsible for waste management. On the way of fulfilling the governmental goal to treat 150,000 tons of OFMSW by the year 2004 mainly by anaerobic digestion, the different municipalities are investigating different concepts of waste collection and treatment. The quality of the OFMSW treated is the key for a smooth operation of the biogas process including a high biogas yield and production of an effluent that is feasible for the use as fertilizer on agricultural land. Comparison of the different concepts leads to the conclusion that source-sorting of OFMSW in paper bags is preferable to collection in plastic bags and successive separation of plastics in a waste processing treatment.

INTRODUCTION

The application of anaerobic digestion as a waste treatment method for the organic fraction of municipal solid waste (OFMSW) has evolved in Europe from a capacity of 122,000 ton per year in 1990 to 1,023,000 ton in the year 2000 (De Baere 2000). This represents, however, only 0.7% of the amount of OFMSW produced in Europe (Mata-Alvarez et al. 2000) and between 6% and 27% of the composting capacity in different European countries (De Baere 2000). De Baere (2000) predicted that the capacity for anaerobic digestion of OFMSW would increase in the new millennium due to establishment of anaerobic digestion as a reliable technology since 1995 and several advantages of this treatment process like the recovery of energy and nutrients. The performance of the anaerobic digestion process depends, however, deeply on the quality of the waste to be treated (Saint-Joly et al. 2000).

In the following we will give an overview of the treatment of OFMSW in biogas plants in Denmark as a case study for different approaches for the anaerobic digestion treatment of OFMSW in order to find the most efficient treatment technology. For the most optimal realization of the treatment method, the environmental and economical advantages have to be weighed against additional costs and energy requirements needed for the treatment. Especially the extra costs for collection and pretreatment of OFMSW in order to get a substrate free of contaminants have to be taken into account.

ANAEROBIC DIGESTION OF OFMSW IN DENMARK

In Denmark, the anaerobic digestion treatment of OFMSW is with one exception generally applied as co-digestion with other types of organic waste like manure, sewage sludge and industrial organic waste. This is due to the fact that a net of centralized biogas plants has been established since the beginning of the 1980's, based on the treatment of cattle and swine manure. Other organic substrates with a high biogas potential like industrial organic waste are added at all of these biogas plants in order to achieve an economically feasible treatment process (Danish Energy Agency (1995). The addition of OFMSW is very attractive since OFMSW is a highly valuable substrate with a biogas potential per ton waste up of to 10 times than the one of agricultural waste like manure (Braber 1995, Hartmann et al. 2001). On the other hand, since the effluent of the biogas plants is used as fertilizer, the added OFMSW has to be of high quality in terms of low contamination. The amount of added OFMSW is restricted to at most 20% of the treated volume by the fact that the biogas plant design is based on wet digestion treatment.

Biological treatment of OFMSW is competing with incineration as the only alternative treatment since landfilling is banned in Denmark. According to the Danish governmental program "Waste 21", the aim is to treat biologically an amount of 150,000 tons of OFMSW by the year 2004, mainly by anaerobic digestion (figure 1). It is expected that in the end of 2002 only 45% of this amount will be achieved to treat by anaerobic digestion and by composting. The potentially treated amount of OFMSW in Denmark accounts for 40-42% of the total amount of municipal solid waste of 700,000 tons. This means that capacities for anaerobic treatment of OFMSW will be further extended and experiences with different collection, pretreatment and treatment processes should lead to optimal solutions in the future with concepts competitive to incineration.

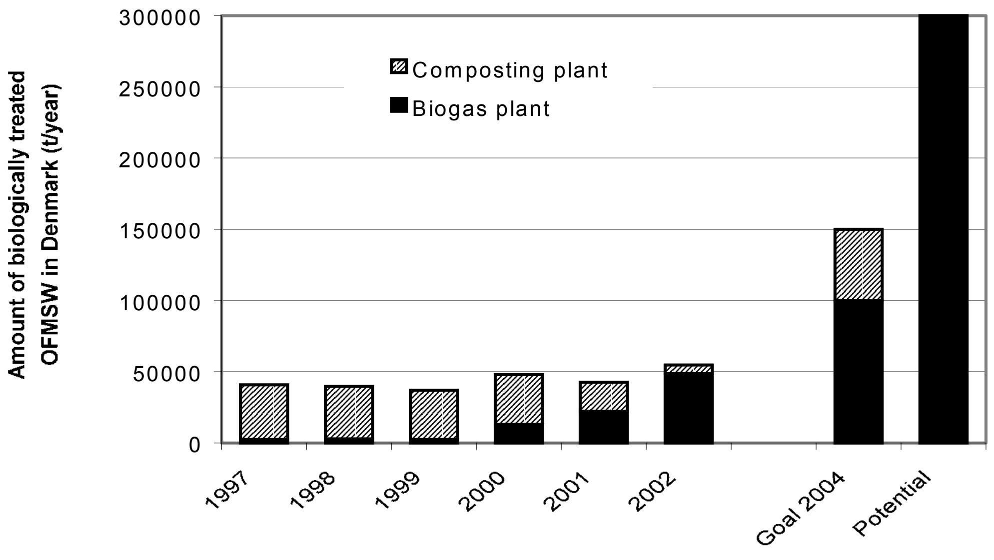

Figure 1: Amount of biologically treated OFMSW in relation to governmental goal and potential

Until the year 2000 anaerobic digestion had only a minor role in OFMSW treatment and composting was the dominant biological treatment. Since the year 2000 a shift from aerobic composting to anaerobic digestion is recognizable (figure 1).

OFMSW is treated in Denmark at eight out of 20 centralized biogas plants: Fangel, Grindsted, Hashøj, Nysted, Snertinge, Studsgård, Ålborg and Århus. The amount of OFMSW treated and the different collection and pretreatment methods used are listed in table 1. In the year 2001, the ratio of OFMSW to other waste in the co-digestion plants was between 1.9%(w/w) (Snertinge) and 8.3%(w/w) (Studsgård).

Five out of the eight biogas plants, Fangel, Hashøj, Nysted, Snertinge and Århus, have started in 2001 treating OFMSW that was previously treated by composting. The amounts treated in 2001 are in some cases (Ålborg, Århus) much below the expected amount for the next years, which is often due to technical problems of start-up of collection and treatment of the waste. Different concepts like the separation of a pumpable wet fraction from OFMSW by a dewaster (for the waste treated at Snertinge and Ålborg) and the separation of the plastic fraction in a drum sieve after addition of straw (for the waste treated at Fangel, Hashøj and Nysted) are still under investigation.

TABLE 1: AMOUNTS OF OFMSW TREATED IN DANISH BIOGAS PLANTS 2001 AND COLLECTION AND PRETREATMENT METHODS USED (ACCORDING TO INFORMATION FROM THE BIOGAS PLANTS)

	Grindsted	FA, HA, NY	Ålborg	Snertinge	Studsgård	Århus
Start	1997	2001	1990's	2001	1990's	2001
OFMSW (t/year)						
2001	2,000	6,000	300	900	11,000	2,000
Expected	4,000	12,000	3,000	1,800	11,000	17,000
Other types of waste (t/year)						
Manure	-	175,000	-	40,000	113,000	100,000
Sewage sludge	28,000	-	-	-	-	-
Ind. waste	4,000	n. d.	-	8,000	9,000	-
Collection system						
Indoor	Paper bags	Plastic bags	Plastic bags	Plastic bags	Plastic bags	Plastic bags
Outdoor	Paper bags or container	Paper bags or container	Paper bags or container	Paper bags or container	Paper bags or container	Plastic bags (green for OFMSW, black for gray waste)
Pretreatment						
Method	Crushing	Drum sieve + addition of straw	Dewaster	Dewaster	Roller sieve	Roller sieve
Ratio of reject	3%	25-30%	15 – 45%	20-40%	15 – 25%	15 – 45%

n.d.: no data; FA: Fangel, HA: Hashøj, NY: Nysted

WASTE QUALITY

The quality of OFMSW treated in biogas plants is crucial for both a balanced biogas process performance, the technical feasibility of the process and the use of the effluent as fertilizer on agricultural soil. Previous studies have shown that because of the complexity of OFMSW and the different possibilities of collection the results of anaerobic digestion of OFMSW can be very different one from another. The biogas yield will be dependent on the composition of the waste in terms of biodegradable fractions. Comparison of source- and mechanically selected OFMSW has shown that the biodegradation of the first is generally much higher (Mata-Alvarez et al. 1990). C/N ratio and nutrient content will influence the process stability. Biodegradability, C/N ratio and the nutrient content of OFMSW vary significantly due to the composition of the single fractions (food waste, yard waste, paper, newspaper etc.) (Kayhanian and Tchobanoglous 1992, Kayhanian 1995, Plaza et al. 1996). Food waste, for example, will lead to high biogas yields due to the high content of biodegradable organic matter, but can also lead to ammonia toxicity. Yard waste and newspaper, on the other hand, contain higher fractions of lignin and hemicellulose and will be characterized by lower biogas yields. The output of the treatment process will, therefore, depend on the regulations regarding which waste fractions are included in the collection system.

In Denmark, all municipalities where OFMSW is treated in the biogas process are collecting organic household waste without diapers, while yard waste and newspapers are collected separately for composting and paper recycling. Since most of the biogas plants are treating OFMSW in co-digestion with manure or sewage sludge, problems of nutrient deficiency, ammonia toxicity and low pH of OFMSW are of minor importance with the amount of OFMSW treated in 2002. The key for successful implementation of anaerobic treatment of OFMSW in large-scale processes is here first of all the technical feasibility of the waste handling and the effluent quality. Influences of the waste quality on the anaerobic process under the treatment of higher amounts of OFMSW in the future and the development of new treatment concepts are currently under investigation (Hartmann et al. 2001).

OFMSW of low quality, particularly in terms of high plastic contamination, causes enormous technical problems at the biogas plant. Other impurities like metal are only of minor importance and can normally be easily removed. Plastics in the form of plastic bags etc. wrap up into the stirring equipment in both the storage tanks and the reactor tanks, wear out pumps and form a top layer in the reactors. This will result in increased operation costs and process disturbances.

Furthermore, plastic contamination can ruin the concept of using the effluent as fertilizer. Farmers will not accept the effluent of the biogas process as soon as there are plastic residues. Since even small amounts of plastic are visible this means that by adding OFMSW to the biogas process there is a risk that the co-digestion treatment at the biogas plant contaminates a large amount of manure that cannot be used as fertilizer in the end. Therefore, the biogas plants intent on addition of OFMSW free of plastic contamination and they rather put up with loosing parts of the organic matter during pretreatment if only the treated fraction is without plastics.

Last, but not least there are restrictions on the content of heavy metals and xenobiotics in the effluent of the biogas plant when used as fertilizer and these compounds are often found in OFMSW, namely phthalates from plastic impurities. Therefore, new concepts for removal of the phthalate DEHP (bis-2-ethyl-hexyl phthalate) from OFMSW under anaerobic conditions are under investigation (Hartmann and Ahring 2002).

TREATMENT CONCEPTS

The overall treatment of OFMSW in Denmark is often divided between two different groups of interest. There is the municipality on the one hand that stands for waste collection and pretreatment and the biogas plants on the other where OFMSW is treated together with other kinds of waste. While the municipality is interested in having low costs for collection and treatment, the biogas

plants are only able to treat OFMSW with low plastics contamination. The total efficiency of the waste treatment concept will, therefore, always depend on the co-operation of the two partners.
A high quality of the OFMSW that is supplied to the biogas plant can be achieved by mainly two concepts: either by establishing a source-sorting collection system with low content of contaminants and avoiding plastic bags in the collection (Grindsted) or by selective removal of plastic bags and other contamination from the collected OFMSW before supply to the biogas plant (for example Ålborg, Århus), see figure 2. This separation has, however, to be very efficient to ensure a high purity of the waste since former experiences have shown that compost derived from mechanical separation will not meet the standards for useful application as soil conditioner (Braber 1995).
So far, only the municipality of Grindsted uses paper bags for collecting OFMSW. The waste is collected in paper bags both inside the house and outside for transportation. Source-sorting makes the single household responsible for the waste quality and a good enlightenment of how to separate the waste and why is necessary for a successful implementation of the collection system. The example of the municipality of Grindsted has shown, that this is mainly necessary at the start-up of the system; later people will get used to it and separate the waste rather automatically.

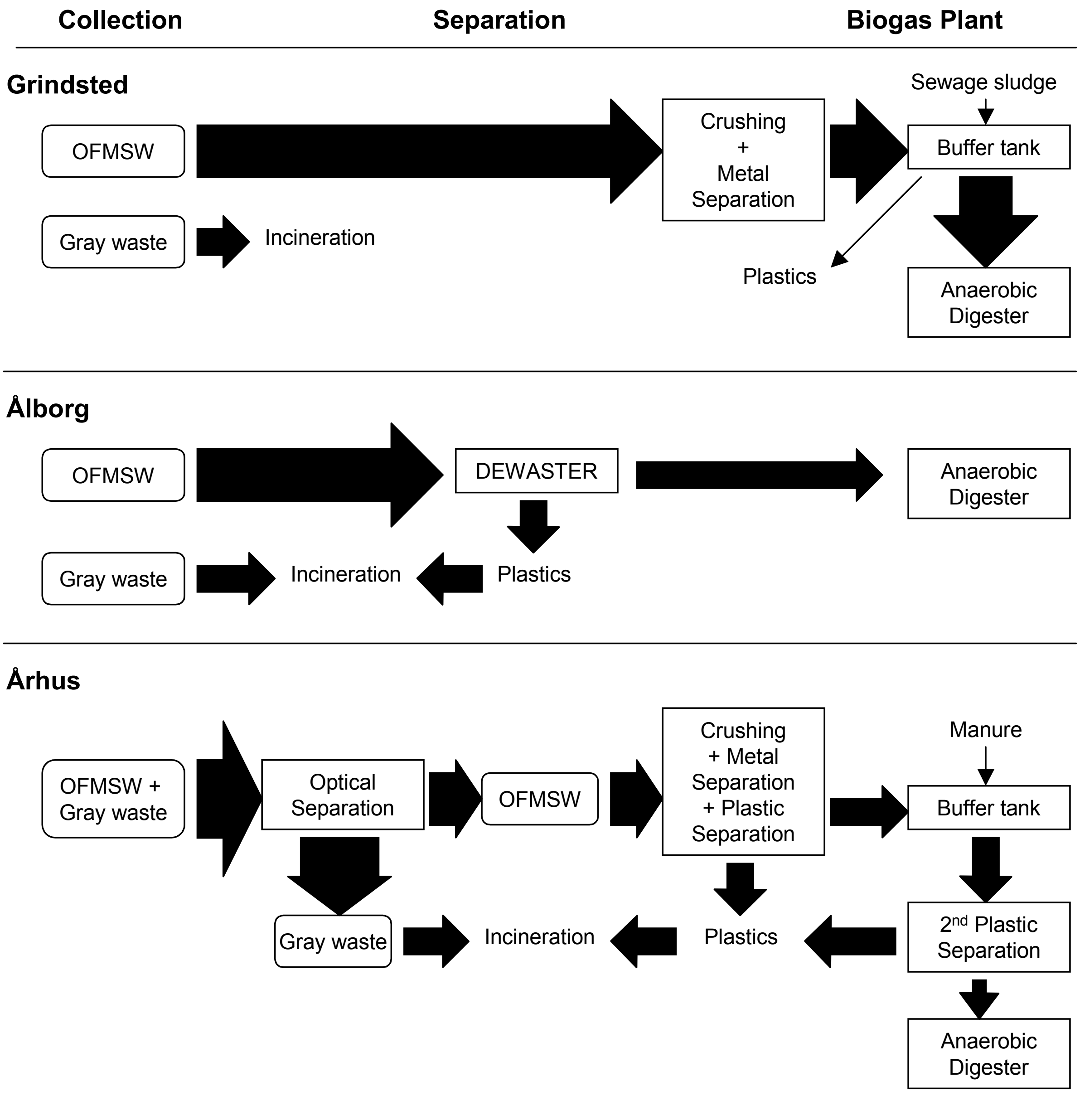

Figure 2: Treatment concepts for OFMSW at Grindsted, Ålborg and Århus

The efficiency of source separation in Grindsted can be seen in the fact that impurities in the waste do only contribute to 1% of the total waste amount, and 97% of the collected waste amount is supplied to the biogas process (table 1). Consequently, the treatment concept is rather simple, including only one pretreatment step for crushing and metal separation. The rest of plastic contamination is withdrawn from the buffer tank where OFMSW is mixed with sewage sludge (figure 2).

In all other municipalities the organic waste is collected in plastic bags that have to be removed before OFMSW is used at the biogas plant. Although OFMSW is in most cases also source-separated with only up to 10% impurities, the separation of plastic bags causes a significantly higher loss of OFMSW that is not treated in the anaerobic digester. There are different methods used for plastic separation.

In Ålborg and Snertinge a pumpable liquid fraction is pressed off the waste using a dewaster (figure 2). The dewaster method is a simple treatment method that ensures a liquid fraction of OFMSW free of plastic contamination, but shows the highest reject mass of up to 45% of the collected material (table 1).

In Studsgård and Århus the plastic is removed by use of roller sieves. In Århus the separation is rather costly including several separation steps due to the fact that OFMSW and gray waste are collected together. After an optical separation of green plastic bags for OFMSW and black plastic bags for gray waste, the waste is crushed and metal and plastics are separated. Again, a significant amount of 15-45% of organic matter of the original collected waste is lost, which is going to incineration. Furthermore, the plastic separation is not yet sufficient so that a second separation is necessary after OFMSW has been mixed with manure at the biogas plant (figure 2).

For OFMSW delivered to Fangel, Hashøj and Nysted a drum sieve is used. Here, the addition of straw has been shown to improve the separation efficiency, but still 25-30% of the collected OFMSW is lost in the reject material (table 1).

Regarding the overall concept from collection to treatment at the biogas plant, it can be seen that the less OFMSW is source-separated and the more contaminated it is, the higher are the reject masses and the more costly is the separation treatment. Since the reject mass is not only plastic contamination, but contains a significant amount of organic material, the benefit from the treatment in the biogas plant, meaning the biogas yield per ton of collected OFMSW, is lowered significantly.

Capital and operating costs for the different concepts are shown in figure 3. For the plants that started in 2002 (Fangel, Hashøj, Nysted, Snertinge, Århus) the capital and operating costs are estimations for long-term operation made by the plant operators. Operating costs are costs for pretreatment and treatment of the collected waste, without collection costs and provision. The benefit from biogas production is calculated from the biogas yield, the price of biogas and the average of the rejected amount per ton collected waste by the pretreatment according to equation (1).

$$B = Y_{biogas} \cdot P_{biogas} \cdot (1 - r) \qquad (1)$$

B = benefit (€/t), Y_{biogas} = biogas yield (m^3_{biogas}/t); P_{biogas} = price of biogas (0.202 €/m^3_{biogas}); r = ratio of reject

Detailed data of the biogas yield at the different plants was not available since the value is concealed in the yield of the co-digestion with manure or sewage sludge. Therefore, a biogas yield of 200 m^3/t, which is derived from lab-scale reactor experiments with OFMSW from Grindsted, is assumed for all plants (Hartmann et al. 2001).

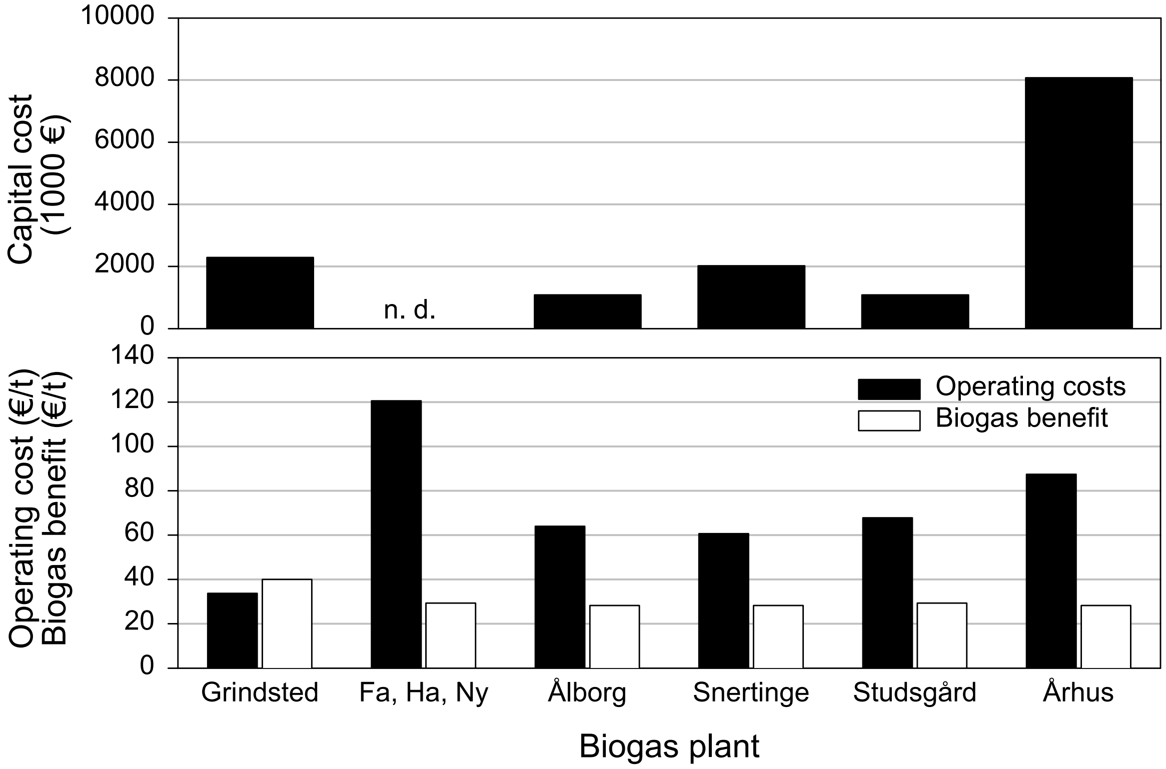

Figure 3: Cost-benefit for different pretreatment methods; n.d.: no data; Fa: Fangel, Ha: Hashøj, Ny: Nysted

Capital costs for the pretreatment are in the range of 1-2 million € for all sites where OFMSW is source-sorted while the capital costs are significantly higher for the optical separation plant for separation of OFMSW and gray waste. Operating costs for the pretreatment of OFMSW delivered to Hashøj, Fangel and Nysted are highest since transportation costs are significant because the biogas plants are situated up to 200 km away from the pretreatment site. The operating costs will be significantly lowered with establishment of a new biogas plant nearby, which is planned for the coming years.

Operating costs at the Grindsted plant are lowest for two reasons: first, the pretreatment process is more simple and less work and energy consuming and, second, all other plants have a considerable amount of reject that has to be treated by incineration, for which a price of 80 €/t has to be paid. This clearly shows how the treatment costs increase significantly with each ton of rejected material. The biogas benefit, on the other hand, is highest for the treatment at Grindsted since the recovery of organic material is 97% while up to 45% is lost at the other plants during pretreatment.

Furthermore, the degradation of the paper bags in which the waste is collected in Grindsted can be suspected to contribute positively to the biogas potential of the waste.

In general, the treatment concept at Grindsted is the only one where the benefit from biogas production is higher than the treatment costs. The investment costs for the optical separation unit in Århus are about four times higher than the average investment costs for the pretreatment at the other plants. These investment costs are, however, not paid back since the recovery of organic material is poor and the treatment costs are high.

It can be suspected that one reason why the Grindsted concept shows the best overall cost-benefit is that both the collection and the biogas treatment of OFMSW are in the hand of the municipality. The collection is, therefore, better adapted to the needs of the biogas process and the profit from the higher collection efficiency pays directly back to the municipality.

CONCLUSIONS

Anaerobic digestion is becoming the predominant treatment of OFMSW in Denmark. In order to establish anaerobic digestion as a low cost waste treatment of OFMSW, the whole treatment costs from collection, pretreatment and treatment at the biogas plant should be encountered. Costs for pretreatment and treatment at the biogas plant can be reduced and biogas production can be enhanced with a collection system that ensures low plastics contamination.

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