**EUROPEAN WASTE-TO-ENERGY SYSTEMS
CASE STUDY OF KØRSØR, DENMARK**

**RESOURCE PLANNING ASSOCIATES, INC.
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PREFACE

Kørsor, Denmark is unusual in operating a waste-to-energy system for only 20,000 persons. Energy is recovered in the form of heat for district heating. Kørsor's small incinerator has a design capacity of two metric tons (2.2 short tons) per hour and has operated reliably for four years. The apparent success of this installation suggests that waste-to-energy systems may have applications in communities far smaller than those which usually consider that option.

This case study of the Kørsor incinerator is one of a series prepared for the U.S. Energy Research and Development Agency by Resource Planning Associates, Inc. An overview of the state-of-the-art of European waste-to-energy technology forms part of this series.

Costs have been converted from Danish kroner to U.S. dollars for the specific year or period of years noted in the text. Where the appropriate year is not clear from the context, the date has been added after the U.S. dollar equivalent. Capital costs have been converted to U.S. dollars for the year in which the expenditure was made and then inflated to 1976 dollars according to the Engineering News Record Construction Cost Index.

TABLE OF CONTENTS

	<u>Page</u>
LIST OF EXHIBITS	iii
LIST OF PERSONS CONTACTED	iv
SUMMARY	1
INTRODUCTION	3
Economic and Demographic Data	3
Waste Collection and Treatment	3
THE DEVELOPMENT OF THE SYSTEM	6
Reasons for New System	6
Project Development	6
TECHNICAL INFORMATION	8
The Incinerator	8
Heat Recovery Equipment	12
Heating Facility	12
Steam Efficiency	13
System Reliability	15
Pollution Control	16
Building and Working Conditions	17
ECONOMICS AND MANAGEMENT	23
Management	23
Capital Costs	23
Direct Operating Costs	25
Overall Costs	27
NOTES	28
CONVERSION TABLES	32

LIST OF EXHIBITS

	<u>Page</u>
1. Quantity of Waste in Kørsor	4
2. Technical Data Sheet	9
3. Schematic Drawing of Kørsor Incinerator	10
4. Bruun & Sørensen Type W Grate	11
5. Production and Sale of Heat	14
6. Furnace Operations 1975	15
7. Aerial View of the Plant	19
8. Model of the Plant	20
9. Interior View of the Plant	21
10. Organization Chart for the Incinerator and District Heating Facility	23
11. Capital Costs 1966-1973	24
12. Dates of Expenditures by the Municipality for the Incinerator and District Heating Facility	24
13. Direct Operating Costs for the Incineration Plant, 1975/76	25
14. Overall Cost of Incineration	27

PERSONS CONTACTED

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Mr. Jensen	Technical Advisor, Council of the Municipality, Municipality of Kørør
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SUMMARY

The incinerator of Kørsor is part of a thermal complex composed of an incinerator with heat recovery equipment and an oil-fired heating facility. Its originality is that it serves a small town of only 20,000 persons.

Incineration was chosen as the method of treatment because of the municipality's view that it is environmentally the best way to dispose of waste. District heating is very common in Denmark, so the decision to recover the heat for that purpose was not surprising. The fact that a Danish company, Bruun & Sørensen, specializes in small incinerators with heat recovery and has already sold many similar plants was certainly an essential factor in the decision. Construction of the incinerator was begun in October 1970, with Bruun & Sørensen as the main contractor, and was completed in May 1972.

The furnace has two combustion chambers and a separate cyclone-shaped post-combustion chamber. Bruun & Sørensen feels that, for small plants, this design allows for more complete combustion of gases and will consequently reduce corrosion.

The grate (an original Bruun & Sørensen design) has two sections with six horizontal axles apiece and grate prongs screwed onto the axles. A hydraulic system advances and agitates the waste by rotating axles 1, 3, and 5 in each section clockwise and axles 2, 4, and 6 counter-clockwise. Heat is recovered by a fire tube boiler which produces steam at a maximum temperature of 120°C (248°F) and a pressure of 6 bars (5.9 atm).

The furnace has a rated capacity of 2 metric tons (2.2 short tons) per hour or 7,000 metric tons (7,700 short tons) per year for 3,500 hours of operation. Estimates of the amount of waste currently treated vary between 6,000 and 7,000 metric tons (6,600 and 7,700 short tons) per year. There are two limitations on the amount of waste treated: first, the amount of waste generated in the municipality and, second, the lack of equipment to dissipate the heat which cannot be sold during the non-heating period.

The design of the incinerator was based on the assumption that Kørsor's waste would have an average lower heating value of 2,000 kcal/kg (3,608 Btu/lb). The actual lower heating value is estimated at 2,200 kcal/kg (3,968 Btu/lb). Household waste makes up about 70 percent of the total; the rest is essentially commercial waste and a little industrial waste.

The energy recovered from the boiler amounts to about 7,000 kilotherms* (kth) per year. The thermal efficiency of the plant is estimated at approximately 50 percent. Taking into account energy which is lost because it cannot be sold, the overall efficiency decreases to approximately 30 percent.

* One kilotherm equals 3.97×10^6 Btu.

The hot water produced is pumped into a district heating network serving a total of 1,350 apartments and houses, but no industrial plants at the moment. The main network is 7 km (4.3 mi) long; the overall length, counting the branches to individual houses, is 13.5 km (8.3 mi)..

During the four years of operation, no major problem has occurred. The most serious problem has concerned the refractory material in the combustion zone. The refractory deteriorated very quickly and had to be changed within the first two years. However, the problem now appears to be solved.

To control pollution, the gases first pass through the post-combustion chamber where the ashes are partly precipitated, then (after the waste heat boiler) through a battery of cyclones. The supplier guaranteed the cyclone unit at 94 percent removal efficiency. No sampling of particulate emissions has been made.

The architecture of the complex is interesting and careful attention was paid to color, shape and structure. The interior is comfortable and the amenities are excellent. Construction costs (not including equipment) amounted to 46 percent of the total cost of the entire plant.

The total work force for the complex is 6 people, including the plant director, two operating shifts of two persons and one person for housekeeping. The plant is highly automated: one operator controls the crane operations, the furnace operations, and the heating facility from a central control room.

The total cost of the complex was 7,000,000 Kr (\$944,700; 1971 or \$1,437,600; 1976) with 4,600,000 of that sum going for the incinerator. There was no subsidy from the Danish government; the plant was entirely financed with municipal funds.

The complex is operated by the municipality as part of the Incineration and District Heating Works. The overall cost of incineration is estimated today at 120 Kr per metric ton (\$18 per short ton) including both capital and operating cost, after making provision for the value of heat recovered.

The cost per ton could be reduced if there were more waste to treat. There is room for a second incinerator, but the complex would have to burn the waste of surrounding municipalities. Moreover, the extension of the district heating network has not been as fast as expected. Since there are no heat exchangers, dissipating the heat during summer months would be a problem unless new markets, especially in the industrial sector, can be found.

The heat is sold for approximately 92 Kr/kth (\$3.78/10⁶ Btu)* which is lower than the market price of individual electric or fossil fuel heating. Surprisingly, the municipality did not try to estimate in advance the cost of incineration or the value of the recovered heat.

* 1975/76 prices.

INTRODUCTION

ECONOMIC AND DEMOGRAPHIC DATA

The town of Kørør is located in the extreme western part of Seeland, the main island of Denmark, about 100 km (62 mi) from Copenhagen. Kørør is a small seaport town of 20,000 people. There are two main industries: the State Railways Company and a glass company. The State Railways Company, which operates the ferries between the central islands, employs 2,000 people there, mainly for its nationwide catering activities. Scanglas operates a float glass plant which employs 800 people.

The town of Kørør has an area of 81.7 km² (31.5 sq mi) with an average population density of 245 inhabitants/km² (635 inhabitants/sq mi). The municipality is divided by a fjord into two districts, each with its own downtown center, linked by a bridge. The downtown centers are composed of stores and offices in one to three story buildings, while the suburbs are composed mainly of single family houses with a few apartment complexes. The Kørør incinerator is located at the southeastern edge of town, in the suburb of Tyreengen.

The town government consists of a borgmester, (currently Mr. P. Hvidtfeldt Larsen) and a town council. The tax revenues of the town are 57,000,000 Kr (\$9,421,000; 1976) for 1976 or 2,850 Kr (\$471; 1976) per inhabitant, which is above average for Denmark.¹ A rough estimate of the average income of a working person is 60,000 Kr (\$9,900; 1976) per year; very often a family will have two incomes adding up to 100,000 Kr (\$16,500; 1976) per year.² As is normal in Denmark, there is relatively little difference between after-tax incomes.

WASTE COLLECTION AND TREATMENT

Waste collection in Kørør, as throughout Denmark, is the responsibility of the technical services of the municipality. Household waste is deposited in 100 liter (3.5 cu ft) paper bags positioned on metal stands outside the houses. When full, the bags weigh between 16 and 18 kg (35 and 40 lbs).³

The bags are collected once a week. The town uses two simple open trucks of 6 and 8 metric ton (6.6 and 8.8 short tons) capacity, with a crew of three, including the driver, on each. Waste is collected from 7,400 residences all year long and from an additional 830 summer residences for part of the year. In a few areas at the outskirts of Kørør, waste is collected by a private company.

Industrial and commercial waste is delivered by its generators to the municipality for treatment. Industrial waste is mainly packaging material, such as plastic from the catering industry. In January 1977, Kørør joined the centralized treatment system of Kommune Kemi A/S which treats oil and chemical waste from the whole country.

The amount of household waste collected by the municipality in 1975 was estimated at 5,200 metric tons (5,730 short tons) per year. This is equal to 0.7 kg (1.5 lbs) per inhabitant per day. A further 2,500 metric tons (2,740 short tons) of industrial and commercial waste was brought to the municipality by private companies for treatment⁴ (see Exhibit 1).

Exhibit 1

Quantity of Waste in Kørsor
(estimated in metric tons*)

	1973	1974	1975
Supplied to Incineration Plant			
Domestic waste	4,523	3,056	4,268
Other combustible waste	2,954	3,056	1,759
Total	7,477	6,572	6,027
Dumped			
Domestic waste	517	524	891
Other combustible waste	1,087	671	842
Total	1,604	1,195	1,733
Total Collected			
Domestic waste	5,040	4,039	5,159
Other combustible waste	4,041	3,728	2,601
Total	9,081	7,767	7,760

* There is no scale at the plant. Number of truckloads obtained from municipal records. RPA estimates based on the following ratio:
2.2 metric tons (2.4 short tons) per truck for domestic refuse and
1.8 metric tons (2.0 short tons) per truck for other refuse (commercial and some industrial refuse). One metric ton equals 1.1 short tons.

The amount of household waste collected apparently varied from 5,040 metric tons (5,552 short tons) in 1973 to 4,039 metric tons (4,450 short tons) in 1974 and back again to 5,159 metric tons (5,682 short tons) in 1975. The quantity of industrial waste also decreased from 3,900 metric tons (4,300 short tons) in 1973 to 3,600 metric tons (3,960 short tons) in 1974, and decreased further to 2,500 metric tons (2,750 short tons) in 1975.⁵ These figures are only estimates, as the municipality does not weigh the waste collected, but only records the number of truckloads. As we shall see, there are differing estimates which would substantially change the cost per ton.

Waste is treated in two ways, incineration and landfill. In 1975, approximately 83 percent by weight of the household waste (4,300 metric tons or 4,736 short tons) and 68 percent of the industrial and commercial waste (1,700 metric tons or 1,870 short tons) were incinerated.⁶

The remaining waste (900 metric tons or 990 short tons of household waste and 800 metric tons or 880 short tons of industrial and commercial waste) was dumped in a sanitary landfill along with wood and other demolition waste. The residues of incineration are also dumped in this landfill.

The total cost of municipal collection amounts to 1,250,000 Kr (\$204,250; '75-'76) in 1975/76, or 240 Kr/metric ton (\$35.60/short ton). This appears high for Denmark for a service which provides one collection per week.⁷ The cost of maintaining the landfill amounted to 120,000 Kr (\$19,600) for 1975/76 or 15 Kr/metric ton (\$2.20/short ton) of waste (household, industrial and commercial, and construction waste).^{7,8}

These expenses are covered by the sale of the collection bags by the municipality. The basic price for these bags is 224 Kr (\$37; 1976) for 52 bags. Additional bags cost less. The basic price for 52 bags is expected to increase from 224 Kr (\$37) to 285 Kr (\$47) in 1977 to cover additional costs, in particular the purchase of a new truck.⁹ The sale of bags brought in 1,480,000 Kr (\$241,830; '75-'76) in 1975/76 and will contribute 2,000,000 Kr (\$330,575) to the 1977 Kørsor town budget. This covers the cost of collection and the cost of maintaining the landfill; there is no profit.

Revenues from the dumping of industrial waste amounted to 60,000 Kr (\$9,800; '75-'76) in 1975/76. Private companies pay 20 Kr (\$3.27) per truckload brought to the landfill.

THE DEVELOPMENT OF THE SYSTEM

REASONS FOR NEW SYSTEM

Before the construction of the incinerator in 1972, the waste generated in Kørør was simply dumped into the fjord, in an area more or less protected by a dam made of construction waste. This practice was abandoned as a detriment to the environment.

The choice of incineration with heat recovery was based on three considerations. First, at the time the decision was made in the 1960s, it was felt that incineration was the best way to protect the environment. Moreover, at that time, incineration, and especially incineration with heat recovery, was fashionable. This solution had been chosen by many other Danish municipalities. Finally the lack of landfill space was an argument in favor of incineration.¹⁰

Other possibilities for waste treatment were apparently not seriously considered. Landfilling was eliminated because of the lack of suitable land for controlled dumping. At that time the municipality was not aware of the environmental quality standards possible in a good controlled landfill. Composting was also eliminated because of environmental considerations.¹¹ District heating is very common in Denmark, and some towns already used heat recovered from incineration for district heating.

PROJECT DEVELOPMENT

In 1965, the housing complex of Tyreengen expressed its interest in a municipal district heating scheme. The Town Council began consideration of the construction of an incinerator in 1966, as the dumping of the waste in the fjord was becoming unacceptable. No study of alternatives was made, but members of the Council and the Technical Services visited several Danish incinerators and consulted with officials of other towns.¹²

In 1967 the Council decided to study sites for an incinerator and district plant.¹³ Through discussion with other town officials, the members of the Kørør Town Council were convinced that the Danish company Bruun & Sørensen offered the best system for Kørør (see Appendix B).

The municipality then asked Bruun & Sørensen and two other Danish incinerator manufacturers, Volund and E. Rasmussen, to submit bids. The amounts of all three bids were similar and the Town Council awarded the contract to Bruun & Sørensen.¹⁴

The Bruun & Sørensen project was formally approved by the municipality at the end of 1969. There was no major opposition in the Council and some very enthusiastic support. There was no opposition at all from environmental groups or private citizens.¹⁵

Because nobody on the Council or even in the Technical Services of the municipality was a specialist on incinerators, Bruun & Sørensen had to help the municipality in drawing up the specifications. Their advice was followed without hesitation. For example, for construction of the building, the Council took Bruun & Sørensen's advice and contracted with the Kjaehr & Trillingsgaard Company.¹⁶

Construction began in October 1970. The district heating plant began operation in November 1971 and the incinerator in March 1972, after 17 months of construction. This seems a little longer than usual, but the municipality insisted that everything be completed before the incinerator start operation.¹⁷

TECHNICAL INFORMATION

THE INCINERATOR¹⁸

Waste is transported by trucks to a closed discharge hall where it is emptied into two bunkers of a total capacity of 560 m³ (732 cu yds) (see Exhibits 2 and 3). One bunker is used for household waste and the other for commercial and industrial waste, so that it is possible to feed the furnace with waste of different calorific values, as needed. The bunker can store three to four days' worth of waste.

A three metric ton (3.3 short ton) moveable crane with a one cubic meter (1.3 cu yd) bucket transports the waste from the discharge bunkers to the furnace hopper. This semi-automatic crane can feed the furnace approximately 16 times an hour. Waste is introduced into the furnace through an inlet hopper, a furnace shaft, and a hydraulic feeding door with refractory lining. The furnace room is designed to accommodate two furnaces, but for the time being there is only one furnace with a capacity of 2 metric tons (2.2 short tons) per hour.

The furnace is built on the two chamber principle with a separately lined cyclone shaped post combustion chamber. Bruun & Sørensen generally use this system for their small municipal incinerators. The design insures more complete combustion of the gaseous emissions, and consequently reduces corrosion.

The furnace itself consists of a steel supporting framework, a refractory lining, and a hydraulically operated grate. The side plates consist of 5 mm (0.2 in) steel; the supporting steel construction is made of sectional iron; the top of the furnace is covered with floor plates.

The grate is Bruun & Sørensen's W Type, an original design by Mr. Sven Alexandersson, manager of their environmental engineering department (see Exhibit 4). It has two sections with six horizontal axles in each section. The cast steel grate prongs are approximately 0.5 m (20 in) length and 5 cm (2 in) breadth and are screwed to the axles. Transport and agitation of the waste are ensured by a hydraulic system which causes axles no. 1, 3, and 5 in each section to turn clockwise, while nos. 2, 4, and 6 turn counter clockwise.

Each grate section can work at a speed adapted to the type and quantity of waste to be burned. Each section rocks through 60°; the whole grate is inclined 28° to the horizontal.

The refractory lining at the center of the furnace is made of different types of charlotte bricks; just above the grate line there are wear resistant cast iron plates. The furnace is insulated with molar bricks and the exterior temperature remains at approximately 35°C (95°F).

The air for incineration is supplied by primary and secondary fans. The primary air is supplied to the individual combustion zones through a system of channels arriving under each grate section. This air is drawn from the

Kørsor Incineration Unit Technical Data

Dates

Start of construction	October 1970
First district heating plant operation	November 1971
First incineration of waste	March 1972

Plant Dimensions

	Metric System	English Equivalent
Dimensions of building	36 m x 26 m	118 ft x 85 ft
Height of discharge hall	12 m	39 ft
Height of furnace room	18 m	59 ft
Height of heating plant	12 m	39 ft
Height of waste heat boiler	14 m	46 ft
Height of smokestack	62 m	203 ft
—diameter of first flue	1.1 m	3.6 ft
—diameter of second flue	0.8 m	2.6 ft

Incinerator

Number of furnaces	1	
Rated capacity (per hour)	2 metric tons	2.2 short tons
Hot water production at normal capacity, lower heating value of 2,000 kcal/kg (3,607 Btu/lb)	3.0 kth/hr @ 6 bars, 120° C	1.2 x 10 ⁷ Btu/hr, 248° F
Volume of waste pit	560 m ³	732 cu yds
Volume of crane bucket	1 m ³	1.3 cu yds
Gas produced	6 m ³ /kg of waste	96 cu ft/lb of waste
Volume of gas in cyclone battery	22,000 m ³ /hr	776,800 cu ft/hr
Efficiency of cyclone battery	94%	
Maximum quantity of particulates	300 mg/m ³	
Average temperature of gas	225° C	437° F
Yearly capacity (3,500 hours/year)	7,000 metric tons	7,700 short tons

Heat Recovery System

Weight of fire tube boiler	25 metric tons	27.5 short tons
Input temperature of gas	900° C	1,652° F
Output temperature of gas	225° C	437° F
Water content of boiler	14 metric tons	15.4 short tons
Heat production	3 kth/hr	1.2 x 10 ⁷ Btu/hr
Maximum water temperature	120° C	248° F
Working water pressure	6 bars	5.9 atm

Heating Facility

1 oil fired boiler	5 kth/hr	2.0 x 10 ⁷ Btu/hr
1 oil fired boiler	4 kth/hr	1.6 x 10 ⁷ Btu/hr
1 oil fired boiler	2 kth/hr	7.9 x 10 ⁶ Btu/hr
Length of main network	7 km	4.3 mi
Length of total network	13.5 km	8.4 mi
Number of housing units served	1,350	
Outlet temperature	85-110° C	185-230° F
Return temperature	60-70° C	140-158° F

Schematic Drawing of Kørsor Incinerator

1. Tube arrangements	16. Stairway
2. Gas return	17. Secondary cyclone
3. Incinerator	18. Vibrating conveyor
4. Conveyor fan	19. Primary air duct
5. Secondary fan	20. Gas burner (igniter)
6. Waste chute	21. Screw conveyor
7. Waste hopper	22. Grate
8. Duct for combustion air	23. TV monitor
9. Crane with 1 m ³ bucket	24. Control desk
10. TV camera	25. Control panel
11. Gas duct	26. Post combustion chamber
12. Exhaust fan	27. Boiler
13. Dust collector	28. Hoist
14. Primary fan	29. Slag silo
15. Slag discharge	30. Panel for crane and hoist

Bruun & Sørensen Type W Grate

discharge hall in order to reduce air pressure slightly and thus contain odors.

The flue gases from the incinerator are kept between 800°C (1470°F) and 1,050°C (1920°F). The lower limit has been designed to produce odorless flue gases, the upper limit is the melting point of the ash. The ash goes from the last incineration grate into the ash shaft where a ram moves it onto a vibrating conveyor located under the furnace. Before the ash enters the vibrating conveyor, it is cooled and dust is reduced by a water spray. The ash is finally lifted by a hoist into a silo with an outlet at the bottom.

HEAT RECOVERY EQUIPMENT¹⁸

The flue gases from the furnace pass into the post combustion chamber, then into a fire tube boiler which recovers the thermal energy they contain. The input temperature of the flue gases is approximately 900°C (1650°F); they leave the boiler at approximately 250°C (480°F). The output of the waste heat boiler is 3 kcal (3.6×10^7 Btu) per hour at a working pressure of 6 bars (5.9 atm) and a maximum temperature of 120°C (240°F).

To prevent overheating in the boiler there is a sensing device which can automatically shut the feeding door. The boiler is cleaned with compressed air.

After the boiler, the gases pass through a battery of 26 cyclones; the fly ash separated in the cyclone battery is transported pneumatically to a secondary cyclone, and from there to the ash conveyor.

The exhaust fan placed after the cyclone units draws the gases up the stack. The stack is clean when the incinerator is operating.

HEATING FACILITY¹⁹

The oil fired heating facility, located in the same building as the incinerator, also produces hot water for the district heating network. In addition to the heat recovered from incineration of waste, the heating facility burns oil to fire three boilers rated at 5, 4 and 2 kth*/hr. There is room for an additional boiler in the facility. The different capacities of the three boilers allow them to operate at nearly full capacity, which results in greater efficiency. The water comes from the municipal distribution system and is treated in the plant.

The oil fired boilers are only used during the heating season. Water is heated to 85°C (185°F) and returns at 60°C (140°F). During the summer, the oil fired boilers are not used. However, because there is still more heat available from the heat recovery system than needed during the summer, steam is pumped into the network at a temperature of 110°C (230°F) and returns at 70°C (158°F).

* One kth equals 3.97×10^6 Btu.

The hot water is pressurized and pumped into a district heating network with a total length of 13.5 km (8.4 mi). The main network is 7 km (4.3 mi) long and there are 6.5 km (4.1 mi) of branches to houses. This network serves 1,350 apartments and houses, but no industrial plants at the moment.

STEAM EFFICIENCY

According to municipal records, the incinerator burned 6,000 metric tons (6,600 short tons) of waste in 1975. However, as pointed out above (p. 4) this figure has been disputed and some estimates are that 7,000 metric tons (7,700 short tons) were treated. The municipal records show that 4,300 metric tons (4,700 short tons) of household waste and 1,700 metric tons (1,870 short tons) of industrial and commercial waste were treated.

The furnace has a rated capacity of two metric tons (2.2 short tons) per hour, or 7,000 metric tons (7,700 short tons) a year for 3,500 hours of operation. In practice, it is possible to treat 2.3 to 2.5 metric tons (2.5 to 2.7 short tons) per hour.¹⁹ The plant operates 80 hours a week, with the incinerator operating an average of 66 hours a week.²⁰

The furnace was designed for waste with a lower heating value of 2,000 kcal/kg (3,608 Btu/lb), while actual lower heating value is estimated at 2,200 kcal/kg (3,968 Btu/lb),¹⁹ although no sample has been measured. The energy which can be recovered is estimated by the municipality at 1,300 kcal/kg (2,345 Btu/lb) of waste burned for a thermal efficiency of almost 60 percent. RPA estimates that this figure is probably too high. An efficiency of 50 percent seems more realistic.

In practice during the operating year 1975/76, a total of 7,046 kth (2.8×10^{10} Btu) of heat was recovered from the incinerator* (see Exhibit 5). On the basis of 6,000 metric tons (6,600 short tons) of waste burned per year and a lower heating value of 2,200 kcal/kg (3,968 Btu/lb), the overall efficiency rate of the plant would be 53 percent. If 7,000 metric tons (7,700 short tons) are treated per year, the rate would be only 46 percent.

The heat obtained from the incinerator provides 25 percent of the total energy for district heating (1975/76). The remaining heat, or 20,707 kth (8.22×10^{10} Btu), was furnished by the oil fired heating facility. The thermal efficiency of the oil fired boilers in the heating facility is estimated at 87 percent.

Further inefficiencies, external to the incineration plant, are due to losses in the district heating network and the fact that not all available heat can be sold. During the summer there is no market for the heat produced.

* Measured at the level of the waste heat boiler.

Production and Sale of Heat

	1973/74	1974/75	1975/76	1976/77
District Heating Facility Incinerator				
Oil consumption (metric tons*)	2,156	2,323	2,511	3,318
Calorific value (kcal/kg)	9,700 [†]	9,700	9,700	9,700
Efficiency (percent)	87	87	87	87
Heat production (kth**)	18,196	19,604	20,707	28,000
Incinerator heat production	7,383	6,580	7,046	7,000
Total heat production (kth)	25,579	26,184	27,843	35,000
Heat sold (kth)	21,986	19,841	21,283	26,500
Losses (kth)	3,593	6,343	6,560	8,500
Total heat loss (percent)	14.0	24.2	23.5	24.3

SOURCE: Municipal sources—budget for 1977.

* To convert metric tons to short tons, multiply by 1.1.

** One kth (kilotherm) equals 3.97×10^6 Btu.

[†] 9,700 kcal/kg = 17,500 Btu/lb.

The plant has no heat exchange system to dissipate the heat which cannot be used. Even when there is no need for district heating, the heat must be sent through the district heating network. During the summer months, the only energy needed in the houses is for hot water which is obtained through heat exchangers located in each house. In order to dissipate the heat which cannot be sold during these periods, the water temperature at the exit of the plant is raised to 110°C (230°F) (instead of 85°C 185°F during the heating season) so that energy losses in the district heating network are maximized. The return temperature of the water is 70°C (158°F) during the non heating season, instead of 60°C (140°F) during the heating season.

Thus the energy losses in the district heating network result in part from technical inefficiencies, but are partly voluntary. The losses in the district heating network amounted to 23.5 percent of the total energy sent into the network in 1975/76. They have varied between 14 and 24 percent from year to year, depending on the energy demands of the customers. It is estimated that a loss of roughly 10 to 15 percent represents the real technical inefficiency of the distribution network and that an additional 10 percent represents heat sacrificed because of the lack of a market.²¹ In 1975/76, losses due to lack of a market amounted to about 2,800 kth (1.11×10^{10} Btu) or from 18 to 21 percent of the energy available in the waste incinerated.

Overall, based on the 1975/76 figures and on the assumption of 6,000 metric tons (6,600 short tons) of waste treated, the efficiency of the energy transformation can be estimated at 53 percent in the incineration plant. If one takes into account the heat which is lost because it cannot be sold, this efficiency decreases to 32 percent. Based on the assumption of 7,000 metric tons (7,700 short tons) of waste treated, efficiency of energy transformation can be estimated at 46 percent; subtracting the heat lost because it cannot be sold, this efficiency would decrease to 28 percent.

SYSTEM RELIABILITY

The furnace was designed to operate 3,500 hours a year at a capacity of 7,000 metric tons (7,700 short tons) per year. In practice, during the year 1975, the furnace operated for 3,433 hours, or 98 percent of the available hours. Cleaning operations took a total of 252 hours and the furnace was not operating because of a breakdown for 20 hours (see Exhibit 6).²²

Exhibit 6

Furnace Operations 1975

	Furnace in Operation (hours)	Breakdown (hours)	Cleaning (hours)
January	296	18	18
February	277	0	23
March	258	0	21
April	317	5	24
May	297	1	22
June	306	0	23
July	108	0	0
August	295	0	22
September	331	3	25
October	330	3	28
November	303	3	19
December	315	0	27
Total	3,433	20	252

SOURCE: Plant records.

All breakdowns have been very short. During 1975 they averaged only a few hours each month. The furnaces were cleaned on a regular monthly basis. The budget for maintenance was 150,000 Kr (\$24,500; '75-'76) in 1975/76 and 200,000 Kr (\$30,050; 1976) in 1976/77.

During its four years of operation, no major problem has occurred at the incineration plant. The most significant problem concerned the refractory material in the combustion zone of the furnace. This deteriorated within the first year, and six square meters (65 sq ft) of refractory material were

replaced under the guarantee. During the second year, a further six square meters (65 sq ft) had to be replaced. According to the manufacturer, the damage could be due to the high calorific value of the waste. According to the plant manager, it was due to bad workmanship. In any case, no further repair of the refractory has been necessary. It has also been necessary to replace the cast steel liners on each side of the grates; these liners deteriorate from the heat and need to be changed every three years.

A number of minor modifications were needed. A vibrator was put on the ash silo to shake the ash down and the cable on the crane and the cooling jacket of the screw conveyor were replaced.

According to the manager, the incineration unit is in good shape and should last for 25 years with the replacement of a few essential parts such as the boiler and the cyclones. It is, however, also his opinion that the heating facility is more reliable and of better quality than the incinerator.

POLLUTION CONTROL

The volume of gas produced is $6 \text{ m}^3/\text{kg}$ (96 cu ft/lb) of waste incinerated.²⁴ After leaving the furnace, the gases pass through the post combustion chamber and the waste heat boiler, then through multi-cyclone collectors before being evacuated by the exhaust fan through the stack. The ashes are removed partly in the post combustion chamber and partly in the multi-cyclone collectors. From the post combustion chamber, the fly ash is transported by screw conveyor to the ash conveyor of the plant. The fly ash separated in the cyclone battery is transported pneumatically to a secondary cyclone and, from there empties onto the ash conveyor.

The particulate content of the gases has never been tested, so it is necessary to rely on data from similar plants and on the manufacturer's guarantees. According to the manufacturer, the separation of fly ash in the post combustion chamber is highly effective and plays an important role in preventing corrosion of the boiler. Another plant by the same manufacturer in Rosendall, Holland, has two furnaces, each having a capacity of 4 metric tons (4.4 short tons) per hour. At Rosendall, tests have shown that 60 kg (132 lbs) per hour of fly ash are separated in the post combustion chamber; 40 kg (99 lbs) per hour of fly ash are separated by electrostatic precipitation. The remaining particle content of the exhaust gases is $100 \text{ mg}/\text{m}^3$.²⁵

The Kørsor plant is not equipped with an electrostatic precipitator, but only a battery of cyclones. According to the manufacturer, an electrostatic precipitator is much more efficient than a cyclone battery, (on the order of $150 \text{ mg}/\text{m}^3$ after treatment with an electrostatic precipitator against $400 \text{ mg}/\text{m}^3$ with cyclone battery), but an electrostatic precipitator is more expensive. The manufacturer also claims that it is not necessary for a plant such as Kørsor's. The municipality of Kørsor confirmed this point by saying

that in Denmark there is no regulation requiring any particular treatment or establishing a maximal level of dust emissions. There are some recommendations from the state environmental agency, but most incineration plants in Denmark do not have electrostatic precipitators at present. The manufacturer guarantees that the multi-cyclone collectors will provide a dust separation efficiency of 94 percent, with no particulates weighing more than 400 mg and a total particulate content no greater than 300 mg/m³.

The stack has two flues, one for the oil fired boilers (1.1 m or 3.6 ft in diameter) and one for the incinerator (0.8 m or 2.6 ft in diameter). The temperature of the flue gases at the exhaust is approximately 225°C (437°F). No analysis of the chemical content of the gases has been made.

The slag and ash amount to approximately five percent of the original waste by volume and 20-25 percent by weight. The manufacturer guarantees that unburned material will represent between four and six percent, by weight, of original waste, and that putrescibles will be less than 2.5 percent by weight.* The dumping of the residues in the landfill does not present any problem; non-incinerated waste is dumped along with the residues of incineration.

According to the municipality, there have been no complaints from the neighborhood or environmental groups. A large housing complex is located 100 m (110 yds) from the incineration plant and new dwellings are under construction within 30 m (33 yds) of the discharge hall (see Exhibit 6).

At this distance, we estimate that, without some protective barrier, odors and noise from the discharge hall will be perceived by the future inhabitants. When we mentioned this, we were told by representatives of the municipality that the managers of the development are aware of this problem. The Bruun & Sørensen representative told us that in another municipality, Alberstlund, the incinerator is located just as close to the mayor's office.²⁶

According to the municipality, environmental groups consider incineration favorable to the environment and will not take any action against it. The municipality held a two-day open house when the incinerator was inaugurated in order to show those interested how it operates.

BUILDING AND WORKING CONDITIONS

The building is 36 m (118 ft) long and 26 m (85 ft) wide. The discharge hall is a closed building, 12 m (39 ft) high, and has two main doors. Behind the discharge hall, the two bunkers and the crane form another block 18 m (59 ft) high. Part of the furnace room is on the left, behind the bunkers; the heating facility, the post combustion chamber, and the battery of cyclones occupy a third block 12 m (39 ft) high with a projection 14 m (46 ft) high for the

* According to EAWAG method (Eidgenössische Anstalt Für Wasserversorgung Abwasserreinigung Und Gewässerschutz, Zurich).

waste heat boiler. The plant is located next to the fjord without any fence or screen of trees. The construction and civil engineering work was done by Kjaehr & Trillingsgaard under the supervision of Bruun & Sørensen.

The buildings were carefully designed both for external appearance and for interior comfort and amenities. We particularly liked the structure, shape, and outside colors of the building which made an attractive contrast with most industrial plants. Working conditions appear very satisfactory. The plant is operated essentially from the glass enclosed control room which has a view of the silos and crane on one side and of the furnace on the other side.

The plant is highly automated and is operated by a single person in the control room. The operator controls the furnace automatically and the crane semi-automatically. The crane moves automatically to precoded positions but the opening and closing operation must be performed by the operator. A TV camera mounted on the crane makes it possible to supervise the feeding operation itself. The control room also has time recorders which control all keyed functions, e.g., the start up of the vibration conveyor and the ash hoist which run intermittently.

As we visited the plant we were impressed by the cleanliness of the working areas and especially of the machinery. According to the plant manager, cleaning operations are very important, not only to insure satisfactory working conditions, but also to insure proper maintenance of the machinery and reduce risk of accident (see Exhibits 7 - 9).

No accident has ever occurred in the plant.²⁷ At night, the heating facility works automatically during the heating season and the entire plant is linked to an alarm system by telephone. The alarm has gone off a few times but nothing serious has ever happened.

Model of the Plant

Interior View of the Plant

ECONOMICS AND MANAGEMENT

MANAGEMENT

Incineration of waste and production and distribution of heat are managed by the municipality of Kørsor. The Chief Mechanical Engineer of the municipality is in charge of the Water Works, the Gas Works and the Incineration and District Heating Works. He reports to the Town Council (see Exhibit 10). The director of the plant reports to the Chief Mechanical Engineer.

In addition to the director, the Incineration and District Heating Works employs eight people. Two shifts of two people each carry out the operation of the plant and one person is responsible for housekeeping; in addition, three persons work at the maintenance of the district heating network. One of the members of each shift is in the control room operating the crane and the furnace; the other is on the floor and helps with cleaning and maintenance.

The manufacturer provided some training assistance when the plant opened. The workers at this plant come from other municipal departments. They are usually given a few weeks trial on the job before being permanently assigned to this department. Three to four months experience is required before the employee can control operations, particularly for the furnace. According to the plant director, the employees have only three to four hours of operational work per day; most of this time is spent in housekeeping.

The plant director has 8 years experience as a ship's engineer and 7 years experience with the boiler manufacturer, Bruun & Sørensen. The Chief Mechanical Engineer of Kørsor also worked for Bruun & Sørensen.

The town of Kørsor exercises supervision and control through budgets and financial reports. Apparently the town has never requested a technical report or cost evaluation of the incinerator or heat production facilities.

CAPITAL COSTS

The cost of the incinerator with the heat recovery system was 4,600,000 Kr (\$620,800; 1971) and the cost of the heating facility was 2,400,000 Kr (\$323,900; 1971) for a total cost of about 7,000,000 Kr (\$944,700; 1971 or \$1,437,600; 1976)²⁸ (see Exhibit 11). The largest expenditures were made in 1970/71 (28 percent of the total cost) and in 1971/72 (55 percent of the total cost) as shown in Exhibit 12.

Of the total cost of the incinerator, 50 percent went for construction and 37 percent for mechanical equipment. For the heating facility, construction costs were 37 percent of the total and mechanical equipment costs were 56 percent. The estimated value of the land is 240,000 Kr (\$32,400; 1971) or 3 percent of the total cost of the plant (see Exhibit 11).²⁸ There was no subsidy from the national government. The plant was financed entirely by municipal funds; no loans were necessary.²⁹

Organization Chart for the Incinerator and District Heating Facility

SOURCE: Personal communication with Mr. Samer.

Capital Costs, 1966-1973

Incinerator		
Land	172,324.45 Kr	
Building	2,344,765.87 Kr	
Equipment	22,853.65 Kr	
Mechanical installation	1,699,861.60 Kr	
Design and other	382,071.57 Kr	
Total, Incinerator	4,621,877.14 Kr	
District Heating Facility		
Land	67,310.63 Kr	
Building	915,874.99 Kr	
Equipment	8,926.73 Kr	
Mechanical installation	1,303,624.69 Kr	
Design and other	149,238.70 Kr	
Total, District Heating Facility	2,444,975.74 Kr	
Total	7,066,852.88 Kr	\$953,700 (1971 dollars)

SOURCE: Municipal Report, Project Account for Incinerator District Heating Facility

**Dates of Expenditures by the Municipality
for the Incinerator and District Heating Facility**

1966/67	2,969.12 Kr	
1967/68	2,811.33 Kr	
1968/69	14,675.10 Kr	
1969/70	493,283.70 Kr	
1970/71	1,935,367.73 Kr	
1971/72	3,916,504.73 Kr	
1972/73	659,241.17 Kr	
Reserve fund for major repairs	42,000.00 Kr	
Total	7,066,852.88 Kr	\$953,700 (1971 dollars)

SOURCE: Municipal Report, Project Account for Incinerator District Heating Facility.

For amortization purposes, the life expectancy of different components is assumed to be:

buildings:	33 years	3 percent amortization rate
equipment:	12.5 years	8 percent amortization rate
machinery:	12.5 years	8 percent amortization rate

Thus, the cost of amortization for the plant is 220,000 Kr (\$36,360; 1976) per year.²⁸

Although there was no financial cost because the municipality used funds on hand, the municipality applies an opportunity cost of nine percent to the portion of the cost which has not been yet amortized. This opportunity cost will be 315,000 Kr (\$52,070; 1976) for the operating year 1976/77. Adding the opportunity cost to the cost of amortization gives a total capital cost of 535,000 Kr (\$88,430; 1976) to the operating year 1976/77.

DIRECT OPERATING COSTS

The cost of operation of the incineration plant is reported by the municipality to be 943,164 Kr (\$154,100) for the operating year 1975/76 (see Exhibit 13).²⁹ This figure includes 77,000 Kr (\$12,600) for administration of the Incinerator and District Heating Works (part of the salary of the Chief Mechanical Engineer and his secretary). The administrative offices are not located in the plant.

Exhibit 13

Direct Operating Costs for the Incineration Plant, 1975/76

Salaries for operating personnel	464,654 Kr	
Salaries for administrative personnel (part of joint expenses)	63,000 Kr	
Pension fund	14,307 Kr	
Taxes and insurances	10,211 Kr	
Maintenance of building	15,044 Kr	
Maintenance of mechanical installation	152,784 Kr	
Electricity and water	70,178 Kr	
Office expenses (part of joint expenses)	12,138 Kr	
Removal of ash	25,848 Kr	
Value added tax	115,000 Kr	
Total	943,164 Kr	\$154,100 (1975/76 dollars)

SOURCE: Data taken from municipal reports.

Salaries make up 57 percent of direct operating costs. The average salary of a worker at the plant is about 65,000 Kr (\$10,620) per year, while the salary of the Chief Mechanical Engineer is about 150,000 Kr (\$24,510) per year.²⁹ Maintenance of the building and mechanical installations accounts for 18 percent of total operating costs and taxes represent 13 percent of total operating cost.

The direct operating costs according to the city's figures would be either 134 or 157 Kr per metric ton (\$19.90 or \$23.40 per short ton) incinerated, depending upon whether it was assumed that 6,000 or 7,000 metric tons (6,600 or 7,700 short tons) of waste were incinerated.

However, these official figures are too high, as the salary account covers all personnel working in the plant. According to the director, his employees spend 75 percent of their time working on the incinerator and 25 percent working on the heating facility. If, therefore, we allocate 75 percent of the salaries to the incinerator and 25 percent to the heating facility, we arrive at a total cost of 827,000 Kr (\$136,700) or a cost per ton incinerated of between 118 and 138 Kr per metric ton (\$17.50 or \$20.40 per short ton), depending upon assumptions of tonnage.

The fees paid by private companies which bring their waste to the plant to be incinerated should be subtracted from this figure. In 1975/76, revenues from these fees were estimated at 20,275 Kr³² (\$3,350) or about 20 Kr (\$3.30) per truckload. This reduces the cost by approximately 3 Kr (\$0.50) per ton incinerated.

A figure representing the value of the heat recovered from waste should also be subtracted. The municipality has never made an estimate of this amount.

In 1975/76 the town sold 21,283 kth of heat at a total price of 1,958,000 Kr (\$320,100) or 92 Kr (\$15.21) per kth. The amount of heat exported from the plant was 27,843 kth (1.1×10^{11} Btu) of which 7,046 kth (2.8×10^{10} Btu) were produced from waste. It is estimated that the operating cost of the heating facility alone amounts to roughly 1,410,000 Kr (\$230,400) in 1975/76 of which 84 percent represents fuel costs.

It is also necessary to estimate the capital cost of the heating facility. The amortization rate is estimated at 93,000 Kr (\$15,200; '75-'76) based on a depreciation rate of three percent (33 years) for the building, eight percent (12.5 years) for the equipment and five percent (25 years) for the mechanical installation. To this amortization rate has been added a financial cost of 9 percent per year of the portion of the cost which has not yet been amortized or 184,000 Kr (\$30,065; '75-'76).

We estimate that the cost of producing approximately 21,000 kth (8.34×10^{10} Btu) in the heating plant is 1,687,000 Kr (\$275,650; '75-'76) or 80 Kr (\$13.10) per kth. Consequently we estimate the value of the 7,000 kth recovered from waste in 1975/76 at 560,000 Kr (\$91,500) or 80 to 93 Kr per metric ton (\$11.90 to \$13.80 per short ton) incinerated, again depending upon which assumption of quantity is adopted.

If we deduct the revenues received from private companies and the estimated figure for the value of the heat recovered from the direct operating cost of the incinerator, we arrive at an operating cost of 246,725 Kr (\$40,800; 1976) or 35 to 41 Kr per metric ton (\$5.20 to \$6.10 per short ton) in 1975/76 depending upon the assumption about the quantity of waste incinerated.

OVERALL COSTS

The total cost of incineration to the municipality can be obtained by adding the capital cost of 535,000 Kr to the operating cost of 246,725 Kr. This gives a total cost in 1975/76 of 781,725 Kr. This equals 112 Kr per metric ton (\$16.30 per short ton) based on the assumption of 7,000 metric tons treated or a total cost of 130 Kr per metric ton (\$19.40 per short ton) based on the assumption of 6,000 metric tons treated. An average value would give a total cost of incineration of about 120 Kr per metric ton (\$18 per short ton). Exhibit 14 summarizes the overall cost.

The figure of 120 Kr per metric ton is only a rough estimate, as it was necessary for RPA to allocate joint costs between the incinerator and heating facility. This figure will decrease as the financial cost (which is an important element of the total cost) was obtained by applying a nine per-cent opportunity cost to the portion of these costs which has not been depreciated.

Surprisingly the municipality has not tried to evaluate these costs. As a result, fees for the incineration of waste and charges for the sale of heat do not represent the true costs. For example, district heating, which is less expensive than individual gas or electric home heating, does not cover the cost of recovering the heat. Also the price that private companies pay for the treatment of their waste is far from covering the total cost of incineration or even the operating cost of the incinerator.

Exhibit 14

Overall Cost of Incineration

	<u>Kr</u>	<u>\$ (1976)</u>
Capital Costs		
Amortization	220,000	36,360
Opportunity Cost (9%)	<u>315,000</u>	<u>52,070</u>
	535,000	88,430
Operating Costs		
Direct Operating Cost	827,000	136,700
Less: Revenue from private generators of waste	20,275	3,350
Estimated value of heat from waste	<u>560,000</u>	<u>92,550</u>
	246,725	40,800
Total Cost	<u><u>781,725</u></u>	<u><u>129,230</u></u>
Cost per Ton (on the basis of 6,500 metric tons per year)	120 Kr/metric ton	\$18/short ton

SOURCE: Data taken from municipal reports.

NOTES

1. Personal communication, Mr. Samer.
2. Personal communication, Mr. Alex Boisen.
3. Personal communication, Mr. Samer.
4. Municipal records.
5. RPA estimate based on municipal records.
6. *ibid.*
7. Municipal budget.
8. The cost of maintaining the landfill rises to 70 Kr per ton if construction waste is excluded.
9. Personal communication, Mr. Samer.
10. Personal communication, Mr. Jensen, Vice-Mayor of Kørør, Member of the Council and Chairman of the Technical Committee.
11. Personal communication, Mr. Samer.
12. Personal communication, Mr. Jensen and Mr. Samer.
13. Municipal reports.
14. Personal communication, Mr. Samer.
15. Personal communication, Mr. Jensen.
16. Personal communication, Mr. Samer.
17. Personal communication, Mr. Boisen.
18. All data provided by the manufacturer.
19. Data provided by Mr. Riegels Jensen, Plant Manager.
20. Data taken from plant records.

21. Personal communication, Mr. Riegels Jensen, Mr. Boisen.
22. Plant records.
23. Personal communication, Mr. Riegels Jensen
24. Data supplied by the manufacturer.
25. Personal communication.
26. Personal communication, Mr. Samer and Mr. Boisen. A visit to the Albertslund incinerator confirmed this.
27. Personal communication, Mr. Riegels Jensen.
28. Municipal Report - Project Account for Incineration - District Heating Plant.
29. Municipal records.

BRUUN & SØRENSEN A/S

Address.

Bruun & Sørensen A/S, Aarhus
Aaboulevarden 22, 8000 Aarhus C, Denmark

Brief History of the Company

Bruun & Sørensen was established in 1893 as a one man business, and became a limited company in 1937. Since 1972 the share capital has been held by the present directors together with 15 of the senior staff.

Turnover 1974

360,500,000 Kr

Number of Employees

1300

Board of Directors

G. Løber Chairman
Mrs. A. Hammer Sørensen
IB Bjerregaard
Poul Jensen
Sven Rasmussen

Offices

Branch offices: Copenhagen, Fredericia and Aalborg.
Subsidiary companies in: Denmark, Germany, United Kingdom, Sweden, Switzerland, Spain, and Kenya.
Licensees in: France and Italy

Activities

Main departments:
mechanical services
fire fighting systems
building design
waste treatment
sludge treatment and refuse conveyance
district heating
electrial installations

Waste Treatment Department, Aarhus

Manager: SA Alexandersson

This department designs, constructs and installs waste treatment plants such as municipal incinerators, shredders and industrial incinerators. Their incinerators can be equipped for materials and heat recovery. The company has built 70 incineration plants (the majority in Scandinavia) since 1964.

District Heating Department, Aarhus

Manager: W. Mikkelsen

This department designs and builds complete district heating systems. It has installed district heating systems in more than 125 towns and cities in Denmark since 1927.

CONVERSION TABLES

English to Metric Conversions

<u>To Convert</u>	<u>Multiply By</u>	<u>To Obtain</u>
ton (short)	.9078	ton (metric)
feet	.3048	meters
square feet	.0929	square meters
cubic feet	.0283	cubic meters
cubic yards	.7646	cubic meters
gallons	.003785	cubic meters
square miles	2.59	square kilometers
atmospheres	1.0133	bars
British thermal units	.252	kilocalories
British thermal units	2.52×10^{-7}	kilotherms
British thermal units	1055	joules

Metric to English Conversions

<u>To Convert</u>	<u>Multiply By</u>	<u>To Obtain</u>
ton (metric)	1.102	ton (short)
meter	3.281	feet
square meter	10.76	square feet
cubic meter	35.31	cubic feet
cubic meter	1.308	cubic yards
cubic meter	264.2	gallons
square kilometer	0.386	square miles
bar	0.987	atmospheres
kilocalorie	3.9685	British thermal units
kilotherm	3.97×10^6	British thermal units
joule	9.486×10^{-4}	British thermal units
kilowatt-hour	1.1	Therms

Danish Kröner to U.S. Dollars

<u>Year</u>	<u>Kr/\$</u>
1969	7.52
1970	7.50
1971	7.41
1972	6.98
1973	6.28
1974	5.65
1975	6.18
1976	6.05

Source: "International Financial Statistics" International Monetary Fund.

Abbreviations

k	Kilo	thousand
M	mega	million
G	giga	billion
m	milli	one thousandth