**EUROPEAN WASTE-TO-ENERGY SYSTEMS
CASE STUDY OF THE THERMAL COMPLEX
OF TOULOUSE-LE MIRAIL
(FRANCE)**

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PREFACE

The thermal complex of Toulouse-Le Mirail (France) has been converting waste into energy for the past seven years. It is an integral part of the new town of Le Mirail which currently houses 28,000 people. The thermal complex provides 40 percent of the domestic heat and hot water required in Le Mirail while incinerating nearly all the solid waste of the City of Toulouse (400,000 inhabitants).

This case study is one of a series prepared for the U.S. Energy Research and Development Administration 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 translated from French francs into 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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SUMMARY

The waste treatment system of Toulouse-Le Mirail (France) is a complex composed of an incinerator with heat recovery equipment and an oil-fired heating facility. It was designed to burn the household waste of a city of 400,000 inhabitants, while at the same time providing central heating and hot water to a suburb of 100,000 inhabitants.

The choice of incineration as a means of waste treatment by the city of Toulouse was originally due to the lack of suitable landfill sites in the area. The decision to recover the heat was closely linked to the beginning of the development of a complete new suburb of 100,000 inhabitants. This new suburb had considerable energy requirements for central heating and hot water, and a district heating network was planned. Moreover, the municipality of Toulouse was receptive to the idea of heat recovery from waste, as an old incinerator with heat recovery had been operating since 1926.

Construction of the thermal complex was carried out in two phases: the first two incinerators and the oil-fired heating facility began operation in 1970; the third incinerator was completed in 1975.

The three furnaces (see Exhibit 1) are equipped with roller grate stokers of the VKW Dusseldorf type; each stoker is composed of six steel rollers containing cast iron inserts; the air for combustion is blown through the inside of the rollers. Each furnace has an air pre-heater and a supplementary burner. The first two furnaces have classic water tube boilers. The third is a waterwall.

Each furnace has a rated capacity of 8.15 metric tons (8.97 short tons) per hour. Normal use is 24 hours a day, 330 days a year. The theoretical steam production is 23.2 metric tons (25.6 short tons) per hour with an assumed lower heating value of 2,200 kcal/kg (3970 Btu/lb).

In reality, the amount of waste treated annually is approximately 100,000 metric tons (110,000 short tons), compared with a rated capacity of 130,000 metric tons (143,000 short tons) for two furnaces and 190,000 metric tons (209,000 short tons) with the addition of the third furnace. This limitation is due to the quantity collected. The furnaces are run at a capacity of 9 to 10 metric tons (10 to 11 short tons) per hour, which is above the rated capacity of 8.15 metric tons (8.97 short tons) per hour. In fact, the furnaces are larger than needed because the lower heating value of the waste was assumed to be 2,200 kcal/kg (3970 Btu/lb), while the actual lower heating value is about 1,560 kcal/kg (2,808 Btu/lb).

The energy recovered is used to provide central heating and hot water for the suburb of Le Mirail and to produce electricity for use in the plant. The electricity generated from heat recovery amounts to 5,000,000 kWh/year; the heat recovered for central heating to 44,000 kth*/year (1.75×10^{11} Btu/year) and the heat recovered for domestic hot water to 7,000 kth/year

* Kilotherms. One kilotherm equals 1,000 kcal. or 3.97×10^6 Btu.

Toulouse-Le Mirail Thermal Complex

Technical Data

Dates

Start of construction	March 1968
First incineration of household waste	October 1969
Completion of Phase I	January 1970
Completion of Phase II	August 1975

Plant Dimensions

	Metric System	English Equivalent
Area of site	4.5 hectares	11 acres
Area of building	5,700 m ²	61,000 sq ft
Dimensions of building	119 m x 54 m	390 ft x 177 ft
Height of central block	30 m	98 ft
Height of smokestack	45 m	148 ft
—diameter of first flue	4.4 m	14.4 ft
—diameter of second flue	2.4 m	7.9 ft

Capacity of Transformers

6,000 KVA

Weight of the Structural Steel

1,200 metric tons 1,320 short tons

Incinerators

Number of furnaces	3	
Rated capacity (per hour, per furnace)	8.15 metric tons	8.97 short tons
Minimal capacity (per hour, per furnace)	4.8 metric tons	5.3 short tons
Steam production per furnace at normal capacity, lower heating value of 2,200 kcal/kg (1,000 Btu/lb) of waste	23.2 metric tons/hour	25.5 short tons/hour
Height of furnaces	24 m	79 ft
Volume of waste pit	4,300 m ³	5,624 cu yds
Volume of crane bucket	3,600 litres	4.7 cu yds
Volume of residue pit	630 m ³	824 cu yds
Flue gas produced (per hour, per furnace)	46,500 m ³	1,642,000 cu ft
Efficiency of electrostatic precipitator	97%	
Maximum quantity of particulates	150 mg/m ³	
Average temperature of gases	235° C	455° F
Daily capacity per furnace	195 metric tons	215 short tons
Daily capacity for entire plant	585 metric tons	644 short tons

Heat Recovery System

1 turbo-generator (1,500 kW)	16 bars/2 bars	15.8 atm/1.9 atm
1 heat exchanger for hot water	2 kth/hour	7.94 x 10 ⁶ Btu/hour
1 low-pressure heat exchanger for heating	16 kth/hour	6.35 x 10 ⁷ Btu/hour
1 high-pressure heat exchanger for heating	10 kth/hour	3.97 x 10 ⁷ Btu/hour

Heating Facility

1 generator	20 kth/hour	7.94 x 10 ⁷ Btu/hour
1 generator	40 kth/hour	1.59 x 10 ⁸ Btu/hour
Maximum temperature	210° C	410° F
Length of distribution network	2 @ 18 km	2 @ 11 mi
Pumps for distribution network	2 @ 700 hp	
Direct production of hot water for in-house use	2 kth/hour	
Capacity of water softening equipment	160 m ³ /hour	42,272 gal/hour

SOURCE: BETURE

Thermal Complex of Toulouse-Le Mirail

(2.8×10^{10} Btu/year), which gives a total energy recovered of 56,000 kth/year (2.22×10^{11} Btu/year). The thermal efficiency of the system is estimated at 65 percent. Twenty-five percent of the heat theoretically available is lost in the furnaces and boilers, and another ten percent in the heat exchangers. Moreover, some potential heat is not recovered because of the lack of demand during the summer. Actual recovery of heat usually varies from 30 percent to 90 percent of the theoretical limit, and can even reach 96 percent according to the months considered. Overall, based on the experience of the 1974/75 operating year,* it is estimated that 40 percent of the energy content of the waste is effectively recovered.

Operation of the incinerator and the heating facility has been normal during the first five years of existence. No unexpected major problem has occurred. Each furnace is shut down one month per year for maintenance. Non-routine maintenance costs (including replacement parts) during the first five years of operation ran about 1 percent of the cost of construction per year, rising slightly after the first three years.

In order to reduce atmospheric pollution, the gases pass through an electrostatic precipitator before escaping from a stack 45 meters (148 ft) high. The efficiency of precipitation is better than 97 percent. Sampling of the emissions has shown a high level of HCl, about 5 g/kg (.005 lb/lb) of waste. The concentration of particulates is 100 mg/m³. Nearby residents complain quite frequently but it is difficult to say at the present time if these complaints are legitimate.

The architecture of the complex is interesting although there is disagreement about its aesthetics (see Exhibit 2). Working conditions in the plant have had to be improved, but they now appear satisfactory.

Forty-seven people are employed in the operation of the thermal complex, of whom 6 are concerned only with the steam distribution network. Of the 41 people working at the incinerators and the heating facility, 20, organized in 4 groups, are directly involved in operations. The workers, especially those who run the furnaces, are highly skilled.

The first phase, comprising two incinerators with heat recovery equipment, cost 25,200,000F (1969). The second phase, consisting of the addition of a third furnace, cost 17,700,000F (1975). Subsidies obtained from the national government amounted to 12 percent of total cost. The balance was funded through low interest loans (about 6 percent for the first two furnaces and 10 percent for the third). The amortization rate for the first two furnaces has been estimated at 34 F/metric ton (\$6.80/short ton; 1975) incinerated, based on approximately 100,000 metric tons (110,000 short tons) per year.

The complex is operated by a private company which receives subsidies from the municipality and repays the municipality for the heat recovered. In the operating year 1974/75, the municipality paid fees equal to 34 F/metric ton (\$6.80/short ton; '74-'75) incinerated, and recovered revenues equal to 27 F/metric ton (\$5.40/short ton; '74-'75) incinerated. Direct operating cost

* September 1974 to August 1975.

for the municipality was therefore, 7F/metric ton (\$1.40/short ton; '74-'75) incinerated.

The heat recovered is sold by the private operators of the thermal complex at 90 F/kth (\$5/10⁶ Btu; '74-'75) (tax included), which is equal to or under market price. No market has yet been found for the residues of incineration which are dumped in a landfill.

The overall cost of incineration including amortization and operating costs, has been estimated at approximately 41 F/metric ton (\$8.20/short ton; '74-'75) incinerated, taking into account only the first two furnaces. The addition of the third furnace was probably a mistake, as it adds to the cost without increasing the amount of waste treated. The cost of incineration would be lowered by finding new sources of waste in nearby communities or by finding new clients for the heat recovered during the non-winter periods.

BACKGROUND

ECONOMIC AND DEMOGRAPHIC DATA

The thermal complex of Toulouse-Le Mirail is located in Toulouse, the fourth largest city in France with a population of 380,000. Situated in the southwest of France, Toulouse is a provincial city, the administrative and commercial center of a region of grain and general agriculture. Toulouse is, however, also a center for sophisticated industries and research; for example, the supersonic plane, Concorde, is a local product.

The city has an area of 120 km² (45 sq mi) with an average density of 3,200 persons/km² (8300/sq mi). The historic center, which is centuries old, consists of three-story red buildings and very narrow streets. The suburban fringe, which grew considerably in the 1950s, is a mixture of large modern buildings and individual houses. Farther out, urbanization is dispersed and there are even some farms. Average income in Toulouse is comparable to that of other French cities, but with extremes of high and low incomes even more pronounced. Because of the increase in population in the 1950s and because of fear of disorderly growth, the municipality of Toulouse decided in 1960 to concentrate its expansion in one area, the suburb of Le Mirail. The goal was to build a whole new town of 100,000 people with its own administrative and commercial center. So far, 7,000 dwelling units have been built, housing 28,000 people. The thermal complex of Toulouse-Le Mirail has been an integral part of this development. The goal was to provide heat and hot water for a town of 100,000 inhabitants, while eliminating the household waste of a metropolis of 400,000 inhabitants.

WASTE COLLECTION AND TREATMENT

Waste collection in Toulouse, as in many other French cities, is the direct responsibility of the technical services of the municipality. Household waste is collected six times a week, except in a few outlying areas with low density, where it is collected only three times a week.

The city is divided into 55 districts, each served by a team of four people with a packer truck. These districts are very dissimilar. In the historic center, small vehicles with a three metric ton (3.3 short tons) capacity are used; in the suburban fringe, trucks of 14 m³ (18.3 cu yds) with a capacity of 5 to 8 metric tons (5.5 to 8.8 short tons) are used, each truck making two trips a day. In the suburbs, trucks of 16 m³ (21 cu yds) with a capacity of 8 metric tons (8.8 short tons) are used.¹

Approximately 110,000 metric tons (121,000 short tons) of waste are collected annually from a population of almost 400,000 (including two other small municipalities besides Toulouse). This amount includes not only household waste but also some commercial waste coming mainly from the center of the city.² (See Exhibit 3.)

**Quantity of Waste Collected
and Population Growth in Toulouse
1936-1975**

SOURCE: Noirot, "L'Usine Du Mirail-Traitement Des Ordures," Ingénieurs Des Villes De France; May, 1976.

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

The collection service employs 270 people (of whom 20 are administrators) and 60 vehicles. The cost of collection in 1975 was 151 F/metric ton (\$31.90/short tons; 1975) or 42 F/inhabitant (\$9.80/inhabitant; 1975). This amount is relatively high compared to other French cities.³

Most of the waste collected is incinerated in the thermal complex of Toulouse-Le Mirail. Another incinerator at Toulouse-Le Ramier, which dates from 1926, treats approximately 22,000 metric tons (24,200 short tons) per year. Incinerator residues are dumped in a landfill located in a nearby community. This site is also used for other kinds of waste, such as construction and demolition waste.

DEVELOPMENT OF THE SYSTEM

REASONS FOR THE NEW SYSTEM

In the early 1960s, before the construction of the thermal complex of Toulouse-Le Mirail, 50 percent of the municipal waste was incinerated in the old incinerator of Toulouse-Le Ramier, 5 percent was treated in an experimental compost unit, and the remaining 45 percent was dumped in landfills.⁴

The old incinerator of Toulouse-Le Ramier, which is equipped with Venien furnaces and heat recovery systems, had been built in 1926. After more than 35 years of operation, it was then in need of a complete overhaul. Moreover, the area in which it had been built had become one of the favorite spots in Toulouse for sports and leisure activities. Consequently, the city is planning to phase out this facility in the near future.

The Pratt compost system was tried as an experiment. This process involved aerobic fermentation in open-sided cages, with sorting and crushing carried out after fermentation. Doubts concerning the potential market for compost produced in this way and concern over competition from cities having already embarked on this experiment led Toulouse to reject further extension of the Pratt system.*

Finally, the landfills were becoming completely full. Moreover, because of the lack of suitable sites within the city limits of Toulouse, these landfills were located mainly in the nearby small town of Blagnac. In addition to the potential problems of tolerance which could be created by surrounding communities, the distance of the landfills from Toulouse (7 km or 4.3 mi) added considerably to the cost of disposal.

To all these elements, one must add the great increase in the population of Toulouse in the past twenty years and the decision, at the beginning of the 1960s, to develop the new town of Le Mirail within the Toulouse city limits, which added to the need for a new treatment system.

The final choice of incineration with heat recovery was thus linked to the development of Le Mirail. The facility which was planned to provide district heating and hot water for the dwelling units had considerable energy requirements, which could be met in part by the incinerator.

The integration of the incinerator in the development of Le Mirail was certainly facilitated by the governmental agency which has a financing role in such municipal operations, the *Caisse des Dépôts et Consignations*. This public agency has under its corporate umbrella several engineering firms which often participate in the development of these programs. One such firm, BETURE, specializes in urban and municipal engineering projects including incineration and waste treatment.

* Given the present state of the market for compost in France, this decision seems to have been wise.

Finally, an element which was certainly important was the fact that the municipality of Toulouse had already had experience with heat recovery from incineration. The old incinerator of Toulouse-Le Ramier had been equipped with heat recovery systems and the energy recovered used to heat municipal buildings, such as the swimming pool, and to produce electricity for street lighting. This incinerator, which has operated satisfactorily for about 50 years, is still in operation in 1977.

PROJECT DEVELOPMENT

The preliminary studies for the incinerator with heat recovery equipment and the oil-fired heating facility were carried out by the municipality in the early 1960s. The detailed technical and economic studies which led to the specifications adopted in the invitation for bids were carried out by municipal engineers and economists.

The invitation for bids for the heating facility was published in 1965, the contract was awarded in 1966, and construction began in 1967. For the incinerator, the invitation for bids was published in 1968, construction of the first two furnaces began in 1969 and operations began in 1970.* Construction of the third furnace began early in 1974 and was completed in 1975.

SETOMIP,** a semi-public corporation (a *Société d' économie mixte*, a form of economic organization common in France) was created to manage the overall development of the new town of Le Mirail. The contracts for the heating facility and the first two incinerators were awarded by SETOMIP; the contract for the third incinerator was awarded directly by the municipality.

Invitations for bids for the incinerator and the heat recovery equipment were published in accordance with rules imposed by the national government upon municipalities for this kind of program. Bidding was open to companies selected by prequalification.

The following companies or their French representatives sent prequalification packages:

- Martin (Germany)
- Von Roll (Switzerland)
- VKW (Germany)
- Alberti Fonsard (France)
- Combustion Engineering (U.S.)
- Volund (Denmark)

* According to the contractor, a one-to-two year period is necessary for construction of an incinerator.

** Acronym for *Société Economique pour Toulouse et Midi Pyrennées*.

All these companies except Alberti Fonsard actually entered bids. The selection was made on the basis of two sets of criteria.

- a complex set of governmental guidelines for comparison of such proposals⁵
- total cost.

The Tunzini engineering firm (which represents VKW in France) obtained the best rating on each of the sets of criteria⁶ and received the contract. VKW, Germany participated directly in the deal, as it provided the furnaces and other equipment, as well as technical assistance.

TECHNICAL INFORMATION

THE INCINERATOR⁷

The waste is transported by truck up a ramp to the tipping platform. (See Exhibit 4.) The trucks are weighed upon entering and leaving, in the presence of a representative of SETMI and one from the city. The volume of the waste pit is 4,300 cubic meters (5,624 cu yds) which allows storage for two days of collection.

An overhead crane with a capacity of 3,600 liters (4.7 cu yds) mixes the waste before loading it into the hoppers (see Exhibit 4 and 5). These hoppers lead directly into the combustion chambers of each furnace. A hydraulic ram at the bottom of each hopper feeds the waste into the furnace.

All three furnaces use VKW mechanical stokers. The waste from the hoppers falls onto a cascaded series of six rollers which agitate it during combustion. The rollers are made of steel with cast iron inserts. Each roller has a diameter of 1.5 m (4.9 ft) a useful length of 2.5 meters (8.2 ft) and a useful area of 32.4 m² (348.6 sq ft).

Air for combustion is blown through the inside of the rollers and is regulated by shutters. This air is drawn from the refuse pit, reducing the air pressure in the pit and so reducing the amount of dust and odor.

The refuse in the hopper forms a seal for the furnace. Safety of the system is ensured by a control device using radiation to monitor the waste level in the hopper. Each furnace has an air preheater and a supplementary burner for use when the waste is too damp for proper combustion. Combustion takes place at temperatures between 500°C and 1000°C (932°F and 1832°F), which is not excessively high.

The first two furnaces are lined with refractory brick and have classic water tube boilers. The bundles of tubes are arranged vertically. The combustion gases make four passes.

The third furnace is a waterwall. The combustion chamber is lined with refractory brick to a height of approximately one meter (39 inches), so that the water tubes come down quite close to the grate. The combustion gases make only three passes in this unit.

Each of the three furnaces is 24 m (78.7 ft) high and each has an hourly rated capacity of 8.15 metric tons (8.98 short tons).

The combustion residues fall into a water-sealed ash trough. The residues from all three furnaces are gathered on a conveyor belt which carries them to a single ash pit with a capacity of 620 m³ (810 cu yds). This pit is equipped with a grab-bucket operated from an overhead crane. The ashes are then removed by truck.

The flue gasses pass through electrostatic precipitators and the dust is collected on plates which are cleaned by shaking. At the outlet of the precipitators, a fan draws the gases up into a 45 m (148 ft) smokestack.

The ash pit is also used to store the dust removed from under the roller by means of an Archimedean screw and the fly ash removed from the smoke by electrostatic precipitators.

The steam produced by incineration of domestic waste is at a pressure of 16 bars (15.8 atm). It is expanded into a turbo-generator (see Exhibit 4) with the following characteristics:

- intake pressure: 16 bars (15.8 atm)
- normal continuous power: 1,500 kW
- back pressure at the exhaust: 2 bars (1.97 atm)
- steam consumption: 31 metric tons (34 short tons) per hour

Exhibit 4

Schematic Rendering of a Furnace (Phase I)

This system is sufficient to furnish all electric power for the thermal complex. Furthermore, the temperature of condensation of the exhaust steam, which is 134°C (273°F), allows it to be used to heat both the domestic hot water and the return water from the urban heating network.

The feed pump of each boiler is driven by a turbine also powered by steam produced by incineration. The intake pressure is 16 bars (15.8 atm) and the back pressure at the exhaust is 2 bars (1.97 atm).

The domestic hot water is heated by steam at 2 bars (1.97 atm) exhausting from the turbo-generator or from the steam turbine. The heat exchanger has a capacity of 6 kth/hour (2.38×10^7 Btu/hour).

The return water of the heating network is heated by two methods, either separately or in combination:

- back pressure steam from the turbines at 2 bars (1.97 atm) through a heat exchanger from 90°C to 119°C (194°F to 246°F)
- steam of the incineration boilers at 16 bars (15.8 atm) 10 kth/hour (3.97×10^7 Btu/hour) through a heat exchanger

The thermal complex also includes an additional recovery system for the summer period when the heating requirements of Le Mirail are very small but when the incineration must still continue. This system consists of:

- an air cooled condenser for the steam at 2 bars (1.97 atm) with a capacity of 20.5 metric tons (22.6 short tons) per hour
- an air cooled condenser for the steam at 16 bars (15.8 atm) with a capacity of 22.5 metric tons (24.7 short tons) per hour
- two heat exchangers of 6 kth (2.38×10^7 Btu) per hour between the water for heating and the domestic hot water

HEATING FACILITY⁸

An oil-fired heating facility also provides hot water for domestic use and home heating for the new town of Le Mirail. It is located in the same complex as the incinerator (see Exhibit 5).

The thermal complex will eventually contain one boiler rated at 20 kth/hour (7.94×10^7 Btu/hour) and four boilers rated at 40 kth/hour (1.59×10^8 Btu/hour). Currently, only the boiler of 20 kth/hour and the first of the four boilers of 40 kth/hour have been installed.

Heat and Steam Flow

A Furnace No. 1	L Oil fired boiler (20 kth)
B Furnace No. 2	M Oil fired boiler (40 kth)
C Furnace No. 3	N Reservoir
D Primary low pressure heat exchanger	O Expansion chamber
E Primary high pressure heat exchanger	P Thermal degasser
F Domestic hot water heat exchanger	Q Turbo-pump
G Domestic hot water tank	R Turbo-generator
H High pressure condenser	S Water softener
I Low pressure condenser	T Fuel oil tank
J Cooling circuit	U Fuel oil preparation
K Compressed air circuit	

In addition to the heat recovered from the incineration of waste, these boilers are also fired by oil. The heat derived from waste incineration accounts for 41 percent of the annual total produced by the thermal complex. In summer, almost no fuel oil is used (see Exhibit 6). The boilers use heavy fuel oil which is stored into a tank with a capacity of 2,900 cubic meters (766,180 gal). A second tank is planned. The steam is superheated to 210°C (410°F) and is circulated in the heating system of Le Mirail at 30 bars (29.6 atm) by two variable speed electric pumps of 700 horsepower each.

The steam distribution network is 18 km (11 mi) long and serves the three districts of Bellefontaine, La Reynerie, and Le Mirail, or a total of 7,000 dwellings. The pipes are made of steel. A central electronic system automatically controls the steam distribution network and its 63 substations. In two of these substations, the water is reheated by natural gas. One of them is a primary school where the heating equipment already existed. The other is a school at the furthest end of the network. The other 61 substations are equipped with heat exchangers. Flow and pressure are regulated automatically.

The boilers also feed a network distributing hot water for domestic use. The cold water provided by the city is first softened in an installation treating up to 160 m³ (42,272 gal) per hour. The water is heated to 70°C (158°F) in a succession of heat exchangers using the heat provided by the incinerator. It is then stored in two horizontal insulated tanks with a capacity of 100 m³ (26,420 gal) apiece.

The domestic hot water network has return pipes and circulates the water continuously to maintain a temperature of 65°C (149°F). The pipes are of cast iron. This network serves only the Bellefontaine district which is located about 800 m (half a mile) from the plant. Originally, there were plans to extend this service to the two other districts of Le Mirail and La Reynerie which are 3-4 km (1.8-2.4 miles) from the plant. This extension was rejected partly because of the poor quality of the water provided by this system and partly because the greater distance would make the cost of the network prohibitive. The provision of domestic hot water by this method is considered an experiment which has failed.

SYSTEM EFFICIENCY

The quantity of waste incinerated at Toulouse-Le Mirail varies between 86,000 and 100,000 metric tons (94,700 and 110,000 short tons) per year. It decreased during the years 1973 and 1974, (following a decrease in the amount of waste collected due to the economic recession) but again reached 100,000 metric tons (110,000 short tons) in 1976 (see Exhibit 3).

Theoretically, with two furnaces operating at full capacity, almost 130,000 metric tons (143,000 short tons) of waste could be incinerated annually. It is clear that, with no more than 100,000 metric tons (110,000 short tons) per year actually treated, the two furnaces have been operating below capacity.

Thermal Balance Sheet, 1974-1975

Period of Operation	Quantity of Waste Incinerated (metric tons*)	Heavy Oil Consumed (metric tons)	Heat Derived from Fuel (kth**)	Heat Recovered from Waste (kth)		Total Heat Produced (kth)	Heat Sold (kth)			Network Yield	Energy Loss in the Network (kth)
				For Home Heating	For Hot Water		Home Heating	Hot Water	Total		
September 1974	7,756	36.36	288	2,261	1,084	3,633	95	1,358	1,453	0.399	2,180
October 1974	7,721	587.80	4,651	5,902	411	10,964	6,674	1,186	7,860	0.717	3,104
November 1974	7,052	1,261.55	9,983	4,188	0	14,171	11,208	1,773	12,981	0.916	1,190
December 1974	7,724	1,539.99	12,186	3,262	92	15,540	12,553	1,861	14,414	0.927	1,126
January 1975	7,791	1,581.82	12,517	4,885	532	17,934	14,203	1,997	16,200	0.903	1,734
February 1975	6,993	1,412.46	11,177	4,679	655	16,511	12,670	1,944	14,614	0.885	1,897
March 1975	7,491	1,275.43	10,092	3,994	860	14,946	11,373	1,770	13,143	0.879	1,803
April 1975	7,909	1,175.67	9,303	4,382	951	14,636	10,700	2,116	12,816	0.875	1,820
May 1975	7,864	338.01	2,675	3,690	567	6,932	3,413	1,675	5,088	0.734	1,844
June 1975	7,602	15.50	123	2,715	868	3,706	96	1,813	1,909	0.515	1,797
July 1975	6,806	9.50	75	2,488	593	3,156	77	1,301	1,378	0.436	1,778
August 1975	6,116	6.33	50	1,379	402	1,831	63	888	951	0.519	860
Total	88,825	9,240.42	73,120	43,825	7,015	123,960	83,125	19,672	102,807	0.829	21,133

SOURCE: Annual Report to the City of Toulouse by BETURE, 1974-75 (*Rapport Technique et Economique*).

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

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

The addition of a third furnace at the end of 1975 has increased this problem by bringing total capacity to 190,000 metric tons (209,300 short tons) per year. One solution would be for the municipality of Toulouse to incinerate the waste of smaller surrounding communities. To date, though the city has tried, this had not proved possible, partly for reasons of regional politics.

Exhibit 7 shows the monthly performance of each furnace for the operating year 1974/75. According to these data, the average amount of waste incinerated in each furnace was 9.6 metric tons (10.6 short tons) per hour of use. This indicates that, when in use, the furnaces have operated well above their rated capacity of 8.15 metric tons (8.97 short tons) per hour. The explanation is that the furnaces are larger than necessary. The lower heating value on which size computations were based was 2,200 kcal/kg (3,970 Btu/lb). Municipal solid waste was analyzed in Toulouse during the acceptance tests for the first furnace in 1970. The average lower heating value was 1,750 kcal/kg (3,150 Btu/lb). This average appears to have remained stable until 1973, when the price of used paper climbed rapidly and a paper collection drive began.⁹ In 1974, the average lower heating value was down to 1,500 kcal/kg (2,700 Btu/lb). The average climbed up somewhat the following year, and during the acceptance tests for the third furnace in 1975, the average was measured at 1,560 kcal/kg (2,808 Btu/lb). In the last quarter of 1975, samples of waste from four different sections of Toulouse were analyzed. In the commercial center, the lower heating value was 1,570 kcal/kg (2,826 Btu/lb); in a central residential area, it was 1,650 kcal/kg (2,970 Btu/lb); in a single-family home area, it was 1,550 kcal/kg (2,790 Btu/lb); and in an area of new high-rise apartments, it was 1,570 kcal/kg (2,826 Btu/lb).¹⁰ These values appear to have remained stable.

Operation of the Thermal Complex
(first two furnaces)

Exhibit 7

Operating Period	Quantity of Waste Incinerated (metric tons*)	Incinerator Operation (hours)			Average Metric Tons/Hour	Turbo-Generator Operation (hours)
		First Furnace	Second Furnace	Total		
September 1974	7,756	711	0	711	10.9	713
October 1974	7,721	657	256	913	8.5	735
November 1974	7,052	253	512	765	9.2	700
December 1974	7,724	737	0	737	10.5	722
January 1975	7,791	417	517	934	8.3	720
February 1975	6,993	277	476	753	9.3	670
March 1975	7,191	89	658	747	9.6	668
April 1975	7,909	706	0	706	11.2	677
May 1975	7,864	730	67	797	9.9	725
June 1975	7,602	28	706	734	10.4	681
July 1975	6,806	0	730	730	9.3	654
August 1975	6,116	234	448	682	9.0	509
Total	88,525	4,839	4,370	9,209	9.6	8,174

SOURCE: Annual Report to the City of Toulouse by BETURE, 1974-75
(*Rapport Technique et Economique*).

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

Since the actual lower heating value is smaller than the theoretical lower heating value*, it is possible to surpass the capacity rating given by the manufacturer. In fact, the only real limitation is the amount of steam produced, which cannot exceed 23.4 metric tons (25.7 short tons) per hour.¹¹ It has proved possible to incinerate waste at a rate as high as 11.2 metric tons (12.3 short tons) per hour, for example in April 1975 (see Exhibit 7).

Exhibit 7 shows also that the amount of waste treated each month never exceeded 7,900 metric tons (8700 short tons) in the operating year 1974/75. This is less than the 10,000 metric tons (11,000 short tons) per month which represents the minimum necessary for continuous use of two furnaces, based on a minimum capacity of 7 metric tons (7.7 short tons) per hour for each furnace.¹²

The potential heat which can be recovered is estimated at 1.01 kth/metric ton (3.65×10^6 Btu/short ton or 1823 Btu/lb).¹³ This number is calculated from the average lower heating value of the waste and the thermal efficiency of the system. The average lower heating value has been estimated at 1,600 kcal/kg (2885 Btu/lb) and the thermal efficiency at 65 percent.¹⁴ The figure of 65 percent is based on the estimation that 25 percent of the theoretical potential is lost in the furnaces and in the production of steam, and a further 10 percent in the heat exchangers.

The amount of heat effectively recovered can be calculated by adding the electricity produced and the energy effectively used for heating and hot water. The electricity has to be translated into its thermal equivalent on the basis of 1 kWh = 1.1 therm to take into account the efficiency of the turbo-generator.¹⁵

The amount of heat which could theoretically be recovered from the waste incinerated and the amount of heat actually recovered have been compared on a monthly basis for the operating year 1974/75 (see Exhibit 8). To analyze the results one must distinguish between two periods:

- the heating period, from October to May, during which the amount of heat actually recovered depends mostly upon the potential heat which could be recovered. The need for heating during this period is greater than the energy available from the waste.
- the non-heating period during which the amount of heat actually recovered depends mostly upon the need for hot water.

During the heating period in 1974-75, the potential heat which could be recovered from waste has been estimated at 61,400 kth (2.44×10^{11} Btu) and the heat actually recovered at 43,300 kth (1.72×10^{11} Btu) which gives a recovery rate of 71 percent (see Exhibit 8). Some energy was lost because of insufficient demand for heating at the beginning and end of the period; consequently the heat was simply dissipated into the atmosphere. Some heat was also lost by keeping the condensers under pressure at a temperature of 100°C (212°F).

* The actual lower heating value is low even for France. This is probably due to the provincial character of Toulouse.

Energy Recovery

Period of Operation	Quantity of Waste Incinerated (metric tons*)	Recoverable Heat (kth**)	Energy Recovered				Percentage Recovered	Heat Sold at Substation Level (kth)
			Electricity (kWh)	Hot Water (kth)	Central Heating (kth)	Total (kth)		
September 1974	7,756	7,865	305,000	1,084	2,261	3,680	46.8	1,453
October 1974	7,721	7,829	512,800	411	5,902	6,877	87.8	7,860
November 1974	7,052	7,150	496,300	0	4,188	4,734	66.2	12,981
December 1974	7,724	7,832	429,200	92	3,262	3,826	48.8	14,414
January 1975	7,791	7,900	583,400	532	4,885	6,059	76.7	16,200
February 1975	6,993	7,090	547,400	655	4,679	5,936	83.7	14,614
March 1975	7,491	7,595	451,000	860	3,994	5,350	70.4	13,143
April 1975	7,909	8,019	516,600	951	4,382	5,901	73.6	12,816
May 1975	7,864	7,974	340,600	567	3,690	4,632	58.1	5,088
June 1975	7,602	7,708	379,900	868	2,715	4,001	51.9	1,909
July 1975	6,806	6,901	339,600	593	2,488	3,455	50.1	1,378
August 1975	6,116	6,201	236,600	402	1,379	2,041	32.9	951
Total	88,825	90,064	5,138,400	7,015	43,825	56,492	62.7	102,807

SOURCE: Annual Report to the City of Toulouse by BETURE, 1974-75 (*Rapport Technique et Economique*).

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

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

During the non-heating period of 1974/75, the potential heat which could have been recovered from waste has been estimated at 28,700 kth (1.14×10^{11} Btu) and the heat actually recovered at 13,200 kth (5.24×10^{10} Btu) (see Exhibit 8), which gives a recovery rate of 46 percent. Energy was lost because the amount needed for hot water was less than the amount available. Thus, there is a market inefficiency as well as a thermal inefficiency.

In October 1975, shutters were added to the condensers which considerably increased the percentage of potential energy actually recovered. It has been estimated that 96 percent of the potentially usable energy was recovered in the month of February 1976.¹⁶ To reach such levels in non-heating months would require an increased demand for hot water because of the addition of dwelling units, or the use of energy for air conditioning or industrial activities. However, at best only 65 percent of the energy content of the waste would be recovered, because of the limit of the thermal efficiency of the system.

SYSTEM RELIABILITY

The furnaces were designed to operate 24 hours a day, 330 days a year with a one-month period for routine maintenance. In reality, because of a shortage of waste to be treated during the operating year 1974/75, the two furnaces were in operation for a combined total of about 9,200 hours (see Exhibit 7), which gives a level of activity of 58 percent.

Non-routine maintenance costs amounted to approximately 1,300,000 F (\$261,000; '69-'75) over a five year period, or 5 percent of the construction cost. These costs include all replacement parts. Maintenance costs were very low during the first three years and increased moderately during the next two years. It is, however, difficult to guess what would have happened if the two furnaces had operated at full capacity.

A landfill site is still maintained in the nearby town of Blagnac in case the incinerator should have to shut down. Thus far, however, this has never happened. In fact, the design of the system considerably reduces the risk of failure in the incineration of waste and the production of heat. The three furnaces are completely independent except for the overhead crane which introduces the waste, the ash pit for the incineration residues and the smoke-stack. The two oil fired boilers of the heating facility can compensate for any decrease in heat recovery. The internal electrical system is coupled with the outside network which cuts in automatically in case of a breakdown.

A number of problems have been noted during the first five years operation:

- Since there is no preliminary crushing or compacting of the waste, large objects such as car engines or refrigerators are occasionally introduced, with the risk of damaging the furnace. Although the crane operator is supposed to watch the waste as it is unloaded from the trucks, bulky objects have slipped in a number of times and the furnace had to be stopped for hours.
- Some materials, especially aluminum, melt and stick to the rollers.

- Unless the condensers operate continuously (though not necessarily at full capacity) they corrode rapidly. One condensor has had to be replaced completely.
- Originally, a metal conveyer belt was used to carry the residues of incineration. This belt corroded, however, and a rubber belt was substituted.

Except for the change in design of the third furnace relative to the first two (see p.12), most of the other changes in the system have been made to improve working conditions in the plant. The thermal complex now appears to be a modern, pleasant workplace.

POLLUTION CONTROL

The volume of fluegas produced is 46,500 m³ (1,642,000 cu ft) per hour per furnace.¹⁷ The gas passes through electrostatic precipitators, the efficiency of which exceeds 97 percent.¹⁸ It then escapes into the air through a 45 meter (148 ft.) high smokestack.

The height of the smokestack had to be limited to meet the requirements of aviation safety because of the proximity of an airport. It contains two flues, the diameters of which are 4.4 and 2.4 m (14.4 and 7.9 ft). The first leads from the heating system and the second from the incinerator.¹⁹

Current French legislation requires that particulate emission remain below 150 mg/m³. The maximum permissible rate of CO₂ emissions is 7 percent; the maximum permissible rate of CO emissions is 0.1 percent.

Official pollution tests, performed during two separate months, gave the following results:²⁰

April 1970 (start of operations for the first two furnaces)

CO₂ = 12.7 percent

Particulates = 114 mg/m³

CO = nil

October 1975 (start of operations for the third furnace)

CO₂ = 7.7 percent

Particulates = 75.5 mg/m³

CO = nil

Additional tests were performed for the city of Toulouse by INSERM, the French Institute for Medical Statistics and Research (*Institut de la statistique et de la recherche medicale*) (see Exhibits 9 and 10). Their measurements were carried out near the top of the stack at a level of 40m (131 ft) high for the gaseous emissions and 15m (49 ft) high for the particulates. The results showed that all the particulates and gaseous compounds were in compliance except for HCl. The values found for the particulates ranged from 50 to 200 mg/m³ with an average representative value of 100 mg/m³. For the HCl, values ranged from 400 to 1,200 ppm with an average value of 750 ppm, which represents an emission of 5g of HCl per kg of waste (.005 lb HCl/lb waste).²¹

The relatively high amount of HCl apparently results from the presence of PVC bottles*, which make up 1 percent of the weight of refuse throughout France. At present, there is no regulation in France limiting the emission of HCl. However, the municipality seems to view this problem seriously and is trying to find a solution.

Exhibit 9

Analysis of Gaseous Emissions

Component	Number of Tests	Concentration (ppm)			Observations
		Minimum	Maximum	Average	
Cl ₂	8	0	0	0	
COCl ₂	10	<0.25	<0.25	0 or 0.25	
Aldehydes & ketones	10	0.3	5	3	expressed as HCHO
H ₂ S	12	0	6	0	
Phenols	16	0	0.10	0.05	
CO	25	0	1,500	<100	
CO ₂	25	50,000	120,000	85,000	
NO	20	45	120	75	
NO ₂	10	0.2	1	0.4	
SO ₂	20	50	120	100	
HF	20	4	15	8	
HCN	20	0	50	5	
Organic acids	20	40	250	100	expressed as CH ₃ COOH
HCl	20	400	1,200	750	
PO ₄ [≡]	20	1	25	8	PO ₄ [≡] mg/m ³
NH ₃	10	2	20	5	

SOURCE: Data gathered by INSERM, furnished by the municipality.

NOTE: Samples taken in the stack at a height of 40 meters (131 feet).

* These bottles are used mainly for mineral water, vegetable oil and *vin ordinaire*.

Particulate Analysis

Component	Electrostatic Precipitator	Smokestack
Cl ⁻	4.45	22.00
SO ₄ ⁼	5.20	10.00
MO ₃ ⁻	0.001	0.07
F ⁻	0.15	0.20
PO ₄ ⁼	2.40	1.40
SiO ₂	37.0	1.80
C	8.3	7.50
Na ⁺	1.1	5.40
K ⁺	2.3	11.00
Ca ⁺⁺	6.9	3.35
Mg ⁺⁺	2.7	2.10
Pb ⁺⁺	0.56	3.60
Fe	2.62	6.10
Zn ⁺⁺	1.70	7.00
Ti ⁺⁺⁺⁺	0.55	0.40
Mn ⁺⁺	2.20	0.11
Sn ⁺⁺	0.15	0.30
Al ⁺⁺⁺	8.92	0.50
Cu ⁺⁺	0.072	0.22
Cd ⁺⁺	0.030	0.10
Ag ⁺	0.006	0.01
Cr ⁺⁺⁺	0.05	0.02

SOURCE: Data gathered by INSERM,
furnished by the municipality.

NOTE: Sampling showed a concentration of
particulates ranging between 50 and 200 mg/m³,
with an average concentration of 100 mg/m³.
Results are given in percentage of total particu-
lates. Samples taken in the stack at a height of
15 m (49 ft).

The problem of HCl emissions, and the fact that special exceptions were required for the limited height of the stack and for the use of residual fuel oil in the heating plant, have led the municipality (with the help of INSERM) to set up five monitoring stations at ground level. The analysis began in June 1976 and will last for one year. The concentration of HCl in the atmosphere ranged from 3 mg/m³ to 50 mg/m³. Particulate Cl ranged from 2 mg/m³ to 8 mg/m³. HCl was chosen as a tracer for gaseous emissions and tin was chosen as a tracer for particles. However, the concentration of tin has proved to be so low that it cannot be traced with the instruments available. Another choice may be made. In any case, it will not be possible to obtain a clear picture of the emissions resulting from the incinerator as background emissions were not recorded before construction began.

The combustion residues have been estimated at 30 percent by weight of the wastes incinerated, including 3.5 percent (by weight) of unburned material.²² These residues are landfilled (along with the untreated waste of a nearby town), but space is becoming a critical problem.

The results of the analysis at ground level will probably be presented to the regional environmental groups. The nearest residents complain quite frequently to the municipality, but it is difficult to say if these complaints are legitimate as there are never complaints about the old incinerator of Toulouse-Le Ramier which registers higher levels of emissions on tests.

PLANT BUILDING AND WORKING CONDITIONS

The thermal complex is situated on a 4.5 hectare (11 acre) tract in an industrial zone some ways from residential areas. The building itself is 121m (397 ft) long and 57m (187 ft) wide. Its general height is 17m (56 ft), however, a large concrete block 36m x 36m x 30m (118 ft x 118 ft x 98 ft) and a 45m (148 ft) stack protrude. (See Exhibits 2 and 11.) The plant was designed by M. Alexis Josic, working under the supervision of M. Candilis, a well known architect, who designed the new town of Le Mirail where the plant is located.

Several factors which are often neglected in industrial architecture have received careful attention: land use, organization of space, and grouping. The external aspect is somewhat heavy. The general impression is cold and colorless - even a bit crude - though pure and well balanced. Working conditions have been constantly improved since construction: overhead lighting in the central block, insulation for the furnaces, air conditioning, and a large window in the furnace control room have all been added.

Working conditions now appear satisfactory from the standpoints of ambient temperature, air quality, and building cleanliness. In certain places there is a problem with the noise level, but these are not permanent work posts. Deodorants are used to reduce the smell in the waste pit. The draft in the pit is still inadequate, probably because of the underutilization of the furnaces. The door leading to the tipping platform is now remotely controlled and is closed after the entry of each truck. This has reduced the emission of odors to the outside somewhat.

Only one major accident has occurred.* It has led to the addition of an emergency stop on the conveyor belt which carries the incinerator residues.

Traffic is something of a problem since all the trucks tend to arrive during the same period (between 10:00 and 11:30 a.m.). This problem cannot be overcome for labor reasons, since it would require that the truck drivers change their breakfast time!

Exhibit 11

Plan of the Thermal Complex

* The employee involved, however, is still working at the plant.

ECONOMICS AND MANAGEMENT

MANAGEMENT

The operation of the incinerator and heating facility, has been conceded to a private company SETMI, according to a system called *affermage*. The city of Toulouse retains ownership of the thermal complex which is operated by SETMI for a period of 20 years. SETMI was created specifically to operate this complex, the shareholders being the various companies which participated in the construction, including Tunzini.²³ Other companies participating are SITECO which is in charge of technical control, and Est et Nord which has financial control.

The head of SETMI is a former technical adviser to the city of Toulouse. He is assisted by a director and a technical vice-director. Total employment is 47 people, most of them working throughout the thermal complex. However, five mechanics and one maintenance supervisor work specifically on the heating facility and the distribution networks (see Exhibit 12).

Among the 41 employees at the central unit, there are 5 executives, 13 maintenance workers, 20 workmen and 3 other administrative personnel. The workmen are organized in five shifts of 4 people working under the 3 x 8 system (3 teams working 8 hours each). There are fewer employees at Le Mirail than at other thermal plants of similar size in France.

The operation of the central unit is performed by 20 workers who incinerate between 88,000 and 100,000 metric tons (97,000 and 110,000 short tons) of waste annually. It would be possible to increase the amount of waste incinerated considerably (at least to 130,000 metric tons [143,000 short tons]) without increasing the personnel.²⁴ In fact, SETMI is considering the transfer of incineration control from separate control centers for each furnace to the central control room in order to reduce the number of employees still further.²⁵

Certain jobs appear to demand considerable skill, particularly those of the furnace supervisor, who has to monitor the operation constantly, and the crane operator. It takes at least a year of experience to learn to supervise a furnace. The foremen have more than ten years experience in heating operations and the vice-director has 20 years experience in thermal operations. A foreman earns between 40,000 F and 50,000 F (\$8,368-\$10,460; 1976) per year, an unskilled workman earns 20,000 F (\$4,184; 1976) per year.²⁶ A foreman's salary is average for that job category. The unskilled workmen earn the minimum wage.

The city exercises its overall control through the engineering firm BETURE which receives monthly reports from SETMI and presents an annual report to the city. This report includes technical and economic data but does not contain any financial information. Since SETMI is a private company, the financial statement, with the real costs of operations and their distribution, is not available to the city.

Organization Chart of SETMI (Operator of the Thermal Complex)

SOURCE: Derived by RPA from data provided by SETMI: M. Lartigue.

CAPITAL COSTS

The construction of the first two incinerators of phase I cost 25,200,000 F in 1969 (\$4,846,000; 1969 or \$9,121,000; 1976) (see Exhibit 13). Phase II, construction of the third incinerator, cost \$17,700,000 F in 1975 (\$4,126,000; 1975 or \$4,476,000; 1976).²⁷ A plant with equivalent capacity might cost less today, due to technical improvements leading to increased productivity.

Exhibit 13

Construction Costs

Phase I (1969)		25,200,000F (59%)	\$ 9,121,000-1976
Two incinerators	16,800,000F (39%)		
Heat recovery equipment	8,400,000F (20%)		
Phase II (1975)		17,700,000F (41%)	\$ 4,476,000-1976
Third incinerator	11,800,000F (27.5%)		
Heat recovery equipment	5,900,000F (13.5%)		
Total		42,900,000F	\$13,597,000-1976

For phase I, out of a total cost of 25,200,000 F, 16,800,000 F was for the incinerators themselves and 8,400,000 F for the heat recovery system (see Exhibit 14). The contract was awarded not by the municipality itself, but by SETOMIP, the agency in charge of the new town development. SETOMIP received a subsidy from the national government of 3,500,000 F (21 percent) for the incinerator.²⁸

For phase II, out of a total cost of 17,700,000 F, 11,800,000 F was for the third incinerator and 5,900,000 F for the heat recovery system (see Exhibit 12). This contract was awarded directly by the municipality which obtained a subsidy from the national government of 1,600,000 F (14 percent) for the incinerator.

Distribution of Construction Costs

Phase I (two incinerators—1969)

Incinerators

Construction	5,920,000F
Equipment	9,250,000F
Engineering services	960,000F
General expenses	560,000F
Total	16,800,000F

Heat Recovery System Equipment

Construction	2,275,000F
Equipment	4,735,000F
Engineering services	430,000F
Debt service	700,000F
General expenses	300,000F
Total	8,400,000F

Phase II (third incinerator—1975)

Incinerator and Heat Recovery Equipment

Construction	885,000F
Equipment	14,103,000F
Engineering services	443,000F
Debt service	145,000F
General expenses	2,124,000F
Total	17,700,000F

SOURCE: M. Seman, SETOMIP

The subsidies from the national government (which amounted to 12 percent of the total cost of the thermal complex) were only for the incinerators and not for the heat recovery system. This may seem curious in a country where energy savings are considered highly important by the government. The project was funded essentially through the *Caisse des Dépôts et Consignations* (which plays the role of state banker for municipal projects) at the relatively low interest rates of 6.5 percent for phase I and 10.2 percent for phase II (see Exhibit 15).²⁹

Exhibit 15

Financing

Phase I (two incinerators--1969)*

3,500,000F	Subsidy for incinerator from national government
7,700,000F	Loan from SAMTAS at 8.75% for 15 years
8,740,000F	Loan from <i>Caisse des Dépôts et Consignations</i> at 6.5% for 20 years
7,960,000F	Loan from <i>Caisse des Dépôts et Consignations</i> at 5.25% for 20 years

Phase II (third incinerator--1975)**

1,660,000F	Subsidy for incinerator from national government
16,040,000F	Loans from <i>Caisse des Dépôts et Consignations</i> at 10.2%

* SOURCE: M. Seman, SETOMIP

**SOURCE: M. Derbogossian, City of Toulouse

The amortization cost, including debt service,* has been estimated by the municipality at 35 F/metric ton (\$7.40/short ton; 1975) incinerated in 1975 on the basis of 130,000 metric tons (143,000 short tons) incinerated.³⁰ RPA estimates that for the first two furnaces only, the amortization cost would be 22 F/metric ton (\$3.80/short ton; 1969) incinerated.

OPERATING COSTS

SETMI obtains three separate forms of revenue from the city of Toulouse.

- a fixed fee corresponding to fixed costs,
- a proportional fee corresponding to variable costs and proportional to the amount of waste treated,
- a fixed depreciation fee for major repairs and replacement.

These revenues are computed from an indexed formula which was set out in the initial contract. The fixed fee goes mainly for salaries and amounted to more than 1,200,000 F (\$264,000; '74-'75) during the operating year 1974/1975 (see Exhibit 16). The proportional fee corresponds to costs of materials and maintenance. It amounted to 1,100,000 F (\$242,000; '74-'75) in 1974/1975 or 12.4 F/metric ton (2.50/short ton; '74-'75) incinerated. Finally the depreciation fee amounted to 680,000 F (\$149,500; '74-'75) in 1974/1975. This fund is put into a special account and drawn on only when major repairs and replacements are actually needed. Credit is carried forward to the following year.

* Excluding subsidy.

Direct Operating Costs

(francs, before tax)

Operation	1971/72	1972/73	1973/74	1974/75
Quantity of waste (metric tons*)	92,759.00	100,101.00	86,329.00	88,826.25
Heat recovered (kth**)	47,515.20	54,368.00	47,058.00	50,840.19
Heat recovered (kth/metric ton)	0.512	0.543	0.545	0.572
Gross cost of incineration				
—Fixed contribution	766,341.30	976,237.31	1,036,703.28	1,244,835.11
—Proportional contribution	730,490.23	872,666.69	866,484.62	1,098,811.48
—Contribution for major repairs	427,879.11	510,876.09	547,040.94	681,271.55
Total	1,924,710.64	2,359,780.09	2,450,228.84	3,024,918.14
Francs/metric ton	20.75	23.57	28.38	34.05
Price of heat recovered	806,993.58	984,194.00	1,425,853.46	2,361,214.06
Francs/kth	16.98	18.10	30.30	46.44
Net cost of incineration	1,117,716.86	1,375,586.09	1,024,375.38	663,704.08
Francs/metric ton	12.05	13.74	11.87	7.47

SOURCE: Annual Report to the City of Toulouse by BETURE, 1974-75 (*Rapport Technique et Economique*).

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

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

Conversion Rates:	F/\$
1971/72	5.27
1972/73	4.75
1973/74	4.63
1974/75	4.55

On September 1, 1975, the balance of this account was 1,400,000 F (\$326,000; 1975) (see Exhibit 17) which indicates that to that date, no unexpected expense for major repairs had occurred. Total non-routine maintenance costs for the operating year 1974-75 were 571,243 F (125,500), as shown in Exhibit 18.

The total amount paid by the City of Toulouse to SETMI was approximately 3,000,000 F (\$659,000; '74-'75) during the operating year 1974/1975. (See Exhibit 16). In return, the city receives from SETMI a sum proportional to the amount of heat which has been recovered. This sum is also computed from a formula set in the initial contract and indexed on the price of N^o2 oil. This repayment amounted to 2,400,000 F (\$527,000; '74-'75) for 1974/1975 or 46 F/kth (\$2.54/10⁶ Btu; '74-'75) (see Exhibit 16). A market for the residues of incineration has not yet been found.

Non-Routine Maintenance Account

(francs)

Operating Year	Receipts from City of Toulouse	Expenditures	Conversion Rates (F/\$)
1969/70	189,318.96		5.36
1970/71	385,149.85	137,840.71	5.52
1971/72	427,879.11	161,448.00	5.27
1972/73	510,876.09	92,213.01	4.75
1973/74	547,040.94	331,708.97	4.63
1974/75	681,271.55	571,242.85	4.55
Total	2,741,536.50	1,294,453.54	
Balance as of Sept. 1, 1975	1,447,082.96		

SOURCE: Annual Report to the City of Toulouse by BETURE, 1974-75
(*Rapport Technique et Economique*).

Thus, while the total amount paid by the municipality to SETMI in the three categories was approximately 3,000,000 F during 1974/75 (or 34 F/metric ton [\$6.80/short ton; '74-'75] incinerated) the total amount received by the municipality from SETMI during the same period was approximately 2,400,000 F (\$527,000; '74-'75) (or 27 F/metric ton [\$5.40/short ton; '74-'75] incinerated). On balance, the costs incurred by the municipality of Toulouse for the operation of its incinerator during 1974/75 can be estimated at 7.5 F/metric ton (\$1.50/short ton; '74-'75). This figure has been computed without value added taxes (17.6 percent), and is the equivalent of approximately 9 F/metric ton (\$1.80/short ton; '74-'75) including taxes.³¹ Based on equivalent computations, RPA has developed the following estimates for overall direct operating costs (see Exhibit 16):

12 F/metric ton (\$1.96/short ton) in 1971-72

13.7 F/metric ton (\$2.61/short ton) in 1972-73

11.9 F/metric ton (\$2.33/short ton) in 1973-74

7.5 F/metric ton (\$1.49/short ton) in 1974-75

The reduction in cost is due mainly to the increase in the value of the heat recovered as a result of the general increase in the price of energy.

OVERALL COSTS

Considering the first two incinerators only, the total cost of incineration to the municipality can be obtained by adding the cost of amortization, or 34 F per metric ton (\$6.80 per short ton; '74-75) to the direct operating cost, or 7 F per metric ton (\$1.40 per short ton; '74-75). This gives a total of 41 F per metric ton (\$8.20 per short ton; '74-75) incinerated in 1975. However, this figure should be considered as only a rough estimate for at least four reasons:

- In addition to the revenues received from the city (see Exhibit 16), SETMI (the operator of the thermal complex) receives revenue for

**Non-Routine Maintenance Costs
for Operating Year 1974-75**
(francs)

Furnaces	
—Mechanical parts	48,730.97
—Electricity	7,815.95
—Repair of flues	40,320.90
Waste crane	18,718.45
Ash crane	5,749.86
Ash conveyor belt	220.42
Electrostatic precipitators	84,346.45
Rebuilding of flues and installation of ground-level ventilators*	200,000.00
Turbo-generator	20,080.15
Compressors	1,239.32
Air condensers	3,418.80
General electricity	4,518.55
Skilled labor	82,094.65
Insurance premium	24,988.38
Total	571,242.85 (\$125,500)

SOURCE: Annual Report to the City of Toulouse by BETURE, 1974-75
(*Rapport Technique et Economique*).

* Work carried out in July, 1974, but carried on accounts of Operating
Year 1974-75.

which the city receives no credit, from the sale of heat and hot water to the households of Le Mirail. In the operating year 1974/75, SETMI charged 72.7 F per kth ($\$4/10^6$ Btu) before taxes (90 F/kth [$\$5/10^6$ Btu] including taxes). This price was at or below the market price of such substitutes as fuel oil and gas, and may thus represent a small subsidy to the homeowner.

- The cost of the distribution network is not included.
- A subsidy of about 12 percent of total cost was obtained from the national government, moreover interest rates are relatively low.
- No cost for the land on which the incinerator was built has been taken into account as it belonged to the municipality.

However, these estimates give a first approximation of the total costs of incineration of Toulouse.

CONCLUSIONS

A new town is probably the optimal location for a waste-to-energy system. The decision to recover energy at Toulouse-Le Mirail in the form of heat rather than electricity (except for in-plant use) seems to have been wise. There is a state-owned monopoly for power generation in France (*Electricité de France*) which provides electricity at relatively low rates. Furthermore, the recovery of heat is more efficient than the recovery of electricity would be.

The system has no apparent fundamental technical problem. The VKW furnaces are simple and robust, although they have never been tested to full design capacity. Incineration, recovery of energy, and provision of domestic heat and hot water are well integrated.

The thermal complex operates relatively inexpensively. This is due, in part, to the decision not to generate electricity and also, in part, to the low cost of unskilled labor in France. Operation would be still less expensive if more waste were incinerated and if more markets for the recovered energy could be found. The relationship between the City of Toulouse and the private company which operates the thermal complex appears to be very good and cost-effective.

Construction of the third incinerator while the first two were operating well below capacity was a mistake. Provision had been made for such a facility in the Sixth National Plan, a 14 percent subsidy was available, and inertia prevailed.

NOTES

1. Personal communication with M. Cazaux, economist, Departmental Division of Public Works, Toulouse
2. Noirot, "L' Usine du Mirail-Traitement des Ordures," Ingénieurs des Villes de France, May 1976.
3. Personal communication, M. Bressand, Technical Services, City of Toulouse
4. Internal report of the City of Toulouse
5. Circular of October 18, 1965
6. Personal communication, M. Roger, Director of Technical Services, City of Toulouse
7. All technical data on the incinerator are taken from:
 - Noirot, op. cit.
 - Information provided by the contractor, the engineering firm of Tunzini
 - Information gathered on a visit to the thermal complex by RPA staff
8. All technical data on the heating system are taken from:
 - Noirot, op. cit.
 - Information gathered on a visit to the thermal complex by RPA staff
9. *Ministère de la Qualité de la Vie*
10. BETURE
11. Personal communication, M. Noirot
12. BETURE, Annual Report to the City of Toulouse, 1974-75. (*"Rapport Technique et Economique"*)
13. Personal communication, M. Noirot
14. BETURE, op. cit.
15. Ibid.
16. BETURE, op. cit.
17. INSERM
18. Information furnished by contractor, confirmed by City of Toulouse

19. Information furnished by Contractor
20. *Association des Producteurs d' Appareils à Vapeur et Electriques*
21. INSERM
22. BETURE, op. cit.
23. The shareholders are *Tunzini, Cie Générale de Chauffage à Distance, SITECO, Cie Générale des Eaux, Industrielles d'Exploitation de Chauffage, Streichenberger and Est et Nord*
24. Personal communication, M. Lartigue, SETMI
25. Ibid.
26. Ibid.
27. Personal communication, M. Derbogossian, City of Toulouse
28. Personal communication, M. Derbogossian
29. Personal communications, M. Derbogossian, and M. Seman, SETOMIP
30. Estimate developed by the City of Toulouse; personal communications, M. Roger, M. Bressand
31. Noirot, op. cit.

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

French Francs to U.S. Dollars

<u>Year</u>	<u>F/\$</u>
1969	5.20
1970	5.53
1971	5.51
1972	5.04
1973	4.45
1974	4.81
1975	4.29
1976	4.78

Source: "International Financial Statistics" International Monetary Fund.

Abbreviations

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