By
Heron Kleis, Babcock & Wilcox Vølund
and
Søren Dalager, Rambøll

100 YEARS OF WASTE INCINERATION IN DENMARK

From Refuse Destruction Plants to High-technology Energy Works

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The bottom ash from both the first and the second incineration plants in the municipality of Frederiksberg was taken to a crushing plant in front of the old stack. After crushing, the bottom ash was brought by tippers to the area in the front where it was allowed to age prior to being sold.

Preface

In September 2003 the Municipality of Frederiksberg celebrated its centenary as the first municipality in Denmark ever to supply its inhabitants with district heating.

The heat was produced on the basis of waste collected in the municipality. The original district heating plant was therefore also Denmark's first incineration plant, and waste has in fact been incinerated in at least one plant in Denmark throughout the period of 1903 to 2003.

Waste incineration therefore also celebrated its centenary in 2003. Initially, there were only a few plants, but approximately 40 years ago the situation changed. It became more and more common to exploit the energy content of the waste for the production of heat, and today the technology and pollution control methods applied are so highly developed that incineration has become the officially prescribed method for the treatment of incinerable waste in Denmark.

Consequently, Denmark has achieved a leading position regarding the percentage of waste incinerated and know-how in the area.

During this 100-year period the Danish society has undergone tremendous developments – in terms of national income as well as technology – and the way of life significantly differs from what it used to be 100 years ago. These changes have had an impact on the incineration plants too. The waste composition and the way in which the waste is collected and transported have changed. The plants have become more complicated because of increasingly stringent environmental standards. They are now however operated by a lot less staff.

The authors of this book have been involved with incineration for 50 and almost 40 years, respectively. They are both approaching retirement and therefore feel called upon to look back on the first 100 years of waste incineration in Denmark.

The authors hope that this book will preserve a corner of Danish history, and naturally they also hope that the readers will find it interesting.

1. The Beginning

1903-1962

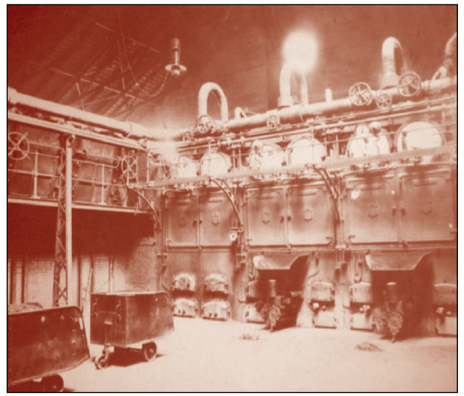
It Began in Frederiksberg

In September 1903 incineration was introduced as a method for the treatment of waste in Denmark.

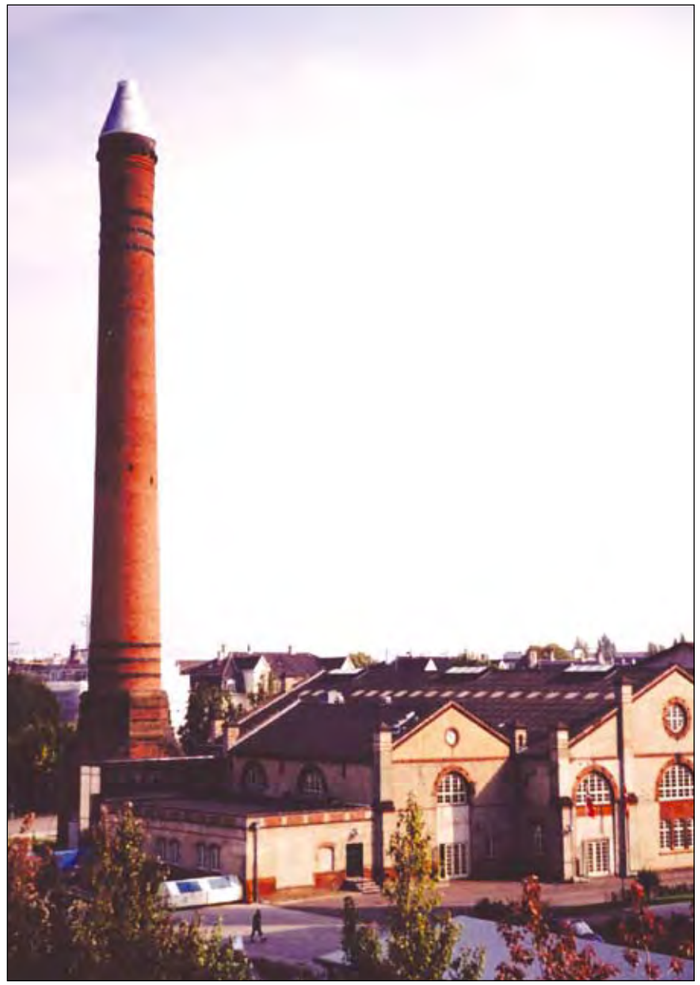
Even before a municipal reform in 1970, Frederiksberg – an enclave located in the middle of the capital of Copenhagen – was one of the smallest municipalities by area in Denmark. On the other hand, it was the most densely populated one. It is therefore not surprising that this municipality '*… realised in 1897 that soon it would not be possible to identify sites suitable for the landfilling of municipal solid waste within the boundaries of Frederiksberg… which is why the possibility of establishing a waste incineration plant was investigated… With a view to examining the combustibility etc. of the municipal solid waste generated in Frederiksberg, a sample was sent by rail to the waste incineration plant in Hamburg where the waste was incinerated on a test basis. The result of the test was that the waste was combustible, and much heat was produced so that steam could be generated in steam boilers. Moreover, the quality of the bottom ash was good and could be applied for various technical purposes.*

At the same time… in August 1898 it had been decided to build a complex of buildings nearby for a new municipal hospital in Frederiksberg… An obvious solution was to exploit the heat produced from the incineration of municipal solid waste to supply steam, hot water and electricity to the new hospital.

Consequently, in February 1902, it was decided to establish an incineration plant… with three units from the British company of Hughes & Stirling and steam boilers… from Babcock & Wilcox as well as two coal-fired steam boilers, a hot water system and an electricity generator so that the incineration plant in effect became a combined heat and power plant… The plant was commissioned in September 1903'.



One of the furnaces at Frederiksberg's first incineration plant.
Source: Frederiksberg Forsyning.



Frederiksberg municipal culture and sports centre, *The Boiler Hall*. The buildings, which were erected in 1903 on the basis of drawings prepared by the chief architect of the Danish state-owned railway company, Heinrich Wenck, housed Denmark's first incineration plant until 1934. From 1934 to 2000 the buildings were used as a steam heating plant.

This is the introduction of a description from 1948 of the – at the time existing – second plant for the incineration of municipal solid waste in Frederiksberg.

The plant from 1903 was not only Denmark's first waste incineration plant, but also Denmark's first district heating plant, even in the form of a combined heat and power plant. The plant was located on a site opposite to what is today *Frederiksberg Hospital*.

Vølund was there too

The district heating contract was assigned to Vølund, which was a young company at the time. In the company's 25th anniversary book from 1923, it reads that: '*A large contract… worthy of a mention was the district heating plant located at the incineration plant of Frederiksberg. The piping work was the most comprehensive work of its kind ever performed, and it had to be concluded in just four months. It consisted of high-pressure steam pipes, hot water pipes and return water pipes installed in tunnels from the boiler system of the plant to all the buildings at Frederiksberg Hospital and an Old People's Home, and was later extended by hot water pipes… leading to the public baths of the municipality of Frederiksberg. A total of 8500 m of pipes were installed and approximately 800 valves and taps were applied. For this work Vølund received due recognition, not just because of the good workmanship, but also because of the tight time schedule within which the comprehensive work had been performed'.*

The adverse impacts of the many landfills of the time, slowly paved the way for the introduction of waste incineration.

The plant was what would today be called a batch-fired plant. *'The waste was fed to the furnace in batches, and a long time passed until ignition. When this finally happened, an amount of polluted gas and steam was formed and emitted directly to the air. Even with a very high stack, this could be a nuisance to the surroundings. Another negative impact was the formation of "bottom ash cakes", which consisted of poorly combusted waste'*, wrote Vølund in 1936.

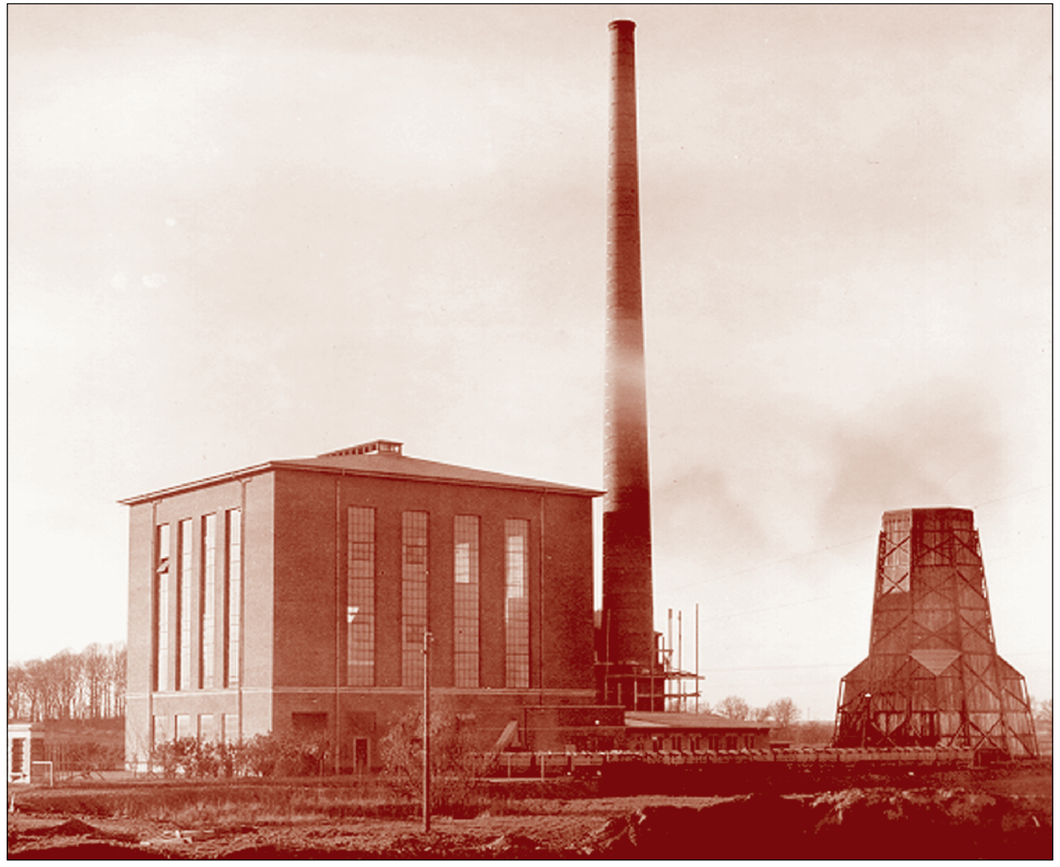
Vølund's former chief engineer, Evald Blach, noted in 1962 that *'the plant consisted of a number of cells, each with a capacity of approximately 1 t/h … The manual operation was expensive and the deslagging was difficult, very unpleasant and gave rise to a lot of false air'*.

A new plant was planned

By the 1920s the plant had become too small, and in the summer of 1925 the technical department of the Municipality of Frederiksberg had prepared a proposal for a new plant. The 1948 description continues:

'At that time, however, Vølund had brought it to the Municipality's attention that the machine works of "Aktiebolaget Landsverk" in Landskrona, Sweden [Vølund's licensee] *was testing the incineration of municipal solid waste in a rotary kiln… The proposal for the new plant… was therefore dropped, and the tested rotary kiln was installed by Vølund at the old incineration plant of Frederiksberg. A number of tests were then carried out until January 1929… The tests convinced the Municipality that the rotary kiln was perfectly suited for the incineration of municipal solid waste – and even better than other well-known furnaces – which is why Vølund was requested to prepare a proposal for a new incineration plant based on such rotary kilns'*.

A couple of years passed before a final decision was made.



Gentofte incineration plant was inagurated in 1931. The plant was the first plant to be supplied by Vølund.

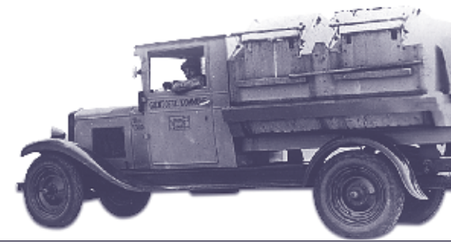
Gentofte Incineration Plant

The description of the Frederiksberg plant continues: *'Following a test for the incineration of Gentofte's municipal solid waste in the rotary kiln at the incineration plant of Frederiksberg, the Municipality of Gentofte decided to establish a new incineration plant based on Vølund's rotary kilns. Therefore Frederiksberg suspended its plans for the construction of its own incineration plant pending the operating results from Gentofte'*.

The plant in Gentofte – one of the municipalities in the 'cocktail belt' north of Copenhagen – was inaugurated in 1931 in the presence of Prime Minister Thorvald Stauning. The plant consisted of two steam producing incineration units with a joint condensing turbine, and the cooling water was re-circulated across a large wooden cooling tower. It did not only incinerate waste from Gentofte, but also from the adjacent municipality of Lyngby-Taarbæk.

Collection by motor-driven vehicles

Motor-driven vehicles constructed by Vølund and equipped with two separate waste containers collected the

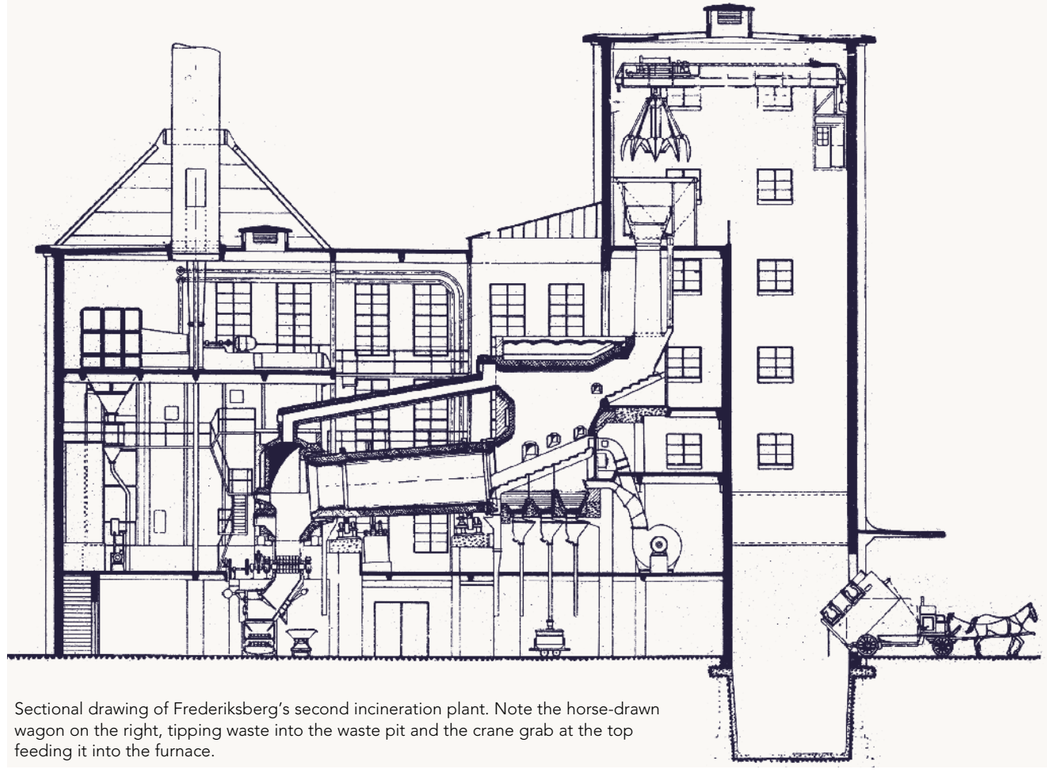


Prime Minister Th. Stauning (third from the right) visiting Gentofte incineration plant.

waste. Upon arrival at the plant, the containers were lifted by a crane from the vehicles to the feeding chute of one of the furnaces. Here, the bottom of the container opened, the waste was emptied into the chute and the crane lifted the container back to the vehicle.

In time this approach became too impractical, and it was decided to furnish the plant with a reception pit. The pit was designed by the consulting engineering company, *Rambøll & Hannemann A/S*, and was the company's first project in the area of waste incineration.

The plant was in operation until 1970 when both municipalities joined *Vestforbrænding*, see p. 25, and the buildings were later on demolished.



Sectional drawing of Frederiksberg's second incineration plant. Note the horse-drawn wagon on the right, tipping waste into the waste pit and the crane grab at the top feeding it into the furnace.

The New Plant in Frederiksberg

'As these [the operating results from Gentofte] *fully met everybody's expectations, Frederiksberg decided, in November 1932, to establish a completely new incineration plant based on Vølund's rotary kiln system.*

The plant was commissioned in… September 1934… Its central location is not inconvenient to its neighbours, even though it is a rather densely populated housing area.

Only municipal solid waste from Frederiksberg – not from Copenhagen – is incinerated, and the waste is not separated or screened, but fed to the furnaces in the form in which it is delivered from the municipality.

The municipal solid waste is collected from each property three times a week (every other weekday)… from 6 a.m. to 4.30 p.m. The wagons are drawn by two horses as … this has proven to be … by far the cheapest solution, both in terms of initial cost and the cost of applying horse-drawn wagons rather than motor vehicles.'

Private hauliers collected the waste. For more information on working with horse-drawn wagons (see box on p. 11).

First plant with reception pit

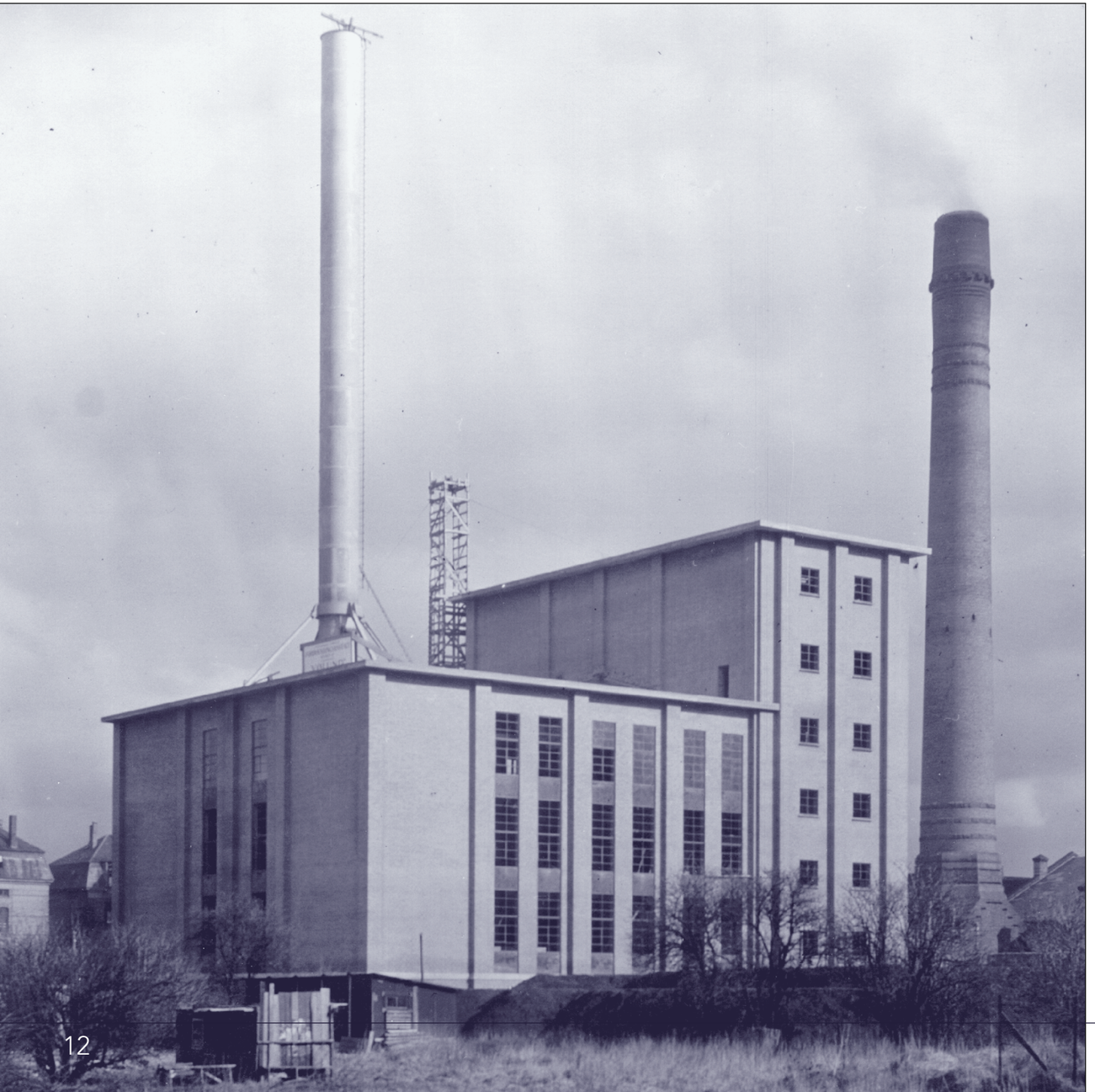
As opposed to the plants in Gentofte and Aarhus (see p. 11), the new plant in Frederiksberg was from the outset equipped with a reception pit complete with cranes for feeding the waste.

'The incineration plant is in continuous operation six days a week with Sunday being the usual day off for the operating staff. Usually 1 furnace/boiler is operated by 3 shifts of 8 hours, each shift consisting of 1 crane operator, 1 furnace/boiler operator, 1 bottom ash discharge operator, 1 bottom ash remover, 1 relief man and 2 workers at the waste reception from 6 a.m. to 5.30 p.m. Hence, for the operation of 1 incineration unit 17 staff per day are required, not including workers for the operation of the bottom ash crusher or for cleaning or holiday/

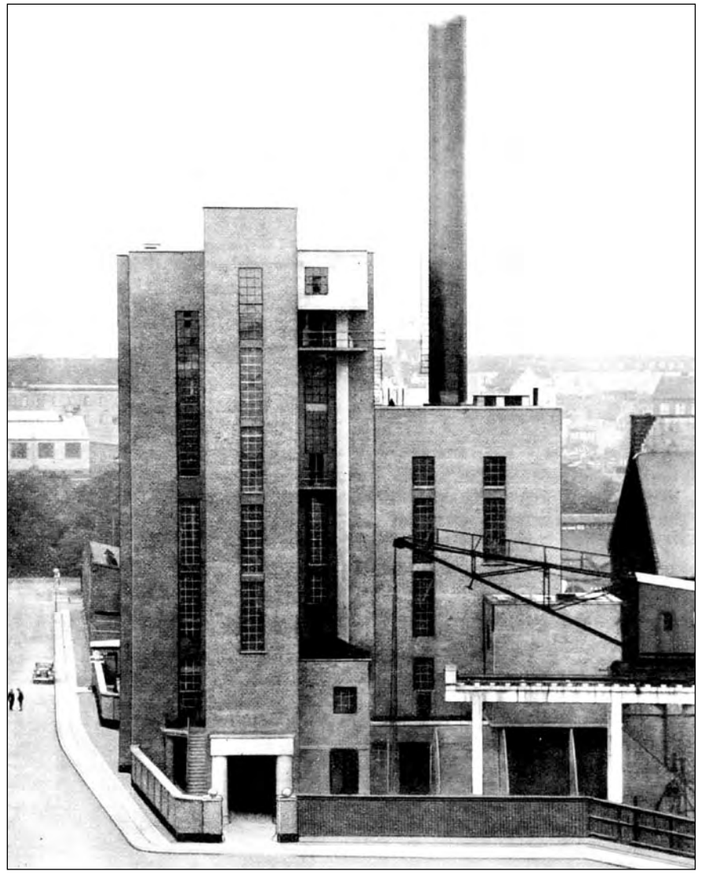
illness relief. At the old incineration plant, incineration of the same amount of municipal solid waste required 40 staff to continuously operate all three furnaces on week-days and partly on Sundays'.

The plant was in operation until 1975 and was later on demolished.

Frederiksberg's second incineration plant shortly before completion in 1934. On the right is the stack of the old plant from 1903, see page 5.



Aarhus Incineration Plant



Aarhus incineration plant was commissioned in 1934. The front gates were used by the collection wagons exiting the plant.

This plant was also commissioned in 1934. On this occasion the Municipality of Aarhus – the second largest city of Denmark – published a small folder written by *Holger Eriksen: The Municipal Refuse Destructor Plant in Aarhus*. The folder reads: *'In many respects Aarhus has gained a leading position also in the area of sanitation, and at the turn of the century it was considered whether it would be a better solution to incinerate the waste rather than to landfill it'*. Nothing ever became of it, though – *'it was a time when no rash decisions were made'* – and in 1911 a new landfill was established in the municipality.

'It was not until October 1926 that the municipality again began to take an interest in the matter of an incineration plant'. DSB – the Danish state-owned

Working with horse-drawn wagons

In 1898 *Renholdningsselskabet af 1898* (The Public Cleansing Company of 1898, in short R 98) got concession on the collection and disposal of latrine in the Municipality of Copenhagen. In the 30s it became clear that the days of latrine collection were about to end, and R 98 started to engage themselves in the collection of municipal solid waste.

In their 100th anniversary book from 1998 R 98's former employee, Helmer Sondergaard (born 1911) writes:

'A friend of mine introduced me to a private haulage contractor in Frederiksberg. We drove with horses at the time. We had a stable near the centre of the municipality, and we watered and fed the horses every day – also on Sundays. We took turns at doing that. Many of the old scavengers were shabby; some of them lived on the hay-loft above the stable. They were almost bums'.

railway company – wanted to make use of the area where the landfill was located and asked for the removal of the landfill. *'The rats* [on the site] *are alive and kicking; they are present in huge numbers… A subsequent campaign mentioned that millions of rats were there.*

Now was the time to act, and the Pavement Committee… now worked at full speed. There were many plans to buy farms in the suburbs and zone the purchased areas for landfills. But the municipalities in question… did not want to move the rat Eldorado to their preserves.

Also the Lighting Committee now starts to make experiments… Maybe it would be possible to combine the incineration plant with the extension of the municipal power station. The Lighting Committee then goes on a journey… One is impressed by the filth prevailing at the British incineration plants and equally impressed by the unfailing cleanliness found at the incineration plant in Cologne. The Committee visited the incineration plant under erection in Hamburg and then came to Gentofte where Vølund was erecting the first incineration plant based on the rotary kiln principle… The Committee agreed that of everything they had seen, there was no doubt that the Vølund system from back home was the best'.

Grumblers

The mayor of Aarhus, *H.P. Christensen,* known as the *'blacksmith'*, had for many years been a keen supporter of incineration and achieved his aim by strong-arm methods. *'Of course, some hostility arose – some discontent. People complained about bad odours, dust and fumes – but when has a major project ever been realised without birth pangs and without professional grumblers having a field day?'*

The plant, which was equipped with two identical units, was established next to the municipal power station so that the steam produced could be sent to the power station and converted into electricity and heat. It was *'first and foremost designed for household waste… The household waste has to be collected once or twice a week, and the first big issue was the way in which the waste should be collected. Vehicles are the order of the day, but an investigation showed that with the relatively short distances to be covered and the many stops along the way the application of motor vehicles is uneconomical, and the old horse-drawn wagon was therefore selected.*

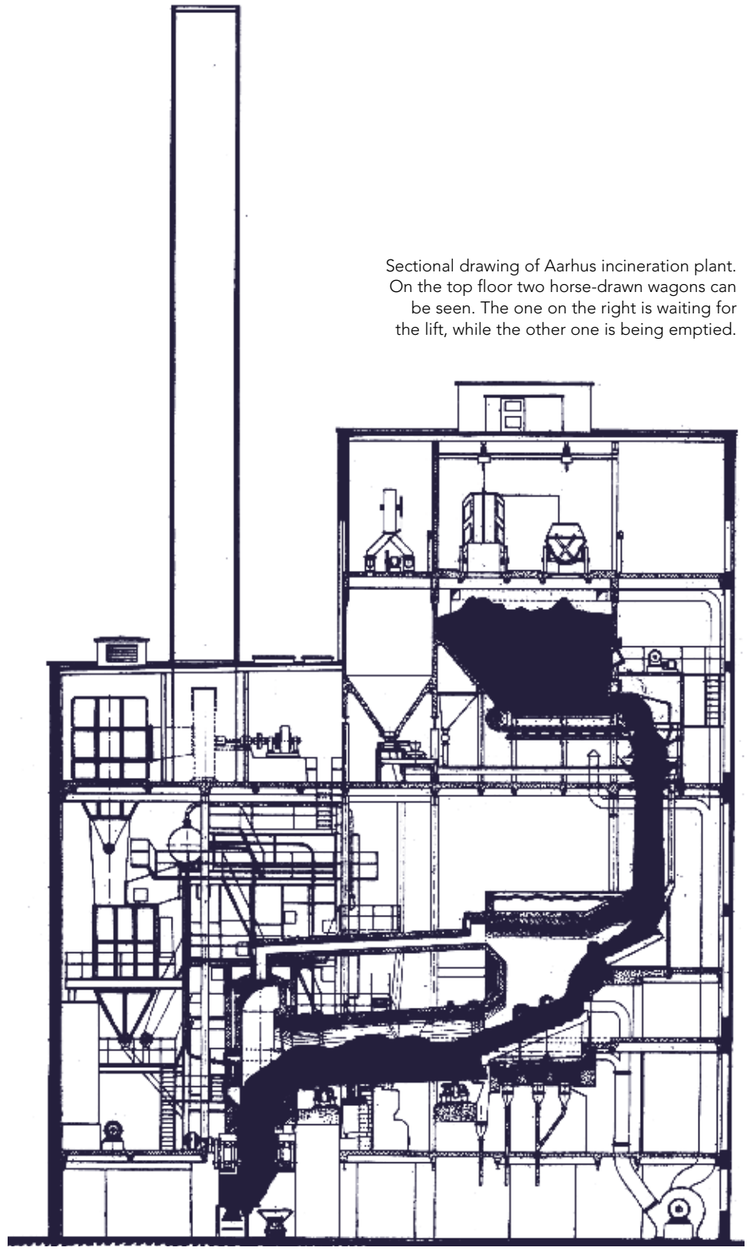
Waste is collected in dedicated horse-drawn wagons equipped with closed containers. The body of the wagon has a hatch in the back and is designed in such a way that it can be tipped.'

Up we go!

'When the wagon arrives at the incineration plant, it drives into the western lift and then both the wagon and horses ascend… There has not been any difficulties related to lifting the horses. On the top floor the wagon drives to a free bay, and the body of the wagon is tipped… so that the waste is emptied into the waste pit… Absolutely nobody gets into physical contact with the waste. When the wagon has been emptied, it drives on to a lift across the building and then descends the same way it ascended.

Horse-drawn wagons at Aarhus incineration plant. The wagons were taken up and down by lifts.

Sectional drawing of Aarhus incineration plant. On the top floor two horse-drawn wagons can be seen. The one on the right is waiting for the lift, while the other one is being emptied.



The waste is temporarily stored in… the bay, and subsequently transported by two scraper conveyors to a vibrating feeder, which is continuously moving back and forth, taking the waste to a chute that leads to the drying grate of the furnace'. Then followed an ignition grate and a rotary kiln, cf. sectional drawing. The bottom ash was taken to a sorting plant with a magnetic separator *'so that the bottom ash is sorted into three fractions as well as an iron fraction.*

The incineration products have an average temperature of approximately 1000°C in the flue gas chamber after the rotary kiln. The heat contained in the incineration products is recovered in a Babcock & Wilcox high-pressure boiler. The rotary kiln system generates very little fly ash – only approximately 2 per cent of the amount of waste incinerated… In order to be able to perform a complete cleaning of the flue gas both the boiler and the economiser are equipped with 'soot pockets'… and after the economiser a special flue gas cleaner capturing approximately 80 per cent of the fly ash has been established so that the flue gas, when emitted from the stack of the incineration plant, is light and free of solid matter'.

Festive inauguration On 24 August 1934 the plant was officially inaugurated. In the evening there was a banquet at Hotel Royal. For this occasion a popular Danish newspaper poet wrote:

Now waste is gathered everywhere
and with horse and wagon
brought to here.
Against this all consuming flame
the heat of Hell is very tame!

His Majesty King Christian X (in the grey suit in the photo) visited the plant in Aarhus on 14 August 1934. To the right of the King is the Mayor of Aarhus, H.P. Christensen.

The plant in Aarhus was closed down in the 50s in connection with an extension of the nearby power station, and the buildings were demolished. The waste was then composted until the municipality in 1978 inaugurated a new incineration plant (see photo on p. 21). Consequently, they celebrated their 25th anniversary in 2003.

Vølund – an Established Supplier

With the three plants in Denmark as well as three plants in the UK and one in Sweden, Vølund had established itself as a supplier of waste incineration plants.

In 1933 and 1936 the company published articles in English in *Danish Foreign Office Journal* with a presentation of particularly the Danish plants. The following table containing key plant data is from the 1936 article.

The guarantee for the plant in Frederiksberg was based on the assumption that the calorific value would be 1200 kcal/kg = 5.0 MJ/kg.

Thanks to the company's other activities, it had become a significant company in the iron and metal industries, which from time to time put up leader candidates for the industrial unions and whose opinions could not be disregarded.

In april 1921 Vølund moved into their former head office at Øresundsvej in Copenhagen.

Table 1: Key plant data for the plants in Aarhus, Frederiksberg and Gentofte

Plant	No. of units	Capacity/furnace, t/h		Steam pressure	Steam temperature	Guaranteed steam product.
		Guaranteed	Achieved	bar	°C	kg/kg waste
Aarhus	2	6.25	10	30	425	1.0
Frederiksberg	2	6.0	9	12	190	1.0
Gentofte	2	4.0	7	16	350	0.9

From Vølund to Babcock & Wilcox Vølund

A/S Vølund (A/S = Aktieselskab = Limited company) was founded in 1898 on the basis of F.A.H. Petersen & Ludvig Christensen's Machine Factory & Iron Foundry. The company was given its name after Vølund – the ingenious smith – a Nordic mythical character in the Elder Edda.

At the beginning the company primarily produced heating systems and steam laundries, for instance to the *State University Hospital* in Copenhagen, which was established in the period of 1907-10. In 1910 Vølund started making crude oil engines for marine propulsion. Later it produced steam drums and iron structures for, for instance, Forum – a cultural centre in Copenhagen, which was originally built for a car exhibition in 1926 and for many years hosted the annual bicycle-race, one of Copenhagen's flag ship events. In the following years Vølund constructed a bridge connecting Copenhagen with the island of Amager and supplied steam boilers for e.g. Tuborg Breweries.

In the 30s the company supplied the three incineration plants in Gentofte, Frederiksberg and Aarhus, *'the first continuously operating incineration plants in the world'*. Before the Second World War, Vølund produced both horse-drawn wagons and motor-driven vehicles for the collection of waste.

After the war the company supplied the boiler for the utility plant of Vestkraft in Esbjerg, Jutland, and in the 50s large tank installations were produced for petrol and oil companies in Aarhus and Copenhagen. When the amusement park of Tivoli in Copenhagen had to be reestablished after the war, they wanted a ferris wheel, which was then designed by Rambøll and supplied by Vølund.

In Esbjerg, Vølund opened a factory for the production of incineration plants, boilers, iron structures etc. Around 1960 the company expanded its production of washing machines. This activity was later divested, but the brand continues to exist under the name of *Asko Vølund*.

Around 1980 the company was divided into sections. The waste treatment part was transferred to Vølund Ecology Systems, whereas the responsibility for the boiler part was assigned to Vølund Energy Systems and Vølund Danstoker. In 1992 the Italian industrial group of Ansaldo acquired these companies.

Today, Babcock & Wilcox Vølund is further developing Vølund's long-standing expertise in waste incineration. Since 2002 the company has also owned B&S's W grate technology (see separate box on p. 21).

Including B&S's plants, Vølund's list of references includes 300 incineration units. When measured in this way, the company is the largest company of its kind in the world, and the list covers countries as distant as Argentina and Taiwan. Almost 100 units have been supplied to Denmark, 55 to Japan, 39 to France, 33 to Sweden and 17 to the USA.

Vølund-manufactured waste collection vehicle from the beginning of the 50s.

Whatever Happened to Copenhagen?

In Copenhagen the power stations started to supply district heating to the inhabitants in 1925, and Vølund followed up on its success in Gentofte, Frederiksberg and Aarhus. According to the 25th anniversary book of I/S Vestforbrænding, which was published in 1995, Vølund *'offered in 1935 – free of charge – to build and operate for six years an incineration plant located on a site to be made available by the Municipality. This – apparently philanthropic – offer was not accepted as it was estimated that a collaboration with a private incineration plant operated under the conditions made by Vølund would be un-economical for the Municipality… Moreover, the City Council wanted to reclaim new urban areas by landfilling… and the waste in Copenhagen did not burst into flames until the two metropolitan incineration plants of Amagerforbrænding and Vestforbrænding were commissioned* [in 1970]'.

The last statement is not entirely correct. Until 1970 the Municipality of Copenhagen disposed of its waste in a reclaimed area, and at the end of a day's work, the waste was set on fire.

Open-air burning of waste on a landfill.

The German Occupation 1940-45 And The Post-war Era

Shortly before the outbreak of the Second World War Vølund entered a contract for a plant in Basle, Switzerland. The German Occupation of Denmark on 9 April 1940 cut off connections, and the plant had to be completed by a Swiss company, which later developed into *vonRoll Umwelttechnik*, which is a well-known company today.

Denmark soon encountered a shortage of almost all imported goods such as fuel and rubber. Substitutes had to be found. Two domestic materials began to be used, lignite and peat. Copenhagen Energy provides a fine description of the situation:

'[On 9 April 1940] *H.C. Ørsted Værket* [power plant in Copenhagen] *had coal stored for approximately 5 months' consumption. It soon became necessary to conserve the stocks by using other fuels. Prospects of new coal supplies were poor, and it took a long time to establish domestic production of peat and lignite.*

There was no lack of inventiveness. Fly ash that had been applied for land reclamation purposes was taken back and burned again as there was still a small amount of coal in it that could be used. Copenhagen Energy's reserves of waste oil, tar etc. were all used.

Tar waste etc. from cleaned gas pipes made a contribution. Trade and industry supplied wastes such as wood, shaving and sawdust – everything capable of burning could be used. Peat in particular was a problem as it was often so moist that it could not be ignited without some prior heating in the furnaces. Eventually, even dry green waste from cemeteries was applied as kindling …'

No more than 10°C in churches and cinemas

In its 75th anniversary book from 1973 Vølund writes: *'During the war a palpable shortage of materials naturally prevailed, but we succeeded in maintaining our production by making various changes such as the introduction of peat gasworks and stationary generators. The strict fuel restrictions also had a great impact on the company's production – also with the sale of the production in the heat technical department. The products of this department were not interesting in a time when hot water supplies were prohibited and an indoor temperature of only 18°C – in museums, churches and cinemas even only 10°C – was allowed'.*

Rationing and other 'schemes' were introduced. The Rubber Committee of the Confederation of Danish Industries called upon everybody to sell rubber waste to a product dealer or give it to a refuse salvager (see separate box).

No data is available on the calorific value of the waste incinerated during the war at the three existing incineration plants. However, the 1948 description from Frederiksberg states: *'In the period of 1942-47 it has been necessary to remove peat ash prior to incineration'* and goes on to say that the waste collection wagons were *'equipped with roller bearings in the wooden wheels, which had pneumatic tyres (temporarily partly steel framed)'.*

L.A.B.'s refuse salvagers

Unemployment in the 30s was high. When the Second World War broke out in 1939, many people thought that unemployment would increase even further, and therefore L.A.B. – the National Society for the Combating of Unemployment – was established in order to prepare for the end of the war and massive unemployment.

'By the end of April 1940 L.A.B. had the first refuse salvagers in the streets, because waste was no longer just waste, but raw materials that could be used for new production. For example, kitchen waste, including beer slops from restaurants, was processed into swill. The old pre-war scavenger who went through the dustbins in his search for rags and bottles, was ousted by the L.A.B. man with his big carrier cycle …', writes the Danish historian Erik Kjersgaard.

The L.A.B. man on his carrier cycle.

The calorific value of the waste in 1948 was around 1000 kcal/kg in the summer and around 1400 kcal/kg in the winter. It was therefore necessary, particularly in the summer, to use coal as an auxiliary fuel.

Vestforbrænding's 25th anniversary book states: *'The incineration plants that existed during the occupation also had to incinerate things other than waste… In 1944 the resistance movement started to remove national registers all over the country as they feared that the Germans would misuse the registers… Thousands and thousands of files were taken to Frederiksberg incineration plant and thrown into the flames – causing the administration of the municipalities concerned a great deal of inconvenience.'*

During the German occupation waste salvaging was so well organised that there was practically no incinerable waste left for the waste incineration plants. The sign on the vehicle in the photo says: *'Waste is not a waste when the refuse salvagers get it'*. Also note the gas generator in the front of the car.

After the war

The initial post-war period was a time of deprivation. Many goods were still rationed. Vølund's 75th anniversary book notes that *'the post-war reconstruction activities took up everybody's time and attention, so building "luxuries", such as incineration plants, was not really an option until well into the 50s'*.

By the end of the 50s the national economy had improved, and women started joining the labour force. This entailed a radical change in family patterns, which also had an impact on the waste composition. The heavy milk bottles were replaced by milk cartons, cotton diapers by disposable diapers, and a number of new plastic products were introduced. Racks with disposable paper waste bags replaced the old dustbins. It no longer paid off to repair things. Denmark had become a 'use-and-throw-away' society, and the calorific value of the waste increased dramatically.

Or, as expressed by Vølund's Evald Blach in 1968: *'The waste composition reflects the way of life in society, and … from the average composition you can even read the development and welfare state of that particular society. The more developed and wealthy a society, the better the waste. The density becomes smaller and the calorific value higher as the percentage of combustible parts, particularly easily combustible parts with a short burnout time… increases substantially.*

The amount of slowly combustible parts such as coal and coke residues is reduced… On the other hand, the waste will contain the new synthetic materials with an often high calorific value and a very short burnout time. In great amounts they may result in an almost "explosive combustion". More-over, they often contain unpleasant substances such as chlorine and sulphur'.

Convenience goods were now purchased from the supermarket instead of from the small grocer's shop, and the numerous small dairies and slaughterhouses were closed down and replaced by larger, 'central' or 'united' facilities.

The municipal power supply companies had already before the war begun to recognise the advantages of large-scale operations and combined to establish larger partnerships. It was no longer profitable to produce power decentrally even though this meant that new power stations had to cool away a significant part of the fuel energy in condensing turbines.

Also the municipal gasworks began to disappear one by one. However, in Kolding they fought in vain to preserve the city's old gasworks as a waste gasworks.

Waste gasworks in Kolding

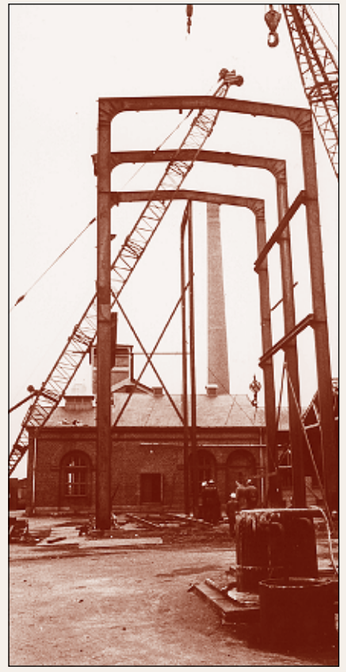
In the beginning of the 60s experiments with – what is today termed – *pyrolysis* of waste were made at the gasworks in the municipality of Kolding.

At the time the waste had a calorific value of 1300 kcal/kg (=5.4 MJ/kg). The waste was heated to a temperature of 900-1000°C in a retort by heavy fuel oil added in an amount of 100 g per kg of waste. This temperature was maintained for approximately eight hours. In the process a gas amount of approximately 0.4 Nm^3 per kg of waste with a calorific value of 3500 kcal/Nm^3 (=14.7 MJ/Nm^3) was generated.

The gas production turned out to be highly dependent on the content of plastics in the waste, and it was suggested that the target should be to produce a gas with the calorific value of 4200 kcal/Nm^3 (=17.6 MJ/Nm^3) typical of coal gas – by adding propane if need be.

The process was called the *Destrugas* process, and it was actually used for a while in Kolding, in parallel with the coal gas production. Eventually the municipality of Kolding chose incineration instead. Several other municipalities showed an interest in the process, but no full-scale plant was ever established.

In retrospect, the decision of the municipality of Kolding was probably wise. In recent years, however, the pyrolysis and gasification processes have attracted renewed interest – mostly in the UK.



The first Danish coal gasworks was established in the city of Odense in 1853, and in 1949 there were around 120 gasworks nationwide.

In 1937/38 the works converted coal in the amount of 665,000 tonnes into 266 million Nm^3 of gas, 365,000 tonnes of coke, 32,000 tonnes of tar, 2,000 tonnes of ammonium sulphate and 1,500 tonnes of benzene.

The gas was purified of hydrogen sulphide by marsh ore from the moors of Jutland before being distributed to the consumers through a network of cast iron pipes. The coke had a calorific value of approximately 25 MJ/kg and was applied for heating in private stoves or central heating units. But since the ash content was around 10 per cent, a significant contribution to the amounts of household waste generated was made. However, it was difficult to ignite the coke so a great deal of kindling wood and paper had to be applied.

The photo below shows Kolding gasworks. In the 60s experiments with waste-based production of gas were made with a view to developing a waste gasworks. The photo on the left shows the construction of rafters for the waste gasworks.

Top photo: N. Lisberg, 1966. Photo from Kolding municipal archives.
Bottom photo: Friis Fotografi.

2. The Break-through

1963-1989

Incineration Re-emerges in the 1960s

The difficult post-war economic situation had put an end to the development of incineration plants in Denmark, but Vølund's expertise was upheld, thanks to contracts in France, Sweden and the USA. It was not until the 1960s that the establishment of new plants gathered momentum in Denmark.

At that time a large number of new builtup areas – condescendingly called dormitory towns – began to sprout, and the obvious thing to do was to supply these areas with district heating instead of having an oil burner in each house. Growing environmental awareness also favoured this solution. One of the companies that were very active in the district heating sector was *Bruun & Sørensen A/S* (B&S) in Aarhus, see separate box on p. 21.

Herning was first

Originally, these district heating stations were fuelled with fuel oil, but B&S realised that waste was a useful, supplementary source of energy. In 1963 a Swedish designed incineration furnace was supplied to the municipality of Herning in Jutland. However, soon B&S developed its own type W grate system.

From 1965 to 1990 B&S signed new contracts for waste incineration plants all over Denmark in rapid succession. Most of these plants were, however, relatively small and few of them still exist.

Furthermore, plants were supplied to *Torshavn* on the Faroe Islands and *Nuuk* in Greenland as well as to countries abroad, including Sweden.

Other Danish companies, including *Helsingør Jernskibs- og Maskinbyggeri, A/S E. Rasmussen* (based on technology from the American company of *Plibrico*) and *Staalmontage*, supplied plants to various Danish municipalities. In some of these plants the heat produced during incineration was not recovered. Therefore the plants could be located in out-of-the-way places and were typically operated in one shift, Monday to Friday. Staalmontage's inter-municipal plant in Varde near the west coast of Denmark was situated on a downward slope. The waste was unloaded on the floor in the reception hall and pushed into the furnace by a loader tractor. At the foot of the slope the bottom ash was discharged. The uncleaned and 1000°C hot flue gas was emitted through a stack located on top of the furnace.

In the 80s the plant in Varde was subjected to the first dioxin study performed by the *Danish Environmental Protection Agency*, see p. 30.

Albertslund district heating station. Architects: Friis & Moltke A/S. The building previously housed an incineration plant, too. This part of the building is now used as a regional music and culture centre called 'Forbrændingen' (The Incineration Plant).

Aarhus Nord incineration plant, 1978. Architects: Friis & Moltke A/S. The plant was given its original name (Aarhus North) due to the plans also to build a plant in the south end of the municipality. But instead, a third unit extended Aarhus Nord in 1992, and a new unit 4 will be ready in 2005.

Bruun & Sørensen A/S

Bruun & Sørensen A/S (B&S) was founded in 1893 and turned into a limited company in 1937.

In 1960 the company formed a Thermal Department for the purpose of building waste incineration plants. In the period of 1960-67 the company applied a Swedish designed water-cooled forward movement grate, for which B&S purchased the rights. This type of grate could, however, only be used at plants with a capacity of up to 3.5 t/h, which is why the development of a new type of grate was initiated. The first version of this air-cooled grate – the W grate – was constructed in 1968, and the W grate has been the distinctive feature of B&S and its successors ever since.

In the beginning of the 70s B&S took over A/S E. Rasmussen's activities in the area of waste incineration (see pp. 20 and 23).

In the 80s B&S encountered pecuniary embarrassment, and the company was split into several parts. The company succeeded in maintaining its expertise within waste incineration, initially vested in the company of B&S Miljøteknik A/S, later known as BS Miljøteknik A/S. This company was for some time in foreign hands, but was in 1992 brought back home by Krüger A/S, which carried on the business under the name of Krüger Waste Systems. In 1998 FLS miljø bought the activities, but sold it again in 2002 to Babcock & Wilcox Vølund ApS.

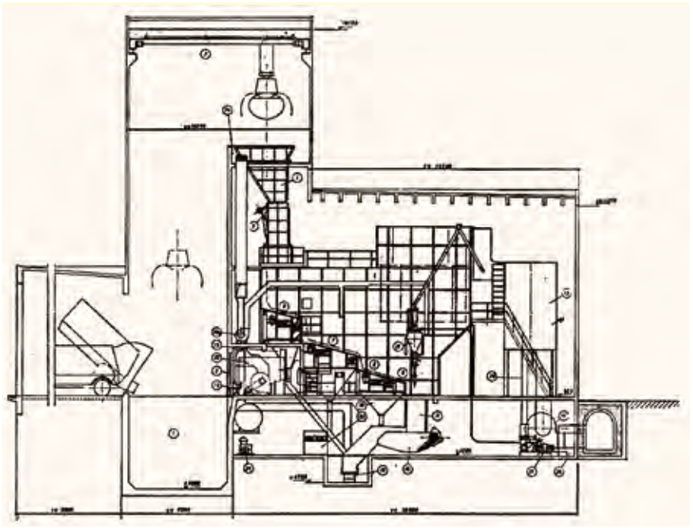
B&S W grate

Vølund develops a new plant

So Vølund was up against fierce competition and was perhaps somewhat slow at acknowledging district heating rather than waste treatment as the ticket to the market. In addition, Vølund's rotary kilns were too expensive for the relatively small plants that were in demand. Vølund therefore had to develop a plant without the rotary kiln.

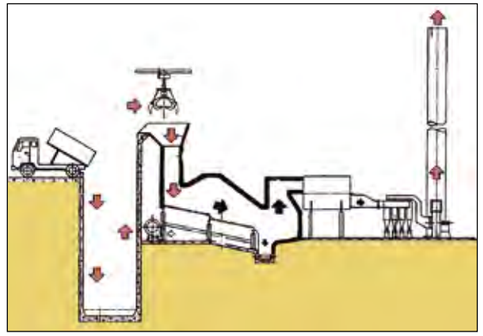
From 1964 to 1992 Vølund supplied a large number of plants in Denmark, and on the Faroe Islands the company supplied a plant in *Leirvik*.

In 1984 there was a total of 48 incineration plants treating municipal solid waste in Denmark (see overleaf) as well as the three plants on the Faroe Islands and in Greenland. The Danish plants incinerated a total of 1.55 million tonnes of waste in 1982.



Vølund's step grate at a small plant. The furnace and boiler are partly inter-connected.

Below: The incineration plant in Leirvik, located in majestic surroundings.



Sectional drawing of the incineration plant in Fredericia, supplied by A/S E. Rasmussen.
At this plant the flue gas was cleaned in a cyclone battery installed immediately before the stack.

Nordforbrænding 1969.
Architect: Finn Monies.

A visit to three incineration plants of the 60s

In 1967 as a young engineer, Søren Dalager, employed by A/S Dansk Shell (the Danish branch of the Royal Dutch/Shell Group), visited three quite new incineration plants in Haderslev, Fredericia and Herning supplied by A/S Vølund, A/S E. Rasmussen and Bruun & Sørensen A/S, respectively. The following are extracts from his report from the visits:

Haderslev:

'The incineration plant is located near the scenic inlet of Haderslev. Therefore a great effort has been made to make the building look good. Presently, there is only one unit with a capacity of 3.5 t/h, but allowance has been made for a second unit. The unit consists of three inclined grates (drying grate, combustion grate and burnout grate). The bottom ash [slag] is used as filling material, while the flue gas is cooled in a boiler and sent through cyclones to the stack. The stabilising oil burner is located on one of the walls in the furnace, above the drying grate, but it is hardly ever used … Currently, the plant is in operation eight hours on Mondays and Fridays and 14-16 hours on Tuesdays, Wednesdays and Thursdays… The initial investment was DKK 5.7 million [~EUR 760,000]. The plant is operated by two staff'.

Fredericia:

'This incineration plant consists of two identical units, each with a capacity of 2.3 t/h. A stoker moving in strokes every three minutes conveys the waste through the furnace. At one side of each furnace there is an oil burner … The plant had been out of operation for some time in the morning, which is why the combustion efficiency was poor during the visit (pieces of paper passed through the furnace in an uncombusted form). In the summer, one unit is operated in two shifts, while in the heating season both units are in operation eight hours a day'.

Herning:

'The plant had been established in the building freeze period [economic measure to counteract inflation]. It was therefore necessary to install the plant in an old building, which had previously housed Herning gasworks. As this building did not allow room for a waste pit, a pit was established in an adjacent building, and a conveyor was then installed to fill the chute… This was not very rational and aesthetic, and it was even a labour-intensive solution as two workers were required to load sacks onto the conveyor. The unit has a capacity of 3 t/h. This unit also has an oil burner, applied when the waste is particularly wet. During the visit the temperature in the furnace was higher than 1000°C… In the period of 1 April 1966 to 31 March 1967 the plant was in operation for 2550 hours with only 19 hours of outages'.

The report concludes

'At all three plants the calorific value of the waste is estimated at 1800-1900 kcal/kg [=7.5-8 MJ/kg], and as the efficiency is around 60 per cent, approximately 1100 kcal/kg is recovered. The plants are not equipped with any magnetic iron separators. The major part of the iron contained in the waste is annealed in the furnace to such an extent that it easily disintegrates at the landfill'.

Amagerforbrænding.
Architect: Jørgen Maglebye.

Incineration plants in Denmark in 1984

The first inter-municipal plants

The plant in Hørsholm north of Copenhagen was Denmark's first inter-municipal incineration plant. In January 1965 a partnership was formed between five municipal and parish councils to establish and operate *Hørsholm Incineration Plant and District Heating Station*. In the 70s the name was changed to *I/S Nordforbrænding* (I/S = Interessentskab = Partnership).

In July 1965 *I/S Amagerforbrænding* and *I/S Vestforbrænding* were founded (see separate box), and the three first inter-municipal waste management companies had now been created. The three companies copied the organisation that had already been applied in utility companies. Since then, this organisation has successfully been applied by a number of other inter-municipal waste management companies in Denmark.

Disposal of bottom ash

With the commissioning of the two large Copenhagen plants of Amagerforbrænding and Vestforbrænding the Danish incineration capacity almost doubled. This, however, also entailed a corresponding increase in the amount of bottom ash generated. On the issue of bottom ash management, see separate box.

Amagerforbrænding and Vestforbrænding

As in other parts of the country the lack of landfill capacity was a pressing problem in Greater Copenhagen. Without any luck, three municipalities applied for connection to Frederiksberg incineration plant in 1960, and another municipality investigated sites for the establishment of a new plant. When the municipality of Copenhagen also began to take an interest in the matter, it became clear to everybody that they had to think big.

To make a long story short, the two partnerships were eventually established in 1965, each with the primary purpose of establishing an incineration plant.

The Municipality of Copenhagen was a partner to both companies and later became a waste supplier for them, too.

It soon became clear that Vølund would supply the process equipment for the two plants, while Rambøll & Hannemann (see separate box) would act as consulting engineers. In terms of process equipment the two plants were initially identical. They both consisted of three units with rotary kilns, each with a capacity of 12 t/h. However, the two companies chose different architects. As a result, the plants look very different.

Amagerforbrænding was connected to the district heating network of Copenhagen Energy, but could originally only sell the heat generated in the winter. Today, all of the heat produced at the plant is sold to the Metropolitan Copenhagen Heating Transmission Company – known as CTR.

Initially, only the birds profited from the production of heat at Vestforbrænding, but in 1972 the company landed a big contract for the supply of heat to Herlev Hospital. Furthermore, a district heating network supplying heat to more than 60,000 inhabitants was established in two adjacent municipalities. All surplus heat is today sold to CTR and the heating transmission company in the western suburban area of Copenhagen called VEKS.

The flue gases were cleaned in electrostatic precipitators before they were emitted through the stack, which is 150 m tall at both plants. In 1977, Vestforbrænding was extended by unit 4, which has a capacity of 14 t/h, but is otherwise similar to units 1-3. When environmental regulations in 1986 required an upgrading of the flue gas treatment systems, the two plants were expected to choose the same solution: semi-dry flue gas treatment. But in 1989 Vestforbrænding chose a wet system instead. As the first plant in Denmark, Amagerforbrænding engaged in combined heat and power production, initially in a new unit 4 and later by upgrading units 1-3, whereas Vestforbrænding did not become a combined heat and power plant until unit 5 was commissioned in 1998. Vølund also supplied this unit, but this time without the rotary kiln. The plant was the first plant in Denmark to have a $DeNO_x$ process: SNCR and a limestone scrubber for the removal of SO_2. Currently, yet another combined heat and power producing unit – unit 6 – is under construction at Vestforbrænding.

The two plants have a standing cooperation in many fields. They have, for instance, joint ownership of the landfill of AV Miljø where two different types of flue gas cleaning residues have been landfilled for a period of time: fly ash + hydroxide sludge from Vestforbrænding and the residues from the semi-dry flue gas treatment system at Amagerforbrænding.

In 1975 the Municipality of Frederiksberg acknowledged that the time had come to close down the old incineration plant from 1934, and the Municipality became a partner of I/S Amagerforbrænding.

Vestforbrænding's partnership has been extended several times and today includes 29 municipalities.

Vestforbrænding seen from the ground and from the air.
Architects: Poul Kjærgaard (buildings); Ole Nørgaard (park).

Rambøll

The consulting engineering company of Rambøll & Hannemann (R&H) was founded in 1945 by Professor DEng Børge Johannes Rambøll (born 1911) and Professor DEng Johan Georg Hannemann (1907-1980).

Originally, Rambøll & Hannemann was first and foremost a civil engineering company, but gradually its activities have extended to include e.g. oil and gas, energy and environment, telecommunications, traffic planning, information technology and management.

As civil engineers the company was soon assigned projects for incineration plants, but it was not until the establishment of Vestforbrænding in the late 60s that the company's consulting expertise within the field of process equipment for incineration plants was founded. Since then, this activity has developed to such an extent that Rambøll has today assumed a leading position in Denmark and is a significant consultant in this field internationally. Incineration has therefore become a core activity in the company.

In 1992 the company merged with the consulting engineering company of B. Højlund Rasmussen A/S founded by DEng Bent Højlund Rasmussen (1918-1987) in 1951.

Since 1995 the merged company has traded under the name of Rambøll and has developed into one of Denmark's largest consulting engineering companies. In 2002 approximately 20% of its turnover originated from activities abroad.

Part of the international turnover is generated by projects at waste incineration plants in, for instance, Oslo, Bergen and Trondheim in Norway; Malmö, Halmstad and Uppsala in Sweden; Wasa in Finland; the Isle of Man and Guernsey; Budapest in Hungary; Moscow and Murmansk in Russia; Cairo in Egypt; Hong Kong and Taiwan.

After the acquisition in 2003 of the Swedish company of Scandiaconsult, founded in 1947, Rambøll has become the largest consulting engineering company in Scandinavia with more than 4000 employees and 70 offices worldwide.

Rambøll has been a consultant to the majority of incineration plants in Denmark as well as a large number of plants abroad. One of the company's international references is a new plant in the Isle of Man.

Bottom ash management

'From the beginning of time man has produced waste, but in primitive societies it was not a problem to get rid of it. This is attested by the kitchen middens generated by the people of the Stone Age'.

This is the introduction of Vestforbrænding's 25th anniversary book from 1995, which contains vivid descriptions of the waste situation in times past. After a cholera epidemic in Denmark in the 1850s it was clear that waste could not just be disposed of in the streets, but had to be collected and landfilled.

Although this method of treatment removed the waste from the streets, it only shifted the problem from one place to another. The residual amount of waste continued to be 1000 kg per tonne of waste. As previously mentioned, this caused problems to Frederiksberg 100 years ago and to Gentofte and Aarhus in the 30s, which is why these municipalities started to incinerate the waste. If the Second World War had not broken out, this development would have continued, but instead it was postponed for a period of approximately 25 years.

Incineration reduces the volume of waste by 90 per cent and the weight by 80 per cent, but the waste does not disappear altogether. There is still a residue of 200 kg per tonne of waste in the form of bottom ash. The residue was originally taken to *filling sites* – a term that is no longer found in Danish environmental law. From 1974 onwards waste, including bottom ash, could no longer be disposed of at such sites, but had to be taken to *'sanitary landfills'* – or recycled.

Automatic bottom ash container system at Nordforbrænding.

Previously the disposal of waste itself was the problem, but now the bottom ash had become the problem. *'When Vestforbrænding was commissioned, it had not yet been decided what to do with the 60,000 tonnes of bottom ash generated at the plant annually… A convenient intermediary solution was to create decoratively planted embankments from bottom ash… blocking the view from the adjacent recreational areas to the giant incineration plant. However, one day the embankments were finished, and then the huge amounts of bottom ash had to be taken elsewhere'.* Initially the bottom ash was disposed of in a nearby forest, later on it was landfilled at AV Miljø.

Generally, the bottom ash residue from waste incineration had become a waste problem that required a solution involving recycling – without posing a threat to the groundwater. A solution was provided in the *Bottom Ash Order* of 1983, which made it possible on certain conditions to apply (screened) bottom ash in construction works. Whether the order was too liberal or not, it was replaced by a new order in 2000. Previously, the total content of lead, cadmium and mercury was in focus, but now the leaching properties of these and other substances have become the decisive factor in determining the purposes for which the bottom ash can be applied.

The Pollution Board and the Environmental Protection Act

During the 60s, people became more and more environmentally aware. Maybe the *Danish Academy of Technical Sciences* (ATV) was instrumental in this development. By the end of the 50s, ATV had a Fish Odour Committee. In 1962 the Smoke Committee was established, and in 1963 the Industrial Wastewater Committee saw the light of day. The latter developed into *VKI* (Institute for the Water Environment), which is today part of *DHI Water & Environment* (Danish Hydraulic Institute). At the grass roots level *Danish Anglers' Federation* and *NOAH* (the Danish section of Friends of the Earth International) were examples of active environmentalists, whereas *Greenpeace* did not emerge until 1980.

The Liberal government in power at the time had to do something and therefore set up the *Pollution Board* in 1970. In a matter of just two years the board produced 31 reports, including one on air pollution from waste incineration.

A very unorthodox step was the publication of a pamphlet on waste incineration, in which the board recommended a reduction of the emission of dust, HCl and SO_2 to 150, 600 and 1500 mg/Nm^3, respectively. It was not well received by all parties: *'How can you regulate on the basis of a pamphlet?!'* In its leading article, the periodical published by the Society of Danish Engineers called it 'emission of hot air'. However it served as a guideline until 1986.

First Minister of the Environment

In the autumn of 1971 the Social Democrats returned to power, and Denmark had its first Minister of the Environment or Minister of Pollution Control as he was called at the time. The new Minister immediately set out to prepare an up-to-date Environmental Protection Act, and in April 1972 the *Danish Environmental Protection Agency* was established.

It took a long time to formulate the new Environmental Protection Act, which was not adopted by the Danish Parliament until June 1973 and entered into force on 1 October 1974.

Kommunekemi – the first treatment plant for hazardous waste in Denmark

Kommunekemi A/S was founded on 18 November 1971. It was decided to establish the company on a site adjacent to a tar works (today trading under the name of TARCO) in the hope of being able to exploit the tar works' already existing process equipment, e.g. for the processing of waste oil to fuel oil. However, waste products that could not be handled by the tar works started flocking at the gate of Kommunekemi. Consequently, Kommunekemi had to establish its own treatment facilities.

The history of Kommunekemi's establishment and extension is well documented in its 20th and 25th anniversary books, but in brief the company has had four incineration units:

- Unit I: supplied by *vonRoll*, Switzerland, in 1975.
- Unit II: special unit for the incineration of halogenous waste, supplied by *Celloco AB*, Sweden, in 1974. This unit was not a success and was closed down after the establishment of Unit III.
- Unit III: supplied by *Widmer + Ernst*, Switzerland, in 1982. This unit was equipped with a semi-dry flue gas treatment system from *A/S Niro Atomizer* and was therefore the first plant in Denmark with treatment facilities for acidic gases (HCl, HF and SO_2). In 1986 the unit was equipped with a turbine/generator, making Kommunekemi a combined heat and power plant.
- Unit IV: supplied by *A/S Vølund* in 1989. The unit was from the outset a combined heat and power-producing unit.

In 1994 an EU Directive on the Incineration of Hazardous Waste was adopted. Kommunekemi therefore had to upgrade the flue gas treatment systems of Units III and IV. New wet systems supplied by *FLS miljø* did this.

Kommunekemi and Tarco in Nyborg, situated close to the bridge across the Great Belt.

It took some time to formulate the new Environmental Protection Act, which was not adopted until June 1973 and entered into force on 1 October 1974. Quick results were therefore called for, so 1972 saw the adoption of, for instance, the Act on the Disposal of Oil and Chemical Waste, which authorised the Minister to stipulate more detailed rules on the collection and treatment of these types of waste. The background was a wish set forth by the municipalities to establish *Kommunekemi A/S* (see separate box).

The approval scheme

An important part of the Environmental Protection Act was Part V: *Heavily Polluting Enterprises*. According to section 35 such enterprises *'shall not be established or commenced without prior approval'*. This rule also applied to extensions of existing enterprises subject to the stipulations laid down in Part V.

Consequently, as from 1 October 1974 all new incineration units had to have an environmental approval. The plants that were already in operation were assumed to already have an approval in compliance with previous legislation. According to Section 36, the Minister could require certain existing enterprises to submit an application for an environmental approval. Section 44 enabled the authorities to order the adoption of anti-pollution measures.

However, the approval provided legal protection against such orders. The legal protection period was initially unlimited, but an amendment to the act in 1986 limited the period to eight years in general, for waste incineration plants – as from 1988 – to just four years.

The Energy Crises of 1973 and 1979

After fuel, as the last commodity, had been taken off the post-war ration in 1953, Denmark did not have any actual energy policy and even stopped recording statistical energy data after 1968. The market forces ruled, and oil was in demand to such a degree that 92 per cent of Denmark's energy consumption in 1973 was based on oil.

When the Arabian oil sheikhs in October 1973 suddenly cut back oil supplies, it came as a shock to Western Europe. In Denmark, the first step was to call for oil savings immediately. It was now forbidden to drive a car on Sundays, and all unnecessary consumption of power had to be avoided – also during Christmas sales in 1973. *'Now Denmark is put on the back burner'*, read a slogan.

Promotion of district heating ...

A long-term energy policy had to be developed, and in 1976 the *Danish Energy Agency* was established. At first the policy focused on reducing dependency on oil and increasing the supply reliability. The power stations were requested to reconvert to coal firing, and large district heating networks, including *CTR* and *VEKS* in the metropolitan area, were established in order to ensure the greatest possible exploitation of the surplus heat generated at the local power stations.

The incineration plants also benefited from the new energy policy as it became easier to sell district heating. When taxes on oil and later coal for heat supply purposes were introduced, the plants could raise their – untaxed – heat prices correspondingly.

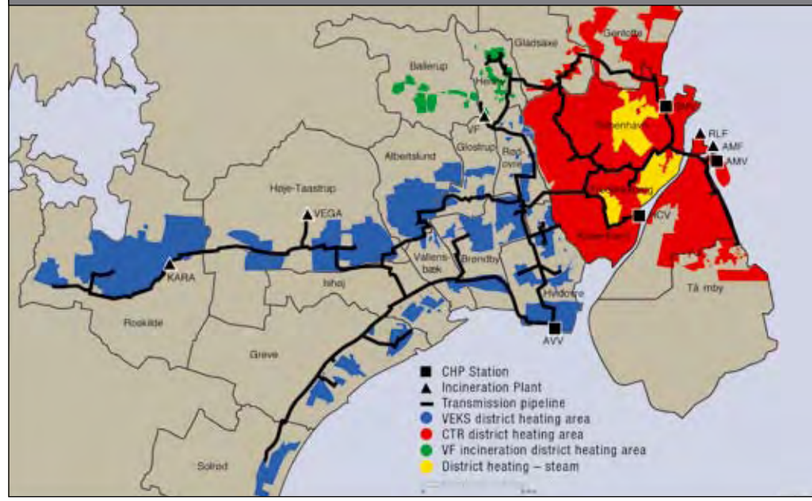
... and natural gas

In early 1979 'The Islamic Republic of Iran' was proclaimed. This entailed a decrease in the oil production and a steep rise in oil prices. The second energy crisis had set in.

In Denmark one of the outcomes of the crisis was that later on that year it was decided to bring ashore *natural gas* from the Danish part of the North Sea and eventually also crude oil. Although Denmark in time became self-sufficient in energy, the high level of taxation remained. However, the market for natural gas was a bit sluggish, and the regional gas companies sank deeper and deeper into debt. Consequently, the energy policy had to be adjusted several times, for instance by a combined heat and power scheme in 1986 and an action plan called *Energy 2000* in 1990.

Due to the energy crisis it was forbidden to drive a car on Sundays in the period from 25 November 1973 to 10 February 1974. One was however allowed to drive on Christmas Day, Boxing Day and New Years Day as these non-working days were on weekdays. Motorists came to terms with the situation, while pedestrians and cyclists enjoyed the peace and quiet that had suddenly descended on the country.
Photo: Polfoto

Combined heat and power in Greater Copenhagen



District heating transmission in Greater Copenhagen. Note the four waste incineration plants: Vestforbrænding, Amagerforbrænding, KARA and VEGA and the sludge incineration plant at the wastewater treatment plant of Lynetten. Source: VEKS

The Dioxin Debate

Guideline no. 3/1986

The requirements for new plants included: The flue gas shall have a 2-second retention time at temperatures higher than 875°C. In order to meet this requirement the plants shall be equipped with a minimum of three auxiliary burners.
The Guideline established limit values for the emission of CO, dust, HCl, HF, SO_2, Pb, Cd and Hg to the air and as far as the latter three were concerned also to water. In addition, the requirements for instrumentation, monitoring and reporting became more stringent. The goals were the same for the existing plants, but they should be achieved in three phases:

1. As from 1 January 1988:
Not more than one start-up a week, unless auxiliary burners have been installed. Continuous recording of, for example, the afterburning temperature, excess air and CO. *'If by June 1988 the plant cannot comply with a CO concentration … of max. 200 mg/Nm³ as the daily average value, it has to be closed down or upgraded by June 1989'.*

2. As from 1 June 1989:
'The CO content of the flue gas … may not exceed 200 mg/Nm³ as the daily average value, 750 mg/Nm³ as the 10-minute average value and 1000 mg/Nm³ as the one-minute average value'.

3. As from 1 June 1991:
The plants shall comply with the same requirements as those made for new plants.

It was not until the issue of Order no. 162 of 11 March 2003 (transposing EU Directive 2000/76/EC) that Denmark introduced an emission limit value for dioxin from waste incineration plants. This is an odd contradiction with the fact that dioxin had been on everyone's lips since the beginning of the 80s whenever the conversation turned to waste incineration.

The debate initially lead to the first dioxin study carried out by the Danish Environmental Protection Agency in 1984. The study took place at the plant in Varde, and on this basis the total Danish emission from waste incineration was estimated at 500 g/year, calculated as Toxic Equivalents (TEQ).

Requirement for environmental approval

Even though this estimate was subject to considerable uncertainty, the Danish Environmental Protection Agency found that the sector had to be upgraded, so in September 1985 a new order was issued. Under the provisions of section 36 of the Environmental Protection Act, the order stipulated that all existing, not yet environmentally approved waste incineration plants should submit an application for an approval by the end of 1986. For administrative purposes the Danish Environmental Protection Agency issued a guideline *(no. 3/1986)* on the limitation of pollution from waste incineration plants.

The guideline refrained from setting an emission limit for dioxin, but suggested such a limit to be set in 1991. However, it never materialised. In the meantime the Danish Environmental Protection Agency had carried out yet another – this time very comprehensive – dioxin study, which was reported in 1989. The conclusion was that the dioxin emission from waste incineration plants was in the order of 34 g/year TEQ, i.e. far less than reported from the 1984 study.

EU directives

Furthermore, the EU had in 1989 issued two directives on air pollution from municipal waste incineration plants. These were transposed in Denmark by an order in early 1991. In practice it was therefore the order that determined the third phase in the upgrading of the existing plants, cf. box on the left-hand side.

The most debated requirement in the order was the one requiring auxiliary burners (see separate box).

Guideline no. 3/1986 was replaced by Guideline no. 2/1993 on the limitation of pollution from incineration plants.

The three phases for compliance forced some of the existing plants to immediately close down, while others managed to survive phases 1 and 2 and then closed down.

Dioxin molecule. Source: PVC Information Council, Denmark.

This photo taken around 1970 shows an incineration plant in Skagen (The Skaw) on the most northern tip of Jutland. The plant did not recover the energy produced and was therefore located in a remote area. As can be seen, the 'afterburning zone' was located on top of the stack. Plants of this type were targeted by Guideline no. 3/1986 issued by the Danish Environmental Protection Agency. However, the Municipality oaf Skagen prevented any intervention as in 1979 it replaced the plant shown by a new, still existing, district heating producing incineration plant supplied by B&S.

Incineration becomes environmentally accepted

The other existing plants took on the challenge of complying with the new requirements. The standard significantly improved, and incineration became generally accepted as an environmentally friendly waste treatment method. Although a few new plants were established, the total number of plants in Denmark decreased to approximately 30.

As a consequence of the new emission limit values for dust and HCl etc. the flue gas treatment also had to be upgraded. The upgrading led to the production of new residues at the incineration plants.

Interior of Nordforbrænding, 1969. In the front there are two multi-cyclone systems for the treatment of flue gases. In the mid-70s, electrostatic precipitators replaced the multi-cyclones, and in 1987 completely new, dry flue gas treatment systems with lime reactors and bag house filters were installed.

Auxiliary burners

As mentioned elsewhere the logical thing to do was to equip the plants established in the 60s with auxiliary burners, but as the calorific value increased, they became more and more superfluous. Yet Guideline no. 3/1986 made the requirement that new plants should be equipped with at least three auxiliary burners. In compliance with this requirement *VEGA* – a plant in the suburbs of Copenhagen – was equipped with such burners. Since their application was problematic, and they were soon dismantled with the supervising authorities' blessing.

The Danish Environmental Protection Agency's dioxin study from 1989 made the recommendation that the requirement should be reassessed, and in Guideline no. 2/1993 the requirement was taken out. In the meantime the two (old) EU directives from 1989 had become effective. The directives stipulated the use of auxiliary burners, but the Danish Environmental Protection Agency managed to find a 'shrewd' wording requiring that only green-field plants should install auxiliary burners.

In 1994 the European Commission published its first draft of the incineration directive. This directive also required auxiliary burners, but thanks to determined lobbying, also by Danish organisations, the final version of the directive – and hence the Danish order – contains an exemption clause.

Start-up and auxiliary burner.

Flue gas treatment at Danish incineration plants

No information is available on the flue gas treatment at Denmark's first incineration plant in Frederiksberg, but the three plants from the 30s were equipped with a kind of *deflecting separators* for the removal of the fly ash. The plants established in the 60s were typically equipped with *cyclone batteries or multi-cyclones*, while the plants from the 70s, starting with Amagerforbrænding and Vestforbrænding, had *electrostatic precipitators.*

The relatively small plants that were without energy recovery, however, did not have any kind of flue gas treatment. This was one of the primary reasons why they were closed down in the 70s or 80s.

Electrostatic precipitator, Vestforbrænding

Limestone scrubber, Vestforbrænding

Dioxin filter, Vestforbrænding

Removal of HCl was not required until the issue of the above-mentioned Guideline no. 3/1986. Initially the plants chose *dry* (typically the former *Fläkt*'s Dry Absorption System, DAS) or *semi-dry* (typically *FLS miljø*'s GSA process) solutions in which HCl reacts with hydrated lime added in dry or in an aqueous suspension. The reaction products are collected together with the fly ash in a subsequent bag house filter. An environmental off-spin of these processes is that SO_2 is also separated to a level far below the emission limit values stipulated in Guideline no. 3/1986 and the two EU directives of 1989. A disadvantage, however, is the production of quite a large quantity of hygroscopic and alkaline solid *residues* that have to be disposed of. *Niro Atomizer*, which had supplied a plant for Kommunekemi (see separate box) did not pursue this new development in time as in the autumn of 1985 the company sold its rights to its spray absorption system to Fläkt, which then – together with Vølund – supplied four systems to Amagerforbrænding.

Around 1990 *wet treatment methods* started attracting attention. In such systems the fly ash is first separated in an electrostatic precipitator and then the flue gas is washed with water in order to separate HCl. Today, some Danish plants have these two steps only, whereas others have installed an additional scrubber for the removal of SO_2 resulting in a gypsum residue. Fläkt (today *Alstom*), FLS miljø (today *F.L. Smidth Airtech*), and *Götaverken Miljö* have supplied such plants. The water applied for HCl separation is neutralised and cleaned of heavy metals and subsequently discharged to the municipal sewer system or in a few cases directly to the recipient. Hence, the HCl separated in a wet system is discharged in the form of a saline solution. Consequently, the wet processes result in a somewhat smaller amount of solid residues per tonne of waste incinerated than the dry/semi-dry processes.

In 1994 the European Commission issued its first draft of what eventually became *Directive 2000/76/EC of 4 December 2000 on the incineration of waste*. This directive stipulates more stringent emission limit values for the substances that were already subject to limit values and new limit values for e.g. dioxin and NO_x. As a consequence of the conversion to combined heat and power production (see pp. 34-35) quite a large number of plants were contracted after 1994 and these were all immediately designed to comply with the dioxin requirement. The newest plants comply with the NO_x requirements too. The dioxin treatment consists in the addition of activated carbon or Herdofen coke in a bag house filter or a special scrubber designed by the French company of *LAB*. Today, the very limited number of plants that reduce NO_x emissions have all chosen the *SNCR process.*

The EU directive was transposed into Danish legislation by *Order no. 162 of 11 March 2003 on plants incinerating waste* issued by the Danish Ministry of the Environment. In accordance with the Order, all existing plants have to comply with the more stringent requirements by the end of 2004 (dioxin) and 2005 (the other requirements, although with certain exceptions), respectively.

On the issue of residues from flue gas treatment, see separate box.

Residues from flue gas treatment

As mentioned elsewhere even the plants from the 30s were equipped with some kind of fly ash collector. Initially, the fly ash was mixed with the bottom ash, but in accordance with Guideline no. 3/1986 issued by the Danish Environmental Protection Agency this was forbidden. Fly ash became a separate residue generated in quantities of approximately 20 kg per tonne of waste incinerated.

At the same time the Guideline required cleaning of the flue gas of, for instance, HCl and SO_2. If this treatment is effected by applying the dry or semi-dry systems (see separate box on flue gas treatment), a residue consisting of fly ash and solid reaction products (calcium chloride from the separation of HCl and calcium sulphite/sulphate from the SO_2 removal) as well as surplus lime is produced. The total amount is approximately 30 kg per tonne of waste.

In the wet treatment system the fly ash is removed separately, HCl is transferred to the scrubber water, and during neutralisation hydroxide sludge is formed, which is dewatered or applied for moistening the fly ash. If SO_2 is removed, it is usually transformed into gypsum. A total of 20-25 kg of solid residues is generated per tonne of waste, i.e. a smaller amount than in the dry/semi-dry system.

As mentioned elsewhere Amagerforbrænding and Vestforbrænding disposed of a semi-dry residue and a mixture of ash and sludge, respectively, at the sanitary landfill of AV Miljø. This took place under extremely well-controlled conditions, making it possible to observe the formation of leachate. As it turned out, considerable amounts of chloride and heavy metals leached from both types of waste. Therefore landfilling of such residues in Denmark has been banned. Instead the residues are exported as a filling material for underground German salt mines or to the island of *Langøya* in the Oslo Fiord in Norway where they are used to neutralise acidic waste. These applications imply a certain degree of *recovery*.

Export of waste is subject to the EU's regulation on shipments of waste. One of its cornerstones is the *principle of proximity*, i.e. that waste shall be disposed of as close to its origin as possible. If this is not possible, then the waste can be exported subject to permission by the environmental authorities of the recipient country. Export of residues from flue gas treatment is handled by e.g. *Dansk RestproduktHåndtering*, DRH (Danish Residue Handling).

Both DRH, DHI (Danish Hydraulic Institute) and Vølund have developed methods for treating residues, but a full-scale plant has yet to be established.

Sanitary landfill of AV Miljø, which is jointly owned and operated by Amagerforbrænding and Vestforbrænding.

3. From District Heating to Combined Heat and Power

1990-2003

CHP plant in Horsens in Jutland, established in 1991.
Architects: Boje Lundgaard and Lene Tranberg.

CHP Again

The energy producing incineration plants commissioned in the period of 1963-89 all produced heat only. In 1986, the Danish Parliament arrived at an energy policy compromise, which required that a number of small-scale combined heat and power plants based on domestic fuel and with a total capacity of 450 MW should be established. This was meant as a demonstration programme.

A report published by *Dakofa* (the Danish Waste Management Association) in 1988 noted that *'the establishment of combined heat and power plants in major urban communities, where the majority of the waste incineration capacity is also concentrated, makes it interesting to consider the option of including waste incineration plants as combined heat and power base load units'*.

This challenge was taken up in different ways. In Jutland some of the power supply companies chose to actively engage themselves in waste incineration by establishing new combined heat and power plants.

East of the Great Belt the already existing incineration plants demonstrated the combined heat and power principle by establishing new CHP producing units e.g. at Amagerforbrænding, which established unit 4 in 1990 and later converted units 1-3 too.

Energy 2000

The 1986 combined heat and power scheme must be considered a success. In its plan of action called *Energy 2000* the Danish Energy Agency therefore set the stage for the *'encouragement of cogeneration of heat and power… the expansion should primarily be linked to district heating systems and other areas of consumption capable of using surplus heat'*. The objective was to reduce power production at the large sea water cooled power plants. The Ministry of the Environment followed up on this plan by announcing its intention to ban the landfilling of incinerable waste.

As a consequence, in 1992-94, a number of municipalities with district heating plants, including incineration plants above a certain minimum capacity, received a so-called *stipulatory letter* from the Danish Energy Agency. In brief, the letter required the conversion from district heating production to combined heat and power production.

This policy led to the establishment of a further five new green-field plants, seven new units and the upgrading of a couple of existing plants.

I/S KARA in the municipality of Roskilde: New combined heat and power plant commissioned in 1999.
Consultant: Rambøll. Architect: Tage Nielsens Tegnestue.

Waste pit and grab at Vestforbrænding

Taxes and Subsidies

In order to promote recycling, which ranks higher in the waste hierarchy, incineration and landfilling of waste are taxed in Denmark.

In 1987 an – although modest – tax of DKK 40 (~EUR 5.5) per tonne of waste incinerated or landfilled was introduced. Later on this tax gradually increased to DKK 330 (~EUR 44) and DKK 375 (~EUR 50) per tonne, respectively.

Energy 2000 focused on the increasing emission of CO_2 and the ensuing risk of a greenhouse effect, so a number of the measures in the plan of action aimed at limiting the CO_2 emission from the energy sector. In order to enhance this objective a CO_2 tax on coal, oil and power was introduced in 1992/93. As an almost CO_2 neutral fuel, waste was exempt from the tax.

When, on the other hand, the government wanted to support the conversion from district heating to combined heat and power production, a subsidy of DKK 0.10 (~EUR 0.015) pr kWh for power produced on the basis of renewable energy sources, biomass and natural gas was introduced in 1992. In 1997 this subsidy was reduced to DKK 0.07 (~EUR 0.01) pr kWh, which is still the case today. At the same time the incineration plants got prioritised access to the power supply network pursuant to the law on power supply. Hence the power produced must be received by the network in accordance with a differentiated tariff structure in which the tariff depends on whether the electricity is produced in periods of peak, high or low consumption.

However, in 2003 the Danish Energy Agency presented its plans to liberalise the energy market.

In 1995 a new tax on SO_2 emissions was introduced. It also included waste incineration, and the latest initiative is a tax on 'waste' heat (i.e. heat produced from the incineration of waste).

I/S FASAN's incineration plant in Næstved. Architects: Gottlieb & Paludan, Arkitekter MAA. In the foreground Næstved CHP Plant can be seen. The plant was recently acquired by FASAN.

The Plants of Today

Following the commissioning of Denmark's latest incineration plant in Esbjerg on the western coast of Jutland, Denmark now has 32 plants and four new units are under construction.

Of the approximately 30 combined heat and power producing units presently existing in Denmark Vølund has supplied a little more than half, and BS/Krüger (now Vølund) has supplied approximately one third. But in recent years also *Swiss ABB W+E* (today part of the German company of *Martin*) and German *Steinmüller/Babcock Borsig Power Environment* (now *Fisia Babcock Environment*) have entered the Danish market.

The combined heat and power plants required a new type of boiler: the steam boiler. Vølund was capable of supplying such boilers itself, whereas B&S joined forces with *Aalborg Industries* and later on, when boilers with a horizontal convection pass were in demand, with *BWE*. The steam parameters are typically 40 bar, 400°C. The steam turbines were supplied by *ABB* (today *Siemens*), British *W.H. Allen* (out of business) and German *B+V Industrietechnik*.

Increased demand for consultancy

The complexity of the CHP plants required consultants to assist the plant owners in specifying, tendering, procuring, erecting and commissioning the plants. In addition, the environmental regulatory framework became more diverse, again calling for qualified consultants. Rambøll decided to actively engage itself in this line of business and soon became the leading consultant.

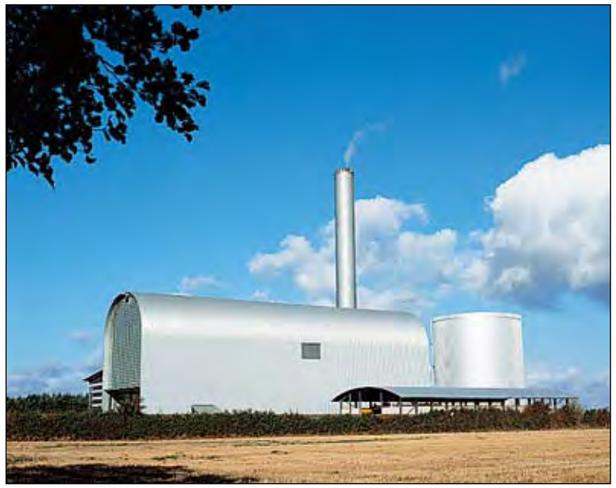
Måbjergværket in Holstebro in western Jutland. Architect: Torsten Riis Andersen.
The plant does not only incinerate waste, but also straw.
The steam produced is superheated in natural gas fired superheaters before it is applied for combined heat and power production.

Conveyors and feeding of straw at Måbjergværket.

Control and monitoring of the incineration plants have naturally followed the technological development in general.

Top:
Control panel at Frederiksberg incineration plant, 1934.

Bottom:
Control room at Vestforbrænding today.



Sønderborg combined heat and power plant.

The plant consists of a 9 t/h waste incineration unit and a combined cycle gas turbine.

The waste incineration plant is located in the long rounded building, while the gas and steam turbines are located in a (partly hidden) building behind the incineration plant. The cylindrical tank on the right is the heat accumulator for the plant.

Architects:
Friis & Moltke A/S.

Great buildings call for great architecture

The conversion to combined heat and power producing incineration plants required quite large buildings. In a flat country like Denmark they become relatively visible to the surroundings. Luckily, the sector has succeeded in engaging some of the leading architects of the country for the structural design of the plants, cf. text below photos.

Another essential development is the increasingly extensive and sophisticated automation of the plants, which has made it possible to operate the plants with a very limited staff.

Most of the plants are purely waste incineration plants, however some have separate oil or gas fired peak load boilers. A few plants do not have their own steam turbines, but sell the steam to adjacent decentral combined heat and power plants based on straw or natural gas.

Competition from natural gas

Until 1993 natural gas, which is also a domestic fuel, was a competitor to waste. The municipality of Elsinore could have built a new incineration plant to replace the old one, but instead ended up establishing a natural gas fired combined heat and power plant and introduced source separation of the waste at the same time. The green waste was treated at a biogas plant (Nordsjællands Biogasanlæg) in Elsinore, while the residual waste was incinerated at a plant outside the municipality. However, the biogas plant was not a success and was closed down in 1996.

In some cases a compromise had to be found. One plant therefore has natural gas fired superheaters in order to maximise power production, while another has tried out reburning, i.e. NO_x reduction by injection of natural gas. The price of natural gas is too high for these ideas to have spread to other plants. Other plants have installed a gas turbine or a gas engine in which the surplus heat is transformed into steam, which is led to a joint steam turbine for the waste and gas parts of the plant.

The gas turbines and gas engines are primarily in operation in periods when the power consumption is high. Then so much heat is produced that part of it is stored in a *heat accumulator*.

Incinerable waste *must* be incinerated

Not until the political 'biomass agreement' in 1993 was it officially established *'that the application of waste for combined heat and power production must continue to take precedence over other kinds of fuel'*. The agreement provided the clarity and certainty that were required to continue the extension of combined heat and power production, and as from 1 January 1997, as the first country in the world, Denmark introduced a *ban on the landfilling of incinerable waste*. The adoption of the EU landfill directive in 1999 was therefore not a problem for Denmark – at least not the part of the directive that makes the requirement that waste disposed of at landfills has to undergo prior treatment (at for instance incineration plants).

In 2002 the Danish incineration plants treated approximately 2.9 million tonnes of waste, corresponding to around 600 kg per capita. Hence, Denmark is competing with Switzerland and Japan for being the country in the world that incinerates the most waste per capita.

Thanks to the massive political support to district heating the Danish incineration plants are able to sell the entire amount of heat they produce almost all year round. The overall system is therefore characterised by a very high degree of energy efficiency. The plants have become *high-technology energy works* equipped with the *best available technique*.

L90 - waste incineration plant in Esbjerg.
Architects: Friis & Moltke.

4. The Future

After 2003

Best Available Technique (BAT)

With the adoption of the so-called IPPC directive, the term *best available technique*, BAT, was introduced into the European legislation. The directive contains specific definitions of the term, including a requirement that it must be possible to apply the technique under *economically and technically viable conditions* as well as an annex listing 12 considerations to be taken into account when determining BAT. The twelfth and last of these considerations is to acknowledge the *BAT Reference Documents* (BREFs) published by the Commission.

What is the best available technique for treatment of waste? The directive does not answer this question. Instead, in another annex, it lists a number of industrial activities covered by the directive, including *installations for the incineration of municipal waste with a capacity exceeding 3 tonnes per hour*.

Hence, the question does not arise until the decision to thermally treat the waste has been made. Accordingly, a special technical working group has been set up for the purpose of preparing a BREF on waste incineration. In May 2003 the working group published its first draft and in March 2004 its second.

Although much work still has to be made on the BREF, it is fair to conclude that *BAT differs from project to project*.

I/S Vestforbrænding seen from the West. Architect: Poul Kjærgaard A/S.

Best available technique

What is the best available technique for thermal treatment of waste?

Waste is thermally treated either by adding sufficient amounts of air, whereby the waste is simply *combusted* resulting in completely burned out bottom ash and flue gas, or by maintaining an air deficiency, whereby the waste is *pyrolised* or *gasified*. In the latter case, the result is a partly burned gas, which can be sent on to a separate incineration plant, e.g. a gas engine or, preferably, a gas turbine for energy production. Potentially, the quantity of power produced per tonne of waste would be larger than when applying the direct incineration method. However, depending on the circumstances, the gas is to some extent polluted by tar and heavy metals. It therefore has to be washed prior to incineration – whereby the energy applied in the pyrolysis/gasification process is cooled away. 'On the other hand, it is possible to extract and exploit the heavy metals, and – if fossil energy and/or clean oxygen are added – a better annealed and less leachable bottom ash is obtained' is the counterargument. The best known of these alternative processes is the *Thermoselect* process, which must, however, still be considered to be at a development stage.

What is the best available technique for incineration of waste?

Incineration of waste is usually effected by *mass burn incineration*, i.e. by incinerating the waste as it is, except for the shredding of very large items. A few plants incinerate the waste on a *fluidised bed*, whereby a relatively larger gross power production can allegedly be achieved. On the other hand, this technique requires very extensive, power consuming shredding of the waste, and the amount of fly ash produced is larger.

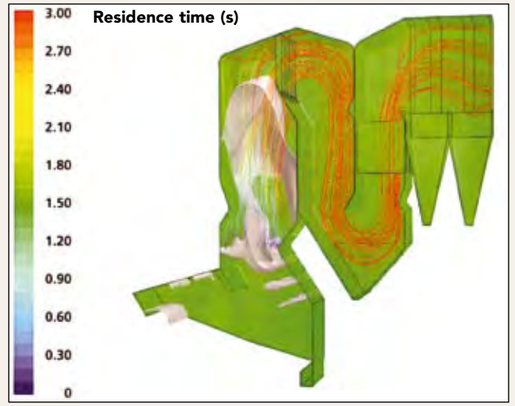
Consequently, it is the authors' opinion that only mass burn incineration on a grate or a combination of a grate and a rotary kiln can today be considered BAT, provided that CFD calculations are used in the design process (CFD = computerised fluid dynamics).

What is the best available technique for flue gas treatment in waste incineration plants?

When having to answer this question a number of issues that are difficult to rank in order of importance present themselves. On a general level it should be considered whether the treatment should be a wet system, which generates wastewater, or a dry system in which wastewater is avoided, but a larger amount of more leachable residues is generated. If the wet system is chosen, should SO_2 then be removed by lime ($CaCO_3$) or sodium hydroxide (NaOH)? In the former case the result is an emission of CO_2, which corresponds to the removed emission of SO_2, whereas in the latter case the emission of CO_2 from the incineration plant is avoided. But if the power consumption and the CO_2 emission that are involved in the production of NaOH are taken into account, the application of lime is more advantageous.

Another example is: Should NO_x be catalytically removed (SCR) at the expense of a larger consumption of steam at the plant in order to prevent the unavoidable ammonia pollution of wastewater or residues involved in the non-catalytical reduction (SNCR)?

The technical working group on waste incineration should include considerations like these in its BREF.



CFD plot for assessment of residence time in an afterburning chamber.

I/S REFA, Nykøbing Falster.
Architect: Mikael Klinge, Klinges Tegnestue.

BAT plants

In conclusion, four recently established Danish plants are presented below: I/S Vestforbrænding's unit 5, I/S REFA's unit 3, Svendborg CHP Plant and I/S Reno-Nord's unit 4. All of these plants can be said to represent BAT; each in their own way.

I/S Vestforbrænding already had the largest unit in Denmark, 14 t/h, but when unit 5 was tendered, a capacity of as much as 26 t/h was selected. At the same time it was decided that the plant should fully comply with the requirements of the then draft version of the EU directive on the incineration of waste. The plant was therefore the first one in Denmark to apply a $DeNO_X$ technique in the form of SNCR complete with ammonia stripping in the water treatment system. The plant was also the first one to have a limestone scrubber for the removal of SO_2. After the scrubber the flue gas is reheated prior to being cleaned of dioxins in a bag house filter.

For *I/S REFA* it was of the utmost importance that the new unit 3 should be established as close to the existing units as possible. The waste reception hall and the waste pit were extended, and the new unit was located around the existing units so that it could apply an available third pipe in the existing stack. On account of the limited area available – as well as the fact that this solution would result in the same flue gas treatment residue as the one generated by the two other units, which could then be handled in a new joint *bigbag* system for the three units – it was chosen to install a semi-dry flue gas treatment system for the new unit.

Hence, at both plants the dioxins are separated in baghouse filters, i.e. at a flue gas temperature of more than 100°C, whereas *Svendborg CHP Plant* as the first plant in Scandinavia introduced the wet method for the separation of dioxins. In this method it is not necessary to reheat the flue gas, which enables the recovery of a larger part of the energy contained in the waste.

Svendborg CHP Plant.
Architects: Boje Lundgaard & Lene Tranberg.

Interior
of Svendborg CHP Plant.

Table 2.
Data on four recently established combined heat and power producing waste incineration plants in Denmark

Plant	Vestforbrænding Unit 5	REFA Unit 3	Svendborg CHP Plant	Reno-Nord Unit 4
Commissioning	1998	1999	1999	2005
Capacity	26 t/h	9 t/h	6 t/h	20 t/h
Consultant	RSV*	Rambøll	Rambøll	Rambøll
Grate	Vølund	Vølund	Vølund	BS W (Vølund)
Steam pressure	52 bar	40 bar	50 bar	50 bar
Steam temperature	380°C	400°C	400°C	425°C
Steam production	28.67 kg/s	9.7 kg/s	6.54 kg/s	22.12 kg/s
Steam production	4.0 kg/kg waste	3.9 kg/kg waste	3.9 kg/kg waste	4.0 kg/kg waste
Steam turbine	Allen	Allen	ABB	BV Industrietech.
Power production	17 MW	6.7 MW	4.5 MW	17.5 MW
Electrostatic precipitator	FLS miljø	no	Rotemühle	Alstom
Flue gas recirculation	yes	no	yes	no
$DeNO_x$ process	SNCR	none to date	none to date	SNCR
Flue gas treatment	wet	semi-dry	wet	wet
Supplier	ABB	FLS miljø	LAB	LAB
SO_2 removal	$CaCO_3$	$Ca(OH)_2$**	NaOH	$CaCO_3$
Gypsum production	yes	not relevant	no	yes
Flue gas condenser	no	no	no	yes
Dioxin filter	baghouse filter	baghouse filter**	Scrubber	Scrubber
Incineration of spent adsorbent	yes	not relevant	yes	yes
Thermal efficiency	86.7%	86.9%	87.9%	98.0%
Electrical efficiency	19.6%	22.3%	22.5%	26.9%

* RSV = Rambøll, SK energi, Vestforbrænding. ** in connection with the semi-dry flue gas treatment

The new unit at *I/S Reno-Nord* is very similar to the one in Svendborg. However, the removal of SO_2 is effected in a limestone scrubber, and due to the fact that the district heating water is returned at a temperature lower than the flue gas temperature after the scrubbers, it is possible to exploit this difference in temperature for further production of district heating.

In this process such a large part of the water vapour content of the flue gas is condensed that the unit becomes self-sufficient in water for both the wet flue gas treatment and the cooling of the bottom ash.

In other words, the part of the waste that consists of water is *recycled*.

This also entails an exploitation of nearly 100% of the lower calorific value of the waste.

Table 2 contains a comparison of data from the four plants. If the data are compared with those applying to the plants from the 30s, cf. table 1 on page 14, it is first and foremost apparent that the steam production per tonne of waste has quadrupled. Part of this increase is naturally due to the fact that the calorific value of the waste has significantly increased, but a reason that is just as important is that the energy efficiency has been given pride of place.

The Challenges of Tomorrow

Denmark has incinerated waste for a period of 100 years. Although initially the purpose was to reduce the quantity of waste that had to be landfilled, the heat produced in the process has always – except at a few minor plants in the period of 1970-87 – been exploited for power and/or heat production.

As the major part of the waste is CO_2 neutral biomass, the plants have made a significant contribution to a reduction of Denmark's emission of greenhouse gases to the atmosphere.

The waste incineration plants existing today are therefore not only incineration plants, but also high-technology energy works that have an important socio-economic mission to fulfil. They do this at a price that most of their counterparts abroad would envy them. The waste, energy and indirect tax policy that Denmark has pursued has been a decisive factor, in that the plants have been certain to receive the incinerable waste arising in their respective areas and have been given a preferential right to sell the energy produced.

Even though the sector celebrated its centenary in 2003 and can look back on constant growth – only temporarily interrupted by the war in 1940-45 – in compliance with new environmental standards even before they have been enacted, it cannot rest on its laurels, but has to keep preparing for new challenges.

One of these challenges is the general trend towards a liberalisation that prevails at present.

- Can the plants remain having the right to receive and treat the waste arising in their area, or will they have to compete for the waste with other incineration plants or industrial installations?

- And will they in future be forced to sell the power produced in a free market economy?

It is the authors' assessment that Denmark will face these challenges as best it can. Internationally, the country will continue to set an example in the field of waste incineration with energy recovery and maintain a leading role as an exporter of incineration knowledge and technology.

Model of I/S FASAN, Næstved, after extension by a new unit 4 with a capacity of 8 t/h.

Rambøll assisted I/S FASAN in the takeover of Næstved CHP Plant (see p. 36) and is the Client's Representative in the planning and erection of the new unit 4. Vølund will be supplying both the furnace and boiler.

Architects: Gottlieb & Paludan.

I/S Reno-Nord, Aalborg, extension by unit 4.
Architects: Arkitektfirmaet C.F. Møller.
Architectural concept and elevations.

Postscript

Why has incineration achieved such a prominent role in Denmark?

Hopefully, the description in this book has provided an answer, at least in an implicit and fragmented way. A more summarising answer could be:

In the second half of the 19th century it was realised that household waste must be collected and taken to landfills. However, major cities like Frederiksberg, Gentofte and Aarhus soon ran out of available landfill sites, and had to turn to incineration to reduce the volume of waste.

From the beginning it was also realised that waste is a source of energy, which could be exploited for combined heat and power production.

The climate in Denmark is temperate, making home heating a necessity almost all year round. Until recent discoveries of oil and gas in the Danish sector of the North Sea, imported fuels have covered practically all our gross energy consumption.

This called for high-efficiency solutions, and in the beginning of the 20th century district heating became quite widespread in cities with major power stations. In the 'happy 60s' everything boomed. New houses and flats, most often heated with district heating, were built at a staggering rate. Bruun & Sørensen (see box on p. 21) realised that waste is a useful fuel for district heating and challenged Vølund's position as the Danish supplier of incinerators. Seen in retrospect, there is little doubt that the resulting fierce competition between Vølund and B&S, which made the plants available at large and at competitive prices, has meant a lot to the prominence of incineration in Denmark.

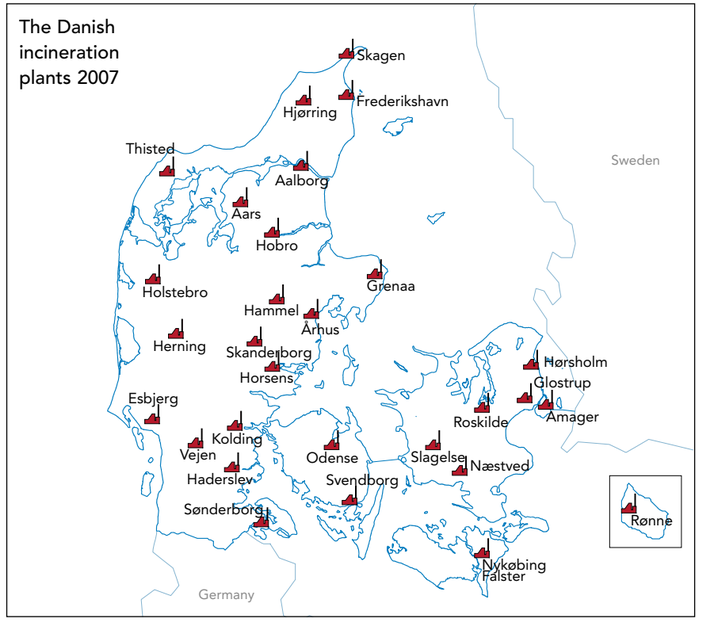
It also paved the way for specialised consultants to stand between the plant owners and the suppliers, and to assist clients in obtaining the necessary approvals from the authorities. Rambøll contributed to the development of waste incineration in Denmark and also aided in achieving publicly acceptable and sustainable solutions.

After the first energy crisis in 1973, energy supply and consumption became a political issue, and since then governmental regulation has been tighter and tighter, always recognising that waste which cannot be recycled is a useful fuel for heat and later on also CHP production – provided that strict environmental standards are fulfilled. In a fairly coherent way, incineration and district heating have been promoted by political agreements as well as by taxes and subsidies.

The waste management policy followed suit. Not only households but also commercial waste producers are obliged to have their waste collected by the municipalities or to deliver it to a treatment installation, e.g. an incineration plant devised by the municipality.

The combined effect of these policies has removed the risks associated with the long-term investments in the necessary incineration capacity, which again has enabled Denmark – as the first country in the World – to introduce a ban on the landfilling of incinerable waste.

In Denmark, incineration is conceived as a sensible, indispensable part of the waste hierarchy.



Municipal Waste Incineration Plants in Denmark and The Faroe Islands updated 2007

Plant	Owner	Address	No.of lines	Tot. capacity, t/h
Aalborg	I/S Reno-Nord	Troensevej 2 9220 Aalborg Øst	2	31
Aars	Aars kommune	Dybvad Møllevej 1 9600 Aars	2	8.5
Aarhus	Århus kommunale Værker	Ølstedvej 20 8200 Århus N	3	31
Esbjerg	L 90	Måde Industrivej 35 6705 Esbjerg Ø	1	20
Frederikshavn	Elsam A/S	Vendsysselvej 201 9900 Frederikshavn	1	5
Glostrup	I/S Vestforbrænding	Ejbymosevej 219 2600 Glostrup	4	83
Grenå	Grenå kommune	Kalorievej 9 8500 Grenå	1	2.5
Haderslev	Elsam A/S	Dybkær 2, Marstrup 6100 Haderslev	2	9
Hammel	Hammel Fjernvarme A.m.b.a.	Irlandsvej 6 8450 Hammel	2	6
Herning	EG. Jylland	Miljøvej 3 7400 Herning	1	5
Hjørring	AVV I/S	Mandøvej 8 9800 Hjørring	2	12
Hobro	I/S Fælles Forbrænding	Hvedemarken 13, Postboks 130 9500 Hobro	2	6.9
Holstebro	Elsam A/S	Energivej 2 7500 Holstebro	2	18
Horsens	Elsam A/S	Endelavevej 7 8700 Horsens	2	10
Hørsholm	I/S Nordforbrænding	Savsvinget 2 2970 Hørsholm	4	19
København	I/S Amagerforbrænding	Kraftværksvej 31 2300 København S	4	48
Kolding	TAS I/S	Bronzevej 6 6000 Kolding	2	19
Leirvik	Intermunicipal Company, Faroe Islands	Hagaleiti FO-520 Leirvik	1	2.5
Næstved	I/S FASAN	Ved Fjorden 20 4700 Næstved	3	15
Nykøbing F	I/S REFA	Energivej 4 4800 Nykøbing F.	3	17
Odense	Elsam A/S, Fynsværket	Havnegade 120, Postboks 928 5100 Odense C	3	32
Rønne	I/S BOFA	Almegårdsvej 8 3700 Rønne	1	2.5
Roskilde	I/S KARA	Håndværkervej 70 4000 Roskilde	3	34
Skagen	Skagen kommune	Buttervej 66 9990 Skagen	1	2
Skanderborg	I/S RENO SYD	Norgesvej 13 8660 Skanderborg	2	9.5
Slagelse	I/S KAVO	Dalsvinget 11 4200 Slagelse	2	10
Sønderborg	Sønderborg Kraftvarmeværk I/S	Vestermark 16 6400 Sønderborg	1	8
Svendborg	Svendborg kommune	Bodøvej 1 5700 Svendborg	1	6
Thisted	I/S Thyra	Industrivej 9 7700 Thisted	1	6.4
Torshavn	Torshavnar Kommuna	Post Box 32 FO-110 Torshavn	1	2.5
Vejen	Elsam A/S	Koldingvej 30B 6600 Vejen	1	4.3

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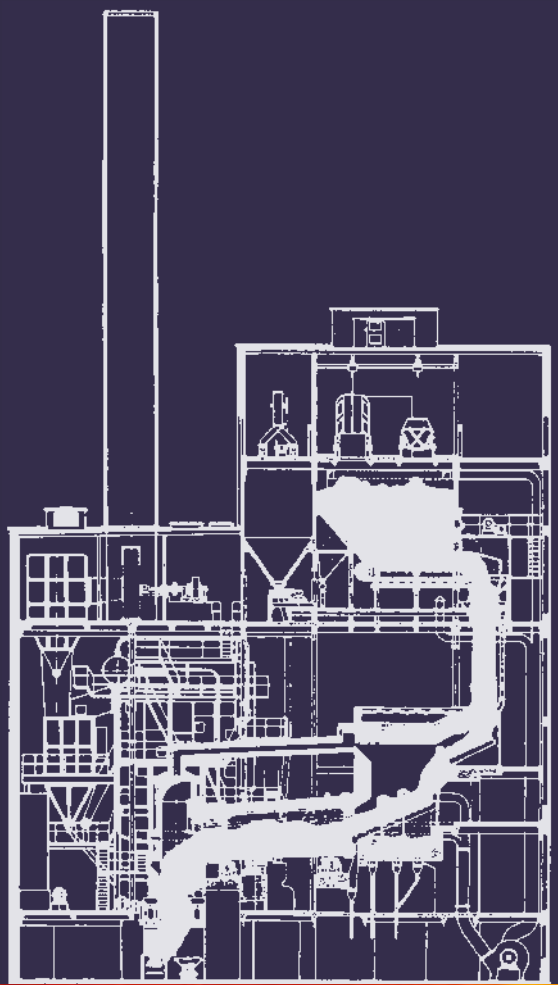
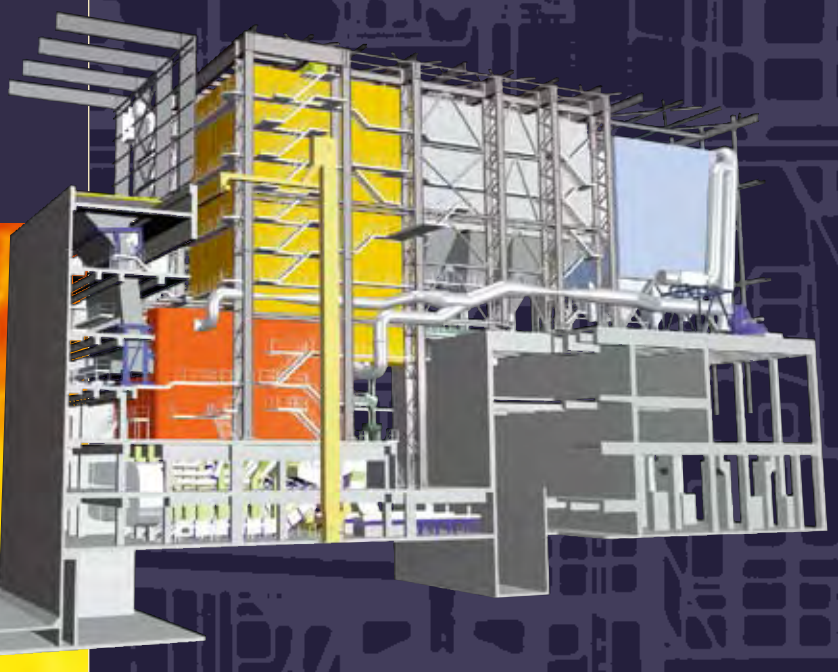


100 years of waste incineration

Why does Denmark not have any mountains of waste? And why does the country no longer have odorous dumps infested with flies, gulls and rats?
This is because Denmark 100 years ago began to realise that waste can be exploited for the production of power and heat; initially in cell furnaces and eventually in grate fired plants with flue gas treatment in up to five subsequent steps.



Vølund and Rambøll have in each their own way contributed to this development – and therefore also have an obligation to celebrate the centenary of waste incineration in Denmark and preserve this particular corner of Danish history.

That is the objective of this book.