**EUROPEAN WASTE-TO-ENERGY SYSTEMS,
CASE STUDY OF MUNICH:
MUNICH NORTH IA & IB
MUNICH NORTH II
MUNICH SOUTH IV & V**

**RESOURCE PLANNING ASSOCIATES, INC.
WASHINGTON, D.C.
AND
CONSULTEX, S.A.
GENEVA, SWITZERLAND**

Date Published - May, 1977

**PREPARED FOR THE
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Buildings and Community Systems**

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Work Performed Under Contract No. EC-77-C-01-2103

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PREFACE

Few cities have made bolder experiments in the recovery of energy from waste than has Munich. Since 1960, this city has built five waste incinerators which capture energy as steam, hot water, or electricity for the city's grid. Furthermore, these five incinerators represent three radically different (and innovative) designs. All, however, fire waste and the fossil fuel to co-generate heat and electrical energy.

This combination has not proved completely satisfactory. The facilities are operated by the municipal Electricity Works, an organization which sees its primary mission as the generation of electricity, not the reduction of the volume of waste. Viewed from their perspective, these combined facilities present major problems. Therefore, the new waste treatment capacity which Munich is about to add will consist of incinerators which burn only waste and which drive smaller turbo-generators. It is hoped that this new capacity for the generation of electricity will be well suited to the city's unusual load characteristics.

These case studies of the Munich incinerators are part 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 German marks 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.

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PERSONS CONTACTED

RPA and its subcontractor, Consultex, wish to thank the following individuals and their parent organizations for their cooperation in providing information about the incinerator plants in Munich.

Mr. Franz	Newly appointed head of Planning for the Heat Section of the Electricity Works, Munich.
Mr. Albat,	Newly appointed head of Operations and Maintenance of all of the Thermal Power Plants in Munich.
Mr. Schroeder,	Head of the Economic Group of the Heat Group of the Electricity Works.
Mr. Kraus,	Director of the Munich North Plant.
Mr. Stache,	Statistical Department of the Electricity Works.
Mr. Walter Martin,	Director of Josef Martin Feuerungsbau GmbH, major suppliers of equipment to the three plants.

Special thanks are due to:

Mr. Eugen Stelze,	Former director of Operations and Maintenance of all of the thermal power plants in Munich - who served as a consultant to Consultex for this study.
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and:

Mr. Dieter Kreuch,	Engineer of Josef Martin Feuerungsbau GmbH, who helped with arranging visits and with furnishing <u>information</u> about the plants.
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SUMMARY

The City of Munich, capital of the West German *Lande* of Bavaria, has a population of 1,315,000. Solid waste is collected by a city department and delivered to the city's own Electricity Works. The Electricity Works incinerates the waste in five incinerators in two separate locations (the North and South plants).

Munich's five incinerators represent three different designs for co-generation of heat and electrical energy. All burn both waste and fossil fuel and all use Benson boilers to produce steam at 184 bars (181.5 atm) and 540°C (1,000°F). The Electricity Works recovers energy in the form of electricity, hot water, and steam. Ash, bulky objects, and non-incinerable waste are dumped on a "garbage mountain" within the city limits.

The first design (North IA and IB) has two separate fireboxes (one burning waste, the other coal), but a shared boiler in each incinerator. The second design (North II) burns both waste and coal in one firebox for one boiler. The third design (South IV and V) has separate fireboxes for waste and fossil fuel, and separate boilers. The waste fired boiler in this arrangement is used as an economizer for the fossil-fuel-fired main boiler. All the plants use Martin grates and Babcock boilers. The designs were developed by the suppliers and city engineers working with planners from the Electricity Works.

The system's priority is to produce electricity for the city grid rather than to treat waste. The hot water and steam produced are used in district heating. The system is peakloaded both for electricity and for district heating, and, as a result, is operated with some diseconomy.

Over 450,000 metric tons (495,700 short tons) of waste were burned in 1975. That amount represents practically all the solid waste collected in Munich (only bulky objects are not incinerated). A shredder with a capacity of 30,000 metric tons (33,000 short tons) per year will be added in 1977 and this will allow for even more complete incineration in the future. Technical data on all the units are shown in Exhibits 1 - 3.

Waste is collected once a week, and both private and industrial and commercial generators pay the city an all-inclusive fee based on volume. Part of this fee goes to pay for collection and part goes towards the difference between the total costs of incineration and the revenue earned from the sale of energy and scrap metal. The rates charged appear to be far below actual costs of incineration, which suggests that the sale of electricity is subsidizing the cost of incineration.

Munich North IA and IB Units Technical Data

(Designed characteristics per unit)

	Metric System	English Equivalent
Daily waste burning capacity	600 metric tons	661 short tons
Hourly waste burning capacity	25 metric tons	27.5 short tons
Heat content of waste	900-1800 kcal/kg	1619-3238 Btu/lb
Guaranteed performance	25 metric tph at 1500 kcal/kg	27.5 short tons per hou at 2700 Btu/lb
Grate area	56.1 m ²	603.6 sq ft
Grate width	6.7 m (three grate runs)	22 ft
Steps per grate	17 (8 fixed, 9 moving)	
Maximum steam rate	100 metric tons per hour	110 short tons
Maximum pressure	205 bars	202.3 atm
Working pressure	184 bars	181.4 atm
Fresh steam temperature	540°C	1000°F
Fresh steam pressure	182 bars	179.6 atm
Feed water temperature	250°C	482°F
Flue gas particle content after the electrostatic precipitator	30 mg/m ³ at 8% CO ₂	
Turbine unit maximum continuous rating	68 MW	
Turbine normal operating rating	62 MW	
Turbine steam inlet pressure	181 bars	180.7 atm
Designed heat from waste	40%	
Designed heat from fossil fuel	60%	
Flue gas temperature		
—coal only	120°C	248°F
—coal and waste	140°C	284°F
Boiler efficiency		
—coal only	92%	
—coal and waste	83%	
—waste only	72%	
Fuel characteristics: coal		
—heat content	7000 kcal/kg	12,600 Btu/lb
—ash	5%	
—water	8%	
Fuel characteristics: municipal waste		
—heat content	1500 kcal/kg	2700 Btu/lb
—ash	20-25%	
—water	28-33%	

Munich North II Incinerator*

Technical Data

	Metric System	English Equivalent
Daily waste burning capacity	960 metric tons	1050 short tons
Hourly waste burning capacity	40 metric tons	44 short tons
Heat content of waste	900-2000 kcal/kg	1619-3600 Btu/lb
Grate area	100.6 m ²	1082.4 sq ft
Grate width	11.3 m (five runs)	37 ft
Steps per grate	17 (8 fixed, 9 moving)	
Maximum steam rate	365 metric tons per hour	402 short tons
Maximum pressure	205 bars	202.3 atm
Working pressure	184 bars	181.5 atm
Live steam temperature	540°C	1000°F
Live steam pressure	182 bars	179.6 atm
Feed water temperature	266°C	511°F
Flue gas particulate matter content after electrostatic precipitation	18 mg/m ³ at 8% CO ₂	
Turbine unit maximum continuous rating	112 MW	
Turbine normal operating rating		
Turbine steam inlet pressure	181 bars	180.7 atm
Designed maximum heat from waste	20%	
Designed heat from fossil fuel	80-100%	
Flue gas temperature		
—waste only	178°C	352°F
—waste/coal	165°C	329°F
Boiler efficiency		
—coal and waste	89.7%	
—waste only	81.4%	
Furnace efficiency		
—combined firing	98.3%	
—waste only	94.1%	
Unburned matter in ash		
—combined firing	1.65%	
—waste only	1.51%	
Organic matter in ash		
—combined guarantee	0.3%	
—combined tested	0.064%	
—waste only guarantee	0.3%	
—waste only tested	0.025%	
Fuel characteristics: coal		
—ash	6.56%	
—heat content	7155 kcal/kg	12,900 Btu/lb
Fuel characteristics: waste		
—ash	35%	
—heat content	1530 kcal/kg	2750 Btu/lb

*The characteristics of the North II incinerator were defined by tests performed upon acceptance in May 1968. Tests were conducted by TÜV Bayern.

Munich South IV and V Units Technical Data

(Designed characteristics per unit)

	Metric System	English Equivalent
Daily waste burning capacity	960 metric tons	1050 short tons
Hourly waste burning capacity	40 metric tons	44 short tons
Heat content of waste	900-2000 kcal/kg	1619-3600 Btu/lb
Guaranteed performance	40 metric tph at 1500 kcal/kg	44 short tons per hour at 2700 Btu/lb
Grate area	101 m ²	1087 sq ft
Grate width	11.3 m (5 runs)	37 ft
Steps per grate	17 (8 fixed, 9 moving)	
Maximum steam rate	365 metric tph	402 short tons per hour
Maximum pressure	205 bars	202.3 atm
Working pressure	181 bars	180.7 atm
Live steam temperature	535°C	995°F
Live steam pressure	181 bars	180.7 atm
Feed water temperature	260°C	500°F
Flue gas particulate content after the electrostatic precipitator	105 mg/m ³ at 7% CO ₂	
Turbine unit maximum continuous rating	124 MW	
Turbine normal operating rating	110 MW	
Turbine steam inlet pressure	180 bars	179.7 atm
Designed heat from waste	20%	
Designed heat from fossil fuels	80-100%	
Flue gas temperature		
—natural gas only	120°C	248°F
—gas and waste (mixed)	175°C	347°F
Boiler efficiency		
—gas only	93.5%	
—gas and waste	84%	
Fuel characteristics: waste		
—heat content	1500 kcal/kg	2700 Btu/lb
—water content	30%	
—ash content	34%	
Fuel characteristics: gas		
—heat content	8600 kcal/m ³	967 Btu/cu ft

The entire North plant (IA, IB, and II) cost 151.1 million DM (\$37.8 million; 1960-1966 or \$88.3 million; 1976). The waste treatment section is estimated to have cost 25.8 million DM (\$6.45 million; 1960-1966 or \$10.2 million; 1976). The entire South plant (IV and V) cost 140.7 million DM (\$39.2 million; 1969-1971 or \$67.9 million; 1976). The waste treatment section cost 35 million DM (\$9.8 million; 1969-1971 or \$13.5 million; 1976). Official figures show the average cost per metric ton of waste treated (after deductions for the sale of the energy recovered) to be 18.75 DM (\$6.92 per short ton) at the North plant and 18.50 DM (\$6.83 per short ton) at the South plant. We feel that these operating costs are serious underestimations, and that the correct figures are approximately 53 DM per metric ton (\$19.56 per short ton) at the North plant and 41 DM per metric ton (\$15.13 per short ton) at the South plant.

None of the designs has proved entirely satisfactory and for its new solid waste treatment facilities, Munich will be building incinerators which burn waste only.

INTRODUCTION

ECONOMIC AND DEMOGRAPHIC DATA

The city of Munich comprises most of the area of *Landkreis München* and is the capital of the *Lande* of Bavaria, the extreme southeastern state of Federal Republic of Germany. The city of Munich covers a roughly oblong area of 310 square kilometers (120 sq m) has a perimeter 117 kilometers (73 m) in length, and is situated at an average altitude of 530 meters (1739 ft) above sea level. The city is generally flat and in its eastern part, the Isar River flows through it. The two incinerator plants are situated on this river, about 20 kilometers (12.4 m) apart.

The population of the city of Munich at the end of 1975 was 1,315,000. The city contains 546,500 dwellings within 101,200 residential buildings. There are a couple of neighboring communities for which domestic solid waste is also treated. This adds an additional several thousand persons to the total served by the city plants. The population density of the city of Munich is 4,242 inhabitants per square kilometer (10,986 per sq m).

The total gross volume of business of the city of Munich in 1974 was 84.0 billion DM (\$32.4 billion). This represents a per capita turnover of 64,000 DM (\$25,500). Average incomes are relatively high compared to most other countries in Europe, and total family incomes tend to be even higher due to a large number of working wives.

There are about one thousand manufacturing companies in Munich with 750 plants of various sizes. However, there is little heavy industry. Much of the activity is confined to office and administrative work, light industry, handicrafts, tourism, and the production of some very good beer.

WASTE COLLECTION AND TREATMENT

Exhibit 4 shows graphically how the generation of incinerable solid waste has evolved in Munich since 1965. The volume increased from 960,000 m³ (1,255,000 cu yds) in 1965 to 1,340,000 m³ (1,724,000 cu yds) in 1975. By weight, incinerable solid waste grew from 180,000 metric tons (198,300 short tons) in 1965 to about 450,000 metric tons (495,700 short tons) in 1975.

Quantity of Solid Waste Collected and Burned Since 1965

* To convert cubic meters to cubic yards, multiply by 1.3.

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

This incinerable waste came from households and other private generators (commercial and industrial) in the following amounts:

Source of Incinerable Solid Wastes

<u>Year</u>	<u>Households</u>	(metric tons)*	
		<u>Other Private</u>	<u>Total</u>
1970	296,368	51,618	347,986
1971	297,861	48,134	345,995
1972	339,781	92,208	431,989
1973	359,716	84,172	443,888
1974	373,586	69,331	442,917
1975	377,626	72,501	450,127

There are no facilities at the present time for the burning of oversized incinerable waste. This is estimated to represent about 40-50,000 metric tons (44-55,000 short tons) per year which are at present being dumped.

Large sized and non-burnable solid waste amounted to 480,000 m³ (627,800 cu yds) in 1975. The corresponding figures were estimated to have been 407,000 m³ (532,300 cu yds) in 1973 and 493,000 m³ (644,800 cu yds) in 1974.

Household waste is collected by a special department of the city of Munich, the *Städtische Müllbeseitigung*. There are 150 packer trucks (MAN/Ochsner) having a capacity of 10 m³ (13 cu yds) or 4-5 metric tons (4.4-5.5 short tons) of waste each. The collection department employs 655, including 213 drivers and 38 vehicle repair personnel. The work week is 42 hours.

Collections are made from Monday morning through Friday afternoon. All of the waste collected is delivered to the two refuse incineration plants (Munich North and Munich South) where the trucks empty their loads into storage pits. Lack of storage capacity at the Munich South plant forces suspension of deliveries of waste to this plant early in the day on Friday.

All other waste, including oversized burnable waste, is hauled to a controlled dump (a veritable garbage mountain). Incinerator ash is also hauled from the two plants to this dump. Almost no burnable waste (other than large size pieces) is now dumped.

* One metric ton equals 1.1 short ton.

The *Städtische Müllbeseitigung* charges private and public generators of wastes an overall collection and treatment charge on the basis of the volume of waste collected. This price includes a waste treatment charge which is calculated by the city Electricity Works. This fee is paid by the waste collection agency to the Electricity Works as it is collected from households.

Certain forms of commercial and industrial waste are also treated if they are similar to household waste. The rates for this waste are the same as for household waste.

The collection and treatment charges are calculated for a three year period on the basis of recent costs and forecasts of the likely evolution of these costs. The principle is that all costs are to be met by the producers of the waste and there is to be neither subsidy nor profit by the city.

As of January 1, 1971, private householders paid 84 DM (\$24.13) a year to have a 110 litre (3.9 cu ft) box emptied once per week. This increased to 115.20 DM (\$43.15) per year in October 1973, and to 134.40 DM (\$53.33) per year in January 1976 (see Exhibit 5). The charges for larger containers are proportionally smaller, but distance is not a factor in the rates.

The Electricity Works calculates the real direct and indirect costs of burning waste over a three year period and deducts the value of the heat produced by the burning of these wastes. The difference is credited to the Electricity Works and paid from the fees collected by the waste collection agency. The treatment fees are not recalculated at the same time as the changes in the collection charges, and usually begin one year after the collection charges have been established for a 2-3 year period.

POLITICAL STRUCTURE OF SOLID WASTE COLLECTION AND TREATMENT

Exhibit 6 outlines the chain of command for administrative and operational control of the collection and treatment of solid waste in Munich. The city is run by its own government under the control of a mayor and several deputy mayors. They sit with other city counselors in a committee and supervise many administrative subdivisions called *Referats*. One of these is the *Werksreferat*. This organization groups city transportation, gasworks, waterworks, city baths, and finally the Electricity Works.

The Electricity Works is broken down into an electricity section and a heat section. The former generates and distributes electricity, the latter operates the thermal power stations and the central heating plants and also incinerates waste. Within this heat group, there are an operating manager and a planning manager. The first controls all incinerator plants. The second supervises the expansion plans for new plants.

Recent Waste Collection and Treatment Charges in Munich

(in Deutsche Marks)

Container Sizes	Total Collection and Treatment Charges ¹			Treatment Charges Alone ²			
	1/1/71 to 9/30/73	10/1/73 to 12/31/75	1/1/76 to Present	Up to 12/31/69	1/1/70 to 12/31/72	1/1/73 to 12/31/75	1/1/76 to Present
110 litre box per week	7/mo 84/yr	9.60/mo 115.20/yr	11.20/mo 134.40/yr	0.80 DM per cubic meter, which was the old cost of landfilling	10.80 DM per metric ton burned	18.80 DM per metric ton burned	Not yet calculated
1.1 cubic meter box per week	58.50/mo 702/yr	80.20/mo 962.40/yr	89.50/mo 1,074/yr				
11 cubic meter box per week	475/mo 5,700/yr	650/mo 7,800/yr	650/mo 7,800/yr				
22-25 cubic meter box per week	—	—	1,105/mo 13,260/yr				
8 cubic meter box of compressed waste per week	605/mo 7,260/yr	780/mo 9,360/yr	780/mo 9,360/yr				
Smaller size pressed container waste per m ³ per week	75/mo 910/yr	45/mo 540/yr	45/mo 540/yr				

1 Charges actually paid by households and businesses to the city collection agency.

2 Credited to the electricity works by the city for waste treated by the electricity company.

Conversion rates:	Year	DM/\$
	69	3.69
	70	3.64
	71	3.48
	72	3.19
	73	2.67
	74	2.59
	75	2.46
	76	2.52

Administrative Structure for Solid Waste Disposal in Munich

THE DEVELOPMENT OF THE SYSTEM

Prior to the decision to burn municipal waste, the city of Munich dumped its waste in a large open area to the north of the city center. During and after World War II, a private recycling company used to hand pick through this waste and recover various types of materials for resale.

In the early fifties, this landfill was closed for economic reasons and all waste was dumped in an area which eventually became known as the "garbage mountain" for its prodigious size. This mountain became more and more offensive, often catching fire, and generally the source of particulate matter that would be picked up by the wind and spread throughout the vicinity. Eventually, there was insufficient dirt to cover the mountain if future deposits were made at the same rate. Thus, incineration seemed imperative.

At the same time, the city was engaged in planning a new thermal electric power station for the north of the city which would also provide district heating for a new development area. Having to solve two different problems at the same time led the city's political leaders to think that there could be some common solution which would not only get rid of the waste (at least in part) but also provide some fuel value. The political leaders and the head of the *Werksreferat* decided to have the electricity works incinerate waste along with fossil fuels in a combined plant for electricity generation and district heating.

No convenient land was available for this new facility within the city limits, but land was available just outside along the Isar Canal. This location, to the east of the city, was especially suitable because the prevailing wind blows from the west. The canal would provide the necessary water and there was room for a large fleet of trucks to bring waste.

The head of the Munich *Werksreferat*, having decided upon this solution, took a team to visit municipal incinerator plants throughout Europe. He was particularly concerned with the problems of smell and particulate matter in the air.

Siemens, a Munich-based company (and the eventual supplier of the electrical equipment), assisted the city in the planning for the new units. It was decided to order units designed for the efficient generation of electricity with the waste burning capacity as a secondary consideration. Benson boilers were specified. It was also decided to order two incinerators connected to a single turbo-generator so that either furnace could be shut down for cleaning and maintenance while keeping the electrical generation in process. A request for proposals was issued and responses were received from a number of suppliers including Von Roll, Babcock, Volund, and KSG. Martin, another Munich-based firm, was an obvious consideration for combustion equipment.

The final decisionmaking process is unknown, but eventually the city itself contracted with individual suppliers for the first unit of the Munich North I plant. Siemens received the general contract for construction, etc. Martin was selected to supply the grate, Babcock the boiler, and Lurgi the electrostatic precipitators. Siemens, the general contractor, also supplied the turbo-generators. This plant was ordered in 1960 and the first unit, IB, was commissioned in June 1964. For the second unit, IA, the city decided to have the individual component suppliers work as subcontractors. The grates were selected and delivery made through the boiler suppliers. Martin thus became a sub-contractor to Babcock for IA.

No alternatives for the operation of the plant were considered, as it was decided at the beginning that it would be integrated into and controlled by the Electricity Works. The city arranged the financing, partly from its own resources, and partly from bank loans.

The decision was initiated by the planning section of the Electricity Works' heat group. It was then approved all the way up to the City Council which gave the final approval. The city architects also approved the plans. A public announcement of the planned investments was made in the press, and the public had the right to comment on these projects. There was no public referendum or organized participation in the decision.

Even while the first two units of the Munich North plant (IA & IB) were being built, it was obvious that the capacity would not match the expected rise in the volume of waste collected. Also, as new areas were attached to the district heating networks, the amount of waste rose both in volume and in heat content (because paper and other burnable matter was no longer burned in homes).

By 1963, when planning for the expansion of the plant began, newer and larger turbines were available. It was decided to install a 120 MW turbine which meant that a larger boiler was required. The unit chosen was based upon an entirely new concept: burning waste and fossil fuel together in the same furnace with a lower relative contribution of heat from the waste, and with a much larger grate than had ever been used before. Early experience of the North I units indicated that there were no major cleaning problems as a result of the burned waste, and that higher temperatures were possible from the burning waste. As in the case of the original North units, there was a conscious decision on the part of the city Electricity Works and municipal authorities to continue experimenting with radically new plant designs.

Bids were solicited and again there were several responses. Eventually Babcock again won the boiler contract and Martin was selected for the grates. This time, however, AEG, rather than Siemens, was selected for overall control of the project and for the supply of the turbines and generators. One reason was pressure from the federal government to provide work for AEG, as this company was based in Berlin and it was politically important for that city to thrive.

North II would be larger than North I, but would occupy the same building. This new unit was commissioned in May 1966.

At about the time the new North unit (North II) was commissioned, it was again necessary to plan an expansion of Munich's waste burning capacity. At the same time, the city's major priorities were to provide additional capacity for electricity generation and a district heating plant for a new region in the southeastern portion of the city at Perlach. The extra waste treatment capacity was needed because the actual operational capacity of the early North plants was lower than originally hoped. This was due both to higher heat content in the waste and to corrosion problems which were discovered. There was also increasing pressure to have the city accept more commercial and industrial refuse.

Once again an entirely new design was chosen. Two large incinerators were planned which would have completely separate waste and fossil fuel furnaces. The waste furnace served as an economizer unit for the fossil fuel furnace, but the latter was designed to operate totally independently if the waste furnace had to be shut down for any reason.

The North II plant was just coming into operation and there was a fear that the corrosion problems which were now quite evident and serious at the North IA and IB units would also occur on the North II plant. Thus, the North II design (which eventually was found to work quite well) was rejected for the South plants. Siemens was again selected to be the general contractor and the supplier of the turbo-generator unit. Martin was again selected to provide the grates and Babcock the boilers.

Munich South V was commissioned in April 1969 and South IV in July 1971. There are some slight design differences between these two units, mainly related to the size of the economizer in the waste-fired boiler and the size of the main boiler.

THE BASIC SYSTEM

The Munich North I incinerator complex consists of two Babcock/Martin furnaces located side by side, fed by common overhead cranes. Both units feed a common turbo-generator and both discharge gases into a common stack. This system co-generates heat and electrical energy.

Exhibit 7 shows a cross section of one of the furnace units. These Benson boilers, equipped with Martin reverse acting grates, have a nominal capacity of 25 metric tons (27.5 short tons) per hour for waste with heat value from 900-1,800 kcal/kg (1,619-3,238 Btu/lb). Steam at 184 bars (181.5 atm) and 540°C (1,000°F) feeds a 68 MW turbine. A re-heat phase is incorporated between turbine stages, and heat is also supplied to heat exchangers for producing 120°C (248°F) steam for district heating.

Waste is fired in the portion of the furnace which is on the left in this diagram, while pulverised coal is fired separately in the parallel chamber to the right of the waste firebox. The gases combine above the coal furnace and pass jointly through the two vertical portions of the boiler convection area. The gases finally pass through a Lurgi electro-static precipitator before escaping through the stack.

The collection trucks deposit waste in the large receiving bin. Overhead cranes, operated from a room where the operator can see the load level in each furnace intake hopper, lift the waste to the loading chutes. There is an automatic feed mechanism at the bottom of the loading chute which injects a controlled amount of waste to be burned.

This waste falls upon the uppermost layer of the Martin grate and starts to burn. The reverse action of the grate elements insures a very good burnout by continuously agitating the waste as it falls under gravitational force toward the ash roller. This roller controls the rate at which the ash falls into the quencher unit. The ash quenchers, also designed by Martin, consist of troughs where the ash and water combine. The ash is then pushed out of this trough onto a rubber conveyor belt which brings it to a separate building where ferrous material is magnetically separated. The remaining ash is stored and then hauled by truck to the city dump where it serves as cover for other waste.

The Martin grate has six inlet areas under each grate run which control the amount of air. There is a certain amount of backpressure resisting this inlet air for each stage of the grate to insure that uniform burnout takes place across the width of the grate. An air blowdown in the inlet manifold periodically removes the accumulated ash.

The plant site is 12 meters (39 ft) higher than the Isar Canal from which the condensor cooling water is drawn. A pump house contains three 12,000 m³/hr (3,170,400 gal/hr) pumps, two of which are on line to service

Section Drawing of Munich North I Incinerators

the entire installation (the two units of North I and the larger North II plant). The third pump is a reserve. The generator has a maximum output of 68 MW.

The plant was designed to operate in several different modes. The boiler can be operated at 100 percent capacity burning only coal. While there are evaporator and reheater tubes in the waste-fired furnace, there are also evaporator tubes and reheater tubes in the coal furnace and these are sufficient to deliver the necessary heat. The boiler can operate at the designed ratio of 40 percent of the heat input from waste and 60 percent from coal. Finally, the plant can operate with only the waste-fired portion. In this mode no electricity can be generated but heat can be delivered to the district heating plant.

In general, the boilers operate more than the waste-fired furnaces. For example, as of February 1, 1968, the IA boiler had operated 17,700 hours while the waste-fired furnace had operated only 13,500 hours. The ratio was similar for the IB unit.

Exhibit 8 shows the arrangement of the boiler elements in the North I units and traces the flow of feedwater through to final super-heated steam and the reheat passage. Exhibit 9 shows the basic steam flow and feedwater flow phases of the North I boiler and turbine combination. The turbine unit is composed of three sections. Steam from the outlet of the first section is mostly reheated before going to the remaining two sections of the turbine. Steam is drawn off at six intermediary stages for various purposes in addition to the reheat stage from the first part of the turbine series.

LEVEL OF AUTOMATION

The Munich North Plant I is highly automated. The crane operator sits in an insulated and isolated cabin from which he controls the operation of the crane. He can see the level in the loading hoppers directly.

The loading hoppers automatically feed waste to the furnaces on a mechanically controlled cycle. The rate can be varied by the furnace control operators in the central control room.

The stoker action is mechanically operated through gear boxes and arms powered by electric motors. These will eventually be replaced by hydraulic units. The stoker speed is also controlled automatically from the control room.

Oil mist lubrication of mechanical parts is controlled from a central unit and automatically applied where needed regularly. The ash roller speed is adjusted for proper operation of the ash quenching process and/or control of delay time on the grate.

Boiler Tube Arrangements in the Munich North I Units

1. Feedwater entry	13. Start-up drum	25. Reheater entry
2. Economizer Unit 3	14. Auxiliary outlet	26. Reheater pass 1
3. Economizer Unit 2	15. Emergency cooler	27. Reheater cooler 1
4. Support tubes 2	16. Superheater 1	28. Reheater pass 2
5. Ceiling wall tubes	17. Bypass ventilator	29. Reheater cooler 2
6. Support tubes in coal furnace	18. Auxiliary steam path	30. Reheater pass 3
7. Ceiling wall tubes	19. Cooler 2	31. Reheater outlet
8. Grate ceiling tubes	20. Superheater 2a	32. Air preheater tubes
9. Grate wall tubes	21. Superheater 2b	
10. Grate entry tubes	22. Cooler 3	
11. Evaporator tubes	23. Superheater 3	
12. Evaporator tubes	24. Live steam outlet	

Heat Flow in the Munich North I Units

a. Boiler	l. Feedwater tank and deaerator
b. Turbo-generator	m. High pressure heater II
c. Turbine for feedwater pump	n. High pressure heater I
d. Reheating in boiler	o. District heating heat exchanger
e. Main condensor	p. District heating heat exchanger
f. Feedwater pump turbine condensor	q. District heating hot water
g. Vacuum water heater	
h. Low pressure feedwater heater	
i. Low pressure feedwater heater	
k. Low pressure feedwater heater	

The air flow rate under the six areas of the grate runs is adjusted twice a year for winter and summer operation. It then runs by itself but is monitored from the central control room and from a gauge under each furnace.

Incineration requires very little direct labor on the furnace. One man is needed to watch for bulky items coming out the ash hoppers to keep from fouling these units. Otherwise, apart from the men in the crane room and in the ash treatment center, almost all of the activity takes place in a central, air conditioned room.

SYSTEM DESIGN REDUNDANCY

There is quite a bit of redundancy in the North I plant. In the largest sense, the presence of two incinerators feeding one turbine unit is a major redundancy for electricity generation. There are three cranes to insure that crane failure will not halt operation (actually, counting those of the North II unit in the same building, there are five cranes).

West German boiler codes are strict in requiring redundancy for pumps and accessories. The feedwater pumps must be at least 100 percent redundant throughout. For the main feedwater, the principal turbine-driven full load pump is supplemented by two half load pumps powered by three-phase electricity.

SYSTEM PERFORMANCE HISTORY

Exhibit 10 shows the operating characteristics of the two units of Munich North I. From the beginning of operations to the end of 1975, a total of 1,239,043 metric tons (1,304,885 short tons) of waste were burned. The average heat value of the waste increased from an initial 1,200 kcal/kg (2,160 Btu/lb) to over 1,800 kcal/kg (3,240 Btu/lb).

The IA unit has accumulated 38,030 hours of service while the IB unit (the first to enter in service) has accumulated 40,920 hours, as of the end of 1975. Neither unit, however, has ever been used for more than 52 percent of the number of hours theoretically available each year. This is due to a variety of reasons which will be discussed later.

The rate of incineration has varied considerably and declined steadily from a maximum of an average of 20 metric tons (22 short tons) of waste per hour of service in 1965 to only about 14 metric tons (15.4 short tons) per hour in 1975. This is also due to a variety of reasons, including the higher heat value of the waste and the corrosion which occurs at high rates of heat release.

Annual Operating Characteristics of Munich North Incinerators IA and IB

Year	Waste Burned (metric tons)*			Average Heat Value (kcal/kg)**		Hours in Service				Average Metric Tons Per Hour	
	IA	IB	Total	IA	IB	IA	%	IB	%	IA	IB
1964	19,401	29,839	49,240	1,178	1,178	1,057	12	1,624	19	18.4	18.4
1965	86,513	91,498	178,011	1,116	1,116	4,336	49	4,579	52	20.0	20.0
1966	81,133	74,892	156,025	1,394	1,394	4,355	50	4,020	46	18.6	18.6
1967	59,471	55,560	115,031	1,515	1,515	3,615	41	3,374	39	16.5	16.5
1968	54,034	68,771	112,805	1,478	1,478	3,137	36	3,985	45	17.2	17.3
1969	39,918	47,621	87,539	1,612	1,612	2,946	34	3,513	40	13.6	13.6
1970	51,364	54,979	106,343	1,594	1,594	3,446	39	3,690	42	14.9	14.9
1971	30,039	28,064	58,103	1,695	1,695	2,269	26	2,120	24	13.2	13.2
1972	47,211	50,736	97,947	1,782	1,782	3,745	43	4,032	46	12.6	12.6
1973	55,855	62,647	118,502	1,793	1,793	3,988	46	4,473	51	14.0	14.0
1974	35,967	47,066	83,033	1,712	1,712	2,534	29	3,316	38	14.2	14.2
1975	36,090	30,374	66,464	1,836	1,836	2,602	30	2,194	25	13.9	13.9
Total	596,996	642,047	1,239,043			38,030		40,920		15.7	15.7

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

**To convert kcal/kg to Btu/lb, multiply by 1.8.

MATERIALS AND ENERGY BALANCE

The Electrical Works personnel watch the materials and energy balance closely at all of their installations. Daily, monthly, and yearly energy balances are calculated. Material balances are calculated in terms of energy contributed each day. Ash content and scrap metal recovery calculations are made less frequently.

For the daily energy balance (see the daily operating report, Exhibit 15), the calculation is based upon known heat values of inputs of fossil fuels and from the known amount of heat recovered from the waste. An assumed heat content is used to estimate the amount of waste burned during the day. The annual balance takes the weight of the waste from known delivery volumes and calculates the actual heat content using assumed values for furnace efficiencies and for some of the losses.

Exhibit 11 shows the most recent annual energy balance for North I (units IA & IB combined) for 1975. The average heat input from waste was 25.6 percent of the total heat intake of the plant.

During the year, it took an average of 2,675 kcal (10,615 Btu) of heat to produce one kWh of electricity. If only fossil fuels had been used it is estimated that 2,645 kcal (10,500 Btu) would have been required while if only waste had been used 3,433 kcal (13,023 Btu) would have been required.

Using a conversion factor of 860 kcal/kWh, the actual operating efficiency of the plant with combined waste and fossil fuel firing was calculated at 32.2 percent. Firing only waste, the efficiency would have been 25.1 percent while firing only fossil fuel the efficiency would have been 32.5 percent.

The acceptance test values, measured boiler efficiency under various firing conditions, and an initial energy balance for a clean boiler are shown in Exhibit 12. The anticipated efficiency for waste only was 27.7 percent; actual performance in 1975 was 25.1 percent.

MAINTENANCE HISTORY, REPAIRS, AND MODIFICATIONS

The North I units were found to be severely corroded after about a year of operation. The most prevalent theory was that this was caused by HCl gas released in burning the waste. However, there were also problems from the alternating oxidizing/reducing atmosphere in the fire-box and from the variations in acid/basic composition of the gases in different parts of the air above the grates.

Energy Balance for the Munich North I Incinerator in 1975

Inputs	Metric System	English Equivalent
Coal		
Amount consumed	6956.5 metric tons	7663 short tons
Heat content	6905 kcal/kg	12,430 Btu/lb
Total heat	48,033 Gcal	1.91×10^{11} Btu
% total heat in	10	
Natural Gas		
Amount (volume)	34,369 thousand m ³	1213 million cf
Heat value	8878 kcal/m ³	997.8 Btu/cu ft
Total heat	305,132 Gcal	1.21×10^{12} Btu
% total heat in	64	
Oil (light oil)		
Amount consumed	183 metric tons	202 short tons
Heat value	10,200 kcal/kg	18,361 Btu/lb
Total heat	1867 Gcal	7.4×10^9 Btu
% total heat in	0.4	
Waste		
Amount consumed	66,464 metric tons	73,214 short tons
Heat value	1836 kcal/kg	3354 Btu/lb
Total heat	122,040 Gcal	4.84×10^{11} Btu
% total heat in	25.6	
Total heat input	477,072 Gcal*	1.89×10^{12} Btu*
Outputs	Metric System	English Equivalent
Electrical energy		
Total produced	173,499 MWh	
Delivered energy	160,148 MWh	
Self-consumed energy	13,351 MWh	
Self-consumed heat	15,602 Gcal	6.19×10^{10} Btu
Total heat in electricity and self usage	153,304 Gcal	6.08×10^{11} Btu
Total heat/heat in	32.1%	
District heat energy out (steam)	38,120 Gcal	1.51×10^{11} Btu
% total heat in	8	
Boiler losses (% heat in)	12.7	
Startup/shutdown losses (% heat in)	2.9	
Condensor and other losses (%)	44.2	
Total losses (% heat in)	59.8	
Total losses	285,648 Gcal	1.13×10^{12} Btu
Specific heat required for electricity production		
Fossil fuel only	2646 kcal/kWh	10,500 Btu/kWh
Waste only	3433 kcal/kWh	13,624 Btu/kWh

* Including 13,003 Gcal (5.16×10^{10} Btu) in a small separate part of the district heating circuit.

**Measured Boiler Efficiency and Energy Balance
of Munich North Incinerators IA and IB**

	Fuel Supplied			
	100% Coal	60% Coal	40% Waste	Mixture: 60% Coal 40% Waste
Boiler Losses and Boiler Efficiency* (percent)				
Unburned matter	2.0	3.3	6.5	} 11.5 6.6
Heat in ash	—	—	5.0	
Flue gas heat	5.6	4.7	15.0	
Radiation heat	0.4	0.6	1.1	0.7
Total boiler losses	8.0	8.6	27.6	16.1
Boiler efficiency	92.0	91.4	72.4	83.9
Energy Balance for a Clean Boiler in Full Operation				
Turbine efficiency (percent)	45.0	(45.0	45.0)	45.0
Self-consumption removed (percent)	92.5	(91.0	93.0)	91.8
Boiler efficiency (percent)	92.0	(91.0	72.0)	83.0
Combined (percent)	38.2	(37.3	30.2)	34.2
Heat-in per kWh (kcal)**	2250	(2300	2850)	2520
Heat-in including an 8.5% factor for unclean tubes, part loads, and startup/ shutdown (kcal)	2450	(2500	3100)	2740
Final expected efficiency (percent)	35.1	(34.4	27.7)	31.4

* Measured during acceptance tests for the Munich North I plant.

**One kcal = 3.968 Btu.

A partial solution, particularly for the visible corrosion on the lower part of the waterwall tubes in the waste-fired furnace, was to fix studs to the outer tube walls and hang silicon carbon insulation on them.

Corrosion was also found on the reheater tubes in the waste-fired furnace but nothing could be done to protect these. Additional corrosion was found in the superheater tube section and in the downdraft convection channel. This downdraft corrosion was attributed to overly high flue gas flow and particulate matter eroding and exposing the tube surfaces. The particulate matter from the coal fired boiler was too great because this furnace seems to be too small. Too much carbon ash is produced.

As a result, it has been necessary to replace tubes throughout the boiler far more often than was intended. Some of these have been thickened to prolong their lives, at a cost of some decrease in their heat absorption capacity. It has been found necessary to reduce the rates of steam generation and waste incineration to reduce the danger of too much corrosion.

Nowadays, since the North II unit performs much better than the North I (A & B), North I is shut down often, sometimes every evening and usually each weekend. This allows frequent inspection of the tubes and permits some minor repairs.

Another design problem is that Babcock did not install water wall tubes right down to the level of the grate. Thus, there are refractory walls part of the way up inside each waste firebox. This causes much more intense heat and subsequent ash fusing on the refractory walls, as well as higher gas temperatures at the evaporator tubes.

In addition to the changes made to protect the tubes in the waste firebox, the two North I incinerators have been modified in other ways. Gas burners were added in 1974 to allow the furnaces to burn cheaper fuel (gas from the Soviet Union is cheaper than West German coal). The system has also been modified to permit the bypassing of tubes in the waste portion, if necessary, for a short period so that waste burning and turbine operation can continue until the next planned shutdown. The fans were found to be too small and were replaced.

Exhibits 13 and 14 show the availability of the waste grates and furnaces for the IA and IB incinerators in 1975. Planned repair and maintenance accounted for 28 and 25 percent of the total available time respectively. Unplanned stoppages accounted for only 1 and 2 percent. The furnaces were actually in operation for 30 and 25 percent of the available hours, leaving them in reserve for 41 and 48 percent of the time (hours when they could have been used but weren't). The furnaces were left idle either because of lack of demand for electricity, or because of lack of waste to burn.

Availability of Munich North Incinerator IB in 1975 by Month
(Hours)

Month	Hours in Service	Planned Stoppages: Repair and Maintenance	Unplanned Stoppages	Reserve Hours	Total
January	—	—	—	744	744
February	—	—	—	672	672
March	—	744	—	—	744
April	—	720	—	—	720
May	—	720	—	24	744
June	558	—	—	162	720
July	253	—	72	420	744
August	281	—	7	455	744
September	113	—	—	607	720
October	276	—	—	468	744
November	450	—	—	269	720
December	263	—	73	408	744
Total	2194	2184	152	4229	8760
Percent	25	25	2	48	100

Exhibit 14

Availability of Munich North Incinerator IA in 1975 by Month
(Hours)

Month	Hours in Service	Planned Stoppages: Repair and Maintenance	Unplanned Stoppages	Reserve Hours	Total
January	235	—	—	509	744
February	230	—	—	442	672
March	—	744	—	—	744
April	—	720	—	—	720
May	—	744	—	—	744
June	106	264	—	350	720
July	464	—	—	280	744
August	326	—	24	394	744
September	446	—	48	226	720
October	304	—	—	440	744
November	183	—	—	537	720
December	308	—	—	436	744
Total	2602	2472	72	3614	8760
Percent	30	28	1	41	100

Both boilers in IA and IB actually operated longer than the waste grates (being fired without waste at times), but both had much higher unplanned stoppages. Unplanned stoppages on boiler IA accounted for 11 percent of total hours per year. The equivalent figure for boiler IB was 17 percent. As Exhibit 10 shows, units IA and IB have never been used more than 52 percent of total yearly hours in any year since they were built.

Planned maintenance is determined by several institutional requirements. All West German boilers must undergo a major inspection every two years as part of the West German boiler code and certification program. The insurance companies require a major inspection of the turbines every three years. In addition, an annual 4-5 week period is scheduled for repairs to the grate and for any necessary modifications of the tubes, additional insulation, etc.

The heavy corrosion in the waste portion of the furnace means that major repair programs have to be planned for replacement of refractory brick, secondary air nozzles, etc. Since these units are shut down nearly every weekend, there is frequent opportunity to perform smaller repairs without having to shut down during planned operational periods.

Exhibit 15 is a daily operation report for the two units on July 27, 1976. The IA unit burned coal, some natural gas, and waste for the full 24 hour period. The IB unit burned only coal for 14.5 hours.

The actual operating rates and values are lower than the design rates shown in Exhibit 1. The average steam rate for IA was 91.5 metric tons (100.8 short tons) per hour instead of 100 metric tons (110 short tons) per hour. Feedwater temperature was actually 232°C (450°F) instead of 250°C (482°F). The temperature of the fluegas was 174°C (345°F), rather than 140°C (284°F) which had been anticipated. Waste was burned at a rate of 14.8 metric tons (16.3 short tons) per hour instead of 25 metric tons (27.5 short tons) per hour.

The plants are rarely run at a constant rate for the 24 hour period because of fluctuations in the daily electrical load in the city of Munich. Thus even this daily operational report represents an average of output figures. Load requirements ran from a maximum output of 60 MW to an average rate for the day of 43 MW.

Daily Operating Report for Munich North I Incinerator

(July 27, 1976)

	Unit	IA	IB	Total
Boiler/Incinerator				
Feedwater volume	metric tons	2,196.0	1,221.0	3,407.0
Feedwater temperature	°C	232.0	234.0	
Live steam volume	metric tons	2,196.0	1,221.0	3,407.0
Live steam pressure	bar	176.0	176.0	
Live steam temperature	°C	530.0	530.0	
Recovered heat/kg	kJ/kg	2,363.0	2,354.0	
Total heat in steam	GJ	5,189.2	2,850.6	8,039.8
Reheating				
—Volume	metric tons	2,019.0	1,130.5	3,149.5
—Pressure—in	bar	39.0	40.0	
—Temperature—in	°C	336.0	343.0	
—Cooling spray	metric tons	13.0	23.0	36.0
—Soot blowing	metric tons	16.0	5.0	21.0
—Pressure—out	bar	36.0	37.0	
—Temperature—out	°C	530.0	530.0	
Recovered heat (reheat) per kg	kJ/kg	466.6	476.0	
Heat in received steam	GJ	942.1	538.1	1,480.2
Total heat in steam	GJ	6,131.3	3,388.7	9,520.0
Flue gas temperature after air preheater	°C	174.0	165.0	
O ₂ content after preheater	%	8.6	7.3	
Air temperature before aph	°C	42.0	46.0	
Boiler losses in				
—Flue gas	%	10.5	7.0	
—Ash heat	%	0.7	0.3	
—Unburned ash	%	—	—	
—Unburned flue ash	%	—	—	
—Radiation losses	%	1.3	1.4	
Boiler efficiency	%	87.6	91.2	88.8
Coal burned	metric tons	107.0	118.7	225.7
—Heat	GJ	3,225.5	2,577.6	6,803.1
Natural gas burned	KCBM I.N	33.5		33.5
—Heat	GJ	1,247.2		1,247.2
Waste burned	metric tons	356.1		356.1
—Heat (7,100 kJ/kg)	GJ	2,528.3		2,528.3
Total fuel heat	GJ	7,001.0	3,714.3	10,715.3
Hours in service	hrs	24.0	14.5	38.5
Turbine				
Steam received	metric tons	3,377.0*		
Live steam pressure	bar	176.0		
Live steam temperature	°C	530.0		
Specific steam consumed	kg/kWh	3.2		

Daily Operating Report for Munich North I Incinerator
(July 27, 1976)

Generator

Electricity produced	MWh	1,040.0
Electricity consumed internally	MWh	70.0
Electricity delivered	MWh	970.0
Maximum power output	MW	60.0
Average power output	MW	43.3
Specific heat consumed	kJ/kWh	11,046.7

SOURCE: Munich Electricity Works.

NOTE: One metric ton = 1.1 short tons
 One bar = 0.987 atmospheres
 One GJ = 0.9486×10^6 Btu
 One kJ = 0.9486 Btu
 One kg = 2.2 pounds

To convert kJ/kg to Btu/lb multiply by 0.431.
 $(^{\circ}\text{C} \times 1.8) + 32 = ^{\circ}\text{F}$

*Thirty tons to low pressure bank.

TECHNICAL INFORMATION: MUNICH NORTH II

THE BASIC SYSTEM

The Munich North II incinerator is built around a high pressure and temperature Benson boiler fired by a combined waste and coal furnace. Steam from the boiler provides heat to a district heating system and also feeds a 112 MW turbine which generates electricity.

Exhibit 16 shows a cross section of the furnace and boiler. The furnace is equipped with Martin reverse acting grates (five runs in parallel) and has a nominal waste burning capacity of 40 metric tons (44 short tons) per hour. The boiler has a capacity of 365 metric tons (402 short tons) of steam per hour at 184 bars (181.5 atm) and 540°C (1000°F).

Waste is burned in the bottom portion of the furnace after being fed in through a loading hopper and controlled feeding chute. Pulverised coal is fired above the refuse grate from three separate firing stages, some or all of which are used, depending on the operating load of the plant.

This design is a radical departure from that of the first combined waste and coal units of the North I installation. Not only is the waste area substantially larger (five runs rather than three) and the waste firing volume 60 percent greater than in the earlier furnaces, but also the coal firing takes place in the same furnace. The new unit produces over three and a half times as much steam and the contribution of waste, although much larger in volume, has fallen relative to coal. At full output waste contributes only 20 percent, rather than 40 percent as in the earlier system.

The only boiler elements in the furnace area are wall tubes. The superheater and reheater, as well as the economizer bundles, are outside the firebox in the two convection passes.

The waste storage bin for the North II unit is an extension of the bin used for the two units of North I. A separate crane control room was built for this new furnace, but cranes from the North I unit can also be used, as the overhead travelling units are connected.

The hopper and feeding mechanisms for supplying waste to the grate are similar in design to the North I unit. The grate runs are exactly the same as in North I: 17 grate steps, eight of which are fixed and nine of which are moveable. The moveable steps are actuated mechanically by electrical motors and gear drives. The air inflow is also similar. There are six inlet zones beneath the grate where air, facing a back-pressure of 300mm, is regulated in a distinct pattern to insure uniform burning across the five runs, despite the non-homogeneous nature

Section Drawing of Munich North II Incinerator

of the waste. The air supply system is the same as in North I and also incorporates air blowdown to remove dust which falls in through the inlet dampers.

The water walls start eight meters (26 ft) above the grate. This, as will be explained, makes cleaning the furnace complicated.

North II shares the pumping station which lifts condensor cooling water from the Isar Canal for North I. When all three furnaces are in operation, two pumps of 12,000 m³ (3,170,400 gal) per hour are on line with a third in reserve.

The generator has a basic rating of 140 MW with a cosine phi of 0.8 giving an effective output of a maximum of 112 MW.

The plant can operate in several different modes at various load levels. Since waste and coal are fired in the same furnace area, the furnace can operate entirely on waste, or entirely on coal, or on a combination of the two. A maximum of 20 percent waste and 80 percent coal can be used at full rated output. It has been found that if the firing of this furnace is begun with coal and the waste firing is started afterwards, there is less corrosion.

The North II furnace is equipped with three Martin ash quenching units. The ash falls into a shallow pool of water, is quenched and pushed out an upward slope. The cooling water does not circulate but either evaporates up into the furnace, or is carried away as part of the ash (15 percent water after quenching).

Like those in North I, the boilers were designed and built by Babcock. The grate, the feeding hopper, and the ash quenchers are from Martin. The turbine is from AEG. The electrostatic precipitator is from Lurgi.

THE BASIC STEAM AND FEEDWATER FLOW SYSTEM

Exhibit 17 shows the basic steam and feedwater flow phases of the North II boiler and turbine combination. The turbine unit is composed of three sections. Steam from the outlet of the first section is mostly reheated before going to the remaining two sections. Steam is drawn off at six intermediary stages for various purposes in addition to the reheat stage from the first part of the turbine series.

LEVEL OF AUTOMATION

The North II incinerator is as highly automated as its predecessors. The remote control system is similar (see page 17).

Heat Flow in the Munich North II Units

365t/h

a. Boiler	l. Feedwater tank and deaerator
b. Turbo-generator	m. High pressure heater II
c. Turbine for feedwater pump	n. High pressure heater I
d. Reheating in boiler	o. District heating heat exchanger
e. Main condensor	p. District heating heat exchanger
f. Feedwater pump turbine condensor	q. District heating hot water
g. Vacuum water heater	
h. Low pressure feedwater heater	
i. Low pressure feedwater heater	
k. Low pressure feedwater heater	

Ash quenching is also controlled automatically. A shovel cycle allows the ash unit to fill with water and a certain amount of ash to be quenched. There is then an expulsion cycle during which the quenched ash is pushed up a slope and then falls through a rough grate (which stops large items: logs, car doors, etc.) on to the ash conveyor belts. These belts continuously move the ash to the separate building where ferrous metal is electromagnetically removed and automatically loaded onto railway cars. The remaining ash is automatically conveyed to another building containing a bunker from which it is finally loaded onto trucks and hauled to the municipal dump.

As with North I, the West German boiler code requires backup capacity for all of the major feedwater pumps, condensor cooling pumps, etc. The cranes for North II can be shared with North I because the overhead rails are continuous. The North II furnace has its own stack and electrostatic precipitator.

There is, however, no crossover capability between the North I and II turbine units. Thus, if the North II furnace is down, the turbine cannot be fed by steam from the North I boilers. This lack of redundancy is explained by the extreme difficulty such a design would pose for the reheating phase of the steam flow.

SYSTEM PERFORMANCE HISTORY

Exhibit 18 shows the annual operating characteristics of North II. From the beginning of operations through the end of 1975, a total of 1,367,081 metric tons (1,505,927 short tons) of waste were burned. The average heat value of the waste has increased from an initial 1400 kcal/kg (2,519 Btu/lb) to over 1,800 kcal/kg (3,238 Btu/lb).

Annual Operating Characteristics of Munich North Incinerator II

Exhibit 18

Year	Waste Burned (metric tons)*	Average Heat Value (kcal/kg)**	Hours in Service	Percent	Average Metric Tons Per Hour
1966	54,059	1,394	1,580	18	34.2
1967	159,978	1,515	5,040	58	31.7
1968	184,891	1,478	6,297	72	29.4
1969	156,519	1,609	6,186	71	25.3
1970	120,413	1,693	4,638	53	26.0
1971	154,113	1,693	6,404	73	24.1
1972	149,746	1,785	5,540	63	27.0
1973	106,635	1,709	4,721	54	22.6
1974	142,263	1,754	6,059	69	23.5
1975	138,464	1,875	5,928	68	23.4
Total	1,367,081		52,393		26.1

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

**To convert kcal/kg to Btu/lb, multiply by 1.8.

By the end of 1975, the North II unit had accumulated a total of 52,393 hours in service. The maximum service that this unit has seen in any one year was in 1971 when the incinerator operated for 73 percent of the theoretical maximum number of operating hours.

The burning rate has varied considerably in terms of average number of tons of waste burned per hour of plant operation. From a high of 34.2 metric tons (37.6 short tons) per hour during the first year of operation, the average has dropped to about 23 metric tons (25.3 short tons) per hour during the last three years. This is only 60 percent of designed capacity.

MATERIALS AND ENERGY BALANCE CALCULATIONS

The daily energy balance for North II (see Exhibit 35) is calculated in the same manner as the daily energy balance for North I (see p. 22)

Exhibit 19 shows the most recent annual energy balance for the North II incinerator. The average heat input from waste in 1975 was 21.5 percent (vs. a designed maximum of 20 percent).

On the average, the plant produced one kWh for a heat input of 2463 kcal (9,774 Btu). Based on the efficiency differential for the burning of waste and of fossil fuel, only 2,446 kcal (9,707 Btu) would have been needed if only fossil fuels were used, while 3,015 kcal (11,965 Btu) would have been required if only waste were used.

Using a conversion factor of 860 kcal/kWh, the average plant conversion efficiency (heat to electricity) was 34.9 percent. The efficiency of fossil fuel conversion was 35.2 percent, while the efficiency of waste conversion was 28.5 percent.

MAINTENANCE HISTORY, REPAIRS, AND MODIFICATIONS

There has been much less corrosion and erosion in North II than in North I. The design of the North II firebox incorporated major changes in the conception of the burning area and air flow. The secondary air pattern was carefully designed to add more turbulence. This produced better burnout lower in the firebox and prevented the alternation of oxidizing and reducing conditions in the area of the wall tubing to a considerable extent. Corrosion has been observed in the lower part of the firebox near the secondary air inlet ports, but no major corrosion problems have been discovered in the superheater or reheater bundles, although some superheater tubes have now been replaced.

Energy Balance for the Munich North II Incinerator in 1975

Inputs	Metric System	English Equivalent
Coal		
Amount consumed	134,495.2 metric tons	148,155.1 short tons
Heat content	6925 kcal/kg	12,466 Btu/lb
Total heat	931,400 Gcal	3.7×10^{12} Btu
% total heat in	77.2	
Natural gas	None	
Oil (light)		
Amount consumed	1469.1 metric tons	1618.3 short tons
Heat value	10,200 kcal/kg	18,361 Btu/lb
Total heat	14,985 Gcal	5.95×10^{10} Btu
% total heat in	1.3	
Waste		
Amount consumed	138,464 metric tons	152,527 short tons
Heat value	1875 kcal/kg	3375 Btu/lb
Total heat	259,659 Gcal	1.03×10^{12} Btu
% total heat in	21.5	
Total heat input	1,206,004 Gcal	4.79×10^{12} Btu
Outputs	Metric System	English Equivalent
Electrical energy out		
Total produced	489,760 MWh	
Total delivered	455,151 MWh	
Self-consumed energy	34,609 MWh	
Self-consumed heat	8960 Gcal	3.56×10^{10} Btu
Heat in electricity and self usage	430,079 Gcal	1.71×10^{12} Btu
Total heat as % of total heat in	35.7	
District heat energy out (steam)	132,360	5.25×10^{11}
% total heat in	11	
Boiler losses (% heat in)	11.6	
Startup/shutdown losses (% heat in)	0.4	
Condensor and other losses (% heat in)	41.3	
Total losses (% heat in)	53.3	
Total losses	643,605 Gcal	2.55×10^{12} Btu
Specific heat required for electricity production		
Fossil fuel only	2446 kcal/kWh	9707 Btu/kWh
Waste only	3015 kcal/kWh	11,965 Btu/kWh

The most significant design problem has been with the water walls which do not extend down to the refuse grate. The lack of any heat absorption in the bottom part of the furnace means that more intense concentrations of heat occur, which leads to slag fusing on the refractory walls. Slag sometimes builds up to several feet in thickness. The furnaces eventually have to be shut down and cleaned out, a difficult and even dangerous process because loosening the lower layers of the fused soot can bring torrents of soot tumbling down from higher in the furnace.

The water walls in the furnace have recently been extended farther down and some more protected tubes have been added. This will lessen the problem of slag fouling the lower furnace walls. The tubes will be protected from the worst corrosion by silicon carbon coverings held in place by studs on the tubes.

Exhibit 20 shows the availability of the Munich North II incinerator in 1975, by month. Planned repair and maintenance activities accounted for 19 percent of the total incinerator time. Unplanned stoppages amounted to only one percent of the time. For 12 percent of the time, North II was in reserve, either because there was not enough waste to burn or because there was no demand for electricity. The plant operated for 68 percent of the year. Combining the operation and reserve time, the plant was actually available 80 percent of the year.

Exhibit 20

Availability of Munich North Incinerator II in 1975 by Month
(Hours).

Month	Hours in Service	Planned Stoppages: Repair and Maintenance	Unplanned Stoppages	Reserve Hours	Total
January	620.5	—	11	112.5	744
February	507.0	—	18	147.0	672
March	660.5	—	—	83.5	744
April	661.5	—	—	58.5	720
May	617.0	—	—	127.0	744
June	—	696	—	24.0	720
July	—	744	—	—	744
August	565.5	—	—	178.5	744
September	612.0	—	74	33.5	720
October	480.0	168	—	96.0	744
November	625.0	—	2	93.0	720
December	578.5	72	—	93.5	744
Total	5927.5	1680	105	1047.0	8760
Percent	68	19	1	12	100

Maintenance is planned around the same institutional requirements as are in effect for the North I units (see p. 27). Thus, external constraints set idle hours for the unit. These periods, naturally, are available for maintenance that may be otherwise necessary on other system components.

The grate usually requires three to four weeks worth of inspection and repair per year. However, stoppages on weekends or when the system is not required (reserve hours) provide opportunities to make inspections and carry out minor repairs which could otherwise later cause stoppages.

Exhibit 21 shows the average operating characteristics of the North II plant on a typical day in 1976. On the 27th of July, the plant was in service for 24 hours and produced 5,270 metric tons (5,915 short tons) of steam. The average hourly rate was 224 metric tons (247 short tons), well under the theoretical maximum of 365 metric tons (402 short tons) per hour. The feedwater temperature was 243°C (469°F) instead of the designed temperature of 266°C (511°F). Live steam temperature was 530°C (988°F) instead of the designed temperature of 540°C (1,004°F). Fluegas temperature was 195°C (383°F) and O₂ averaged 7.2 percent.

Waste was burned at a rate of 23 metric tons (25.3 short tons) per hour, and provided 23.6 percent of the total heat input (compared to the designed contribution of 20 percent). The electrical output during this 24 hour period was 1,730 MWh, for an average of 74.5 MWh. The maximum power out during this period was 85 MW (compared to total capacity of 112 MW).

Daily Operating Report for Munich North II Incinerator
(July 27, 1976)

Boiler/Incinerator

Feedwater volume	metric tons	5,370.0
Feedwater temperature	°C	243.0
Live steam volume	metric tons	5,370.0
Live steam pressure	bar	176.0
Live steam temperature	°C	530.0
Recovered heat per kg	kJ/kg	2,312.9
Heat in steam	GJ	12,420.2
Reheating		
—Volume	metric tons	4,874.6
—Pressure—in	bar	39.0
—Temperature—in	°C	336.0
—Cooling spray	metric tons	—
—Soot blowing	metric tons	36.0
—Pressure—out	bar	36.0
—Temperature—out	°C	530.0
Recovered heat (reheat) per kg	kJ/kg	449.8
Heat in reheater pass	GJ	2,192.5
Total heat in steam	GJ	14,612.7
Flue gas temperature after air preheater	°C	195.0
O ₂ content after preheater	%	7.2
Air temperature before preheater	°C	50.0
Boiler losses in		
—Flue gas	%	9.6
—Ash heat	%	0.6
—Unburned ash	%	—
—Unburned flue ash	%	—
—Radiation losses	%	1.5
Boiler efficiency	%	88.3
Coal burned	metric tons	418.7
—Heat	GJ	12,621.7
Waste burned	metric tons	552.8
—Heat (7,100 kJ/kg)	GJ	3,925.0
Total fuel heat	GJ	16,546.7
Hours in service	hours	24.0

Turbine

Steam received	metric tons	5,340.0*
Live steam pressure	bar	176.0
Live steam temperature	°C	530.0
Specific steam consumed	kg/kWh	3.0

Daily Operating Report for Munich North II Incinerator
(July 27, 1976)

Generator

Electricity produced	MWh	1,730.0
Electricity consumed internally	MWh	100.0
Electricity delivered	MWh	1,630.0
Maximum power output	MW	85.0
Average power output	MW	74.0
Specific heat consumed	kJ/kWh	9,866.9

SOURCE: Munich Electricity Works

NOTE: One metric ton = 1.1 short tons
 One bar = 0.987 atmospheres
 One GJ = 0.9486×10^6 Btu
 One kJ = 0.9486 Btu
 One kg = 2.2 pounds

To convert kJ/kg to Btu/lb multiply by 0.431.
 $(^{\circ}\text{C} \times 1.8) + 32 = ^{\circ}\text{F}$

*Thirty tons to low pressure bank.

TECHNICAL INFORMATION: MUNICH SOUTH IV & V

THE BASIC SYSTEM

The Munich South incinerator complex consists of two Babcock/Martin furnace and boiler units sitting side by side, fed by common overhead cranes. Each furnace and boiler unit has its own turbo-generator, but they share a common stack.

Exhibit 22 shows a cross section of one of these furnace and boiler units. The South IV and V units are a radical departure from the designs of the furnaces in the Munich North plant. The South units are again high pressure and temperature Benson boilers, but instead of having common evaporator, superheater, and reheater elements for both waste firing and fossil fuel firing, the South units completely separate the waste and fossil fuel furnaces. The boilers are coupled in such a way that the waste-fired unit serves as an economizer for the main boiler of the fossil fuel-fired furnace. If the waste-fired boiler is shut down, the fossil fuel-fired unit can operate at 100 percent output capacity on its own.

The waste bunker and the loading crane layout is similar to that at the North plant. However, because land was scarce, the bunker is rather small for the capacity of the two furnaces. The waste feeding mechanism is also different from the installations in the North. The South units have a double action horizontal piston pusher for coarse and fine control of waste volume being fed to the grate. The speed of the two pistons can be varied to regulate the input.

The grate is exactly the same size as in North II, and also consists of five parallel runs. The air inlet system also follows the same basic principle, having six air inlet regions down the length of the grate, each with a regulated amount of air against a 300mm backpressure to insure uniform burning across the grate. The stoker movement is hydraulic rather than mechanical.

As in all of the other furnaces, the water walls do not extend all the way down, but start about 10 meters (33 ft) above the grate area. This causes intense heat in the lowest portion of the firebox and limits the amount of waste that can be burned at any one time to less than the designed capacity.

The waste-fired furnace consists of a single vertical unit with a gas exit at the top leading directly to the air filter and to the stack. The fossil fuel furnace also is vertical with a subsequent set of tubes in a horizontal passage through which the gases pass before continuing to the electrostatic precipitator and to the common exit up the stack. The South plant can burn either natural gas or oil.

Section Drawing of Munich South IV and V Incinerators

Exhibit 22

The condensor cooling water comes from the Isar Canal which runs right next to the plant at the same elevation. Each of the South units (like North II) has three Martin ash quenchers. The ash is conveyed by belt to a processing plant where ferrous material is recovered. The remaining ash is then stored in another bunker prior to being hauled away by truck to the city dump.

The turbine units are rated at 124 MW. (155 MW at 0.8 cosine phi).

The South V unit entered operation in April 1969. The South IV unit followed in August 1971. The South IV is essentially the same as South V except that there is a bigger economizer in the waste-fired furnace and there are more economizer tubes in the fossil fuel-fired furnace.

THE BASIC STEAM AND FEEDWATER FLOW SYSTEM

Exhibit 23 shows the basic flow system for steam and boiler feedwater in the Munich South IV and V combined waste and gas units. The Benson boiler is split into two parts: the waste portion fires an economizer and the feedwater is subsequently transformed into superheated steam in the gas fired section. This steam is delivered to a three part turbine. After the first pass through the initial turbine unit, the exhaust steam is reheated before passing through the two subsequent stages. Steam is tapped off a total of seven times for various heating functions, before the remaining steam is condensed in the main condensor.

The relationship between the two boilers (waste-fired and natural gas-fired) as well as the valve circuitry and the 150 percent redundancy of the feedwater pumps is shown in Exhibit 24. Also shown is the reheat phase with steam at 48.6 bars (48 atm) and 353°C (667°F) at reheater entry and at 46.6 bars (46 atm) and 540°C (1,004°F) at the reheater outlet.

LEVEL OF AUTOMATION

The Munich South incinerator units are as highly automated as the others (see p. 17). The loading hoppers feed refuse down the chute to the furnace input feeding system. This system automatically regulates the desired flow of waste to the top of the waste burner. This system is more sophisticated than that on the North units and allows a more precise control of the waste inlet volume.

Steam and Feedwater Flow System for Munich South IV and V Incinerators

- a. Boiler
- b. Boiler
- c. Turbo-generator
- d. Reheating
- e. Main condensor
- f. Vacuum preheater
- g. Low pressure heater
- h. Low pressure heater
- i. Low pressure heater

- k. Feedwater tank and deaerator
- l. High pressure heater
- m. District heating heat exchanger
- n. District heating heat exchanger
- o. Nozzle preheater
- p. District heating net (Perlach)

Heat Flow in Munich South IV and V Incinerators

- a. Refuse boiler
- b. Main boiler
- c. Turbo-generator
- k. Main feedwater tank with deaerator
- l. High pressure preheater
- r. Full load feed pumps
- s. Half load feed pump
- t. Motor valve
- u. Start-up drum
- v. Relief unit

The air supply system under the grate is also similar to that of the North units (see p. 15). The hydraulically activated stoker is automatically operated from the control room to adjust for furnace gas temperature and economizer outlet temperature. The ash roller speed is also automatically adjusted from the control room.

Ash quenching and evacuation are fully automatic. Ash drops from the ash roller into a shallow trough of water which is constantly refilled. It is then shoved up an incline, and tumbled through a rough grate (to remove bulky items) onto a continuous moving belt. This belt brings the ash to a separate building where ferrous metal is automatically removed and loaded onto freight cars. The remaining ash is conveyed to a bunker to await final trucking to the dump.

All of the critical valves are remotely operable from the main control room with back-up manual capability. The German boiler code requirements for redundancy of valves and other critical elements such as feedwater pumps are the same as for the other units (see p. 27). Other redundant elements include a parallel conveyor belt for ash evacuation.

As in the case of the North units, however, there is no crossover capability for steam from one boiler to the other turbine. This is not possible due to the complexity of the reheating systems and the multiple stages of drawn off steam.

SYSTEM PERFORMANCE HISTORY

Exhibit 25 shows the annual operating characteristics of the South IV and V units. From the beginning of operations through the end of 1975, a total of 718,269 metric tons (792,220 short tons) of waste was burned in South V and 467,351 metric tons (514,817 short tons) of waste were burned in South IV. The average heat value of the waste incinerated in the two waste-fired furnaces has increased from 1,700 kcal/kg (3,060 Btu/lb) to over 1,850 kcal/kg (3,330 Btu/lb).

Exhibit 25

Annual Operating Characteristics of Munich South Incinerators IV and V

Year	Waste Burned (metric tons)*		Average Heat Value (kcal/kg)**		Hours in Service				Average Metric Tons Per Hour	
	IV	V	IV	V	IV	%	V	%	IV	V
1969		58,859		1,710			2,512	29		23.4
1970		121,770		1,682			4,630	53		26.4
1971	22,691	117,617	1,766	1,746	1,272	15	4,994	57	17.8	23.6
1972	106,705	76,170	1,773	1,765	5,404	62	4,919	56	19.8	15.5
1973	115,905	104,942	1,814	1,830	5,201	59	4,921	56	22.3	21.3
1974	99,402	118,009	1,797	1,869	4,407	50	4,739	54	22.6	24.9
1975	122,648	120,902	1,844	1,865	5,754	66	4,824	55	21.3	25.1
Total	467,351	718,269			22,038		31,539		21.2	22.8

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

** To convert kcal/kg to Btu/lb multiply by 1.8.

By the end of 1975, the South V waste-fired furnace had accumulated a total of 31,539 hours in service, while the newer South IV unit had amassed 22,038 hours. The maximum amount that either unit has ever operated in any one year was 66 percent of the total available time, in 1975 for South IV.

The rate of incineration has varied from year to year and from one furnace to the other. In 1975, the average burning rate was 21.3 metric tons (23.5 short tons) per hour of operation of South IV and 25.1 metric tons (27.6 short tons) per hour of operation of South V. The designed capacity was 40 metric tons (44 short tons) per hour per furnace (at 1,500 kcal/kg or 2,700 Btu/lb).

MATERIALS AND ENERGY BALANCE CALCULATIONS

The daily energy balance for South IV and V (see Exhibit 28) is calculated in the same manner as the daily energy balances for the North plants. (see p. 22).

Exhibit 26 shows the most recent annual energy balance for South IV and V. The average heat input from waste was 15.1 percent for the IV unit in 1975, and 15.8 percent for the V unit. The designed maximum heat contribution for these units was 20 percent.

On the average, the units produced one kWh of electricity for a heat input (waste and gas) of 2,363 kcal or 9,377 Btu (unit IV) and 2,568 kcal or 20,191 Btu (unit V). If gas alone had been used, the kcal values required for each plant would have been 2,282 and 2,421 (9,050 and 9,607 Btu). Waste alone would have required 2,969 and 3,870 kcal (11,782 and 25,358 Btu).

Based on a conversion factor of 860 kcal/kWh, the overall efficiencies of each unit in 1975 in terms of heat transformation into electricity were:

	<u>Unit IV</u>	<u>Unit V</u>
Average (mixed fuels)	36.4%	33.5%
Fossil Fuel Only	37.7%	35.5%
Waste Only	29.0%	22.2%

Energy Balance for the Munich South V Incinerator in 1975

Inputs	Metric System	English Equivalent
Coal	None	
Natural gas		
Amount (volume)	134,559.3 thousand m ³	4751 mmcf
Heat value	8920 kcal/m ³	1003 Btu/cu ft
Total heat	1,200,249 Gcal	4.76 x 10 ¹² Btu
% total heat in	84.1	
Oil (heavy)		
Amount consumed	125 metric tons	137.7 short tons
Heat value	9904 kcal/kg	17,828 Btu/lb
Total heat	1238 Gcal	4.91 x 10 ⁹ Btu
% total heat in	0.1	
Waste		
Amount consumed	120,902 metric tons	133,181 short tons
Heat value	1865 kcal/kg	3357 Btu/lb
Total heat	225,504 Gcal	8.95 x 10 ¹¹ Btu
% total heat in	15.1	
Total heat input		
Outputs	Metric System	English Equivalent
Electrical energy out		
Total produced	555,790 MWh	
Total delivered	530,507 MWh	
Self-consumed energy	25,283 MWh	
Self-consumed heat	4122 Gcal	1.64 x 10 ¹⁰ Btu
Heat in electricity and self usage	490,010 Gcal	1.94 x 10 ¹² Btu
Total heat as % of total heat in	34.3	
District heat energy out (steam)	130,749 Gcal	5.19 x 10 ¹¹ Btu
% total heat in	9.2	
Boiler losses (% heat in)	10.6	
Startup/shutdown losses (% heat in)	0.3	
Condensor and other losses (% heat in)	45.5	
Total losses (% heat in)	56.4	
Total losses	805,591 Gcal	3.19 x 10 ¹² Btu
Specific heat required for electricity production		
Fossil fuel only	2421 kcal/kWh	9608 Btu/kWh
Waste only	2969 kcal/kWh	11,782 Btu/kWh

Energy Balance for the Munich South IV Incinerator in 1975

Inputs	Metric System	English Equivalent
Coal	None	
Natural gas		
Amount (volume)	142,538.6 thousand m ³	5033 mmcf
Heat value	8914 kcal/m ³	1002 Btu/cu ft
Total heat	1,270,631 Gcal	5.04 x 10 ¹² Btu
% total heat in	84.8	
Oil (heavy)		
Amount consumed	85.3 metric tons	93.9 short tons
Heat value	9894 kcal/kg	17,810 Btu/lb
Total heat	844 Gcal	3.35 x 10 ⁹ Btu
% total heat in	0.1	
Waste		
Amount consumed	122,648 metric tons	135,105 short tons
Heat value	1844 kcal/kg	3319 Btu/lb
Total heat	266,138 Gcal	1.06 x 10 ¹² Btu
% total heat in	15.1	
Total heat input	1,497,613 Gcal	5.94 x 10¹² Btu
Outputs	Metric System	English Equivalent
Electrical energy out		
Total produced	633,780 MWh	
Total delivered	605,331 MWh	
Self-consumed energy	28,449 MWh	
Self-consumed heat	12,117 Gcal	4.81 x 10 ¹⁰ Btu
Heat in electricity and self usage	558,562 Gcal	2.22 x 10 ¹² Btu
Total heat as % of total heat in	37.3	
District heat energy out (steam)	139,940 Gcal	5.55 x 10 ¹¹ Btu
% total heat in	9.4	
Boiler losses (% heat in)	9.4	
Startup/shutdown losses (% heat in)	0.4	
Condensor and other losses (% heat in)	43.5	
Total losses (% heat in)	53.3	
Total losses	798,202 Gcal	3.17 x 10 ¹² Btu
Specific heat required for electricity production		
Fossil fuel only	2282 kcal/kWh	9056 Btu/kWh
Waste only	2969 kcal/kWh	11,782 Btu/kWh

MAINTENANCE HISTORY, REPAIRS, AND MODIFICATIONS

Unlike the North I furnaces, the waste-fired furnaces in the two South incinerators have not shown major corrosion problems as had been originally feared. The major maintenance of these units is performed during an annual plant stoppage of a month to five weeks. During this period the grate, the waste-fired boiler, and the other elements are checked, repaired and, if defective, replaced.

More frequent maintenance is possible because of the lack of waste to burn on weekends. The waste bunker barely holds a two-day supply, whereas the collection service weekend effectively runs from Friday afternoon to late Monday morning. Thus each waste incinerator can be shut down every other weekend. During these periods they are inspected and minor repairs can be made, thereby preventing more serious problems.

This design, where the waste-fired boiler serves as an economizer for the main boiler of the fossil fuel-fired furnace, has caused some operating problems, however. Sudden variations in the heat intensity of the waste-fired furnace can lead to premature evaporation of the economizer water. This in turn causes steam and water to spurt into the economizer of the main boiler disrupting the evaporation phase of this boiler thereby temporarily lowering the steam temperature. The operating rate of the turbine must then be adjusted. In the meantime heat of the waste-fired furnace has to be lowered, either by reducing feed or by reducing underfire air. This procedure refills the tubes of the economizer but starves the main boiler of feedwater temporarily, and again the main boiler operating conditions must be adjusted to prevent overheating of the steam.

Innovations have been introduced into the automatic compensation of heat fluctuations in the waste-fired boiler. Temperature gauges in the boiler provide a direct input to the system controlling rate of feed of waste to the grate. Higher temperatures slow the rate of the double piston feeding mechanism, and also the rate of action of the grate elements. This change has been credited with reducing possible temperature fluctuations from ± 10 percent to ± 5 percent.

No major modifications have been made to either of the South units, but South IV (which was built two years after South V) is slightly different. More economizer tubes were added to the waste-fired boiler to decrease the fluegas exit temperature which was found to be too high. The economizer section of the main boiler was also redesigned.

The lowest portions of these incinerators are not cooled by water walls, but have a refractory lining (as do all the Munich units) up to a height of about 10 meters (33 ft) above the waste grate. In addition, the furnace narrows at the point where the water walls begin, and this shape, combined with the refractory lining, leads to much more intense heat in the grate area than seems necessary, given the higher heat value of the waste now being burned. The general absence of corrosion in these boilers speaks well of their design and demonstrates the wisdom of having the lowest tubes protected with a ceramic coating from the beginning.

Exhibit 27 breaks the available hours for each waste-fired boiler in 1975 into operating time, scheduled maintenance, unscheduled maintenance and reserve time. Planned maintenance accounted for eight percent of the total annual hours for each unit in 1975. Unplanned stoppages accounted for two and three percent, respectively. The units operated for 66 percent and 55 percent of the time, leaving 25 percent and 33 percent as reserve time. Combined operating and reserve hours show an availability of 90 and 89 percent.

Exhibit 27

Availability of Munich South Incinerators IV and V in 1975 by Month
(Hours)

Month	Hours in Service		Planned Stoppages: Repair and Maintenance		Unplanned Stoppages		Reserve Hours		Total
	IV	V	IV	V	IV	V	IV	V	
January	662.0	73.5					82.0	670.5	744
February	455.5	250.0					216.5	422.0	672
March	491.0	508.5					253.0	235.5	744
April	542.0	462.0				1	178.0	257.0	720
May	410.5	548.5			43	2	290.5	193.5	744
June	478.0	522.0			7	15	235.5	183.5	720
July	650.5	418.0			10	97	83.0	179.0	744
August	28.5	544.4	690	48		66	25.5	85.5	744
September	692.0	3.0		696	9		19.0	21.0	720
October	418.0	637.0				1	326.0	106.0	744
November	426.0	442.5			76	38	218.0	239.0	720
December	500.0	364.0				63	244.0	317.0	744
Total	5,754.0	4,823.5	690	744	145	283	2,171.0	2,909.5	8,760
Percent	66	55	8	8	2	3	25	33	100

The South IV main boiler was available 92 percent of the time (or two percent more than the waste boiler) whereas the South V main boiler was only available only 83.5 percent of the time vs. 89 percent for the waste boiler. The large amount of reserve time is due to two facts, the lack of waste to burn and the demand characteristics for electricity in the Munich area.

The waste boilers were designed to produce 167 GJ (1.58×10^5 Btu) per hour. In 1975, the two South waste boilers provided heat at an average rate of only 121.2 and 119.7 GJ, an average of 72.6 percent and 71.7 percent of their load capacities. Multiplying those figures by the percentage of time these plants were actually in operation gives the effective output of 47.7 percent of total capacity for South IV and 39.5 percent of total capacity for South V.

The output from the main boilers of these same plants in 1975 was 64.1 percent and 57.1 percent. Not only were the main boilers in use more often, but they also ran at a higher percentage of their designed capacity when in use.

Planned maintenance is, as usual, scheduled around institutional and equipment requirements (see p. 27). An annual period for grate and other component repair and replacement also necessitates a shut-down of these furnaces for about 4-5 weeks. As mentioned earlier, frequent routine maintenance is possible in each furnace every two weeks due to shutdown for lack of waste to burn on weekends.

Exhibit 28 shows the average values of the South IV and V waste and main boilers and electricity generation plants on a typical day (September 28th) in 1976. On that day, both waste and main boilers were in service for the entire 24 hour period.

The average steam rates were 306 metric tons (337 short tons) per hour on South IV and 281 metric tons (310 short tons) per hour on South V. This was at 84 percent capacity on South IV and 77 percent on South V. Feedwater temperature was 3°C cooler on South IV than on South V, and the waste fluegas temperature was only 202°C (396°F) on South IV whereas it was 307°C (585°F) on South V.

Waste was burned at a rate of 24 metric tons (26.4 short tons) per hour on South IV and 28 metric tons (30.8 short tons) per hour on South V. This was at 60 percent of capacity for IV and 68 percent for V (at 1,500 kcal or 5,952 Btu) based on a capacity of 40 metric tons or 44 short tons per hour.

The electrical outputs from each plant during the 24 hour period were 2,240 MW and 2,260 MW, respectively. Maximum power output was 116 MW from South IV and 120 MW from South V while average was 97.6 MW for South IV and 94.2 MW for South V. Estimated specific heat consumption was 10,479 kJ/kWh for South IV and 10,247 kJ/kWh for South V, showing marginally better performance from V than from IV.

Daily Operating Report for Munich South Incinerators IV and V

(September 28, 1976)

Boiler/Incinerator	Unit	MK-IV	K-IV	Total	MK-V	K-V	Total
Feedwater volume	metric tons		7,338.0			6,739.0	
Feedwater temperature	°C	242.0	242.0		245.0	245.0	
Raw steam volume	metric tons		7,338.0			6,739.0	
Raw steam pressure	bar	206.0	177.0		220.0	177.0	
Raw steam temperature	°C	335.0	530.0		340.0	530.0	
Recovered heat/kg	kJ/kg		1,899.5			1,856.5	
Total heat in steam	GJ		13,938.5			12,511.0	
Reheating							
—Volume	metric tons		7,026.6			6,598.2	
—Pressure—in	bar		37.0			36.0	
—Temperature—in	°C		330.0			330.0	
—Cooling spray	metric tons		314.0			485.0	
—Soot blowing	metric tons		20.0			20.0	
—Pressure—out	bar		34.0			33.0	
—Temperature—out	°C		530.0			530.0	
Recovered heat (reheat) per kg	kJ/kg		568.2			637.0	
Heat in received steam	GJ		3,992.2			3,992.2	
Total heat in steam	GJ	3,060.0	17,930.8	20,990.8	3,007.0	16,714.3	19,721.3
Flue gas temperature after air preheater	°C	202.0	132.0		307.0	120.0	
O ₂ content after aph	%	12.0	4.0		11.0	4.0	
Air temperature before aph	°C	45.0	45.0		40.0	40.0	
Boiler losses in							
—Flue gas	%	21.6	4.4		33.1	4.0	
—Ash heat	%	1.4	—		1.4	—	
—Unburned ash	%	—	—		—	—	
—Unburned flue ash	%	—	—		—	—	
—Radiation losses	%	2.3	1.2		2.3	1.3	
Boiler efficiency	%	74.6	94.3	90.8	63.1	94.6	87.9
Natural gas usage	KCBM I.N		509.6			473.6	
—Heat	GJ		19,006.5	19,006.5		17,666.9	17,666.9
Waste tonnage	metric tons	577.4			670.9		
—Heat (7,100 kJ/kg)	GJ	4,099.3		4,099.3	4,763.7		4,763.7
Total fuel heat	GJ	4,099.3	19,006.5	23,105.8	4,763.7	17,666.9	22,430.6
Hours in service	hours	24.0	24.0	48.0	24.0	24.0	48.0

Daily Operating Report for Munich South Incinerators IV and V

(September 28, 1976)

Turbine	Unit	T-IV	T-V
Steam received	metric tons	7,338.0	6,739.0
Live steam pressure	bar	177.0	177.0
Live steam temperature	°C	530.0	530.0
Specific steam consumed	kg/kWh	3.1	3.0
Generator		G-IV	G-V
Electricity produced	MWh	2,240.0	2,260.0
Electricity consumed	MWh	102.0	71.0
Electricity delivered	MWh	2,138.0	2,189.0
Maximum power output	MW	116.0	120.0
Average power output	MW	97.6	94.2
Specific heat consumed	kJ/KWh	10,479.8	10,247.0

SOURCE: Munich Electricity Works

NOTE: One metric ton = 1.1 short tons

One bar = 0.987 atmospheres

One GJ = 0.9486×10^6 Btu

One kJ = 0.9486 Btu

One kg = 2.2 pounds

To convert kJ/kg to Btu/lb multiply by 0.431.

(°C x 1.8) + 32 = F°

OTHER COMMON SYSTEM FEATURES

CHARACTERISTICS OF RECOVERED ENERGY AND MATERIALS

The main form of energy recovered at the Munich North and South waste and fossil fuel power plants is electricity which is generated at 50 cycles, three phase, 10,500 volts. This comes from the turbo-generator units of 68 MW, 120 MW and 2 x 125 MW.

At the North plants, energy is also recovered as steam at 120°C (248°F) and used for district heating. At the South plant, energy is recovered both as hot water and as steam for district heating. In the South plant the hot water is at 125°C (257°F) returning at 50°C (122°F). A maximum of 80 metric tons (88 short tons) of steam per hour can be furnished to the city network.

Ferrous materials are separated electromagnetically from all furnace ash. These are shipped to a scrap metal dealer who has a concension from the Electricity Works. This scrap is very dirty and of low quality. It amounts to 1.6 percent by volume of total waste burned in the North plants in 1975 and 2 percent in the South plants. Sometimes the scrap is baled prior to shipment sometimes it is loaded in bulk. The remaining ash is hauled to the dump and serves merely to cover other unburned waste.

THE MARKET FOR RECOVERED ENERGY AND SCRAP IRON

The electrical energy produced in part by the burning of waste is sold by the city Electricity Works to private, public, and commercial and industrial users. The present tariffs charged for electricity in the city of Munich are shown in Exhibit 29.

Electricity Rates

Exhibit 29

	Tariff I	Tariff II
Regular price* (DM/kWh)	0.135	0.104
Additional charges added to regular price (DM)		
Households		
For first 2 rooms	5.00	9.65
For each extra room	1.25	2.15
For heavy appliance usage: each 0.5 kW up to 2kW	5.50	11.10
each 0.5 kW over 2 kW	5.50	11.10
Farms		
For first 5 hectares	4.50	8.50
For each additional hectare	0.95	1.35
Advertising, professional, and other needs		
Lighting (each 100 watts)	2.75	4.20
Other (each 500 watts)	5.50	11.10

NOTE: In 1976, 2.52 DM = \$1.00.

*Special off-peak rates (for Tariff I or II users only): 0.078 DM/kWh.

Small users price (cheapest up to 174 kWh/year for 2-room unit): 0.48 DM/kWh.

The charge for district heating is based on three distinct elements:

- A basic charge of 21 DM* for each 1,000 kcal (3,985,000 Btu) per hour of the user's basic capacity.
- A price of 35.50 DM for each Gcal (3,985,000,000 Btu) of heat supplied.
- Rent for the meter at the following rates:

Meter Size	Yearly Fee
10m /hr	240 DM
10-15m /hr	324 DM
over 25m /hr	420 DM

The city of Munich has a contract with a private scrap metal dealer in Munich who buys the scrap by the train car load. The price received by the Electricity Works is reviewed about every 3 months, with pressure for revision by the dealer if the price for scrap is falling and by the Electricity Works if it is rising.

The 1976 price was about 20 DM per metric ton (18 DM per short ton) FOB incinerators. The Electricity Works pays demurrage charges to the railroad at a rate of:

1st day	11.50 DM
2nd day	30.00 DM
3rd day	64.00 DM
4th day	114.00 DM

There is thus a premium on filling the railroad cars as efficiently as possible.

Total revenues from scrap metal amounted for each plant to the following sums in 1975:

North IA	11,548 DM
North IB	9,719 DM
North II	44,308 DM
South IV	49,059 DM
South V	48,360 DM

* Conversion Rates:	DM/\$
1975	2.46
1970	2.52

ENVIRONMENTAL CONTROL SYSTEMS

West German laws set environmental standards for both the emission of pollution into the air, and the quality of the air breathed by living beings.

The law covering emissions in effect when the Munich North and South plants were built was the TA Luft 1964 (*Technischen Anleitung zur Reinhaltung der Luft*) issued by the Bundesminister des Innern (Federal Minister of the Interior).

The standard which then applied to the plants set a limit of 150 mg of particulates per cubic meter of air, for volumes of 100,000 m³ per hour. For solid fuels, the limit was set at a certain percentage of the total amount of ash generated at full operation. The law also limited fine particulate matter (less than 10 microns) to 150 mg/m³. There were no other limits on emissions from plants.

A new law was passed in 1974 which lowers the particulate limit for such plants to 100 mg/m³ for fine particles and total ash. It also sets limits on CO, NO₂ and SO₂. These standards are not applicable to the present units, however, and no retrofitting is required.

The law concerning air quality specified limits to the amount of particulates deposited per m², both for short and long term periods. Limits were also set for the quantities of various gases in the average m³ of ambient air for short and longer term periods.

In 1964 the short term particulate limit for non-toxic residues was 1.3 g/m². The longer term average limit was 0.85 g/m² per day. These limits were reduced in 1974 to a short term limit of 0.65 g/m² and a long term average limit of 0.35 g/m². Standards have been set for fine particulate matter (less than 10 microns) of 0.2-0.4 for short term and 0.1-0.2 on a longer term average.

For gases, the 1964 short-term limits were 2 mg/m³ for NO₂, 0.6 mg/m³ for Cl, 0.75 mg/m³ for SO₂, and 0.3 mg/m³ for H₂S. The longer term average limits were 1 mg/m³ for NO₂, 0.3 mg/m³ for Cl, 0.4 mg/m³ for SO₂, and 0.15 mg/m³ for H₂S.

The new short-term limits are 0.3 mg/m³ NO₂, 0.6 mg/m³ NO, 0.3 mg/m³ Cl, 0.2 mg/m³ inorganic gaseous form of Cl ions, 0.004 mg/m³ inorganic gaseous form of F1 ions, 30 mg/m³ CO, 0.4 mg/m³ SO₂ and 0.01 mg/m³ H₂S. The new limits for longer term averages are 0.1 mg/m³ NO₂, 0.2 mg/m³ NO, 0.1 mg/m³ Cl, 0.1 mg/m³ inorganic gaseous Cl ions, 0.002 mg/m³ inorganic gaseous F1 ions, 10 mg/m³ CO, 0.14 mg/m³ SO₂, and 0.005 mg/m³ H₂S.

There are no water pollution problems from any of the Munich incinerators because the Martin ash quenchers do not recirculate water. They provide a continuously refilling bath into which the ash drops. After being quenched, the ash is forced out to the discharge conveyors. The water is consumed either as steam which rises into the furnace or as the moisture content of the quenched ash (an average of 15 percent).

The only air pollution controls on these furnaces are Lurgi electrostatic precipitators designed to reduce particulate matter by 99.5-99.7 percent. The North plants originally had 80 meter (262 ft) stacks, but these have been raised to 130 meters (427 ft). The South plants share a common 130 meter (427 ft) stack.

AESTHETICS AND LAYOUT

The general layout of the Munich North Plants I and II is shown in Exhibit 30. Exhibit 31 shows the exterior of the combined North I and II units and the open air electrical installation. The stacks in this picture are only 80 meters (262 ft) in height. They have since been increased to 130 meters (427 ft). Collection trucks have easy access to the plants.

The general layout of the Munich South incinerators IV and V is shown in Exhibit 32. This installation was built on a narrow strip of land bounded on one side by the Isar Canal, on another by a series of railroad tracks, and on the third and fourth sides by an older heating plant and a highway. This restricted space accounts for the limited capacity of the waste bunker which can store only 4000 m³ of waste, barely enough to fire the plants for 2 days. When this plant was built, it was necessary to build a complicated underground passage under the highway to ease the traffic of collector vehicles. Exhibit 33 shows the exterior of the South plant.

Plan of Munich North I and II Incinerators

- a. Machinery building
- b. Boiler building
- c. Waste bunker
- d. Coal conveyor
- e. Coal storage
- f. Coal transfer system
- g. Operations building
- h. Open air transformers
- i. Pumping station
- k. Cooling water conduits
- l. Ash loading building

View of Munich North I and II Incinerators

View of Munich South IV and V Incinerators

ECONOMICS AND MANAGEMENT

ORIGINAL COST AND AMORTIZATION

The original capital cost of the North and South plants and of the waste incineration portions is shown below. Information is only available on the total cost of the North and South plants in aggregate, hence for the North plant units IA, IB and II are combined, and for the South plant units IV and V are combined. In both cases, some of the costs have been allocated by an arbitrary distribution method. (See Exhibits 34 and 35.)

The entire North plant (I and II) cost 151.1 Million DM (\$37.8 million; 1960-'66 or \$88.3 million; 1976*). Of this the waste section is estimated to have cost 25.8 Million DM (\$6.45 million; 1960-'66 or \$10.2 million; 1976). The entire South plant (IV and V) cost 140.7 million DM (\$39.2 million' 1969-'71 or \$67.9 million; 1976), of which the waste portion is estimated to have cost 35 million DM (\$9.8 million; 1969-'71 or \$13.5 million; 1976). For the North plant, average waste burning capacity costs amounted to 286,700 DM per metric ton (\$65-000 per short ton; 1966) of waste per hour. For the South installation, a capacity of one metric ton per hour cost 437,500 DM (\$110,300 for one short ton per hour; 1969-'71).

For the city's accounting purposes, an annual interest charge of 6.5 percent is assumed for unrepaid capital. The costs are amortized on three different schedules. The Munich South plant underpass is given 40 years. The mechanical and electrical installations are given 12 years, and the remaining building and general expenses are given 30 years.

These three periods with the interest charge establish a constant annual annuity value of 7.07 percent, 7.66 percent and 12.26 percent.

This creates an annual amortization charge buildup as follows:

	North Plant (1960-66)		South Plant (1969-71)		Total
	Capital 10 ⁶ DM	Amort. DM	Capital 10 ⁶ DM	Amort. DM	Amort. DM
7.07%	-		3.1	291,170	291,170
7.66%	12.71	973,586	9.5	727,700	1,701,286
12.26%	13.14	1,610,964	22.4	2,746,240	4,357,204
Total	25.85	2,584,550	35.0	3,693,110	6,277,660

* Conversion: DM/\$
1960-66 4.00
1969-71 3.59

Munich South Incinerator Installation

(Costs from Electricity Works Records of May 14, 1969,
in million DM)

Total Original Capital Costs		140.70
Costs for the Waste Portion		35.00
Details of Waste Capital Costs		
Building and construction		
Boiler building (part cost)		2.00
Waste building and discharge stalls		4.10
Waste delivery box doors		0.31
Ash treatment buildings, etc.		1.78
Room for ash bunker		0.33
Partial cost of streets, etc.		0.10
Water drainage and related		0.28
Total construction		8.90
Machinery and equipment		
Total boiler cost	35.4	
Conventional boiler 365 tph	-22.0	
(365 tph x 30,000 DM/t/hr) =		
Additional cost for waste boiler	13.4	
Waste boiler		13.40
Electrostatic precipitator		2.40
Ash treatment		1.16
Tubing (partial cost)		0.80
Measurement and control instrumentation		0.60
Scrap press, railway capstan		0.43
Filter for waste building air		0.34
Air entry and exit from waste building		0.36
Painting and miscellaneous		0.67
Total machinery costs		19.80
Electrical installation		
Total electrical plant	17.5	
Less transformers, generator protection, etc.	-4.0	
Remainder representing self consumption of electricity	13.5	
Total plant consumption	24.0 MW	
Consumed by waste portion	4.4 MW	
Proportion of total cost for waste		2.60
General additional costs (partial cost)		0.60
Special street underpass	3.5	
Less 10% for other use	-0.4	
	3.1	3.10
Final total		35.00

NOTE: From 1969-1971, 3.59 DM = \$1.00.

Munich North Incinerator Installation

(Costs from Electricity Works Records of April 7, 1967,
in million DM)

Total Original Capital Cost	151.100
Costs for Waste Portion	25.800
Details of Waste Capital Costs	
Buildings and construction	
Waste building	4.600
Ash system (breaking tower, ash bunker, conveyor bridge, ash building)	0.610
Water evacuation (partial cost)	0.240
Main boiler building space	1.380
Total	6.830
Access roads (partial cost)	1.000
Machinery and equipment	
Cranes	1.150
Air inlet, conditioning	0.710
Truck weighbridge	0.028
Water evacuation pump (waste building)	0.045
Fire protection system (partial cost)	0.022
Extra cost for boiler system	
—Grates	3.007
—Grate accessories	1.970
—Tubing	1.173
—Larger electrostatic precipitator	0.350
—Measuring and control instruments	0.550
—Ash treatment system	1.155
—Ash extraction equipment (from bunker)	0.190
—Scrap metal recovery equipment	0.299
—Railway car movement capstan	0.009
—Painting and miscellaneous	0.195
Original total	10.853
Plant modification to steam/water separation system as decided on 2/29/72	0.850
Revised total	11.703
Electrical installation (partial cost)	1.441
General overall costs (groundwork, canalization, workshops, social buildings, lighting, etc.) (partial cost)	4.876
Final total	25.850

NOTE: From 1960-66, 4.00 DM = \$1.00.

OPERATING COSTS AND REVENUES

Every three years, the city of Munich's Electricity Works puts together a report of the anticipated costs and revenues for the treatment of waste and recovery of energy and materials from waste for the following three years. This report is the basis for attribution of financial credit to the Electricity Works on the city books.

The cost components for the projected period 1973-1975 were computed in January 1973 and served as the justification of the city's giving the Electricity Works a credit of 18.80 DM per metric ton (\$6.39; 1973 per short ton) of waste to be treated during this subsequent period.

The cost information shown below is taken partly from the 1973 report and partly from more recent information obtained during interviews in Munich in October 1976. From these various bits of information we have estimated approximate cost and income statements for the North and South waste treatment plants.

The 1973 Munich report was divided into seven major cost categories: a capital cost (amortization and interest), a constructed (fictitious) capital tax charge, a constructed (fictitious) industrial revenue tax, personnel costs, other operating costs, repair and maintenance costs, and general overhead costs. There were also two revenue categories, a payment by the Electricity Works for the value of heat recovered from the waste and payment received for scrap metal. Subtracting the revenues from the costs produced the figure 18.80 DM per metric ton (\$6.39 per short ton) as the cost of treatment.

The capital annuity costs are shown on page 63 above.

The constructed capital tax was assessed at 0.84 percent of the industrial capital invested. On an annuity basis, this comes to an annual charge of about 0.45 percent of the original capital costs or a total of 117,639 DM (\$44,060; 1973) for the North plant, and 159,740 DM (59,825; 1973) for the South plant.

The industrial revenue tax was calculated as 21 percent of the annuity interest charge. This varied in application to the three annuity periods from an effective rate of 0.82 percent to 0.96 percent. The total charge for the North plant was 223,409 DM (\$83,670; 1973) and for the South plant of 299,890 DM (\$112,320; 1973).

Personnel Costs were estimated on the basis of the four categories of workers directly attached to the waste portions of each of the incinerator and power plants. The 1973 report showed worker groups and their annual salary levels as follows:

Employee Group	North		South		Total No.
	No.	Cost	No.	Cost	
V (23,534 DM)	18	423,612	19	447,146	37
IV (22,040 DM)	15	330,600	10	220,400	25
III (21,088 DM)	15	316,320	15	316,320	30
II (20,252 DM)	5	101,260	5	101,260	10
<hr/>					
Total	53	1,171,792	49	1,085,126	102
		(\$438,870; 1973*)		(\$406,410; 1973)	

These salaries were expected to increase at an annual rate of 8.5 percent during the three year period giving an average of 18 percent higher value for the median year. Thus the actual cost would be 1,382,715 DM (\$533,870; 1974) at the North plant and 1,280,449 DM (\$494,380; 1974) at the South plant.

It is interesting to note that not only at the individual plants, but also at the general operating staff level there is a distinct separation made between the technical operation and delivery of services on the one hand, and the financial and accounting activities on the other. The plants are run by the technical operators. Their costs are noted according to an elaborate accounting system which includes an attribution of worker hours and other expenses to various sub-units of the plants.

The overall economic performance of these plants, however, is the concern of the top political and planning administrators rather than of the local technical or supervisory staff. For a variety of political reasons, costs are paid from and revenues are received into a number of different accounts. Attributed real costs and charged costs differ. Neither the electricity generation nor the waste burning functions are run exactly as individual cost and revenue centers.

As mentioned earlier, it is difficult to say exactly and unambiguously which operating personnel are used for waste burning and which are used for other firing and electricity generation. There are now about 233

* Conversions: DM/\$
 1973 2.67
 1974 2.54

employees in the North plant (including North IA and IB and North II units). Of this total, 160 are grouped in six shifts of about 26 men apiece. Three shifts work around the clock, a fourth serves as a rest period, a fifth is for reserve, and a sixth is for the accumulated extras of sickness, leave, etc.

The director of the North plant estimated the work force dealing specifically with waste as follows:

- 11 crane operators
- 11 skilled grate men
- 11 ash system tenders
- 17 general workers for cleaning, etc.
- 50 total

It is difficult to ascertain the salary levels of these workers in terms of total charges paid. However, considering take-home pay, social security charges, 13th month, etc., this could average nearly 30,000 DM (\$11,900; 1976) each. This is in excess of the figure shown on the cost statement of the Electricity Works which determines the charges paid by the waste generators.

There are about 170 employees at the South plant, with shifts of 20 men apiece, of whom seven work directly with the waste. The total work force for waste at the South plant is estimated to be:

- 12 crane operators
- 6 men on the grates
- 12 men on the ash quenchers
- 12 men in the ash building
- 5 additional men for weighing of waste, etc.
- 47 total

A slightly different estimate gave the North plant 54 men on the waste side, eight per shift, distributed as follows:

12 crane operators

- 12 men on the grates
- 12 men on the ash quenchers
- 12 men in the ash building
- 6 additional men for weighing of waste, etc.
- 54 total

Thus, even among the technical operating personnel in the two plants, there are differences of opinion as to which workers and which jobs are actually attributable to the waste treatment function.

These personnel figures include no men in the central control room, although there are functions in the control room that deal specifically with incineration of waste. Also, no day personnel are attributed to general repair and other maintenance services.

It is assumed that most of the remaining personnel at each plant are repair and general maintenance workers. No information is available on the number of these workers specifically responsible for work on the waste portions at any of the plants.

One crosscheck of these estimations can be made by consulting the annual financial accounts of the individual plants where hours of work are attributed for each worker to specific parts of the plant when and as this work is performed. In 1975, such information was collected for each plant and that of the South Plant was made available.

These data showed that for four sections of the plant which clearly dealt with waste (the IV and V waste furnaces, the ash treatment section, and the refuse bunker/crane operation), the total operating costs including personnel and supplies were 6,480,492 DM (\$2,634,350; 1975).^{*} This should be compared to a personnel cost estimation of 1,085,126 DM (\$441,100; 1975). There is obviously a major discrepancy here. Cost increases for the North plant are assumed to have been proportional and to total 6,996,000 DM (\$2,843,900; 1975).

Other operating costs were estimated to be 50,000 DM (\$20,325; 1975) each for the North and South plants. These costs (operating supplies, grease, etc.) are included in the total operating costs counted in the paragraph above.

Repair and Maintenance costs for the two plants (including labor and materials) were reported to have increased as follows:

*Conversion: DM/\$
 1975 2.46

EVOLUTION OF REPAIR AND MAINTENANCE COSTS (DM)

Year	North	South	Total	DM/\$
1964	91,825		91,825	3.98
1965	264,290		264,290	4.00
1966	338,415		338,415	3.98
1967	513,621		513,621	4.00
1968	1,186,293		1,186,293	4.00
1969	1,044,075	165,617	1,209,629	3.69
1970	2,467,776	462,346	2,930,125	3.64
1971	3,296,949	782,848	4,079,798	3.48
....				
1975			*6,000,000	2.46

The combined costs were anticipated to rise from 4 to 6 million DM from 1972 to 1975, and an average of 5 million per year was estimated for this category.

A check on the accuracy of the repair estimates from the actual accounting report for 1975 shows that repair costs in the North plant were 2,443,700 DM, and in the South plant, 1,578,438 DM, for a total of 4,022,138 DM (\$1,635,000; 1975). This is less than the forecast. (It is possible that the figures for the North plant were understated.)

The final cost category is the attribution to waste incineration of a part of the total general overhead costs up to and including local and general management of the entire Electricity Works administration as well as the general services, service vehicle operation, chemical laboratory analysis, repair workshops and all of the other non-directly indentifiable costs. Total general overhead costs for the North and South plants grew as follows from 1969-1971:

Year	North	South	Total	DM/\$
1969	5,238,010	2,862,655	8,100,666	3.69
1970	5,544,959	3,826,177	9,371,137	3.64
1971	6,126,492	4,639,295	10,765,787	3.48

The 1973 report showed that according to an internal Electricity Works accounting formula, the overhead burden for the waste portion of the two plants combined should have been:

1969	1,388,700
1970	1,968,300
1971	2,653,840 DM

* Estimated

However, after discussions between the revisions bureau and the Electricity Works, the figure was downgraded to 2,358,000 for 1971 and, on the basis of conservative growth estimates, was fixed at an annual level of 2.5 million DM for the succeeding three years. A crosscheck for this figure is given by the amount shown in the 1975 accounts for the South plant alone where the total came to 2,672,920 DM (\$1,086,550; 1975). This is greater than was forecast for both plants during that year. The general overhead at the North plant was 32 percent higher than at the South plant in 1971 using this same ratio for 1975 would give a North overhead figure of 3,528,254 DM (\$1,434,250; 1975) for 1975. We have, therefore, revised estimates for three cost categories, Personnel and Operating Costs, Repair Costs, and General Overhead.

The original and revised cost accounts for 1975 for the North and South plants are therefore as follows:

ESTIMATED 1975 COSTS FOR MUNICH NORTH AND SOUTH REFUSE PLANTS

CATEGORY			(In thousand DM) *	
	NORTH		SOUTH	
	Original	Revised	Original	Revised
Capital Annuity	2,585	2,585	3,693	3,693
Capital Tax	118	118	160	160
Revenue Tax	223	223	300	300
Personnel Costs	1,382	6,996	1,280	6,480
Operating Costs	50		50	
Repair Costs	3,500	2,443	1,500	1,578
Overhead	1,423	3,528	1,077	2,672
Total Costs	9,281	15,893	8,060	14,883
Cost per metric ton of waste burned	45.29 DM	77.55 DM	33.09 DM	61.11 DM

Revenue for the two plants in 1975 came from the sale of heat recovered from the waste and from the sale of scrap ferrous metal recovered from the ash. The 1973 report estimated that the North plant 1.3 Gcal of heat was

* Conversion: DM/\$
1973/1975 2.67/2.46

delivered for each metric ton of waste burned (4,690 Btu per short ton), while at the South plant 1.13 Gcal was delivered per metric ton (4,077 Btu per short ton). Estimates of likely tonnage were used to calculate the total heat likely to be delivered in the following years. The recent average cost price per Gcal from coal and natural gas was used to set a value on the heat produced from waste. For coal, the cost was estimated at 15.50 DM per Gcal (\$1.46; 1973 per 10^6 Btu) and for natural gas at 13.50 DM per Gcal (\$1.27; 1973 per 10^6 Btu). The amount of waste to be burned each year at each plant was forecast at 237,500 metric tons (261,621 short tons). Thus the North plant would earn 4,785,625 DM (\$1,792,370; 1973) per year, while the South plant, recovering less heat and having a lower fuel competition price, would only earn 3,623,062 DM (\$1,356,950; 1973) for the same amount of waste burned.

A crosscheck for the value of heat recovered in 1975 is the actual revenue from the annual energy balance report. The value of coal and natural gas is taken from the records of the Electricity Works for the actual average price for these fuels in 1975. The price paid for coal was 18.36 DM per Gcal (\$1.88; 1975 per 10^6 Btu) while that actually paid for natural gas was 17.51 DM per Gcal (\$1.79 per 10^6 Btu). Only 204,928 metric tons (225,741 short tons) of waste were actually burned at the North plant in 1975, while at the South plant, 243,500 metric tons (268,285 short tons) were burned. The revenues from heat recovery as forecast and revised were thus:

CATEGORY	NORTH		(In thousand DM)*	
	Original	Revised	SOUTH Original	Revised
Value of Heat Recovered	4,786	4,891	3,623	4,818

Forecast revenues from scrap sales were based on a recovery rate of 1.2 percent by weight and a sale price of 15 DM per metric ton (\$5.10; 1973 per short ton). Actual recovery was 1.6 percent, or 3,333 metric tons (3,672 short tons) in the North and 2 percent, or 4,789 metric tons (5,275 short tons) in the South. The average sale price was 20 DM per metric ton (\$7.50; 1974 per short ton). The forecast and revised revenues from scrap recovery were therefore:

CATEGORY	NORTH		(In thousand DM)*	
	Original	Revised	SOUTH Original	Revised
Scrap Metal Sales	42.75	66.66	42.75	95.78

*Conversion	DM/\$
1973	2.67
1974	2.59
1975	2.67

These accounts do not include the cost of the ash hauling operation (trucks and drivers) or any charge to the Electricity Works for dumping the ash at the municipal dump.

The total cost and revenue statement, with the exceptions noted, may be summed up as follows:

CATEGORY	(In thousand DM) *			
	NORTH Original	Revised	SOUTH Original	Revised
Total Costs	9,281	15,893	8,060	14,883
Total Revenues	4,829	4,957	3,666	4,914
Difference	4,452	10,936	4,394	9,969
Metric Tons Burned	237,500	204,928	237,500	243,550
Short Tons Burned	261,621	225,741	261,621	268,285

Cost Difference per metric ton	18.75 DM	53.37 DM	18.50 DM	40.93 DM

Thus according to the 1973 report, on the basis of 237,500 metric tons (261,621 short tons) burned in each plant, a rough cost average of 18.80 DM per metric ton (\$6.39 per short ton) would remain to be covered by the city after heat and scrap metal were recovered. The real costs for 1975 (still understated, perhaps, in some of the personnel areas) however, even after allowing for higher compensation for heat recovered and scrap metal, showed deficits of 53 DM per metric ton (\$14.56 per short ton) at the North plants and 41 DM per metric ton (\$15.13 per short ton) at the South plants.

These extra costs were absorbed without difficulty by the Electricity Works because electricity rates are such that this section of the City Works has a large operating surplus each year. This surplus helps the city compensate for other services, such as traffic and transportation, which are always in the red. The higher cost of waste treatment seems to have been absorbed by the higher revenues from the sale of electricity and heat, but the cost differential credited to the Electricity Works as per the 1973 estimate report appears far from covering the real gap.

*Conversions:	DM/\$
1973	2.67
1975	2.46

SYSTEM MANAGEMENT AND OPERATIONAL CONTROL

The North and South waste burning incinerators are managed as integral parts of the electrical generation and district heating programs in Munich. Each waste burning plant is under the control of a local director and staff whose primary function is to insure the delivery of electricity and heat. All of the plants are under the overall supervision of the Electricity Works general staff.

The suppliers of equipment to the Munich Electrical Works were required to provide detailed guarantees of performance and equipment life not only for the waste-burning grates, but also for the other special equipment. In the case of Martin grates, these guarantees are impressive multi-page documents listing performance standards that had to be reached before plant acceptance. In some cases, the manufacturers were also required to guarantee the life of their equipment for a certain length of time or number of operating periods.

PLANS FOR THE FUTURE

The Munich City Authorities and the Electricity Works directors are now planning to increase waste incineration capacity. A new federal law on solid waste management was passed in 1972, and amended in 1974. This law required each *Lande* to be responsible for its overall solid waste planning and to make final decisions in that area.

The *Lande* of Bavaria subsequently passed legislation in June 1973, and set out to comply with the federal law by reviewing existing solid waste treatment practice and planning for the future. While no definite plans have yet been adopted, it is likely that the Munich region will be responsible for solid waste treatment for a number of neighboring communities. This, plus the expected growth of the city itself, and the likely increase in per capita solid waste generation all suggest that present capacity is not sufficient.

And yet, considering the installed capacity of 3 units rated at 40 metric tons (44 short tons) per hour and 2 others at 25 metric tons (27.5 short tons) per hour, it may appear surprising that more capacity is really required. The present capacity operating 24 hours a day and 365 days per year at full load could treat 1,489,200 metric tons (1,640,449 short tons) per year. Since the expected requirement by 1980, even from a greater area, will probably not exceed 1,120,000 metric tons (1,233,751 short tons), why shouldn't this suffice?

The explanation is that at present only 37.3 percent of the capacity (based on waste having heat value of 1,500 kcal/kg or 2,700 Btu/lb is used. The remaining 62.7 percent is accounted for by a series of constraints on

the system. The first is an operating rate reduced by 26 percent to diminish corrosion and wear.

The second is a reduction by about 26 percent due to electrical load requirements which are such that the waste-fired plant cannot run at full load all the time. As a result, there is a further loss of capacity during start-up, shutdown and load adjustment periods.

The third is a reduction of 9.7 percent due to annual repair and maintenance. The last constraint is a 1 percent loss of capacity because the bunker at the South plant is too small.

The maximum that could be expected from the system, if the demand for electricity were perfectly constant and if there were no start-up shutdown or load adjustment losses, would be still only 63.3 percent.

The annual heat requirements for electricity and for district heating vary considerably from month to month as shown in Exhibit 36. The contribution of waste to meeting this requirement is apparently the most constant of all the fuels used.

The daily electrical demand by hour is shown in Exhibit 37. There is an extreme peak load at about 8:30 am and low trough at 4-5 am. The winter morning load shows the maximum extreme that the city faces. But, the city also faces some bizarre institutional constraints. During the early morning hours when city demand is low, additional electrical energy can be produced and delivered to the external power grid, but the city is not paid for this. The city has the right to generate its own power, but the surrounding area of Bavaria is the exclusive domain of the Bavarian Power Works. The relations are such that the city must buy power from the Bavarian Power Works when it needs it, but cannot sell it when it has excess capacity.

Because of the highly fluctuating daily electrical demand and the resulting loss in waste burning capacity, and because of other capacity losses due to a need to diminish corrosion, the city authorities have decided to build no more combined waste and fossil fuel power plants.

Munich has experimented with three different complicated designs for integrated waste and fossil fuel firing of Benson boilers. The city is now abandoning this solution, and moving instead toward all waste-fired units with a lower rate of energy recovery. The new plants will be designed so that some of the recovered heat will serve to dry sludge from the water treatment plants. They will incorporate burners to fire this sludge in a manner similar to the firing of pulverised coal on the North I and II units.

Energy Requirements of Munich by Month in 1975 (for heat and electricity)

Fuels Supplying Energy

**Daily Power Requirements in Munich by Hour of the Day
December, 1973**

The new units (requests for proposals are now out) will have a capacity of 25 metric tons (27.5 short tons) per hour (like the original North I units). The boilers will not be Benson boilers and the steam will be at much lower pressure and temperature, although still superheated. Turbines will still be coupled for the generation of electricity, but they will be small, about 20-25 MW, and the steam will not be reheated.

CONCLUSIONS

It is difficult to draw simple conclusions about the various combined waste and fossil fuel electrical generation plants in Munich because there are many different perspectives from which comments need to be made. Cogeneration of heat and electrical energy is clearly feasible. The relative success of the North II unit suggests that the biggest problems may be institutional rather than technical.

TECHNICAL CONCLUSIONS

All three of the basic designs for the plants in Munich were original, first-ever conceptions for very large and very complicated plants. The city authorities, the Electricity Works planners, and the equipment suppliers showed an admirable willingness to experiment with radically new concepts and to bear the consequences which could result.

The first approach, used in the North I units, has waste and coal fired in separate chambers but with the gases joining and a common heating of boiler elements. In these two plants there were several design problems which led to later difficulties. The coal chamber was too small and eventually there was corrosion in the second pass of the boiler unit. The water walls did not extend down to the grate in the waste portion of the furnace, resulting in excessive heat and subsequent ash fusion on the refractory walls. Martin considers this a design fault, but perhaps Babcock would disagree.

North IA and IB had serious problems with corrosion in the boiler tubes, particularly in the waste portion of the furnace. There were several attempts to diminish these corrosion problems, but they were never fully overcome. Both Martin and the Electrical Works personnel concede that this design was interesting, but not one which they would repeat.

Munich North II, with combined waste and coal firing of a common firebox seems to have been a much better solution. Corrosion problems have been less severe than at North I, and, in general, this plant has proven reliable and efficient. The basic vulnerability is that the waste portion is intimately linked to the rest of the plant, hence, if for any reason there is a difficulty with the waste portion, the whole plant, including the turbo-generator, is in jeopardy. Thus the risk of the unavailability of the whole plant is greater than if the waste unit were not an integral part of the plant.

Martin claims that the North II design is probably the best from several points of view including cost, reliability, and flexibility in the firing rate to suit power fluctuations. The company claims that North II is still a very efficient form of heat recovery from waste.

The city Electrical Works personnel, including the recently retired technical manager of all Munich power plants, do not share this enthusiasm. They concede the merits of this plant but feel that there is too much risk in having the waste plant compromise the generation of electricity. This argument cannot be settled easily, as it is influenced not only by operating history but also by the psychology of those responsible for delivering electric power when it is required.

The Munich South units represent a departure from the combined firing philosophy of the North units. In the South, the heat from waste is absorbed in an economizer unit for a subsequent main boiler which delivers the high pressure and temperature steam to the turbo-generator. This design incorporates a complete redundancy of the economizer capacity of the waste-fired boiler.

There are some difficulties in this inclusion of an external economizer in a Benson boiler arrangement, however. They involve a series of complications in running the different parts of the plant at different rates of output, in starting up the plant, in varying the load levels, and in operating the waste portion of the plant alone.

The plant was designed to enable the waste furnace to deliver up to 20 percent of total heat required at full plant output. However, when the plant is operating at less than full power, the waste portion has to reduce its output rate which means that waste incineration is not a function of waste availability, but follows the load of the power plant. There have been attempts to operate the waste portion of the plant when the fossil fuel portion is not on line, but this has proved complicated and possibly dangerous.

Martin claims that this design is good and that it has proven itself in service. They complain about the refusal of the boiler maker to bring the water walls down to the level of the grates, but feel that this design could be applied elsewhere. The Electrical Works authorities also feel that the design is basically sound, but suggest that it may not be suitable for Munich. A better load following capability and better start-up and shut down possibilities would be needed as well as the capacity to burn waste by itself.

Comparing the overall efficiencies of the three types of plants in terms of conversion of heat from waste into electricity, the energy balance report for 1975 showed that North II was the most productive, followed by South IV. Each of these plants represents the most evolved form of its design group.

ECONOMIC CONCLUSIONS

From the information available, it is difficult to make conclusions about the economics of the various plants in Munich. The North I units would not be proposed for further applications but North II and the South plants seem attractive in the light of the costs published by the city. It is apparent, however, that these are not the real costs and that some of the actual cost is hidden and subsidized by the buyers of electricity.

Our rough revision of the costs (see p.73) show that they are probably 2-3 times higher per ton than the published figures. There are still many arbitrary attributions of direct costs (which man works on which part of the combined plant), arbitrary attributions of general overheads (how much the waste portion of the plant should contribute to general overhead), and assumed fictitious tax charges which could be paid, but are not, because the waste turnover and capital charges are buried in the larger total Electricity Works accounts.

There is no doubt that the revised cost estimates in the report will be challenged, and probably should be. However, they rely upon some of the internal accounting data of the city. It has been suggested that the political sensitivity of charges for waste treatment is greater than that of minor variations in the electricity rates. This is perfectly understandable. It appears that waste incineration is much more expensive than is generally believed and that electricity sales subsidize a major part of the cost. Only the true operating costs and revenues could indicate whether building similar plants in other cities would be desirable. Obtaining real and unambiguous costs would probably be impossible. Approximate costs can be estimated reasonably well.

COMMENTS ON FUTURE CITY PLANS

No general technical or economic conclusions can be drawn from the decision of the Electricity Works and city administrators to build no more combined plants, but only all waste burning plants with lower grade steam and small electrical generators. This decision seems dictated more by the peculiar electricity requirements of the city than by any conclusive inadequacy of combined fired units. The authorities claim that they will not build any more large power stations at all, and this seems to be the principle reason for abandoning the combined plant philosophy. Even in the new plants, however, there is an interest in technological experimentation, as these plants will recycle some of their own recovered energy by using heat to dry sludge which they will then burn to generate more heat.

There seem to have been no complaints about the performance of the major system components including the Martin grates, waste feeding systems, and ash quenchers, the Lurgi electrostatic precipitators, or the AEG or Siemens turbo generators.

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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

Abbreviations

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

West German Marks to U.S. Dollars

<u>Year</u>	<u>DM/\$</u>
1960	4.17
1961	4.00
1962	4.00
1963	3.98
1964	3.98
1965	4.00
1966	3.98
1967	4.00
1968	4.00
1969	3.69
1970	3.64
1971	3.48
1972	3.19
1973	2.67
1974	2.59
1975	2.46
1976	2.52

Source: "International Financial Statistics" International Monetary Fund.