envirogenics co.

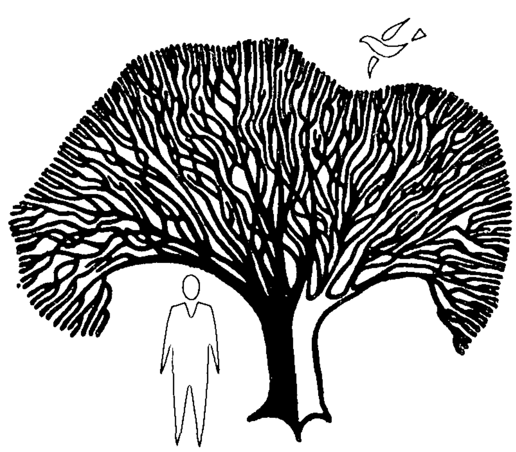
COMBINED FIRING SYSTEMS FOR

SPECIFIC METROPOLITAN AREAS

A Final Report to the

ENVIRONMENTAL PROTECTION AGENCY

Report No. F-0303 November 1971



A DIVISION OF AEROJET-GENERAL CORP.

COMBINED FIRING SYSTEMS FOR SPECIFIC METROPOLITAN AREAS

A Report to

ENVIRONMENTAL PROTECTION AGENCY

CONTRACT NO. EHSD 71-9

By

R. M. Roberts and R. C. Hanson

NOVEMBER 1971

ENVIROGENICS COMPANY
A DIVISION OF
AEROJET-GENERAL CORPORATION
EL MONTE, CALIFORNIA

ABSTRACT

The purpose of the present study was to develop for two major cities design recommendations and procedures for the disposal of refuse, a low sulfur fuel, with heat recovery in utility grade boilers. The guidelines observed were those generated on a previous Envirogenics' program performed on EPA Contract CPA 22-69-22. In that work, optimal system design configurations were identified and the benefits to the environment and the economy quantified. Thus the present program has been one of applying that knowledge to specific case study areas.

Arrangements with two cities having high SO_2 burdens and growing solid waste burdens were made; these were Philadelphia, Pennsylvania, and Cleveland, Ohio. Information required for the study was collected and analyzed. Specific design packages were then developed for each city. Contained therein are projections describing the future nature of the city refuse-fuel inventories, specific recommendations as to plant types, sizes, and sites, cost analyses of operations involving the utilization of such systems, and estimated reduction in SO_2 and particulate emissions. From these data, the conclusion can readily be drawn that the systems recommended would be more cost-effective than the methods that are now in use.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

APPENDIX A

TITLE: COSTS OF OPERATING PLANTS OF OVERSIZED REFUSE CAPACITY

FIGURES

I. INTRODUCTION AND SUMMARY

A. BACKGROUND

The work documented in the present report represents a logical sequel to a larger program effort recently completed for the EPA. The conclusions and recommendations developed therein concerning the economic, technological, and environmental aspects of disposing of refuse in utility class steam generators, have now been applied to specific metropolitan case areas.

The initial study, entitled "Systems Evaluation of Refuse as a Low Sulfur Fuel," was accomplished on EPA Contract CPA 22-69-22. It was carried out by the Envirogenics Co. in conjunction with the Foster Wheeler Corp. and Cottrell Environmental Systems, Inc. The final report has recently been released (Ref. 1) and should be consulted if the background information on which the present work is based is to be fully appreciated. A brief summary of the CPA 22-69-22 program is given in the following paragraphs.

B. SUMMARY OF THE PRECEDING PROGRAM

The ground-laying work done on EPA Contract 22-69-22 was addressed to the assessment and systematic optimization of the mechanics and combustion methodology associated with the utilization of refuse as a fuel for generating steam. While benefiting waste management interests, it was noted that refuse firing could also displace conventional fuels that cause high sulfur oxide emissions. The extent of SO_2 - abatement possible was projected to the year 2000, by estimating the quantities and composition of refuse that would likely be available.

Determining the useful energy from refuse involved the associated task of establishing for this fuel its behavior in and compatability with furnace structures. This required the definition of the various energy utilization opportunities for which refuse might be suited. With emphasis logically aligned to power plant applications, the relevant technology and state-of-the-art (particularly in Europe) of power generation with refuse were documented. In this connection, processes and hardware used in the handling and conditioning of refuse were also reviewed. Criteria were then established for firing refuse in utility-class boilers.

A catalog of ten different combined-fuel (coal + refuse) fired boiler configurations were conceived and then analyzed in terms of process variables (plant power capacity, fuel-ratio, etc.); performance/cost characteristics were also predicted. Similarly treated were five plans for modifying existing plants to refuse-burning systems. At least one of these fifteen systems was identified as being a more cost-effective approach to refuse disposal than is landfill at the present time.

A cost model was developed to consider all the major elements involved in the erection and operation of these refuse-burning systems. From this systematic analysis, two new-plant configurations were extracted and subjected to detailed engineering analysis. Cost estimates were iteratively computed for the resulting preliminary designs.

The two favored steam generator configurations, the end product of the system analysis, represented considerably different levels of cost-effectiveness. However, the system predicted to have the higher disposal cost required more conservative treatment because of performance uncertainties associated with its more advanced design.

In line with the latter problem and extending to all aspects of the study where technical knowledge-gaps were recognized, research and development requirements were itemized. These were analyzed and integrated into discrete task packages. Final organization of these R&D elements took the form of two 5-year plans, each structured to accommodate a specific level of effort.

C. SCOPE OF THE PRESENT STUDY

The technical and economic analysis of a wide range of refuse or combined firing possibilities performed on the initial program showed that the cost effectiveness of a preferred system is dependent on a great many factors and constraints operating within any specific metropolitan area under consideration. The purpose of the present study was to apply these generalized results to two specific and representative metropolitan areas where sulfur oxides and particulate pollution and refuse disposal are problems, and evaluate the influence of the specific local conditions and constraints on the system choice and feasibility. Municipalities interested in a cooperative effort were to be selected, and specific cost-benefit advantage to the municipality determined. Beneficial uses of energy recovery from refuse incineration other than power generation were also to be considered. It was expected that favorable results from these studies would not only suggest implementation in the specific localities studied, but would serve to arouse interest in other metropolitan areas with similar problems.

Attainment of these objectives would involve the acquisition and analysis of information within the case areas pertaining to refuse management and inventory characteristics, steam generation requirements, and urban layout. Specific steam generator systems and sites were then to be proposed and design packages submitted for review by the principals within the two selected municipalities. The responses elicited would then help guide the preparation of the present document, which offers the recommendations deemed potentially most beneficial to the municipalities concerned.

D. PROGRAM SUMMARY

1. Selection of Metropolitan Sites

The selection of the two metropolitan case study areas was limited to those among the first twenty-five cities ranked in terms of SO_2 problem severity shown in Table 1. This tabulation was extracted from Reference 2. Most of the cities listed also suffer from the associated problem of particulate air pollution. Six of the cities were identified as being faced with moderate to acute waste management problems. Local authorities were contacted in these six areas and working arrangements established with two. These were the cities of Philadelphia, Pennsylvania, and Cleveland, Ohio. The respective utilities involved were the Philadelphia Electric Co. and the Cleveland Electric Illuminating Co. The key personnel of these organizations who furnished inputs to this study are named in the Acknowledgement Section of this report.

2. Data Acquisition and Analysis

As a result of the liaison established in the two cities, information was provided on the following factors.

- Demographic trends
- Waste collection rates by districts
- Waste composition and characteristics
- Waste management practices and policies
- Utility-grade steam generator inventories, including design specifications and station sites
- Future energy and waste disposal requirements and related planning.

This information was systematically analyzed and projections developed by Electronic Data Processing (EDP) techniques on solid waste trends pertaining to collection rates, composition and fuel value, and combustion characteristics. Opportunities for establishing refuse-firing steam generators within reasonable reach of the refuse collection systems were then explored. This was conditioned by the decision to locate power plants at shore sites of water bodies within or adjacent to the cities to satisfy cooling water requirements. Both city utilities, however, operate district heating networks, the steam plants of which are not only centrally located but require only modest quantities of

TABLE 1

SMSA's RANKED BY SEVERITY OF SO_2 PROBLEM
(AS OF 1968)

SMSA	SO_2 Rank
New York	1
Chicago	2
Philadelphia, Pa-NJ	3
Newark	4
St. Louis, Mo-Ill	5
Paterson-Clifton-Passaic	6
Washington, Md-Va	6
Jersey City	8
Providence-Pawtucket, Ri-Mass	9
Reading	10
Allentown-Bethlehem-Easton, Pa-NJ	11
Boston	12
Lancaster	13
Cleveland	14
York	14
Wilmington, Del-NJ	16
Baltimore	17
Bridgeport	18
Cincinnati, Ohio-Ky	19
Akron	20
Canton	20
New Haven	20
Worcester	20
Gary-Hammond-E. Chicago	24
Pittsburgh	25

cooling water. Recommendation of refuse-fired steam plants for both cities was thus indicated, although it was recognized that steam demand would permit only the firing of a fraction of the total refuse collected in either city. The solution to this has been to propose a combination of steam and turbo-electric plants, setting the refuse rate of the former as high as possible.

3. Design Recommendations

Specific plant design and performance recommendations were prepared for each of the cities. The guidelines established on the basic program (Ref. 1) were initially followed (except as noted below), then modified after the design packages had been reviewed by the city and utility principals to accommodate local factors. For each city, the design recommendation consisted of one district heating plant (100% refuse fired) and one turbo-electric plant of the Case 3 type.* Key information on these systems is shown in Table 2.

In neither city was an opportunity for the retrofit approach recognized. In Cleveland, this was due to the prevalent use of slag-tap boilers, which are poor retrofit candidates because of structural lay-out and the potential for slag solidification when mixed refuse/coal fuels are fired. In Philadelphia, the utility company suggested that the retrofit approach would not be compatible with their operations.

In preparing the design packages, one notable deviation from the design guidelines established on the initial program was considered advisable. This concerned the manner in which refuse is stored and charged to the furnace. In Reference 1, it is recommended that charging be done by conveyor-belt systems, utilizing live-bottom, high-profile storage structures. Because such a technique has not yet been actually tried on refuse, it was decided that the more conservative, and costly, storage pit and crane method be employed. This required that current cost data on components of such systems be collected and inserted into the existing cost model.

Conversion of boilers to fire low sulfur oil is the present trend, particularly in Philadelphia. This can be done at much lower capital costs than in providing SO_2-removal equipment for coal-fired furnaces. As a result, fuel costs have significantly increased, posing long term economic penalties for power consumers. On the present study, coal has therefore been the fuel of choice. Appropriate gas cleaning equipment for both SO_2 and particulate control (90% and 99% efficiencies, respectively) has been specified and costed.

---

*As described in detail in Reference 1, a design wherein refuse is fired on agitating grates in a feedwater heater or "economizer" that serves a separately situated steam generator fired with fossil fuel.

TABLE 2

CHARACTERISTICS OF PROPOSED STEAM GENERATORS

	Philadelphia	Cleveland
District Heating Plant		
Refuse Rate, tpd	1,400	400
Steam Production, lb/hr	315,000	90,000
Send Out, lb/hr	270,000	75,000
Steam Pressure, psig	225	170
Steam Temperature, ^{o}F	450	425
Plant Factor, %	80	80
Turbo-electric Plant		
Nameplate Rating, MW	300	200
Refuse Rate, tpd	1,500	936
Steam Conditions, psig/^{o}F/^{o}F*	2400/1000/1000	1800/1000/1000
Energy Input from Refuse, %	19.4	17.4
Plant Factor, %	80	80

*Turbine throttle pressure, psig/Superheat temperature, ^{o}F/Reheat temperature, ^{o}F

4. Cost Analysis

With certain notable exceptions, the development of system capital, operating and maintenance, and refuse disposal costs basically followed the approach outlined in Reference 1. The cost model provided in that document was updated to compensate for cost escalations. A number of cost model functions were modified to better represent cost situations operating in the cities studied. Several new functions were added to accommodate system components that were not previously provided.

Capital costs derived include land and land rights, structures and improvements, boiler plant equipment (boiler, water treatment equipment, pumps, piping, coal handling equipment, residue handling equipment, and stacks), turbine-generator equipment (if any), accessory electrical equipment, miscellaneous plant equipment (including turbine room cranes and fire fighting equipment), air pollution control (APC) equipment, and refuse handling equipment and facilities.

Capital costs were annualized on the basis of utility rather than municipal ownership. This was done because of the less favorable rate of the former and not to suggest where proper proprietorship belongs. Operating and maintenance costs (including costs of water and residue disposal) were calculated and added to annualized capital costs to furnish total annual costs. Product credit was then determined, using different approaches for district heating and turbo-electric systems, and subtracted from total annual costs. The difference was then distributed over the quantity of refuse fired per year (80% plant factor) to arrive at unit disposal cost. The culmination of this analysis was the derivation of costs for transporting refuse to the sites selected for the refuse-fired steam generators. This cost was added to disposal cost, the combined transporation-disposal costs thus serving as the primary reference point for comparing the recommended system with methodology now in use.

Assignment of product credit must take into account the nature of the product demand that is to be satisfied by a new installation when it is added to an already operating complex of steam generators. In the case of the refuse-fired turbo-electric system, it was reasonable to assume that it would be built to satisfy a load in excess of the capacity of the existing system, since power demand is increasing rapidly. In this situation the proper product credit would be the cost of generating the same amount of electricity by a conventionally-fired power station of identical capacity and plant factor and one that was built under the same cost conditions as the refuse-fired system. This required of course that complete costs be developed for both the conventional and the refuse-fired power plants.

In the case of district heating plants, a different method of product credit assignment was necessary. This resulted from the fact that in both cities increased steam demand is not expected. Firing a new steam plant would therefore necessitate that the older ones be operated at reduced plant factors. Thus product credit would consist only of the fuel saved and the operating and maintenance (O&M) costs displaced in the older units when operating the refuse-fired systems.

5. Cost Analysis Results

Most of the refuse collected in the City of Philadelphia is disposed of in a system of strategically well-located incinerators. In July 1969, it was estimated that this operation cost $7.35/ton. On the present study, it was estimated that the transportation cost associated with incineration amounts to $1.81/ton. This suggests that current combined transportation and disposal cost are something higher than the sum ($9.16/ton) of these two costs.

The disposal cost for the district heating plant (see Table 2) recommended was calculated and found to range between $3.20 and $5.36/ton, depending on the steam generating costs ($1.00 to $0.55/10 lb steam) of the existing station that it would displace. The cost for transporting refuse to this new plant was calculated to be $1.93/ton, bringing overall costs to between $5.13 and $7.29/ton.

In the case of the recommended turbo-electric plant, disposal costs were estimated to range between zero and $1.75/ton as the cost of the fossil fuel (low sulfur oil) displaced by refuse ranged between $0.44 and $0.40/10^6 Btu's. Refuse transportation cost for this plant was estimated to be $3.30/ton, bringing the overall charge between $3.30 and $5.05/ton.

In Cleveland, landfill disposal is the favored tool of solid waste management. The city currently seeks new landfill sites and aims to reach these through the use of transfer stations. It has been estimated that the combined cost for transportation and disposal by this new arrangement will come to about $7.00/ton. The equivalent costs for hauling to and disposing of refuse at the district heating plant recommended were estimated to be $10.80/ton, including $2.80/ton for transportation. For the turbo-electric system this cost was found to be only $4.53/ton including $2.62/ton for transportation. The relatively high refuse handling cost associated with the district heating installation resulted not only from the unfavorable method of product credit assignment discussed above, but a well-below optimum refuse charging rate. This was unavoidable because of the steam demand situation in Cleveland.

An analysis conducted on the present study that was not treated on the previous program involved the effect on costs of oversizing a plant so as to accommodate future increases in refuse production. Two approaches were analyzed and are discussed in Appendix A. It can be seen from this analysis that if a plant is built intentionally oversized, the refuse deficit should be made up by firing supplemental fossil fuel rather than by turning down the plant.

On the basis of the foregoing considerations, design packages were prepared for each of the municipalities and presented to the principals for review and comments. Conferences were then held in each city; a number of changes were suggested by both city and utility officials. These largely dealt with local costing practices, although site changes and modification of plant capacities were also requested. The design recommendation contained in the present report reflect essentially all of the resolutions reached in these reviews.

6. Potential Reduction of Air Pollutants

The possible significance to air pollution burdens of using refuse as a partial substitute for fossil fuels was also explored. Based on best estimates as to the type of fossil fuel that would be displaced and the pollutant generation rates that would probably be encountered, calculations were performed. The results, which indicate that only modest air purification benefits are available in substituting refuse for fossil fuels that, themselves, have been specified in order to reduce pollutant emissions, can be tabulated as follows:

ESTIMATED AIR POLLUTION REDUCTIONS
FROM SUBSTITUTING REFUSE FOR FOSSIL FUELS

City	Fuel Displaced by Refuse	Refuse Fired, 10^6 tpy	Reduction in Emissions, tpy		
			SO_2	Particulates[1] W/O APC	Particulates[1] With APC
Philadelphia	Oil (0.5% S)	0.875	1000	---	420
Cleveland	Coal (1.0% S, 10% Ash)	0.393	590	4,125	41

(1) Air pollution control (APC) equipment efficiency set at 99%; also see following text.

In this analysis, it was assumed for the Philadelphia case that, because of its low ash content, oil would be fired without the use of APC equipment while refuse would only be fired if such equipment were installed. In the Cleveland case, the comparison was arbitrarily made on the basis of zero and 99% dust control for both coals and refuse.

II. THE PHILADELPHIA STUDY

A. WASTE MANAGEMENT OPERATIONS

The Sanitation Division of the City of Philadelphia's Department of Streets has cognizance of that City's waste management operations. According to its charter, the Sanitation Division is charged with six responsibilities, two of which are:

- "Collection of ashes, rubbish and garbage from households and retail establishments"

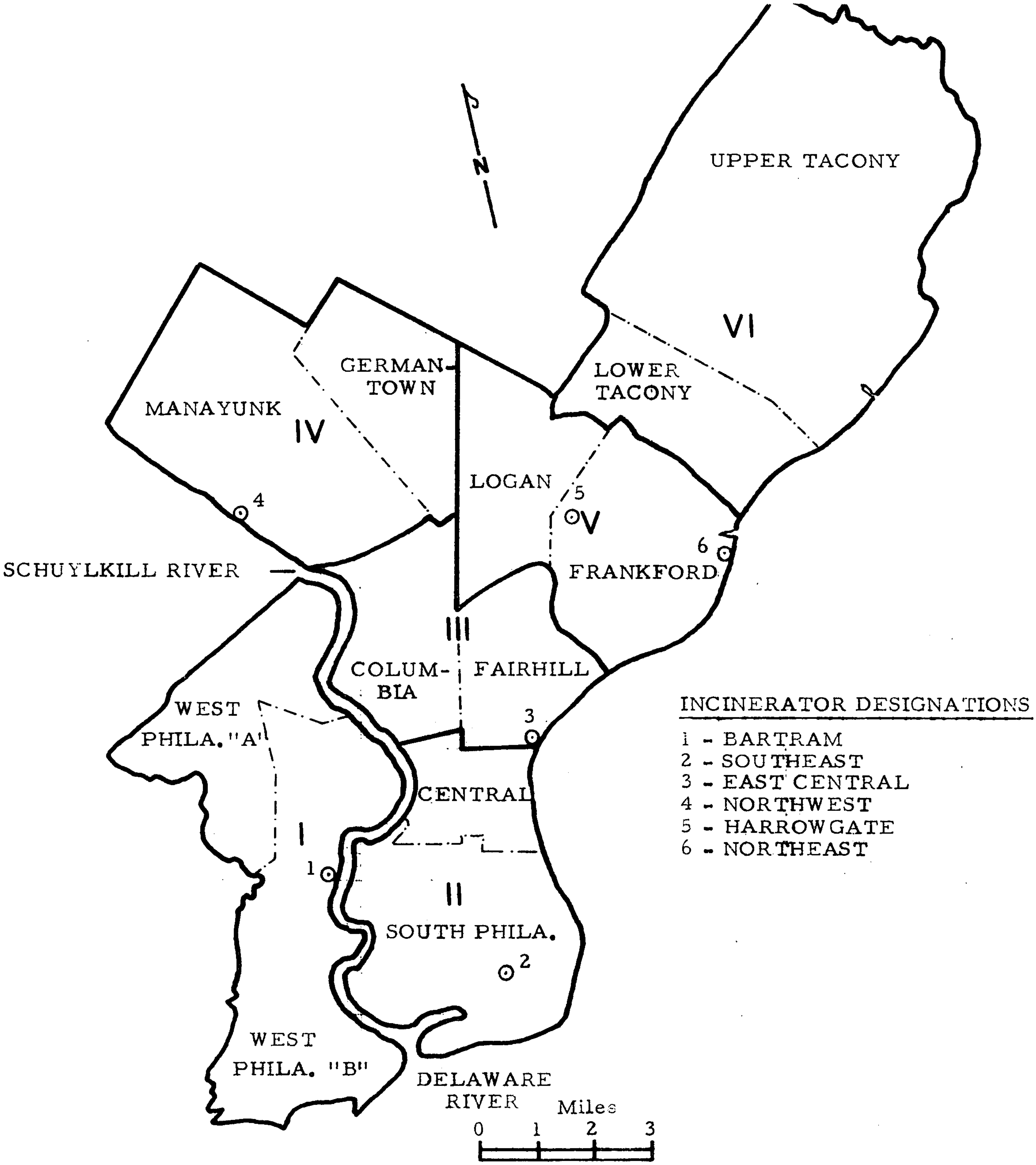
- "Disposal of all refuse removed by city forces by operation of incinerators and sanitary landfills. Also the disposal of combustible refuse collected by private contractors and industrial establishments and delivered to incinerators."

Fulfillment of these mandates is being accomplished by a collection system which functions within six sanitation areas, each of which is divided into two sanitation districts. Disposal is effected largely through the operation of six incinerators. The districting and incinerator locations are shown in Figure 1.

During the one year period from 1 July 1969 to 30 June 1970, the incinerator system fired 683,711 tons of refuse. Of this quantity, 12.4% was combustible refuse delivered by private operators and a small amount of special collection garbage brought in by city trucks. Another 200,245 tons of refuse was disposed of in landfill sites. It was estimated that about 20% of the landfill material was refuse of the oversized type.

Disposal costs, as of 30 June 1969, were estimated to be \$7.35/ton by incineration and \$1.74/ton by landfill. By definition, these costs do not of course include transportation, which in the case of landfill operations is substantial.

A third method of disposal used in Philadelphia is the outhaul of garbage to swine raisers. The demand, however, is not sufficient to absorb the entire production of garbage in Philadelphia. The districts in which separate garbage collections are now made include: West Philadelphia "A", West Philadelphia "B" (excluding Eastwick), South Philadelphia, Manayunk, Germantown, Logan, Frankford, and Lower Tacony. The slop market has steadily declined with time due to the displacement of pig farming by rural urbanization. In the last decade, garbage deliveries to



PHILADELPHIA SANITATION AREAS AND INCINERATOR SYSTEM

Figure 1

farmers dropped an estimated 42%. At the present rate of decline, the market could become nonexistent in another 12 years. Another factor which may make this operation even more short lived is that it requires subsidization by the City of Philadelphia. Elimination of the slop program has been frequently considered by city officials in recent years. It was therefore considered appropriate for present purposes to assume that all garbage now being collected separately would eventually be mixed with other refuse and be put into the regular disposal system.

B. REFUSE INVENTORY AND COMPOSITION PROJECTIONS

1. Refuse Quantities

Collection and disposal statistics for Philadelphia are shown in Table 3 for the period 1 July 1969 to 30 June 1970. Included are all municipal operations involving either the collection or the disposal of solid wastes. Thus, data on solid wastes transported by private haulers for disposal in privately owned facilities is not included. This category is essentially of the commercial/industrial type. It will be noted, however, that some 8.2% of the total solid waste handled by the city is commercial/industrial. Ninety percent of this material is fired in two of the city's six incinerators; these are the Bartram and the Southeastern Incinerators. The small amount of garbage brought in from special collections (in response to complaints, etc.) is also fired in the incinerators.

The amounts of refuse collected per unit area vary widely in Philadelphia. This can be seen from Table 4, which shows refuse densities by districts. Homogenous distributions of the amounts of refuse collected within each district have been assumed. It is recognized of course that large non-residential tracts exist, particularly in West Philadelphia B, South Philadelphia, and the Fairmont Park areas of West Philadelphia A and the Columbia District. The zone of greatest refuse output density is still obviously the block of five districts comprised of West Philadelphia A, Columbia, Fairhill, Germantown and Logan.

The quantities of refuse handled by municipal forces over the past decade and projected for the next decade are shown in Figure 2. This graph was prepared by the Sanitation Division of the Department of Streets and incorporated in an internal report of the City of Philadelphia. The data show the decrease of garbage collections for the slop market discussed earlier, and a decline in the amounts of commercial/industrial solid wastes being hauled to city incinerators. The latter effect does not mean that less industrial/commercial solid waste is being collected, but merely that private haulers are taking more of their collections to privately owned disposal sites. Similarly, the drop in garbage collection rates does not mean that the amount of garbage put out has decreased to that extent. It merely reflects the shrinking of the slop market and that separate garbage collections are giving way to mixed collections, the latter being disposed of in incinerators or landfills.

TABLE 3

PHILADELPHIA REFUSE COLLECTION/DISPOSAL STATISTICS BY DISTRICTS

(1 July 1969 to 30 June 1970)

	Disposal Method, tpy				
District/Source	Incinerators	City Owned Landfills	Contracted Landfills	Animal Feed,[1,2]	Totals
West Phila. A	45,926	12,274	45,613	16,270	120,083
West Phila. B	51,169	0	0	7,040	58,209
Central City	27,756	6,424	0	0	34,180
South Phila.	78,983	22,025	5,122	0	106,130
Columbia	76,316	84	3,071	0	79,471
Fairhill	64,611	2,493	2,937	0	70,041
Logan	50,242	304	529	14,130	65,205
Germantown	56,396	1,939	1,239	16,310	75,884
Manayunk	42,754	1,755	942	12,440	57,891
Frankford	55,578	84	6,572	15,560	77,794
Upper Tacony	33,740	0	86,534	0	120,274
Lower Tacony	15,213	0	304	4,250	19,767
Spec. Garb. Coll'ns.	5,160	0	0	0	5,160
Comm'l/Ind.[2]	79,867	0	0	0	74,867
Totals	683,711	47,382	152,863	86,000	969,956
% of overall total	70.5	4.9	15.7	8.9	100

[1] District garbage data are proportioned estimates. In West Phila. B, allowance was made for Eastwick Section, where separate garbage collections are not made.

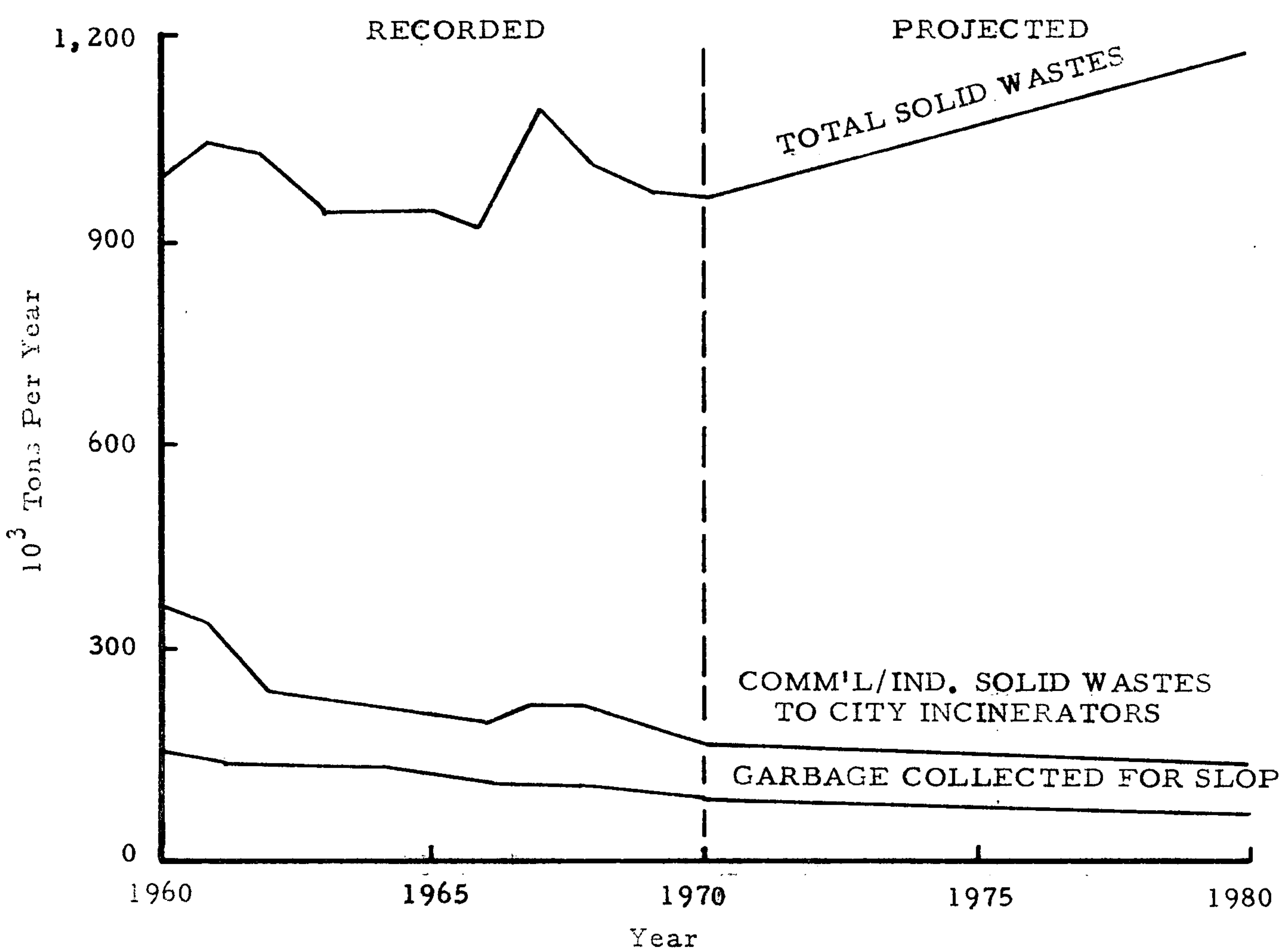
[2] Collected by private haulers.

TABLE 4

PHILADELPHIA REFUSE DENSITIES BY DISTRICTS[1]

District	Total Solid Waste Collected, tpy	District Area, sq. mi.	Refuse Density, tpd/sq. mi.
West Phila. A	120,083	9.5	34.6
West Phila. B	58,209	15.4	10.4
Central City	34,180	4.4	21.3
South Phila.	106,130	13.1	22.2
Columbia	79,471	7.1	30.7
Fairhill	70,041	5.7	33.7
Logan	65,205	6.9	25.9
Germantown	75,884	7.1	29.3
Manayunk	57,891	15.6	10.2
Frankford	77,794	10.3	20.7
Upper Tacony	120,274	33.2	9.9
Lower Tacony	19,767	7.6	7.1
Entire City	884,929	135.9	17.8

[1] Based on collections for the period 1 July 1969 to 30 June 1970 and excluding commercial/industrial and special garbage collections.



REFUSE COLLECTION RATES IN PHILADELPHIA - RECORDED AND PROJECTED

Figure 2

Figure 2 also shows an erratic trend in total waste disposal, which actually reflects a slight net drop over the ten year period. This is because the rate of decline in commercial/industrial receipts at the incinerators has been so much greater than the rate of increase in other urban collections (by far the larger fraction) as to create a small decline in the overall disposal rate. If the industrial/commercial fraction is extracted from these data, an average increase of 1.39%/year for other urban refuse collections is found.

This is considerably lower than the 3.0%/year predicted for the nation on the initial Envirogenics' program. It will be recalled, however, that this rate involves two factors: (1) a per capita refuse production increase of 1.5%/year, and (2) a 1.5% increase in the national population. The population in Philadelphia decreased during the period 1960-1970 from 2,002,512 to 1,948,609 according to Bureau of Census figures. This represents an annual population drop of 0.27%. If this negative rate is combined with the expected rate of increase in the refuse collected per capita (1.5%/year), the resultant estimated increase in domestic refuse collections for 1970 would be 1.23%. This compares reasonably well with the 1.39% actually observed.

It will be noted in Figure 2, that the changes in collection rates projected by Philadelphia's Sanitation Division for the present decade do not appear to be consistent with those of the previous decade:

PROJECTED AND ACTUAL PHILADELPHIA
REFUSE HANDLING RATE CHANGES

	Decade of the Sixties (Recorded)	Decade of the Seventies (Projected)
Change in Urban Refuse Collections,[1] %/year	1.39	2.06
Change in Commercial/Industrial Solid Waste Receipts at City Incinerators, %/year	-9.56	-0.69
Change in Garbage Collections for Farm Consumers, %/year	-5.09	-2.00
Change in Total Quantities of Solid Waste Handled by City Forces and/or Facilities and City Contracts, %/year	-0.30	2.00

[1]Including garbage for farm use but excluding commercial/industrial.

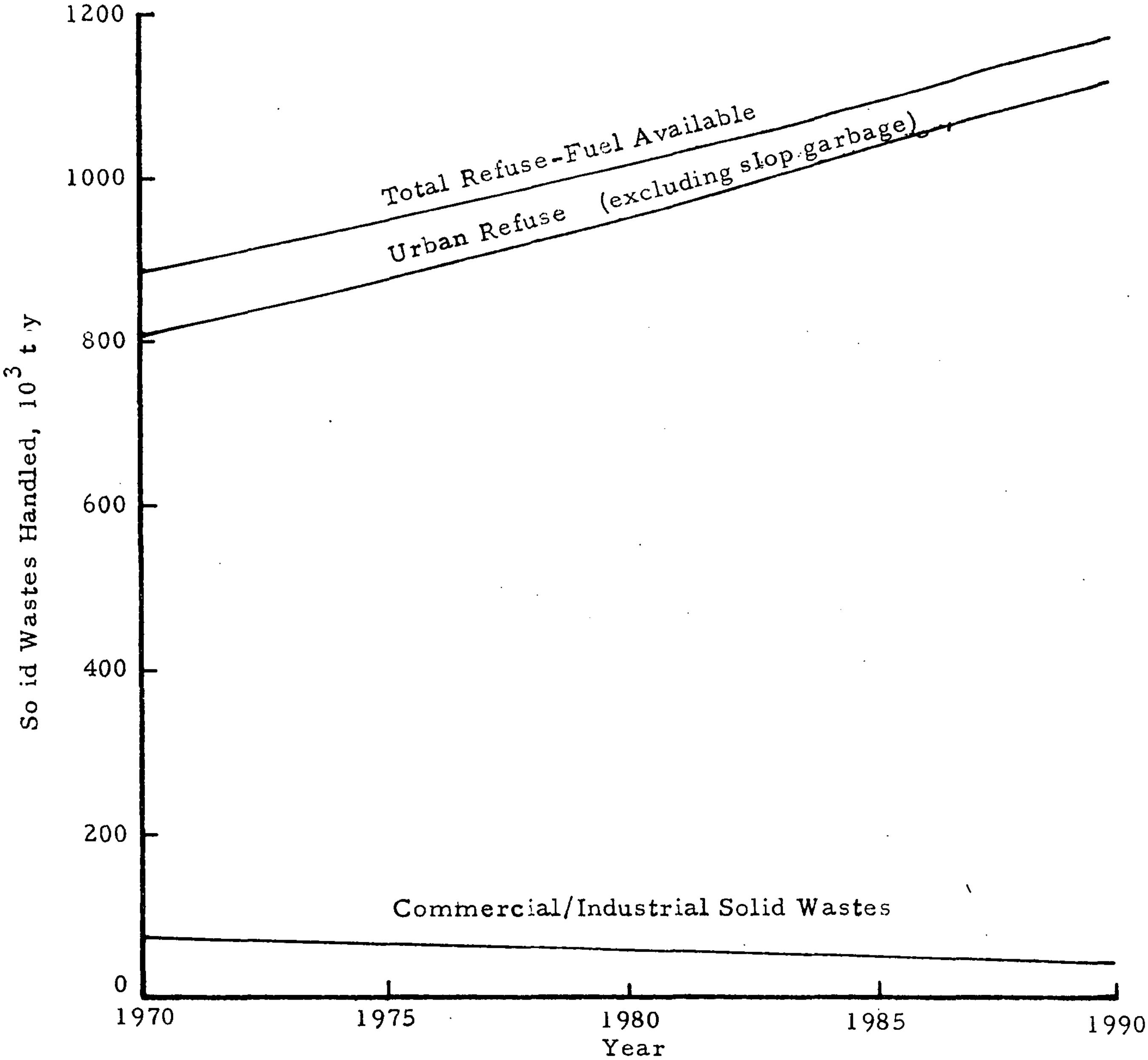
What is actually involved is quite plausible. During the previous decade a sharp decline in commercial/industrial solid waste receipts cancelled the normal increase in other urban refuse collections so that the total waste handled remained about even. In the present decade, however, the Sanitation Division policies regarding incinerator access by private haulers are expected to level out the receipt rates of commercial/industrial waste material. This will then result in an upward trend in the curve of total solid waste collected, which now will reflect the increase in other urban collections. It is questionable, however, whether the urban collection rate would increase from 1.39% to 2.06%/year.

In the preceding discussion, the rate of change in the quantity of garbage collected for farm use was not considered. This is because this operation has no influence on the other rates. The total solid waste collection rate and the rate at which urban refuse is collected involve all the garbage that is hauled. These rates are therefore insensitive to the manner in which the garbage is ultimately disposed of or recycled. In terms of firing refuse in steam generators, however, this factor must be taken into account. Obviously, any garbage taken to farm users must be excluded in considering the quantities of refuse that will be available for firing in boilers.

A twenty-year projection of the quantities of refuse fuel that will be available in Philadelphia from city managed sources is shown in Figure 3. The projections for commercial/industrial solid waste receipts and garbage hauled to farms made by the Sanitation Division have been observed. The rate of increase in urban collections has, however, been based on that (1.39%/year) recorded for the previous decade. It should be mentioned that the amount of slop garbage collected by 1980 will have dropped to about 50,000 tpy. This is probably approaching the level where the practice could well be discontinued as economically unattractive.

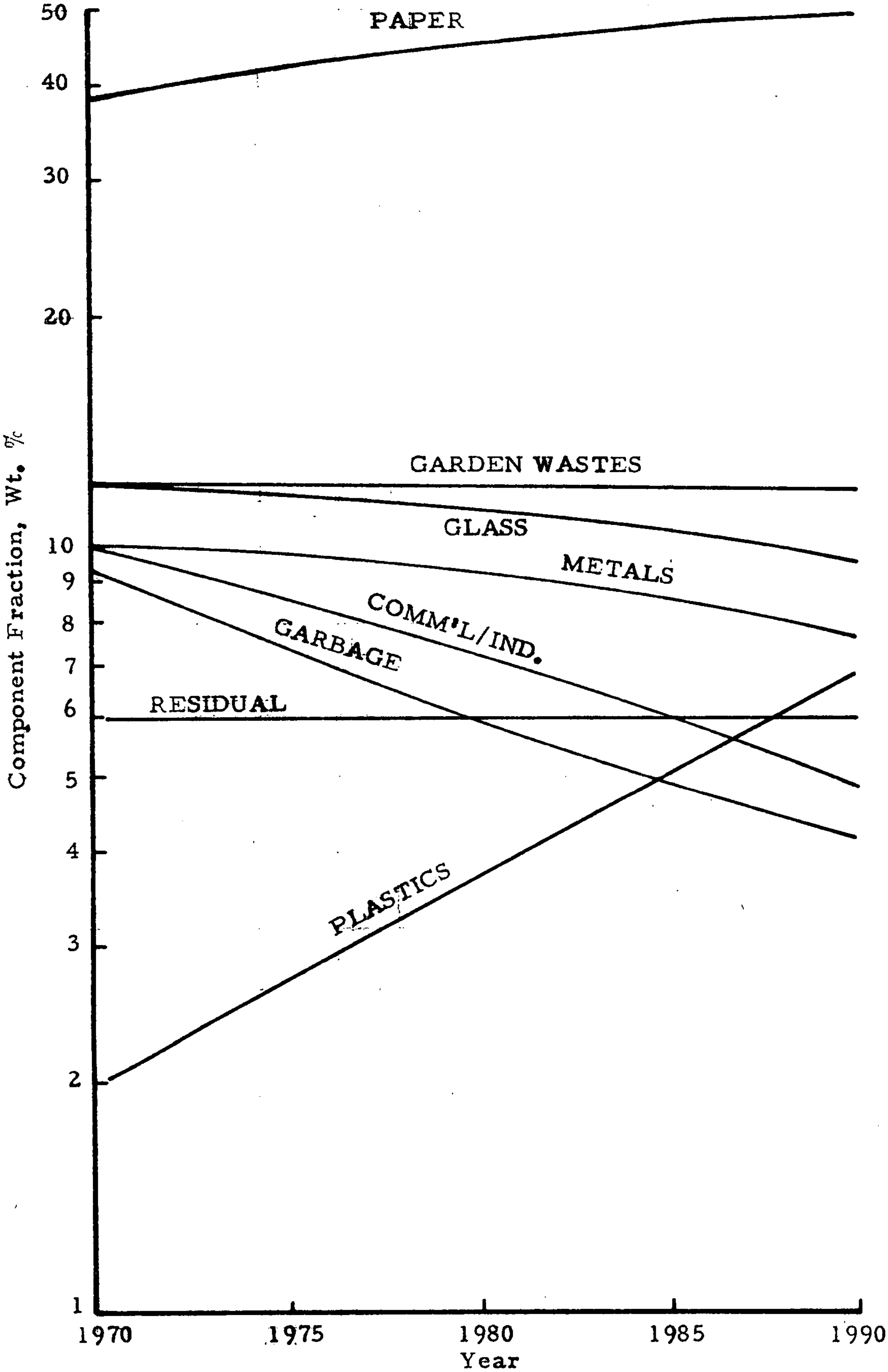
2. Refuse Composition

Establishment of the composition of Philadelphia fuel-refuse is complicated by the fact that two types exist in the various districts. That is, urban refuse with and without garbage is being collected. Because the duration of this situation is uncertain and because the two types would be difficult to isolate in disposal operations, the use of composite data appeared to be most practical. Figure 4, showing compositional projections for the period 1970 - 1990, has been prepared on that basis. The data were obtained using the compositional change derivations developed on the original Envirogenics program and the Philadelphia disposal trends previously discussed.



PROJECTED PHILADELPHIA BOILER
REFUSE-FUEL INVENTORIES

Figure 3



PROJECTED COMPOSITIONAL CHANGES IN PHILADELPHIA MIXED REFUSE

Figure 4

C. FUEL CHARACTERISTICS OF PHILADELPHIA REFUSE

1. Heating Value

Using the compositional values discussed in the previous section and the component calorific values adopted on the previous Envirogenics program, higher heating values (HHV) were calculated for mixed Philadelphia refuse. These are shown in Figure 5 for the period 1970-1990. An increase in the projected HHV for refuse results because the predicted compositional changes (Figure 4) involve increases in the levels of high HHV constituents, paper and plastics, and decreases in low HHV components, such as glass, metals, and garbage.

Work is being done at the Drexel Institute to determine the calorific value of refuse fired at certain of the City's incinerators. In a private communication, Dr. R. Schoenberger of that institute advised that a current typical value would be about 5500 Btu/lb. The material tested was, however, garbage-free.

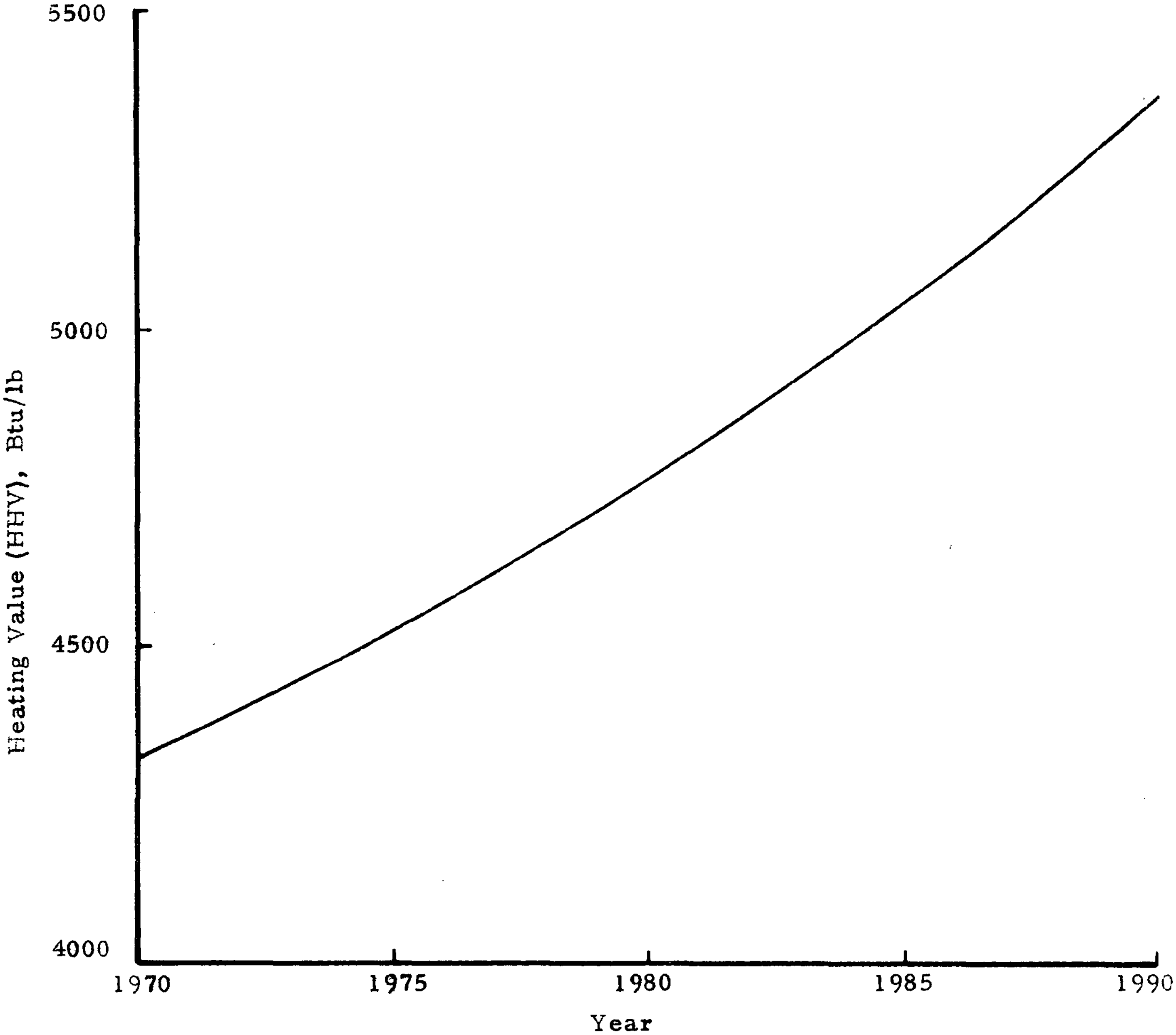
2. Combustion Calculations

In developing preliminary designs of combination-fired systems, some specific refuse composition must be assumed. It is recognized that the design fuel would not be valid except for a comparatively short period of time. It would, however, furnish a reference point for making adjustments in firing rates, etc., when fuel characteristics are significantly different. For the purposes of the present study, the refuse composition projected for 1980 was used. It is tabulated below for easy reference.

PROJECTED 1980 COMPOSITION (WT-%)
OF MIXED PHILADELPHIA REFUSE

Garbage	Plastic	Garden Wastes	Glass	Metals	Paper	Residual	Commercial/ Industrial
5.9	3.7	12.0	11.2	9.2	44.8	6.0	7.2

The heating value, as shown in the last figure, will be about 4700 Btu/lb. Using the same guidelines as observed on the previous program, the following ultimate analysis was computed.



PROJECTED INCREASE IN HEATING VALUE OF MIXED PHILADELPHIA REFUSE (AS RECEIVED BASIS)

Figure 5

PROJECTED 1980 ULTIMATE ANALYSIS
OF MIXED PHILADELPHIA REFUSE

Component	Wt-%
H_2O	17.2
C	26.8
H	3.5
O	22.9
N	0.4
S	0.2
Inert	29.0
	100.0

Combustion air, flue gas, and steam generator efficiency were then calculated. The results are shown in Tables 5, 6, and 7. It will be noted in Table 7 that steam generator efficiencies have been calculated on the basis of three different flue gas exit-temperatures. These values match the flue gas temperatures of the various boiler designs described in the report of the previous program (Reference 1).

D. UTILITY STEAM GENERATION OPERATIONS

1. Steam Generator Inventory

The Philadelphia Electric Co. (P.E.) provides electrical power and some heating steam for the City. The P.E. inventory of power stations is widely distributed. Within the city limits, however, there are four power stations and two steam plants. Their locations are shown in Figure 6. One of the units at the Schuylkill Plant is equipped with a topping turbine. It is therefore linked with the two downtown steam plants in the Center City heating steam loop. This circuitry is discussed in a later section.

The effective electrical capacity of the power stations located within the city limits is about a third that of the entire P.E. system, which includes nine other stations, all well outside the city limits. The Peach Bottom atomic station, for example, is almost 60 miles from downtown Philadelphia. The basic characteristics of the four power stations located within the city limits are summarized in Table 8. The characteristics of the two steam plants, Willow and Edison, are shown in Table 9. Units 23 and 24 of the Schuylkill Station appear in both tables. This is because they are coupled to a topping turbine and thus produce both electricity and heating

TABLE 5

COMBUSTION GAS REQUIREMENTS BASED ON PROJECTED 1980 PHILADELPHIA MIXED REFUSE COMPOSITION

Constituent	Combustion Gas Requirement, lb/lb Refuse: Oxygen	Dry Air
C	0.714	3.077
H	0.280	1.207
S	0.002	0.009
Metal	0.013	0.056
	1.009	4.349
Oxygen	-.229	-0.987
Total Required, Stoichiometric	0.780	3.362
Total Required, 50% Excess Gas	1.170	5.042
Excess Gas	0.390	1.681

TABLE 6

PRODUCTS OF REFUSE COMBUSTION BASED ON PROJECTED 1980 PHILADELPHIA MIXED REFUSE COMPOSITION

Constituent	Gas formed per lb Refuse Lb Mol	Gas formed per lb Refuse Lb	Vol-% Dry Basis
CO_2	0.022	0.983	12.8
H_2O	(0.030)	(0.544	-
- Refuse H_2	0.018	0.315	-
- Refuse H_2O	0.010	0.172	-
- Combustion Air[1]	0.003	0.057	-
SO_2	0.001	0.004	0.03
O_2 (excess)	0.012	0.390	7.0
N_2			
Total Air N	0.138	3.876	80.23
Refuse N	0.001	0.004	
Total Flue Gas (wet)	0.202	5.801	
Total Flue Gas (dry)	0.172	5.257	

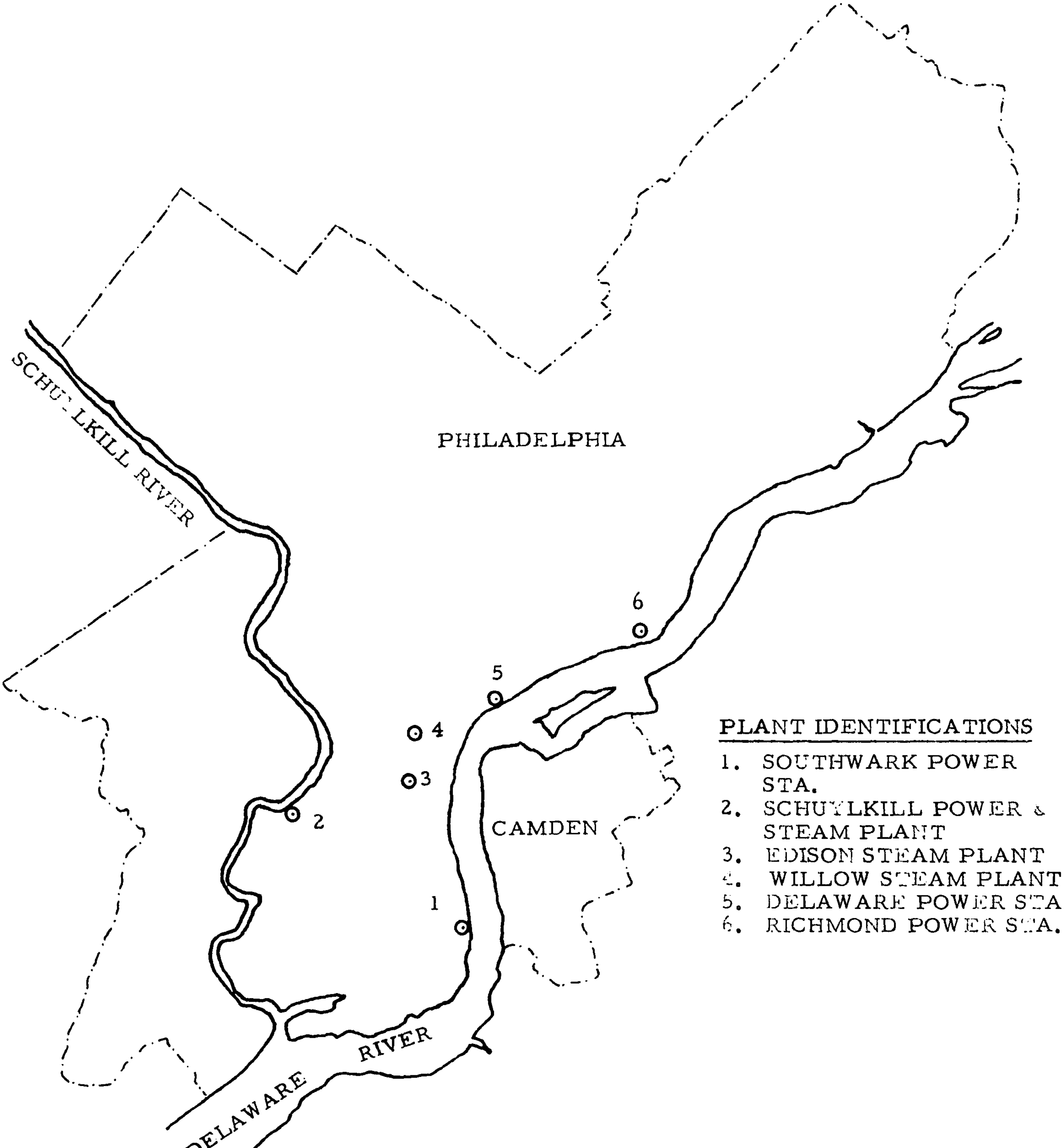
1. Based on standard (60% RH @ 90° F) of American Boilers Manufacturers Association.

TABLE 7

EFFICIENCY OF STEAM GENERATOR FIRING PHILADELPHIA MIXED REFUSE OF COMPOSITION PROJECTED FOR 1980

	Item	Fuel Value Heat Losses at Various Flue Gas Exit Temperatures, Btu/lb of Fuel (% of HHV) 450°F	500°F	575°F
1.	Dry Gas	467 (9.79)	530 (11.11)	625 (13.10)
2.	H_2O in Refuse	209 (4.38)	213 (4.46)	219 (4.59)
3.	From H_2 Combustion	383 (8.03)	390 (8.18)	402 (8.43)
4.	H_2O in Air	12 (0.25)	13 (0.27)	16 (0.34)
5.	Unburned Gas	4 (0.08)	4 (0.08)	4 (0.08)
6.	Unburned Residue	107 (2.24)	107 (2.24)	107 (2.24)
7.	Sensible Heat, Residue	47 (0.98)	47 (0.98)	47 (0.98)
8.	Unburned Fly Ash	40 (0.84)	40 (0.84)	40 (0.84)
9.	Sensible Heat in Fly Ash	5 (0.10)	5 (0.10)	6 (0.13)
	Subtotal	1274 (26.69)	1349 (28.26)	1466 (30.73)
10.	Radiation	(0.20)	(0.20)	(0.20)
11.	Unmeasured	(0.50)	(0.50)	(0.50)
12.	Manufacturer's Margin	(1.00)	(1.00)	(1.00)
	Total % Heat Loss	28.39	29.96	32.43
	Steam Gen. Efficiency	71.61	70.04	67.57

NOTE: Fuel Value (HHV) = 4770 Btu/lb; Combustion Air Inlet Temperature = 80°F (60% R.H.).



LOCATIONS OF UTILITY POWER AND STEAM PLANTS IN PHILADELPHIA

Figure 6

TABLE 8

UTILITY POWER BOILER INVENTORY WITHIN THE CITY OF PHILADELPHIA

Station (Effective Capacity[1], MW)	Boiler No.	Pressure, psig	Temperature, °F	Fuel
Southwark (462)	11,12	925	900	Pulv. coal/ oil
	21,22	925	900	Pulv. coal/ oil
Schuylkill (335)	1	2475	1050	oil
	2, 3	225	545	oil[2]
	11-20	225	503	oil[2]
	23, 24	1350	910	Pulv. coal/ oil
Delaware (422)	13-24	267	637	oil[2]
	71-81	1875	1000	Pulv. coal/ oil
Richmond (464)	49-52	400	703	oil[2]
	57-60	400	703	oil[2]
	63-64	1335	950	Pulv. coal/ oil
	65, 66	425	850	Pulv. coal/ oil

[1] Effective capacity for 75% of the year.

[2] Converted from coal firing.

TABLE 9

UTILITY STEAM PLANT INVENTORY WITHIN THE CITY OF PHILADELPHIA

Station	Boiler No.	Rated Steam Prod., 10^3 lb/hr	Pressure, psig	Temperature, ^oF	Fuel
Edison	1,2	216 ea.	205	435	oil
Willow	1-3	125 ea.	200	438	oil[1]
	4	170	180	434	oil[1]
	5	170	190	430	oil[1]
	6	170	180	434	oil[1]
Schuylkill	23,24	600 ea.[2]	225	450	Pulv. coal/ oil

[1] Converted from coal firing.

[2] Output of topping turbine.

steam. The quantity of steam sent out from these units can be controlled by using a low pressure 20 MW turbine (throttle condition - 200 psig, 440° F) in tandem with the topping turbine. Thus, any steam not required for the city heating system can be diverted into this second turbine to produce electricity. Over the past five years, the Schuylkill has accounted for an average of 64.4% of the district heating steam sent out. All three plants divert about 15% of their production to heat feed water and drive auxiliary plant machinery.

It will be noted in Tables 8 and 9 that all of the units are, or have a capability of, firing oil. This results from an effort on the part of P.E. to shift completely over to (low sulfur) oil, an objective that is now nearly fulfilled. The reason for this of course is to comply with air pollution abatement regulations. A problem this on-going strategy presented to the present study was the current instability of fuel costs. This matter is considered in greater detail in a later section.

2. Effect of Firing Refuse on Pollution Burden

Because of its present predominant use in utility-class boilers in Philadelphia, low sulfur (~0.5% S) oil would likely be the fuel that would in effect be substituted for if refuse were also fired in boilers. The particulates and SO_2 pollutants emitted by refuse would be about a fifth and a half, respectively, that emitted by low sulfur oil, on an equivalent energy basis.* This estimate is based on the air pollution data presented in Reference 1. It also assumes that no flue gas cleaning would be practiced when oil is fired but that a refuse-fired steam generator would incorporate an electrostatic precipitator having an efficiency of 99%.

A ton of fired refuse will produce, on the average, 2.3 lb SO_2, while a quarter ton of oil (0.5% S) -- the equivalent in available energy-- will produce about 4.9 lb of SO_2. Thus, if all the refuse presently collected by city forces (875,000 tpy) were substituted for low sulfur oil, the annual output of SO_2 would be reduced by slightly over 1000 tons.

---

*Assuming, for refuse and oil, fuel values of 4770 and 15,000 Btu/lb and boiler efficiencies of 70% and 88%, respectively, this represents an available energy ratio of about one to four.

In terms of particulates, refuse fired on agitating grates loads the flue gas with about 1.3 gr/SCFD of fly ash, while oil produces a loading of only about 0.1 gr/SCFD. Differences in excess air requirements considered, oil produces about 2 1/2 times as much flue gas as does refuse. This, taken together with a refuse - oil available energy ratio of 1: 4, suggests that refuse will produce 20 times as much fly ash as does oil in developing the same amount of steam enthalpy. Typically, however, a refuse-fired system will be equipped with gas cleaning equipment while an oil fired boiler would not. In the former case, an electrostatic precipitator having an efficiency of 99% would be reasonable to expect. In this situation, the refuse-fired system would produce about 20% the particulates that an uncontrolled oil-fired boiler would that produced the same amount of steam energy. This would represent a reduction of 0.96 lb of particulates for every ton of refuse fired in replacement of oil, an air pollution burden relief of about 420 tons per year, based on present refuse collection rates (875,000 tpy).

It should be pointed out that, in the foregoing discussion, no account has been taken of the fact that considerable refuse is presently being fired in conventional incinerators in Philadelphia. Although the overall dust control efficiency of this system of incinerators is not known, it is said to be considerably less than 99%. An obvious additional benefit would thus result from firing the same refuse in steam generators equipped with high efficiency gas cleaners.

It will be noted that the pollutant reduction estimates shown here are considerably lower than those developed in Reference 1. In the latter, older analysis, the data were derived on the basis of high sulfur (3% S) coal displacement and the use of refuse from the entire Philadelphia Standard Metropolitan Statistical Area (SMSA). In either case, however, the air pollution benefits estimated are not great.

3. Suggested Study Guidelines

During the course of the program a number of very helpful recommendations and observations were offered by officials of the P.E. and the City of Philadelphia. These ranged in content from matters dealing with costing details to the general philosophy of utilizing refuse-fuel energy in utility operated systems. Because these Philadelphia organizations will be the ultimate beneficiaries of the present study, their inputs were incorporated wherever possible. This resulted in changes being made in the original Envirogenics' cost model to accommodate local economic factors and in the modification of specific system design features. It also led to the generation of preliminary design and cost data on refuse-fired, district steam plants. This was done because of P.E.'s expressed greater interest in this type of plant over combined-fired turbo-electric systems.

It will be recalled that the initial Envirogenics study was essentially addressed to the latter type of boiler, thus the consideration of district steam plants on the present program could not be approached from the systematically developed basis that was available in recommending turbo-electric systems. Of the two types, however, the district steam plant is much less complex a structure, particularly in terms of configurational options and the constraints controlling the use of refuse as a fuel. Thus, the basic design described herein involved a fairly straightforward selection process, to which the pertinent criteria developed on the earlier program were applied.

E. PRELIMINARY PLANNING RECOMMENDATIONS

1. Overview

In developing the following systems recommendations, it was necessary to adopt and follow certain general guidelines. These are itemized below.

a. Lead Time

The typical period of time elapsed between construction go-ahead and initial service of a conventional power plant is about seven years. Because of the less conventional nature of refuse-firing systems, 1980 was set as a convenient target date. The refuse characteristics and quantities projected for that time have been discussed earlier.

b. System Input

The overall system recommended should be capable of handling all of the refuse for which the city will be responsible in 1980 and preferably allow for expanded throughput beyond that date. The system should, however, comprise more than one plant so that initial capital cost burdens can be spaced out and so that logistics are manageable. In order that collection forces will have a reliable disposal operation to accept their deliveries, a high plant factor will be necessary. This has been set at 80%, as on the previous Envirogenics' program. During outages, elements of the existing incinerator/landfill disposal system would be substituted.

c. Plant Management

In terms of P.E. and City participation, many management options can be considered. Attempting to influence the decisions involving such alternatives is clearly not an objective of the present program. For costing purposes, however, the capital cost annualization rate selected was that associated with utility ownership. This was done merely in the interest of conservatism. The average utility annualization rate is usually considerably higher than would be obtained under municipal ownership.

2. District Steam Plant

a. Design Characteristics

The plants Edison, Willow, and Schuylkill pump steam into an essentially common distribution loop, the highest steam condition input being from Schuylkill at 225 psig and 450° F (enthalpy ~1235 Btu/lb). The lowest steam demand is of course during the summer months when the steam send-out is below 400,000 lb/hr, little if any of which goes into space heating systems.

The Philadelphia Electric Co. has demonstrated that it is more economical to operate at 100% feedwater make-up than to attempt recycle of the condensate, which becomes heavily contaminated by the district heating circuitry. Because the boilers operate at low steam temperatures, feedwater treatment can be limited to a softening process rather than deionization, although the boiler must then be blown down fairly frequently. A final factor influencing design is that Philadelphia's district heating requirement will probably not increase significantly with time, because the central city served will not be involved in much further growth. Thus, a refuse-firing, district-heating plant can be designed on the basis of today's needs. If sized to summer demand, such a plant can be operated at base-load condition all year around, assuming that, of the three existing plants, only the Willow plant would be fired during the summer months to fill the northern segment of the steam loop and thus reduce the frictional line losses that would result from single plant input. A send-out of 130,000 lb/hour would be sufficient to accomplish this.

It was suggested by the P.E. that the refuse-fired plant have a steam production of no more than 350,000 lb/hour. This is equivalent to a send-out of about 300,000 lb/hour. This size, however, involves a refuse input that would probably require the use of three boilers. By dropping the capacity to about 315,000 lb/hour, two boilers would be sufficient. Production costs would thus be significantly reduced. In order to generate steam at a rate of 315,000 lb/hour (send-out ~ 270,000 lb/hour), a refuse rate of 1400 tpd would be required. Fuel characteristics would, as stated earlier, be based on those projected for 1980.

The plant would consist of a completely indoor structure, housing two units in a side-by-side arrangement. Both units would face upon a common storage pit, which would be separated from the boilers by a 50-ft fire wall running the full length of the pit.

Overhead cranes would transfer refuse from the pit to a water-cooled charging chute on each of the units. Stoking would be promoted by means of a ram or vibratory feeder. In each furnace the grate would be a three-stage, reciprocating device, the ash from which would be quenched within the ash pit by water sprays. Combustion air, 50% in excess of stoichiometric, would be drawn from the refuse pit area so that odor leakage would be minimized. From 60 to 75% of the total air introduced into each unit would be directed to the underfire and sidefire jets. This air would first be heated by a tubular air heater to about 325° F. Overfire air would be introduced so that the hot combustion gases would flow back over the bed and tend to dehydrate the material on the first grate stage. Natural gas burners would be provided, but for start-up and trimming purposes only.

Because of the heterogeneity of the fuel, steam conditions would be more variable than those experienced in firing fossil fuel. In the case of turbo-electric plants, such fluctuations are unacceptable so that other design arrangements are necessary. However, based upon European and domestic experience, this variability is regarded as acceptable for district heating steam and no provisions are needed for fuel augmentation.

In the radiative section of each boiler, standard water wall construction would be employed. This would extend below the grate and partially under it. Because of steam use and radiative superheating, the boilers would have, respectively, no pendant reheat or superheat surfaces. Most of the convective section would be occupied by the economizer and the tube banks communicating with the mud drum. The temperature of the flue gas exiting from the air heater would be about 500° F. Thus the furnace efficiency (see Table 7) would be about 70.0%. The flue gas from each unit would be cleaned in a separate electrostatic precipitator having a dust removal efficiency of 99% and each sized to handle an expected flue gas flow of 135,000 ACFM. After cleaning, the two flows would be blended and released from a common stack. General plant lay-out is shown in Figure 7.

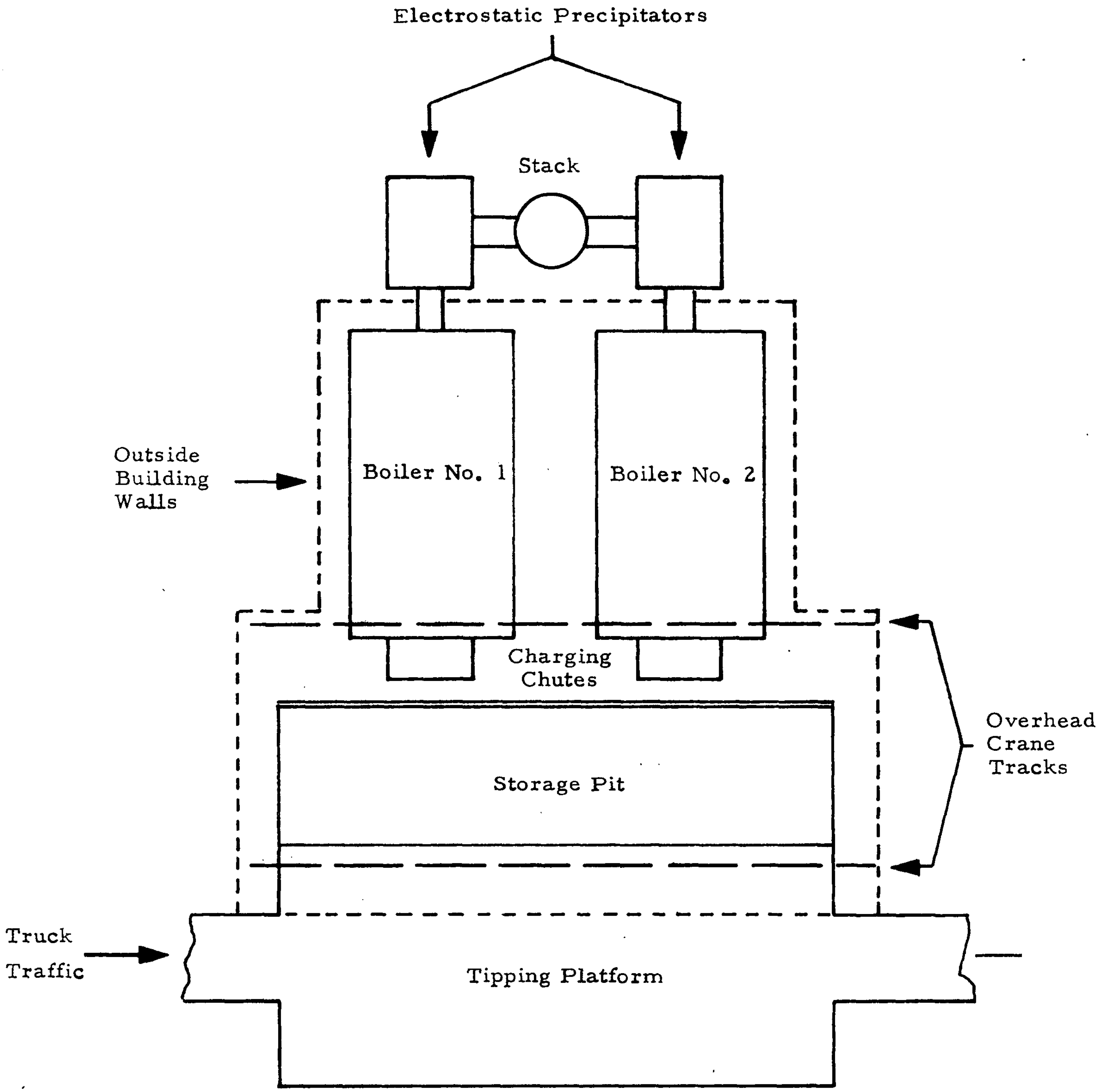
Because of the low sulfur content of the refuse fuel (~ 0.1% S) and the fact that fossil fuel would not ordinarily be fired in the furnaces, provision for an SO_2 control system was considered unnecessary. The plant could be expected to emit about 2800 lb/day of SO_2 and about 350 lb/day of particulates. This would correspond to a stack gas composition of 0.012 gr/SCF and 0.008 vol-% with respect to particulates and SO_2. These estimates are based on emission factors discussed in Reference 1. On this basis, it is assumed that refuse would generate 24 lb of furnace fly ash per ton of refuse fired and that the sulfur content of refuse would be 0.1% S, only half of which would be converted to SO_2. In view of past experience (Reference 1), the expectation of achieving a 99% collection efficiency appears to be reasonable. However, considerable tolerance is available if one compares the expected dust output of 0.24 lb/ton of refuse with the projected national particulate emission standard of 1.9 lb/ton of refuse fired.

Feedwater would be introduced at 220° F. This would be heated in open-type, deaerating feedwater heaters equipped with vent condensers. Steam from the boilers would be used as the heat source. To effect pressure reduction, the steam would first be used to drive the turbines on the boiler feed pumps. It is assumed that 100% feedwater make-up would be practiced and that the water would be softened (through synthetic zeolite) rather than deionized. Salt accumulations within each boiler would be controlled by frequent blow-downs of the oversized mud drum.

The tipping pit would be sized to permit continuous 7-day-a-week firing. Assuming that all packer-truck deliveries are accomplished between 10 A.M. Monday and 12 Noon Friday, and allowing an additional margin of four hours firing time, the pit should be able to accommodate 4300 tons or 6.60×10^5 cu ft of refuse. This would require a pit dimension of 200 (l) x 55 (w) x 60 (d) ft.

Three 100-ft bridge cranes would be installed over the pit, one of which would be used to arrange and mix the pit contents during the receiving hours (day shifts, Monday through Friday). During other shifts, it would be held in stand-by without an operator. Assuming a charging cycle of four minutes, grapples having a capacity of 5 cu. yd. would be sufficient. The lift speed of the cranes should be at least 300 ft/min and provide a horizontal travel speed of at least 350 ft/min.

The storage pit would be able to accommodate 13 tipping stations. Assuming, conservatively, an average load of 4 tons (15 cu yds) per truck and a discharge cycle time of four minutes, an off-load rate of 780 tph would be reasonable to expect. The maximum receiving rate should, however, not exceed 520 tph. This is based on the assumption that all the refuse fired would be delivered according to a 5-day collection schedule (1900 tpd) and that 80% of the daily receipts would be delivered during two 1.5 hour peak periods. Thus, no truck queueing is likely. Weigh-in would be handled by a single automated scale; weigh-out, which is required by the City of Philadelphia, would be accomplished on a second identical scale.



LAY-OUT OF STEAM PLANT

Figure 7

Disposal of bulky refuse should probably also be handled at this plant. This is because it will probably have a centralized location due to its association with the mid-city steam loop. The smallest shredder capable of accepting typical bulky refuse items would have a rating of about 700 h. p. Such a machine could coarsely (7-10 in. top size) reduce bulky items at a rate of at least 30 tph. Thus a single shredder would probably handle the entire city's output of such refuse, which will likely amount to some 250 tpd by 1980.

b. District Steam Plant Costs

The cost model developed on the initial Envirogenics' program was modified extensively. This was done to accommodate cost increases that have occurred since the development of the model and economic factors characteristics of the Philadelphia area. It was also necessary to introduce or substitute new cost elements. These involved design features common to many steam plants (e. g., feed water treatment and heating equipment) that are different from those found in turbo-electric systems. Another costing change arose from the fact that refuse-charging equipment was based on the use of cranes rather than live-bottom storage structures and conveyors, as was done on the original program. The highlights of these changes, as recommended by City and P. E. officials, are as follows:

(1) Land Cost - This was increased from $10,000 to $40,000 per acre, based on the sites considered.

(2) Federal Power Commission (FPC) Boiler Component Codes 311-316 Costs - These and certain other specified capital costs were increased at a rate of 10%/year based on the cost model development date, June 1969. The new base date has therefore been shifted to June 1971.

(3) Annualization Rate - This was reduced to 13.75%.

(4) Water Cost - This was set at 4.5¢/10^3 lb, based on steam send-out.

(5) Maintenance Costs - The present P.E. cost is 12¢/10^3 lb of steam produced. To this was added another 25% in consideration of maintenance problems unique to refuse-firing and the separate costs for maintaining shredders and APC equipment.

(6) Refuse Storage Pit Costs - These were developed on the basis that the pit should be structurally stable if completely flooded with water.

(7) Residue Disposal Costs - This was based on the Philadelphia practice of using truck outhaul. In the present plant this would involve four drivers and six trucks (two standing under hoppers).

(8) Fuel Costs - Because the price of fuel oil is unstable at the present time, refuse disposal costs have been presented as a function of this cost over the range \$0.30 to \$0.60 per 10^6 Btu's.

Costs for the district heating plant are shown in Table 10. Total refuse disposal costs is the difference between total annual costs and the annual credit for steam generated Unit refuse disposal cost is this difference divided by the quantity of refuse handled each year, which is 0.409×10^6 tons, assuming an 80% plant factor. This cost will vary considerably, depending on how the annual credit for steam is derived. If the new refuse-firing, steam plant is added to an existing inventory that is already capable of handling the demand, then the steam credit assignable to the new boiler can only reflect the cost of fossil fuel saved and the O&M costs transferred from the now less active, conventional boilers. If, on the other hand, the refuse-fired plant is added to the system to supply needed additional capacity or to permit the retirement of old equipment, the steam credit should reflect annualized capital costs as well. It was the judgment of the P.E. that the former situation prevails and that the steam production costs of existing plants, preferably the Schuylkill plant, be used to calculate refuse disposal cost.

As can be seen in Figure 8, the steam production cost at Schuylkill was set at $\$0.55/10^3$ lb. This would result in a refuse disposal cost of \$5.36/ton, excluding transportation. As stated earlier, the steam sent out from Schuylkill issues from a topping turbine. Because of this arrangement, all plant labor costs are applied to power production. Thus the Schuylkill steam production cost includes only a fuel cost equivalent to the energy content of the output steam, some supervision, and a small amount of maintenance. As can be seen from Figure 8, if production costs (first ten month of 1970) of P.E.'s straight steam plants are used, considerably lower refuse disposal cost result. Also shown, for comparative purposes, is the tariff steam rate or the official rate of charge approved by the PUC. The rate selected (excluding state tax) is that for large Rate "S" steam users during the minimum demand period, June through September.

c. Site Selection

Because of the built-up nature of Philadelphia, it will be difficult to find suitable tracts of land that are reasonably close to the areas where the production of refuse is the greatest. An obvious solution to this problem would be to locate the steam generator plants at the

TABLE 10

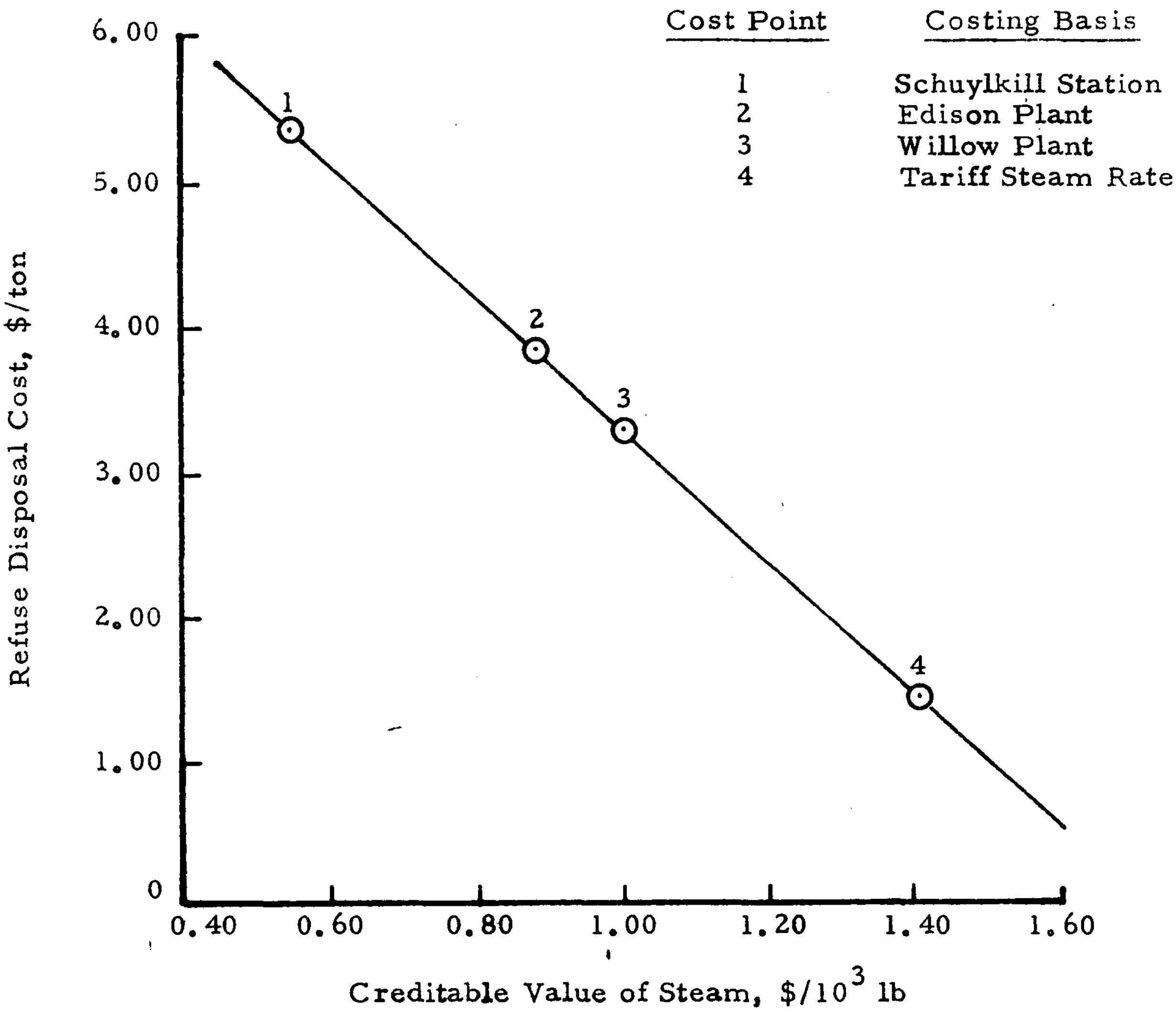
COSTS FOR THE 1400 TPD PHILADELPHIA DISTRICT HEATING PLANT

CAPITAL COSTS

FPC Codes	Description	Cost, 10^6 $
310	Land and Land Rights	1.696
311	Structures and Improvements	1.090
312	Boiler Plant Equipment	6.656
315	Accessory Electrical Equipment	0.531
316	Misc. Power Plant Equipment	0.131
	Air Pollution Control Equipment (98% efficiency)	0.486
	Waste Handling Equipment	2.105
	Engineering and Inspection	1.174
	Total Capital Cost	13.869

ANNUAL COSTS

Annual Capital Cost, 10^6 $ (Effective Annualization Rate = 13.75%)	1.907
Water Cost, 10^6 $	0.085
Operating Labor, 10^6 $	0.578
Maintenance, 10^6 $	0.351
Residue Disposal, 10^6 $	0.300
Total Annual Costs, 10^6 $	3.221



DISTRICT HEATING PLANT - REFUSE DISPOSAL COSTS AS A FUNCTION OF CREDITABLE STEAM VALUE

Figure 8

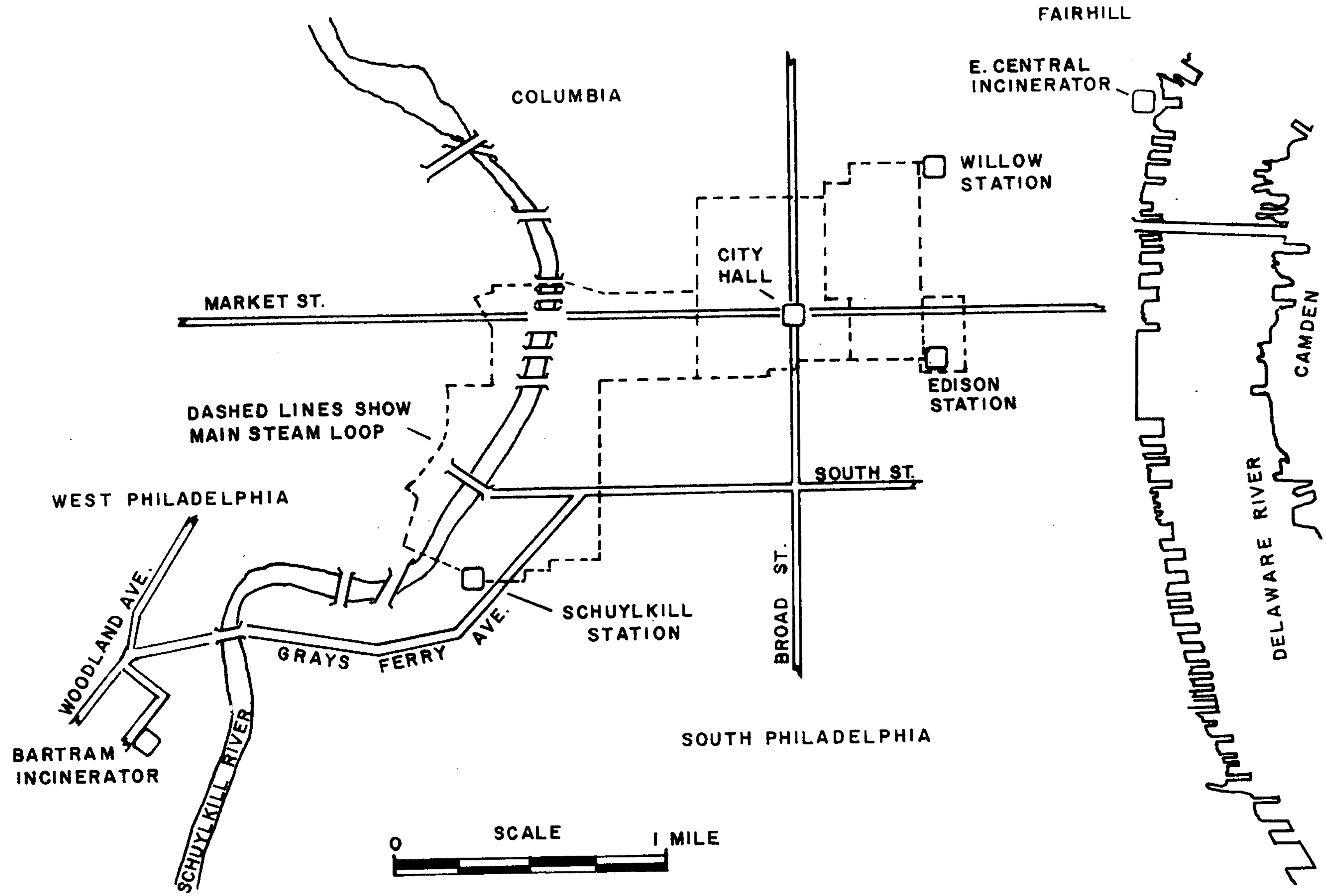
sites where refuse incinerators are now located. With the commissioning of the refuse-firing steam generators, some of the incinerators would have little function except, perhaps, during outages of refuse-fired boilers. Thus the razing of one or two of the incinerators should be acceptable, even if interim refuse disposal by landfilling is required during the construction period. Another possibility is the use of the tract of land now occupied by the Schuylkill Arsenal. This facility is adjacent to the southern property line of the Schuylkill Station and its purchase is now being actively pursued by the P. E.

In the case of the district heating plant, the site selected should obviously be located close to the existing steam lines now used by the Philadelphia Electric Co. The scope of that system, excluding the feeder lines, can be seen in Figure 9. Considering first the incinerator sites, it will be noted that the East Central incinerator is somewhat closer to the loop (i. e., The Willow Steam Station) than the Bartram incinerator is to the loop on the east side of the Schuylkill River. The East Central plant is separated from the loop, however, by a heavily built-up section of center city. Leading a steam line from it to the Willow Steam Station would be a major undertaking. The Bartram plant site provides a more practical easement to the loop. The third potential site, being continguous with the Schuylkill Station, is not shown. It is obviously, however, the preferred site in terms of steam loop access. Its principal drawbacks are that: (1) unlike the city incinerator sites, the land would have to be purchased; and (2) other uses for this plot are being considered by the P. E. It was their advice, however, that the arsenal grounds be given primary attention on the present program.

d. Transportation Costs

As shown in Figure 1, each sanitation area in the city is divided into two districts, many of which are designated by the name of a well-known section of town located within them. The amount of refuse hauled out of each of the districts to both landfill and the incinerators was tabulated in an earlier section. From these data, it was possible to estimate comparative transportation costs for hauling refuse, once the trucks are filled on their collection routes, to the existing incinerators and landfill sites, and to the Schuylkill site discussed in the preceding section. The assumptions adopted were that the refuse production densities within each of the districts were uniformly distributed therein and that landfill hauls averaged 10 miles per round trip. The latter value is a rough approximation.

Each of the Philadelphia incinerators fires refuse from several districts. None, for example, receives from fewer than seven of the twelve districts, while the Northeast Incinerator receives from nine. Each district was therefore roughly divided into zones, the area and



STEAM DISTRIBUTION SYSTEM OF THE
PHILADELPHIA ELECTRIC COMPANY

Figure 9

location of which were selected to correspond with the logical direction of travel to and the proportion of refuse sent out to the various incinerators. The approximate center points of these zones thus served as loci for deriving weight-distance vectors for each district. The travel distance on a grid makeup of surface streets would typically be the sum of the two orthogonal sides of a right triangle. This sum can be anywhere from 0 to 41% larger than the direct or diagonal distance. As a first approximation, the diagonal distance was increased by 25%. Distance travelled included return trip mileage. Thus in multiplying distances by tonnage handled, the resultant "ton miles" is actually about twice the real work performed on the refuse.

From these calculations it was estimated that for the period 1 July 1969 to 30 June 1970 the refuse transportation performed in Philadelphia was 5.8×10^6 ton-miles. Assuming a cost of $0.25/ton-mile, the transportation cost was found to be $1.81/ton.

A similar analysis was performed for the proposed district heating plant. This was done on the basis of the same haul cost ($0.25/ton-mile) used above so as to permit direct comparison to be made. The selection of the sanitation districts to be served by the steam plant was based on refuse collection rates projected for 1980 and the proposition that no refuse produced in these districts would be disposed of by landfill. The plant would be adjacent to the Schuylkill Station. Fortuitously, it was found that the six districts in the central and southern portions of the city would provide just slightly more than the 1400 tpd required to operate the plant. The refuse transportation data derived for these six districts is tabulated below.

STEAM PLANT REFUSE TRANSPORTATION DATA

District	Refuse Hauled, ton-miles/yr
West Philadelphia "A"	1,275,200
West Philadelphia "B"	394,000
South Philadelphia	670,100
Central	171,700
Columbia	844,000
Fairhill	814,100
Total	4,169,100

The projected total tonnage would be 537,400 tons/yr. The transportation cost would thus be $1.93/ton, which compares favorably with the $1.81/ton estimated for the present incineration system.

3. Power Plant

a. Design Characteristics

The steam plant described in the previous sections would be capable of handling about one-half of the refuse that will probably be collected in Philadelphia in 1980. It has been estimated that the refuse available for boiler fuel (see Figure 2) at that time will be about 1.02×10^6 tpy, which is equivalent to slightly over 2800 tpd. It would therefore be appropriate to consider a combined-fired power plant that would have a refuse capacity either the same as or perhaps greater than the steam plant. If oversized, fossil fuel could be substituted for the refuse that would be lacking until such time as the growing collection rates could satisfy design input.

Using the designations developed on the original program, a Case 3 system equipped with two refuse-fired economizers would require about 1500 tpd of refuse. This is based on the heating value and boiler efficiency for the fuel (at an exit temperature of 575° F) projected for 1980. It will be recalled that the Case 3 system consists of a conventionally fired steam generator having little economizer surface and one or more externally situated "boilers." The latter are fired with refuse to deliver high enthalpy feedwater to the drum of the steam generator. This design was found on the previous program to be optimum in terms of cost effectiveness for the range of refuse rates in which the present one falls. A summary of the boiler characteristics is shown in Table 11.

Except for a slightly larger refuse pit, the refuse handling and charging arrangement for the two economizers in the present system would be identical to that described for the district heating plant.

The two identical economizers would be operated in parallel and thus perform the same function. In each, refuse would be fed through a vertical, water-cooled chute and burn on a thick fuel bed. The three-level grates incorporated should furnish both agitation and tumbling to the fuel mass to insure good burnout. High velocity, secondary air nozzles would be provided in the front and rear walls to promote complete combustion of volatile gases and particles rising from the fuel bed. All walls and the roof would be of welded tube-and-fin construction.

TABLE 11

CHARACTERISTICS OF 300 MW, CASE 3 POWER SYSTEM

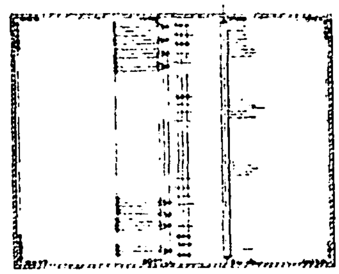
Item	
Refuse Rate (fractional heat input), %	19.4
Steam Pressure, psig	2400
Number of Turbines	1
Total Turbine Heat Input, 10^9 Btu/hr	2.52
Steam Generator Efficiency Due to Refuse, %	67.6
Steam Generator Efficiency Due to Fossil Fuel, %	87.0
Net Steam Generator Efficiency, %	83.2
Heat Input Total, 10^9 Btu/hr	3.036
Heat Input from Refuse, 10^9 Btu/hr	0.596
Heat Input from Fossil Fuel, 10^9 Btu/hr	2.440
Refuse Rate (firing 2 economizers), tpd	1500
Fossil Fuel Rate (as coal), tpd	2440
Net Plant Heat Rate, Btu/kw-hr	10,120

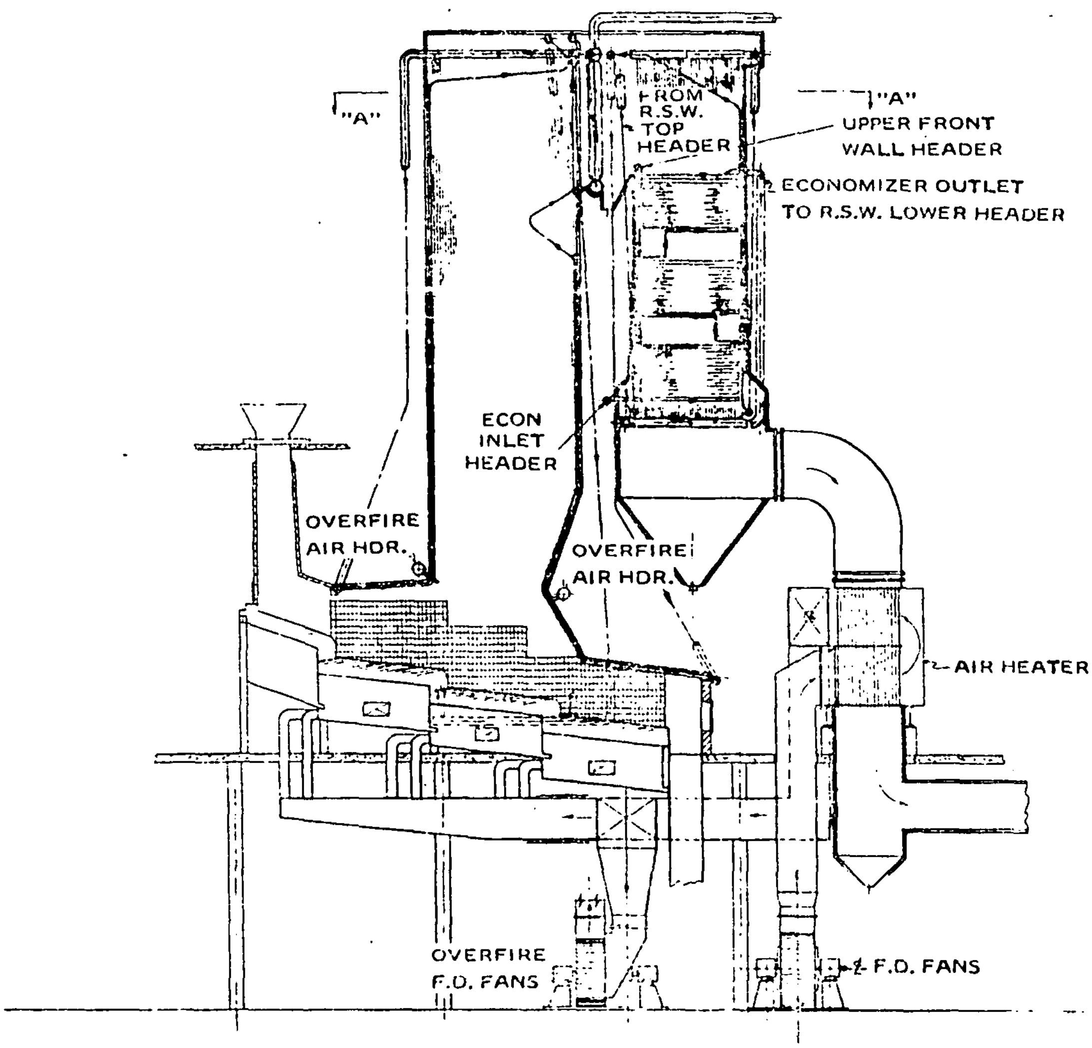
Tube banks, especially in areas of relatively high gas temperatures, would be arrayed vertically. Horizontal tube banks would be of bare tube design in all cases. A tubular air heater, in which the flue gas would be directed downward inside the tubes, would be used because of its ease of cleaning. Ash hoppers would be appropriately located to remove ash where tube banks might act as ash deflectors.

Feedwater at 470° F would be flowed in a single continuous (once through) path. Flue gas would be directed in a two-pass arrangement and be discharged into a dust collector located at grade level. Air, preheated to 316° F, would be delivered as underfire air. This temperature was selected as being compatible with the cast iron grate. Approximately 25 percent of the preheated air would be sent through a booster fan and delivered as high velocity secondary air. A 50% excess of air would be employed and the exit flue gas temperature would be 575° F.

The water wall panels would consist of 3-in. OD tubes spaced on 3-3/4 in. centers with fins continuously welded between tubes. Because of the all-metal construction, slag adhesion should be minimal. Gas-borne, molten slag-particles would be cooled upon contacting the tube or fin and thus tend to shed from the surface. The solid walls would be impervious to gas penetration, so that a costly refractory setting would be unnecessary. In the design of the rear wall of the furnace, a "nose" would be incorporated at the furnace exit to insure good gas distribution. This wall would also form a three-row deep slag screen. The screen would be arrayed with a longitudinal spacing of 5-in. and a transverse spacing of 11-1/4-in. The boiler bank design would consist of 2-1/2-in. OD tubes, three rows deep on 7-1/2-in. spacing, and thirty-one elements across on 11-in. spacing, arrayed in an in-line configuration. The horizontal tubes would be 3-1/2-in. OD tubes, which would also be in-line on 5 x 5-in. centers. The loops would be supported from the front and rear panel-walls of the second pass. Ample space would be provided in the design for the installation of sootblowers, if needed. The air heater would consist of 1200-12 ft-long, 2-1/2-in. OD tubes arranged in a 4-1/2-in. spaced in-line pattern. On the air-side, the gas flow would follow a three-pass, cross-flow path.

Feedwater from the refuse-fired economizers would be blended and sent over to the coal-fired steam generator at a temperature of 660° F, the drum pressure of which would be about 2580 psig. Steam conditions would be 2400 psig at 1000° F with a 1000° F reheat cycle. Excess air would be set at 18% and a steam flow of about 2.10×10^6 lb/hr produced. A drawing of the economizer is shown in Figure 10.





REFUSE-FIRED ECONOMIZER OF THE CASE 3 TYPE

Figure 10

The steam generator fed by the two externally located economizers would be coal-rather than oil-fired, even though the latter is the prevalent mode of operation in the Philadelphia area. This is considered acceptable in that the system would incorporate gas cleaning equipment that would result in lower SO_2 emissions when firing high sulfur coal (~3.0% S) than would be achievable by firing low sulfur oil (~0.5% S) in existing, uncontrolled installations.

In most respects, the design of the coal-fired unit would be conventional. The main differences would be in the design layout of the heating surface. The heat absorbed in this unit would be largely accomplished by the superheater and reheater because of the use of the refuse-fired economizers. Some economizer surface would be included in the steam generator, however. This would be situated under the convection superheater. In conventional units a small section of the total economizer surface is usually located in this area, while the remainder is located to follow the parallel pass.

The furnace would have panel walls consisting of 3-in.OD tubes on 3-3/4-in. centers with continuous fins welded between the tubes. In the upper furnace, "wing" division walls would comprise a radiant superheater incorporating 2-in. OD tangent tubes. A parallel pass arrangement would be used in the second pass. Superheat temperature would be controlled by the firing rate and by spraying. Reheat temperature would be controlled by regulating the gas-flow with dampers.

The air pollution control equipment on the steam generator would consist of a wet scrubber system capable of handling the 745,000 ACFM of flue gas calculated for this boiler. Exit flue gas temperature would be 300° F. The wet scrubber would remove both fly ash and SO_x at expected efficiencies of 99% and 90%, respectively. Sulfur oxide removal would be accomplished by liming the scrubber liquor in accordance with the Mitsubishi process. Gypsum recovery would not be attempted, however. The separated calcium sulfate would instead be discarded. A gas reheater would be included in the system to prevent the formation of stack plume.

The flue gas from the steam generator and the two economizers would not be intermixed at any point in the systems. Each would have its own air cleaning equipment; the economizers would, however, share a common stack. Each would deliver about 160,000 ACFM of flue gas to its individual electrostatic precipitator, each of which would be rated at an efficiency of 99%. The estimated emission characteristics of the overall system can be tabulated as follows:

ESTIMATED STACK EMISSION OF 300 MW, CASE 3 POWER SYSTEM

Stack	Fly Ash		SO_2	
	lb/day	gr/SCF	lb/day	Vol.-%
Steam Generator	4392	0.042	26,352	0.021
Economizers	360	0.010	3,000	0.008
Total	4752	-----	29,352	-----
Composite		0.034		0.018

The above estimates are based on several assumptions concerning fuel characteristics. It is assumed that the coal would have a sulfur and ash content of 3.0% S and 10.0%, respectively, and that 90% of each of these constituents would be entrained in the flue gas as SO_2 and fly ash, respectively. Refuse is assumed to contain 0.1% S, half of which would be converted to SO_2; it is also assumed that 24 lb of fly ash would be formed for each ton of refuse fired.

A subject related to the above discussion is thermal pollution control. In the present analysis, cooling towers for restoring the original temperature of the riverine water discharged from the condenser system were not included. Such devices are not now used by Philadelphia power stations, nor is it expected that they will become a requirement for future thermal plants. This situation apparently results from a number of factors, including good flow and mixing rates within each of the two major rivers there.

b. Power Plant Costs

Capital and annual costs for the 300 MW power plant are shown in Table 12. Those cost model modifications, which were discussed in connection with the steam plant and which are relevant here, have been applied. A fixed annual credit for power generated has not been used because of the current instability in fuel costs. In the Fuel Adjustment Clause of P.E.'s tariff steam rates, fuel costs were increased 38% effective for the quarter starting February 1971. It is safe to estimate that fuel costs are now in excess of $\$0.40/10^6$ Btu and will probably increase considerably in the very near future. On this basis, it can be said that refuse disposal costs for the proposed 300 MW plant would be something less than \$1.75/ton and would probably shift to the asset side if fuel costs exceed $\$0.44/10^6$ Btu. The relationship of disposal costs to energy costs for the proposed plant are shown in Figure 11.

TABLE 12

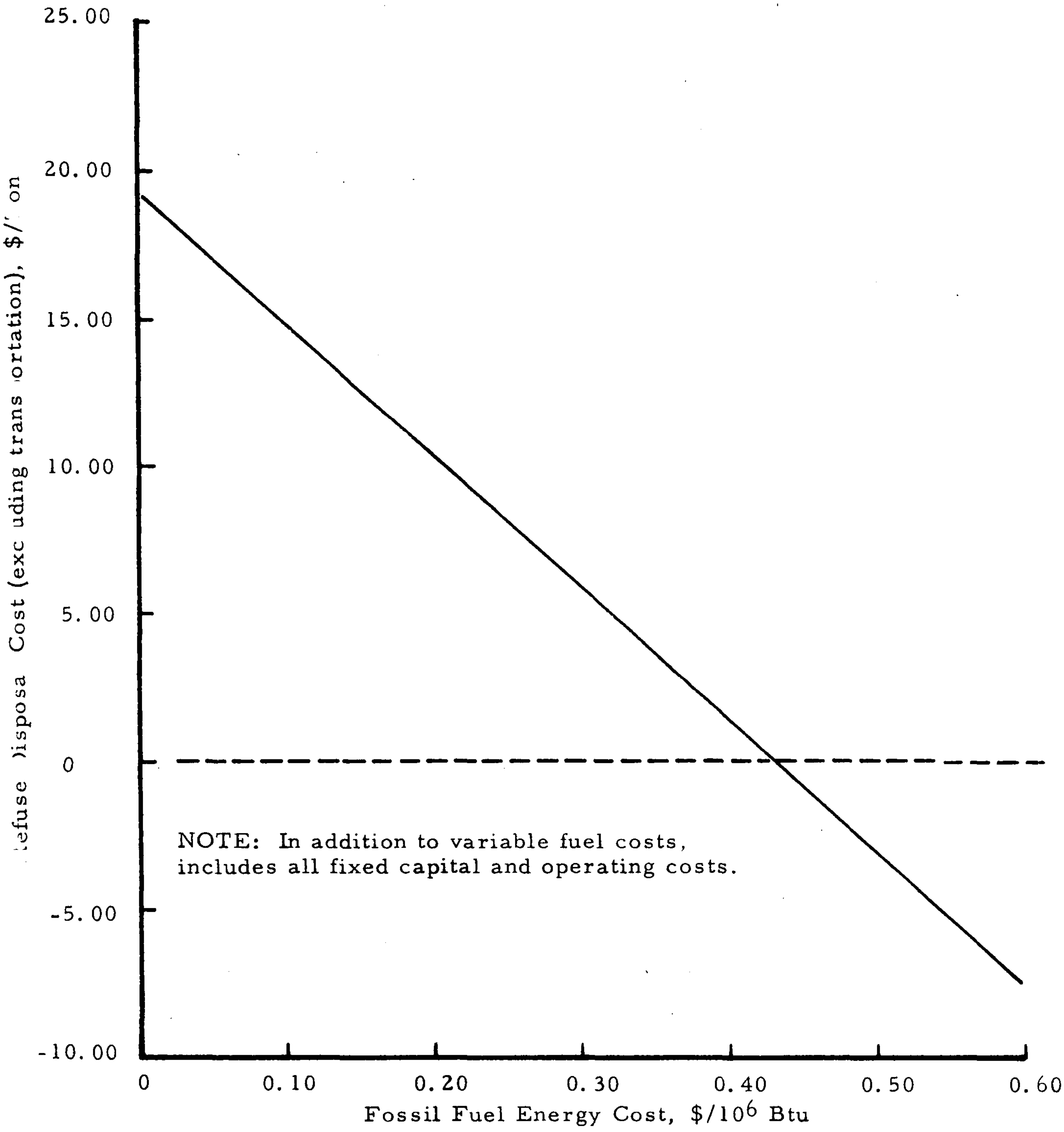
ESTIMATED COSTS FOR A 300 MW COMBINED-FIRED TURBO-ELECTRIC PLANT

CAPITAL COSTS

FPC Codes		Cost, 10^6 \$
310	Land and Land Rights	2.380
311	Structures and Improvements	5.326
312	Boiler Plant Equipment	33.077
314	Turbine-Generator Equipment	13.431
315	Accessory Electrical Equipment	2.783
316	Misc. Power Plant Equipment	0.398
	Air Pollution Control Equipment	3.853
	Waste Handling Equipment	2.316
	Engineering and Inspection	2.812
	Total Capital Cost	66.376

ANNUAL COSTS

Annual Capital Cost, 10^6 \$ (Effective Annualization Rate = 13.75%)	9.126
Water Cost, 10^6 \$	0.006
Operating Labor, 10^6 \$	0.723
Maintenance, 10^6 \$	1.411
Coal Cost, 10^6 \$	5.301
Residue Disposal, 10^6 \$	0.468
Total Annual Costs, 10^6 \$	17.035



DISPOSAL COSTS FOR 300 MW PLANT AS A FUNCTION OF FUEL COST

Figure 11

c. Power Plant Site Selection and Refuse Transportation Costs

The logical location of the 300 MW plant would be on the Schuylkill or Delaware Rivers at some point northwesterly or northeasterly, respectively, of the northern boundaries of the Columbia and Fairhill Districts. As can be seen in Figure 1, two city incinerator sites can be considered. Because few other sites are now known, these were studied to determine which would be optimum in terms of refuse transportation costs. The results of the vector analysis are summarized in the following table:

POWER PLANT REFUSE TRANSPORTATION DATA

	Refuse Hauled, Ton-Miles/Yr	
District	N. W. Incinerator Site	N. E. Incinerator Site
Manayunk	971,300	1,380,700
Germantown	833,100	1,383,000
Logan	270,900	746,700
Frankford	1,685,800	317,000
Lower Tacony	492,700	147,500
Upper Tacony	4,049,100	2,350,800
	8,302,900	6,325,700

Based on the total amount of refuse handled and a haul cost of $0.25/ton-mile, the transportation cost would be $4.34 and $3.30/ton to the Northwest and Northeast Incinerators, respectively. Although the latter site is obviously to be preferred, the transportation cost is still unacceptably high, particularly in comparison with those of the existing incinerator system ($1.81/ton) and the proposed steam plant ($1.93/ton). The difference can largely be explained on the basis of the lower refuse production density that exists in the northern districts of Philadelphia, particularly Manayunk and the Taconys. An obvious solution would be to employ transfer stations in these particular districts, and possibly in Germantown as well. This should bring the costs down by about a fourth.

III. THE CLEVELAND STUDY

A. WASTE MANAGEMENT OPERATIONS

1. Municipal Background Information

Two documents obtained from the City of Cleveland (References 3 and 4) provided important information on refuse collection rates and population distributions. The first furnishes population statistics, by ward, for 1967, when it was estimated that the city population was 814,156. The 1960 and 1970 census figures are 876,050 and 750,903, respectively, a decrease rate of 1.55%/yr.

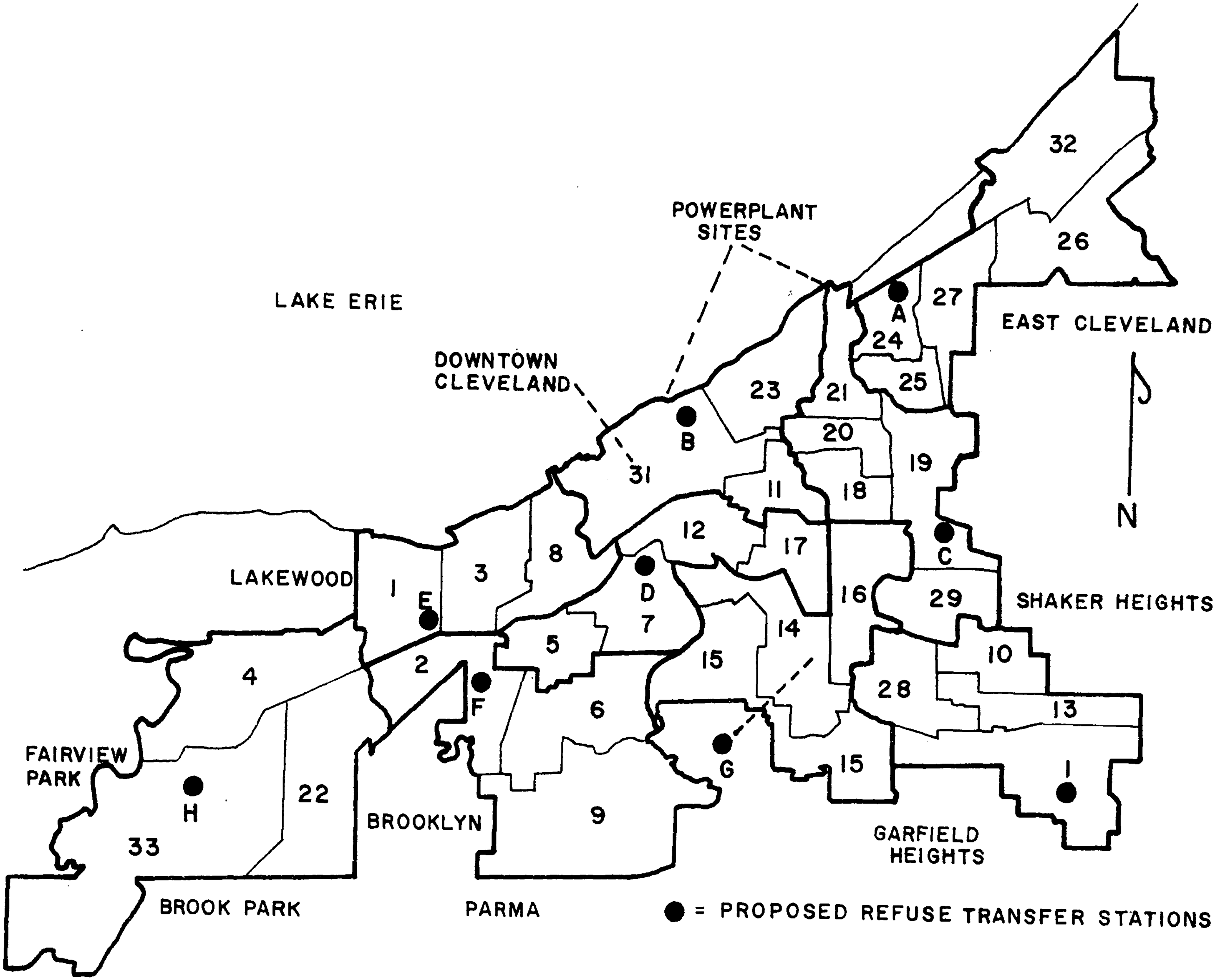
The ward structure of Cleveland is shown in Figure 12. The nine major ward-groupings demarcated represent a new waste management zoning now being considered there. Proposed sites for future transfer stations are also shown on the map. The populations and population densities of these ward groups are shown in the following table.

POPULATION DENSITY IN VARIOUS SECTIONS OF CLEVELAND (1967)

Ward Group*	Area, sq. mi	Population	Pop. Density, Persons/sq. mi
A	9.4	136,132	14,480
B	6.8	59,075	8,688
C	6.5	127,407	19,600
D	5.5	71,398	12,981
E	5.6	73,043	13,043
F	9.7	87,948	9,067
G	7.7	75,462	9,800
H	14.5	90,336	6,230
I	7.6	93,305	12,277

*Letter designations are arbitrary.

It can be seen that regions of highest population densities are those surrounding downtown Cleveland and those along the Eastern end of the city.



WARD MAP OF THE CITY OF CLEVELAND

Figure 12

Figure 13 shows the five (arbitrarily numbered) collection districts operating within Cleveland's Division of Waste Collection and Disposal. It will be noted that all five district yards (and offices) have been proposed as transfer stations. It will also be noted that two of the yards are not located in the districts they serve; in fact, the Harvard station is not even within the city limits. This of course results from land availability problems. The refuse collection rates for the five districts, based on 1969 data, can be tabulated as follows:

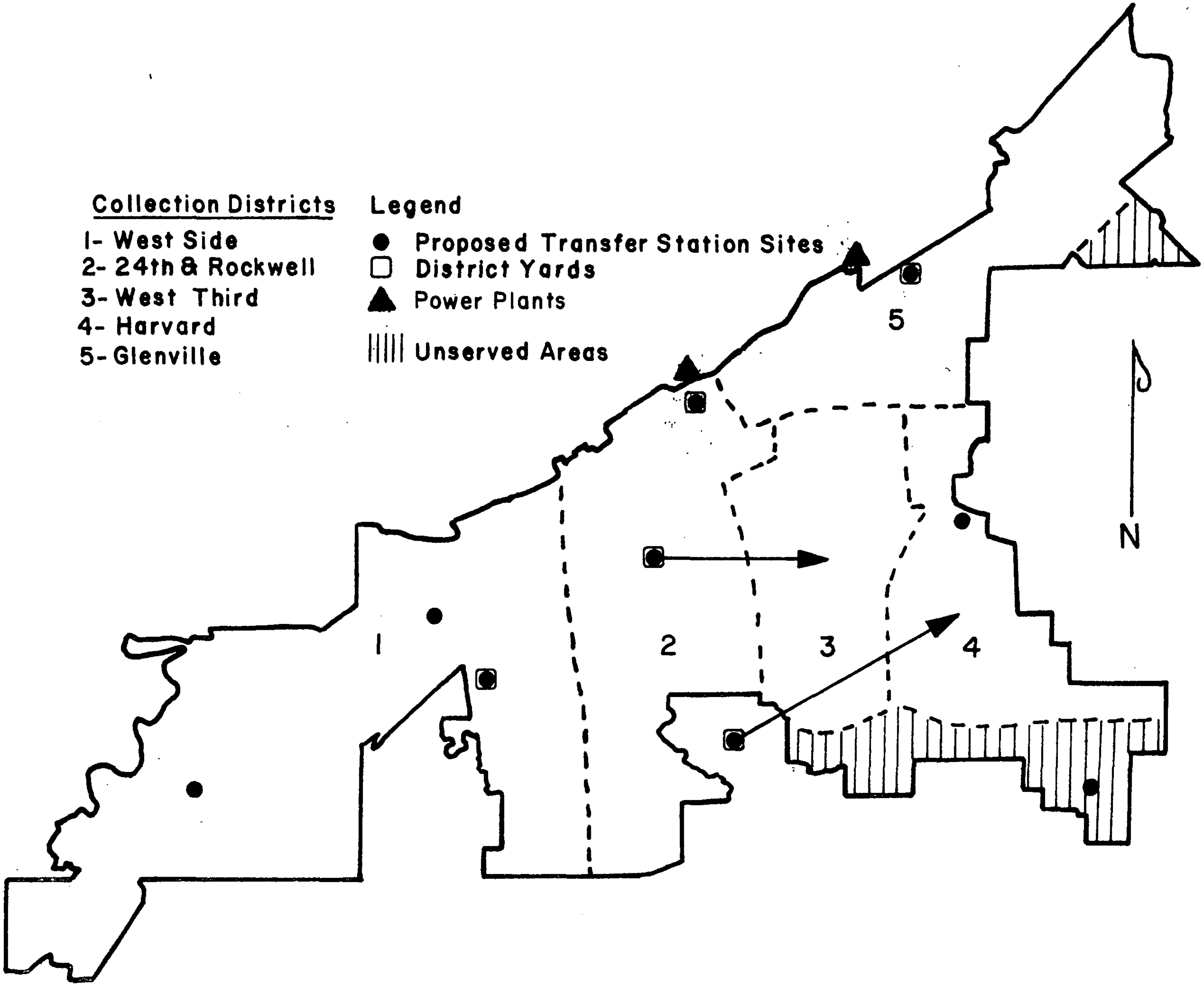
REFUSE COLLECTION RATES FOR
CLEVELAND'S FIVE COLLECTION DISTRICTS

District	Area, Sq. Mi	Refuse Collected		Estimated No. of Homes Served
		Tpd*	Tpd/Sq. Mi	
1. West Side	25.7	380	14.8	80,000
2. 24th & Rockwell	13.1	140	10.7	60,000
3. West 3rd Street	8.8	200	22.7	15,000
4. Harvard	7.7	248	32.2	20,000
5. Glenville	10.0	224	22.4	65,000

*Based on five-day work week.

Although the collection districts are not organized on the basis of ward boundaries, a geographic correlation can still be seen in that the heaviest concentrations of refuse production and ward population densities lie on the east end of town. This is fortuitous, in that the power plants located within Cleveland are in or reasonably close to these areas of high population and refuse production. The two lakeside power generator sites shown in Figures 12 and 13 are, from west to east, owned by the City of Cleveland and by the Cleveland Electric Illuminating Co.

The collection rates shown in the preceding table are regarded as being low by the author of Reference 4. More accurate information was also received for the year 1970, but this included totals only; these have not yet been broken down by districts.



REFUSE COLLECTION DISTRICTS IN CITY OF CLEVELAND

Figure 13

2. Present Waste Management Program

The 1970 budget of Cleveland's Division of Waste Collection and Disposal (DWC&D) is approximately $12,500,000, second only to the budget of the Safety forces. Served on a weekly basis are 240,000 residential units, the cost of which is approximately $1.00/unit-wk. An estimated 395,000 tons of refuse was collected during 1970. The estimated per ton cost of disposing of Cleveland's refuse in 1970 was about $32.50, which included all services from pulling the containers to the curb to final disposal. Because this cost did not include such factors as capital improvements, amortization, interest, etc., the DWC&D regards $35.00/ton to be a realistic value. The payroll of the division in 1970 exceeded 1400 persons, although a reduction in forces through attrition is now in progress to correct for certain archaic manning practices. The rolling stock of the division comprised 189 packer trucks, 28 flat-bed trucks, 48 passenger cars, and 21 specialized vehicles, including bulldozers, animal-carcass trucks, front-end loaders, etc. In general, the vehicle inventory is obsolescent, but new equipment is being actively sought.

Refuse handling within the five districts had been more or less standardized in recent years except as to method of disposal. Crews were first dispatched to move refuse containers to the curbs. Packer trucks next toured their routes and when filled proceeded individually, without intermediate transfer, either to the landfill site operated by the Rockside Hideaway Landfill, Inc., of Garfield Heights, Ohio, or to the Ridge Avenue incinerator. The latter fires material collected only in the West Side and 24th and Rockwell districts, although both of these districts send more than 60% of their collections to the Rockside landfill. Formerly, there were two incinerators in operation in Cleveland. The older of these was phased out a few years ago as being too costly to rehabilitate. It is also planned that the 10 year old Ridge Avenue incinerator be eventually shut down and operations shifted to 100% landfill disposal.

Additional services provided by the DWC&D included the removal of furniture and large appliances from the regular routes, pickup of putrescibles from commercial and semi-commercial establishments, and clean-up of dock areas and city streets. Special vehicles are used for these tasks.

3. Future Waste Management Plans

At the present time the DWC&D is moving forward in the modernization of its operations. This is vitally needed in view of the present high cost of disposal and the fact that the Rockside landfill will soon be exhausted. In anticipation of this problem, bids are being sought for new landfill contracts wherein the operator would remove the refuse in trailers from close-in station(s). This will be done by one of two options, as determined by cost analyses of the submitted bids. The first plan would involve the construction by the contractor of a receiving and storage plant similar in function to that recommended in Section III, B, 7 of Reference 1. It would not, however, involve any refuse grinding and the output from the storage bin would be compacted into trailers for outhaul to landfill rather than being conveyed to a furnace. The second plan would be based on the construction, by the city, of transfer stations at a minimum of two of the sites shown in Figures 12 and 13. There, the packer trucks would tip directly into the contractor's trailers.

When the selected plan goes into effect, the contractor will be expected to outhaul a guaranteed 300,000 tpy. The Ridge Avenue incinerator will continue to operate, although it is uncertain that the old refuse rate of 80,000 to 90,000 tpy will be maintained. Commissioner R. Beasley of the DWC&D has assured Envirogenics that the landfill commitment would not result in the denial of an adequate refuse fuel supply for any envisioned steam generating scheme. It had originally been hoped that the plan selected would be implemented by 1 April 1971. Problems have arisen, however, and a new bidding round will have to be undertaken.

Another economic pressure recently felt by the DWC&D was a significant cut in the budget. This has necessitated an extensive reorganization of operations, which are still under evaluation at the present time. An outgrowth of this economy move has been a reduction in packer truck crews to three men and the abandonment of backyard trash pick-up.

B. REFUSE INVENTORY AND COMPOSITION PROJECTIONS

1. Refuse Quantities

Data received from the City of Cleveland on the quantities of refuse disposed of during 1970 are as follows:

QUANTITY OF WASTE DISPOSED OF
IN CLEVELAND DURING 1970

Refuse Type	Cu Yds/Yr	Tons/Yr	Tons/Day
Packer Truck			
to Landfill	----	301,614	826
to Incinerator	----	73,690	202
Bulky	219,330	17,766[a]	49[a]
Total		393,070	1077

[a] Derived from a published specific volume value, wherein 1 cu yd of bulky refuse = 162 lb. (Reference 5).

Included in this refuse estimate was a predominating quantity of domestic material, together with street litter, dockside trash, and waste from institutional sources, hotels, and markets. The bulky waste constituted 4.5% of the total, which is in good agreement with the 5% figure suggested in Reference 1. Solid wastes from commercial and industrial sources, other than those mentioned, are handled by private companies.

The values shown above are regarded by the author of Reference 4 as being the most accurate yet obtained. The collection data examined for previous years, in fact, do appear to be on the low side, considering the high rates of annual increase they suggest. The earliest estimate on Cleveland's refuse collections was reported for 1966 (Ref. 6). The quantity estimated was 215,000 tpy, which would imply an increase of 14.8%/yr to arrive at the 1970 figures. The quantity estimated for 1969 was 309,922 tpy, which is 21.7% less than the 1970 output (Ref. 4). The last reference also predicts a future growth of 5%/yr due to expansion in the southeast and southwest portions of the city.

The 1.55%/yr decrease in population should have slightly more than offset the expected 1.5%/yr per capita increase in refuse production. Thus a more or less even collection rate should have been seen in Cleveland over the past decade. Because of the inaccuracies associated with older collection data and the prediction that Cleveland's population is soon expected to stabilize (remain constant), it was decided to assume that the 1970 data are accurate and project a growth rate of 1.5%/yr over the next decade. On this basis, refuse rates were predicted to increase to 1250 tpy by 1980. Allowing an additional 10% for commercial/industrial solid waste, the figure was set at 1375 tpd.

2. Refuse Composition

The Martin-Marietta Co. has been conducting a study for EPA's Solid Waste Office. This has involved the compositional analyses of refuse collected at Orlando, Florida; Wichita Falls, Texas; and Cleveland, Ohio. The Project Manager, Mr. William Warren, kindly provided Envirogenics Co. the data which had been acquired in Cleveland. These analyses were made on refuse collected in selected areas serviced by trucks from the Ridge Avenue Station, the 24th and Rockwell Station, and the suburb of Olmstead. The specific routes involved in the three areas were characterized, respectively, as consisting of: (1) public housing, (2) large, older single-family residences, many occupied by several families; and (3) single-family, middle-class residences. The averages obtained for these three samplings are shown below; data reported in Reference 1 are also given for comparison.

AVERAGED COMPOSITIONAL DATA FOR
CLEVELAND REFUSE

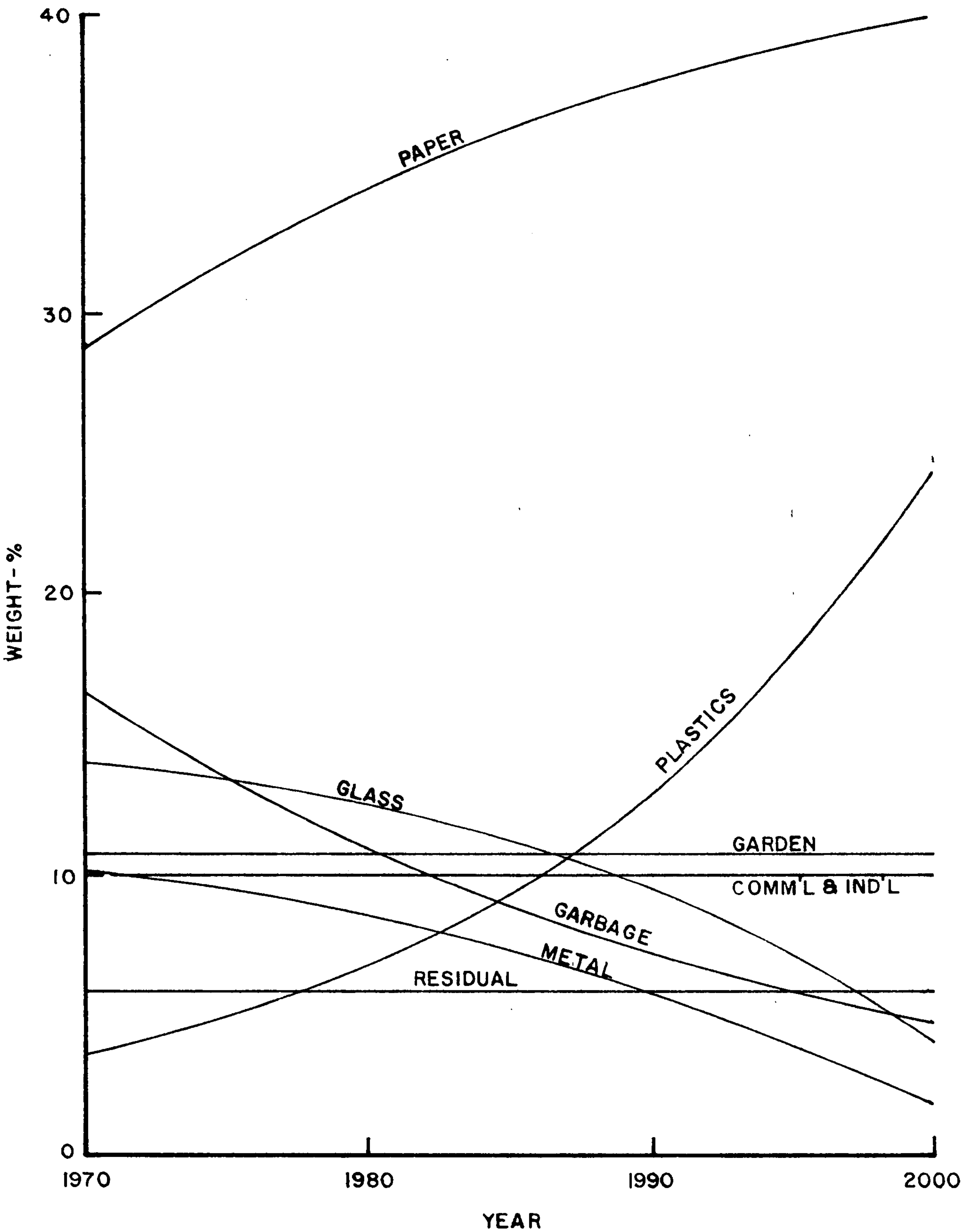
Constituent	Weight-Percent: Martin-Marietta, Cleveland	Weight-Percent: Nationwide (Ref. 1)
Garbage	18.3	20
Paper	32.3	38
Garden	11.9	12
Plastics	4.0	2
Metal	11.2	10
Glass	15.7	12
Residual	6.6	6
	100.0	100.0

The above composition was then adjusted to reflect the presence of 10% commercial/industrial waste. Projections were then made, per Reference 1, for future compositions. The results are shown in Figure 14.

From Figure 14 the composition of refuse in 1980 can be tabulated, for easier reference, as follows:

PROJECTED 1980 COMPOSITION OF
CLEVELAND REFUSE

Constituent	Wt-%
Garbage	11.0
Paper	34.6
Garden	10.7
Plastics	6.7
Metal	8.5
Glass	12.6
Residual	5.9
Commercial/ Industrial	10.0
	100.0



PROJECTED COMPOSITIONAL CHANGES IN CLEVELAND REFUSE

Figure 14

An ultimate analysis was then calculated for the above composition, the results of which are shown in the next table:

PROJECTED 1980 ULTIMATE ANALYSIS OF CLEVELAND REFUSE

Constituent	Wt-%
H_2O	19.8
C	26.3
H	3.5
O	21.0
N	0.5
S	0.1
Inert	28.8
	100.0

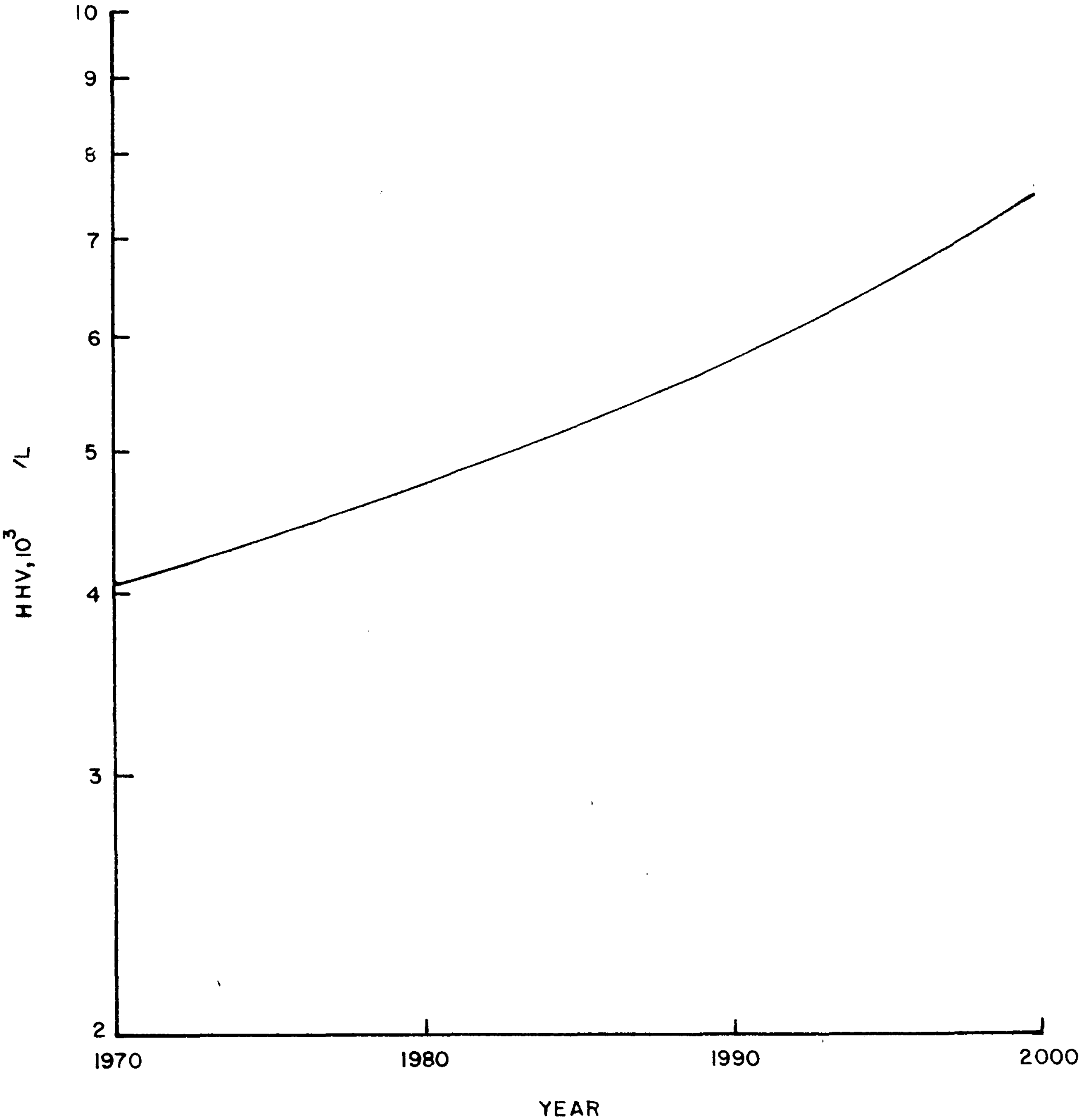
C. FUEL CHARACTERISTICS OF CLEVELAND REFUSE

1. Heating Value

Projections, based on the compositions discussed above and the constituent calorific values for refuse described in Reference 1, were also made for the heating values of Cleveland refuse. These are shown in Figure 15, where it can be seen that, by 1980, Cleveland's refuse will have a higher heating value (HHV) of about 4750 Btu's/lb.

2. Combustion Calculations

Combustion gas requirements, flue gas production rates, and steam generator efficiencies at exit flue gas temperatures of 450°, 500°, and 575° F were then determined. These data are shown in Tables 13, 14, and 15. The three different temperatures correspond, respectively, to the flue gas exit temperatures of (1) the various Reference 1 refuse boiler designs, excluding Case 3, (2) the straight-refuse-fired district heat plant, and (3) the Case 3 refuse fired economizer. The efficiency data shown in Table 15 are graphed in Figure 16 to permit the extraction of values at other flue gas exit temperatures



PROJECTED CHANGE IN HEATING VALUE OF CLEVELAND REFUSE

Figure 15

TABLE 13

COMBUSTION GAS REQUIREMENTS FOR CLEVELAND REFUSE COMPOSITION PROJECTED FOR 1980

Constituent	Combustion Gas Requirement, lb/lb Refuse: Oxygen	Dry Air
C	0.701	3.021
H	0.280	1.207
S	0.001	0.004
Metal	0.007	0.030
	0.989	4.262
Oxygen	0.251	1.082
Total Required, stoichiometric	0.738	3.180
Total Required, 50% excess gas	1.107	4.770
Excess Gas	0.369	1.590

TABLE 14

PRODUCTS OF COMBUSTION OF THE REFUSE PROJECTED FOR CLEVELAND IN 1980

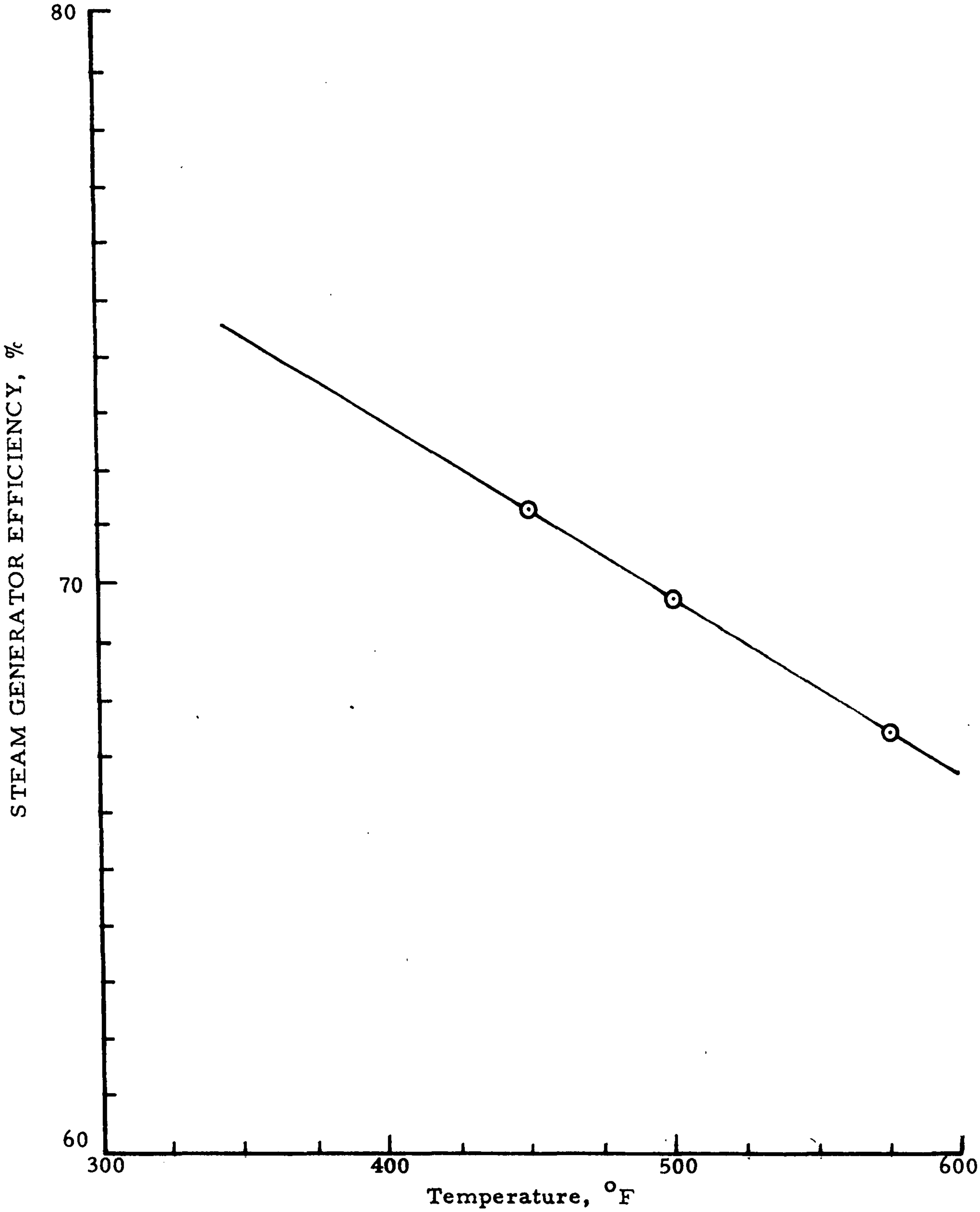
Constituent	Gas Formed per lb Refuse Lb Mol	Gas Formed per lb Refuse Lb	Vol-% Dry Basis
CO_2	0.022	0.964	13.3
H_2O	(0.032)	(0.567)	-
- Refuse H_2	0.018	0.315	-
- Refuse H_2O	0.011	0.198	-
- Combustion Air	0.003	0.054	-
SO_2	<0.001	0.002	0.02
O_2 (excess)	0.012	0.369	7.3
N_2			
Total Air N	0.131	3.666	79.4
Refuse N	<0.001	0.004	
Total Flue Gas (wet)	0.197	5.572	
Total Flue Gas (dry)	0.165	5.005	

TABLE 15

EFFICIENCY OF STEAM GENERATOR FIRING CLEVELAND REFUSE OF COMPOSITION PROJECTED FOR 1980

	Item	Fuel Value Heat Losses at Various Flue Gas Exit Temperatures, Btu/lb of Fuel (% of HHV) 450°F	500°F	575°F
1.	Dry Gas	444 (9.35)	505 (10.63)	595 (12.53)
2.	H_2O in Refuse	241 (5.07)	245 (5.16)	252 (5.31)
3.	From H_2 Combustion	383 (8.06)	390 (8.21)	401 (8.44)
4.	H_2O in Air	11 (0.23)	13 (0.27)	15 (0.32)
5.	Unburned Gas	4 (0.08)	4 (0.08)	4 (0.08)
6.	Unburned Residue	110 (2.32)	110 (2.32)	110 (2.32)
7.	Sensible Heat, Residue	46 (0.97)	46 (0.97)	46 (0.97)
8.	Unburned Fly Ash	41 (0.86)	41 (0.86)	41 (0.86)
9.	Sensible Heat in Fly Ash	5 (0.09)	5 (0.11)	6 (0.13)
	Subtotal	1285 (27.03)	1359 (28.61)	1470 (30.96)
10.	Radiation	(0.20)	(0.20)	(0.20)
11.	Unmeasured	(0.50)	(0.50)	(0.50)
12.	Manufacturer's Margin	(1.00)	(1.00)	(1.00)
	Total % Heat Loss	28.73	30.31	32.66
	Steam Gen. Efficiency	71.27	69.69	67.34

NOTE: Fuel Value (HHV) = 4750 Btu/lb; Combustion Air Inlet Temperature = 80°F (60% R.H.).



EFFICIENCIES AT VARIOUS FLUE GAS EXIT TEMPERATURES OF A STEAM GENERATOR FIRING PROJECTED 1980 CLEVELAND REFUSE

Figure 16

D. UTILITY STEAM GENERATION OPERATIONS

1. Municipally-Owned Boilers

The facilities owned by the City of Cleveland consist of six units, five of which are wet bottom or slagging furnaces. The sixth and newest unit was installed within the past few years. It has a pressurized furnace and is of 75 MW capacity.

The other five units are Foster Wheeler boilers, three of which were placed in service in the early 40's. The other two were commissioned in 1956. All five fire pulverized coal of low ash fusion temperature from horizontally aligned burners. The three old boilers are identical, each being designed to generate 300,000 lb/hr of steam at a heat release rate of 26,100 Btu/ft^3. They are of course refractory-walled furnaces, the monowall construction being of more recent invention. Retrofit of slag-tap boilers to refuse or combined (refuse plus fossil fuel) firing is impractical because of the costly modifications that would be necessary. Pressurized-furnace boilers are also poor candidates for retrofit because of the difficulty of providing a workable gas-seal on the charging chute.

2. Cleveland Electric Illuminating Co. (CEI) - Owned Boilers

Three plants are operated by the CEI which are within reasonable distance of the municipal refuse collection system. These are the Lakeshore power station on East 70th Street and the Cleveland Memorial Shoreway, the Canal Road steam plant beneath Eagle Avenue bridge, and the East 20th Street steam plant between Hamilton and Lakeside Avenues. Five units are operated at the Lakeshore Station, four of which are of the continuous slag-tap type and thus incompatible with refuse firing. The fifth unit is a 250 MW dry-bottom boiler which is fueled with tangentially-fired, pulverized coal. It is of recent enough vintage (1959) that it would not be considered for retrofit treatment.

The steam plant at East 20th Street comprises six units, all of which were commissioned before 1930. The location of the plant is in a highly congested area such that it would not be suitable for refuse processing.

The Canal Road plant contains five boilers, all of which were installed between 1948 and 1950. Each is equipped with forced draft chain grate stokers and is capable of generating up to 150,000 lb/hr of steam. Because of their small sizes, it is doubtful that retrofit would be practical.

3. Effect of Firing Refuse on Pollution Burden

The benefits of firing the refuse as a substitute for fossil fuel would have on the Cleveland air pollution situation is difficult to assess because of the rather transitory nature of present utility fuel-use practices. It was decided, somewhat arbitrarily, that benefit estimates would best be derived based on the assumption that a coal containing about 1% sulfur and 10% ash would be the fuel that would be partially replaced by the use of refuse. Because gas cleaning equipment is not yet generally used throughout Cleveland's coal-burning utility stations, particulate emission changes were calculated on the basis of both zero and 99% control. As in most of the nation, no APC equipment for sulfur oxide emission abatement is in use in the Cleveland area, although plans for one such system are now being considered. For the present analysis, however, zero SO_2 control was assumed.

From these bases, the comparative emissions of refuse and an equivalent (energy-wise) amount of coal were calculated. It was found that coal would produce about twice as much particulate loading and 4 1/2 times as much SO_2 in stack gas than would refuse.

The values assigned to the system variables are tabulated below. They are based on data presented in the foregoing text and typical air pollution data provided in Reference 1.

FACTORS ASSUMED FOR AIR POLLUTION CALCULATIONS

Fuel	HHV, Btu/lb	Boiler Efficiency, %	Flue Gas Loading, lb/ton Fuel Fired: Particulates	Flue Gas Loading, lb/ton Fuel Fired: SO_2
Refuse	4,100	70	24	2.3
Coal	12,000	85	160	19.0

On the basis of the above factors, it was estimated that 3.55 lb of refuse would be required to produce the same working fluid enthalpy as 1 lb of coal. Thus for every ton of refuse fired in substitution for coal, the flue gas exiting the air heater would contain 21 lbs less particulate matter and 3 lbs less SO_2. If an electrostatic precipitator of 99% efficiency were used, the particulate reduction in the stack gas would only amount to 0.21 lb per ton of refuse fired in substitution for coal. The precipitator would of course have no significant effect on SO_2 levels.

If all the refuse now collected in the City of Cleveland (393,000 tpy) were fired in substitution for coal (1% S and 10% ash), the SO_2 atmospheric burden would be reduced by about 590 tpy. Air-borne dust would be reduced by about 4,125 tpy if no APC systems were involved, but only by one hundredth that amount if gas cleaning equipment of 99% efficiency were in use by the hypothetical coal/refuse-fired plants. As found in the Philadelphia analysis, the air pollution abatement benefits available from firing refuse in lieu of fossil fuel are not great.

E. PRELIMINARY PLANNING RECOMMENDATIONS

1. Overview

Undertaking the construction of one or more refuse-firing steam generators in a large metropolitan area (LMA) such as Cleveland is constrained by a number of factors. Obviously, the systems selected must be located near the refuse collection network to minimize transportation costs. Similarly, the operation of a single installation, capable of handling all of the City's refuse, should be avoided. A single disposal plant would necessarily be non-optimum in terms of city-wide accessibility and, too, such an operation would doubtless promote severe traffic problems in the immediate vicinity of the plant. Another key factor which must be considered is that such plants must be situated near their service interfaces. A turbo-electric facility should be within easy reach of the electrical grid system and of copious quantities of cooling water. A process steam or district heating plant must be as close as possible to the steam service lines because easements of any distance are often difficult to arrange. Finally, and perhaps most importantly, the planning interests of the utility companies, the city managers, and potential large users of the product (e.g., process steam) must be served.

In the study of the Cleveland resource system, three aspects of the local energy demand situation were considered. First, as in any LMA, electrical power demand is increasing at a vigorous rate. For a city of Cleveland's size, as much as 700 MW additional capacity per decade may be required. Secondly, heating steam demand, though much more static than the demand for electrical energy, will be difficult to satisfy with the aging inventory of boilers now in service. Thirdly, the East Ohio Gas Co. has an interest in the concept of firing refuse to generate process steam (2 to 3 x 10^5 lb/hr) for the Republic Steel Plant in Cleveland. Unfortunately, the last item became known only late on the program and a working arrangement between Envirogenics and the Cleveland principals that would be consistent with scheduled commitments could not be arranged.

Thus in the preliminary design work, the decision was made to consider a refuse reduction arrangement which would include a district heating boiler and a turbo-electric unit. The combination of these two "strategically separated" facilities would offer the capability of consuming all of the refuse generated in Cleveland by the year 1980.

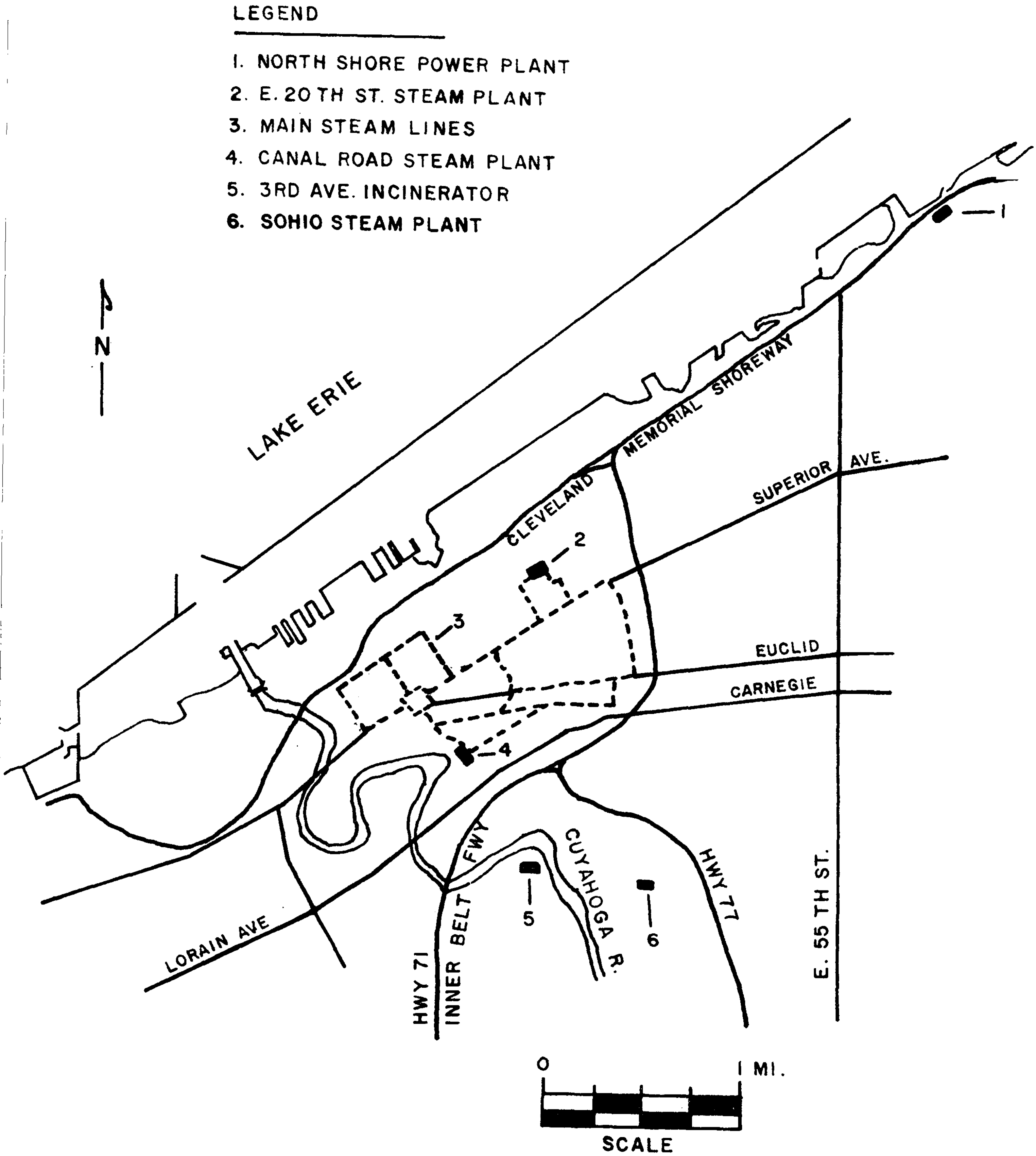
2. Refuse-Fired District Heating Plant

a. Site Selection

The district heating system operated by CEI is shown in Figure 17. The only sites recognized for possible construction of a refuse-fired facility were that of the existing steam plant at Canal Road, the grounds of the now-defunct 3rd Avenue municipal incinerator, and the yard of Sohio's asphalt and steam plant between Broadway and East 34th Street.

The Canal Road plant is obviously the best choice because it is already an element of the existing steam system. The plant lay-out does not offer adequate room for waste handling, but some land is available across the road from the plant. The 3rd Avenue municipal incinerator is only 0.7 miles from the Canal Road steam plant and the existing steam network. However, the construction of a pipe-line does not appear economically attractive. Any steam flowing between the two plants would have to cross the Cuyahoga River, the Inner Belt Freeway, and a number of railroad lines. The Sohio process plant is a little farther (1.2 miles) from the Canal Road plant and is also separated by freeway and railroad systems. It is, however, on the right side of the Cuyahoga and can be considered the second best choice. Purchase of the Sohio steam plant by the CEI is a possibility.

In examining the Canal Road plant lay-out (see Figure 18), a possible accommodation for a refuse-firing unit has been recognized. The existing 5-unit plant was designed with provision for the installation of a 6th unit, the position of which is the closest to the coal storage facility. The latter consists of a concrete walled, 30-ft deep pit having a floor area of about 1/3 acre. Coal feeding, however, is normally done directly from hopper bottom railroad cars over the track hoppers. When this process is interrupted, then charging is done from the pit, but usually only from that portion of the pit under the trestle into which coal cars can discharge. A front end loader moves the coal from this area to a loading hopper which communicates with a conveyor system. The latter carries the feed to coal-crushers and thence to storage hoppers which feed the chain stokers.



CLEVELAND'S DISTRICT HEATING SYSTEM

Figure 17

A major portion of the coal-pit contents is held in reserve for emergencies and has so been held for many decades. If this coal could be stockpiled elsewhere, then the pit could be partitioned and a bulk of its volume used for refuse storage without interfering with normal coaling operations.

Another possibility is that the plant might be converted to fire oil. At the present time, CEI is converting its 20th Street plant to oil-firing. If this were also done at the Canal Road plant, the coal facilities described above could be more easily modified for refuse handling. The new, refuse-fired boiler could of course be installed on the available, 6th foundation site or be located "over-the-fence" on the property across the road. As discussed later, both possibilities have been costed to determine which approach would be the more cost-effective.

The steam from the existing CEI steam plants is sent out at 170 psig, equivalent to an enthalpy of about 1230 Btu/lb. The minimum summer load requires steam production ranging between 90,000 and 120,000 lb/hr of steam. The former value was selected as the rating for the refuse firing unit. This would permit the unit to dispose of refuse collected in designated Cleveland districts at a more or less steady rate all year around. It would also permit the East 20th Street plant to feed some steam into the loop during minimum demand periods and thus minimize frictional line-losses. The duty of the new unit would be 0.105×10^9 Btu/hr. Using the fuel value projected for Cleveland refuse in 1980 (4750 Btu/lb) and an efficiency calculated to be 69.7%, a refuse rate of about 400 tpd would be required.

b. Over-the-Fence Arrangement

The over-the-fence installation would be essentially a self-sufficient system. It would consist of a single boiler, the enclosure of which would include a tipping-pit. The overall system design and operation would be basically the same as that described in Section II, E, 2, a, except of course smaller in scale. The characteristics of the proposed Canal Road steam plant are summarized in Table 16.

As seen, the storage pit would be sized to provide six tipping stations. Based on an average packer truck load of four tons (15 cu yds) and a discharge cycle time of four minutes, an average dumping rate of 360 tph would be expected. The maximum receiving rate during peak traffic hours should not, however, exceed 150 tph. Thus, truck queueing is not probable. Weigh-in would be handled by a single, automated scale. The access streets serving the site are rather narrow and require improvement.

TABLE 16

SYSTEM CHARACTERISTICS OF CANAL ROAD STEAM PLANT (REFUSE FIRED)

Steam Specifications	
Production, lb/hr	90,000
Sendout, lb/hr	75,000
Pressure, psig	170
Temperature, °F	425
Boiler Specifications	
Refuse Rate, tpd	400
Efficiency, %	69.7
Duty, 10^9 Btu/hr	0.105
Flue Gas Exit Temperature, °F	500
Exit Flue Gas Volume, ACFM	76,600
Feed Water Temperature, °F	220
Plant Factor, %	80
Refuse Handling Facilities Specifications	
Tipping Pit Dimensions, ft	100 (l) x 40 (w) x 50 (d)
Number of Bridge Cranes	2 (60 ft long)
Grapple Capacity, cu yd	3
Number of Tipping Stations	6

Because of this, it was felt that oversized refuse should not be handled at this plant.

Costs for the overall system have been derived utilizing the methodology outlined in Reference 1. In these calculations, the present system was considered to be equivalent to a 10 MW turbo-electric system in solving certain of the cost functions. Because the base date of the various cost formulae is June 1969, capital costs have been increased by 10%/yr for a period of two years, bringing the base date to June 1971. The results of this costing are shown in Table 17.

Disposal costs have been derived in two ways. In Method A, it is assumed that the new, refuse-firing steam generator would be added to the system inventory to provide needed capacity. That is, it would replace a unit that had to be retired or would provide a needed increase in the total production of the existing system. In either of these situations, it would then be acceptable to apply the value of the steam generated (based on conventional plant operation) against the annualized capital and O&M costs of the new plant. If, on the other hand, the addition of this base load plant were made to an existing steam plant arrangement that was already capable of handling the demand, a service displacement would occur. Some or all of the conventional units would have to be operated at reduced plant factors in order to permit the refuse-fired installation to operate at full load. In this case, annual credits (Method B) should include only the costs of fossil fuel, labor, and maintenance for the conventional plants partly or totally displaced by the new plant.

The credit used for the Column A costing was derived using a steam value of $\$1.05/10^3$ lb, based on present operating costs. For Column B, a coal-fired steam generator efficiency of 83% and energy cost of $\$0.31/10^6$ were used in determining the coal credit. Labor and maintenance savings were assumed to be the same as the corresponding costs for operating the refuse-fired plant, except that those cost items dealing with refuse handling were deleted. This adjustment, incidentally, showed that the labor costs of the refuse-fired plant would be 67% higher than those of its fossil fuel equivalent.

A drawback to the plant layout just described is the condition of the land adjacent to the Canal Road Plant. It is poorly shaped and contoured, offers a marginal amount of area, and has a transformer building located on the most important section of the plot. A detailed civil engineering analysis of the property would be required to verify the feasibility of utilizing this real estate.

TABLE 17

ESTIMATED COSTS FOR THE OVER-THE-FENCE, REFUSE-FIRED STEAM BOILER

CAPITAL COSTS

FPC Codes	Description	Cost, 10^6 $
310	Land and Land Rights (10 acres)	0.860
311	Structures and Improvements	0.348
312	Boiler Plant Equipment	2.360
315	Accessory Electrical Equipment	0.202
316	Misc. Power Plant Equipment	0.097
	Air Pollution Control Equipment	0.189
	Waste Handling Equipment	0.914
	Engineering and Inspection	0.705
	Total Capital Cost	5.675

ANNUAL COSTS

Annual Capital Cost, 10^6 $ (Effective Annualization Rate = 14.6%)	0.828
Water Cost, 10^6 $	0.038
Operating Labor, 10^6 $	0.455
Maintenance, 10^6 $	0.096
Residue Disposal, 10^6 $	0.090
Total Annual Costs, 10^6 $	1.507

	A	B
Annual Credit, 10^6 $	0.552	0.519
Quantity of Waste Burned, 10^3 ton/yr	117	117
Disposal Cost, $/ton	8.16	8.45

A. Based on revenues for steam generated.

B. Based on coal, labor, and maintenance costs for operating existing steam generator of equivalent capacity.

c. On-Site Arrangement

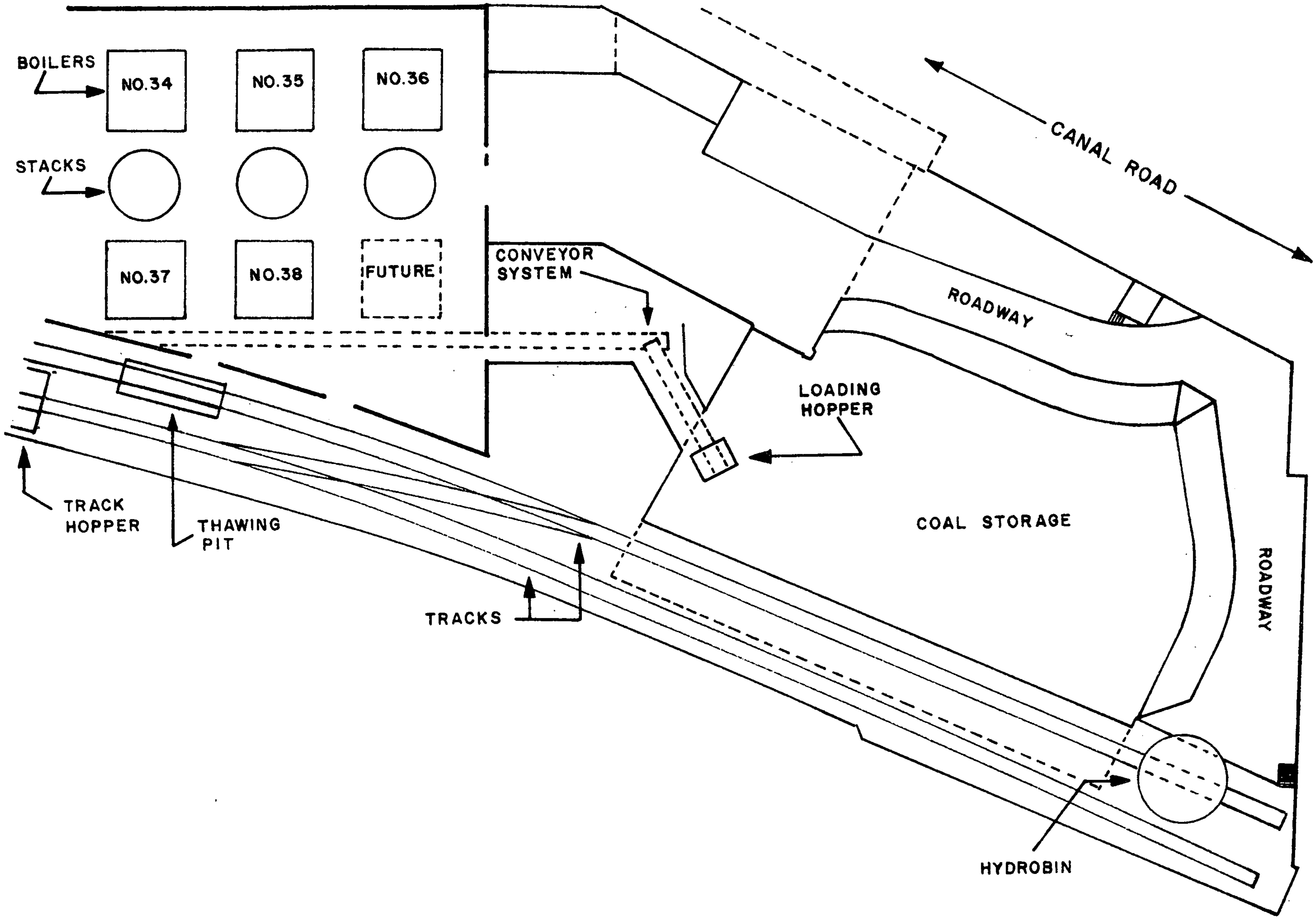
An alternate approach would be to utilize the vacant foundation in the Canal Road Plant for the installation of a refuse-fired boiler (see Figure 18). This would require that at least a portion of the coal pit would be available for refuse storage.

The floor area of the pit is 14,100 sq ft and the walls are 30 ft high except around the trestle. This represents a storage capacity of over 15,000 cu yds, which is well in excess of the maximum refuse storage volume requirement of 7000 cu yds. If the plant were converted to oil firing, the existing coal conveyor system, including the loading hopper on the floor of the pit, would be of no value for refuse charging. The existing components are too narrow and conversion to the 10-ft felt width needed would be excessively costly. A new charging arrangement would have to be installed.

Direct tipping into the pit also will not be practical. The two ramped-roadways are too narrow and the pit wall extends from four to nine feet above them at the highest and lowest elevations of the ramps, respectively. The most economical solution to this problem is to install a four-station tipping pit on the property opposite the plant on Canal Road. An enclosed conveyor system would then be used to bring the material from the tipping pit, over Canal Road, and into the storage structure. The overall arrangement is shown conceptually in Figure 19.

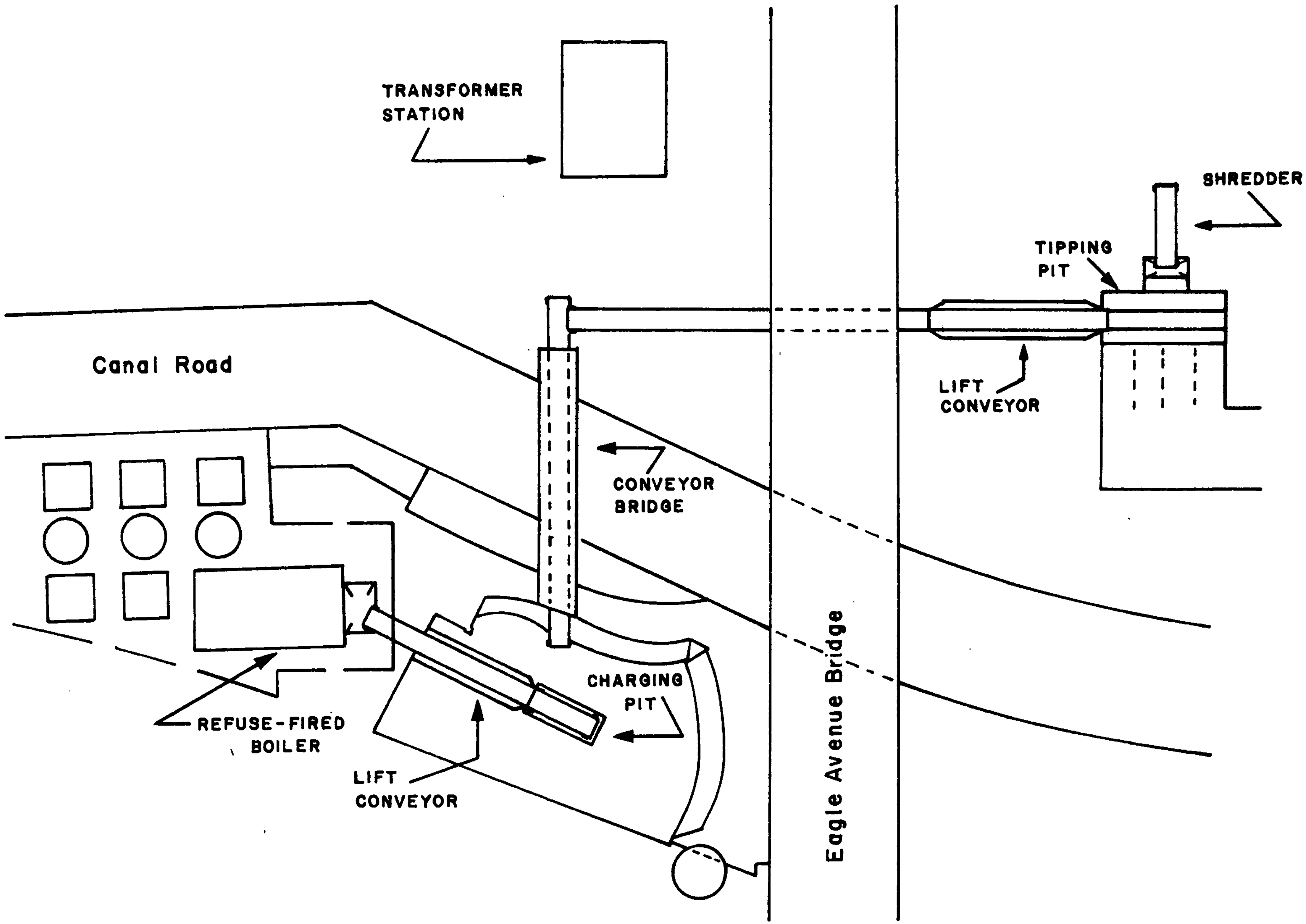
An expensive pit modification will be the installation of a covering structure. Except for a flat portion under the trestle, it would be an arched configuration, supported by columns standing within the pit; the roof would extend just to the walls at the edge of the pit. In the interest of odor control, the structure would be fitted with duct work so that the combustion air for the refuse-fired furnace could be drawn from the pit.

Because of its lower volumetric heat-release rate, the boiler itself would be much larger than the units now fired at Canal Road, such that the existing foundation site would not be adequate. As shown in Figure 19 the boiler would therefore be laid out so as to project out toward the refuse pit. This would require the removal of a portion of the boiler house wall, and the erection of a new ell on the building to house the new boiler. The charging hopper of the boiler would be sealed off from the rest of the building so that refuse odors would not permeate into the plant. The boiler design features would be essentially the same as those described for the over-the-fence plant, except that stoking would be by conveyor and ram injector.



CANAL ROAD STEAM PLANT

Figure 18



PROPOSED MODIFICATION OF CANAL ROAD PLANT

Figure 19

Preliminary costs for this system were derived and are presented in Table 18. It can be seen that both capital and annual costs are lower than for the over-the-fence plant. This is because the operating labor costs will be somewhat lower by having the plant on site and because less land will have to be purchased. In this costing, bulldozer equipment sufficient to support two operators per shift have been included even though such equipment is now being operated.

d. Air Pollution Control (APC) Equipment

In either of the possible plant layouts, the APC system would be the same. A single electrostatic precipitator having a dust removal efficiency of 99% would be used. The system would be sized to handle a gas throughput of 76,600 ACFM based on an inlet temperature of 500° F. Because only refuse (sulfur content ~0.1%S) would normally be fired in the furnace, provision for SO_2 removal is not considered necessary. Using the same emission factors assumed for the Philadelphia study (Section II, E, 2), it can be estimated that the present unit would emit about 96 lb/day fly ash. This corresponds to a stack gas loading of 0.011 gr/SCF. The SO_2 output would be about 800 lb/day; this corresponds to a stack gas concentration of 0.008 Vol.-%.

3. Refuse-Fired Turbo-electric Plant

a. Size Specification

Whichever version of the steam plant discussed in the previous sections were built, it would be capable of handling only slightly more than 1/4 of the total refuse projected to be collected in Cleveland in 1980. Disposal of an additional 975 tpd will probably be necessary. This quantity is about right for a 200 MW Case (936 tpd) system, deriving 16.6% of its heat input from refuse. Adding this much power capacity to the existing CEI inventory does not appear to pose any problem, considering the growing power demand in Cleveland. The Case 3 design, as discussed in Reference 1, is considered to be optimum for this power rating among the many conventional and advanced (e.g., suspension firing) designs analyzed for cost effectiveness.

A question concerning plant sizing was whether to provide additional capacity to accommodate refuse production growth beyond 1980. This was not done in the present case, because the possibility also exists in Cleveland for the erection of a third refuse-fired plant sized for the production of 2 to 3 x 10^5 lb/hr of process (steel mill) steam.

TABLE 18

ESTIMATED COSTS FOR REFUSE-FIRED STEAM BOILER INSTALLED ON-SITE AT CANAL ROAD PLANT

CAPITAL COSTS

FPC Codes	Description	Cost, 10^6 \$
310	Land and Land Rights (5.5 acres)	0.471
311	Structures and Improvements	0.400
312	Boiler Plant Equipment	2.311
315	Accessory Electrical Equipment	0.202
316	Misc. Power Plant Equipment	0.050
	Air Pollution Control Equipment	0.189
	Waste Handling Equipment	1.022
	Engineering and Inspection	0.660
	Total Capital Cost	5.331

ANNUAL COSTS

Annual Capital Cost, 10^6 \$ (Effective Annualization Rate = 14.6%)	0.778
Water Cost, 10^6 \$	0.038
Operating Labor, 10^6 \$	0.416
Maintenance, 10^6 \$	0.133
Residue Disposal, 10^6 \$	0.090
Total Annual Costs, 10^6 \$	1.455

	A	B
Annual Credit, 10^6 \$	0.552	0.519
Quantity of Waste Burned, 10^3 ton/yr	117	117
Disposal Cost, \$/ton	7.72	8.00

A. Based on revenues for steam generated.

B. Based on coal, labor, and maintenance costs for operating existing steam generator of equivalent capacity.

b. Site Selection

Studies of possible sites for the plant revealed that the plant would probably have to be located on the shores of Lake Erie. The Cuyahoga River is too contaminated to be considered even as a source cooling water. Along the lake front, however, relatively few sites, which are within reasonable reach of the waste collection system, appear to be available. The best approach would therefore be to install the new boiler at the existing Lake Shore Plant. This already accommodates five units, but has provisions, including an empty turbine room, for expanded capacity. Installation of a Case 3 system could be accomplished by locating the fossil fuel steam generator on the "future-site" provided and locating the refuse-fired economizer on adjacent property. The general plant lay-out is shown in Figure 20.

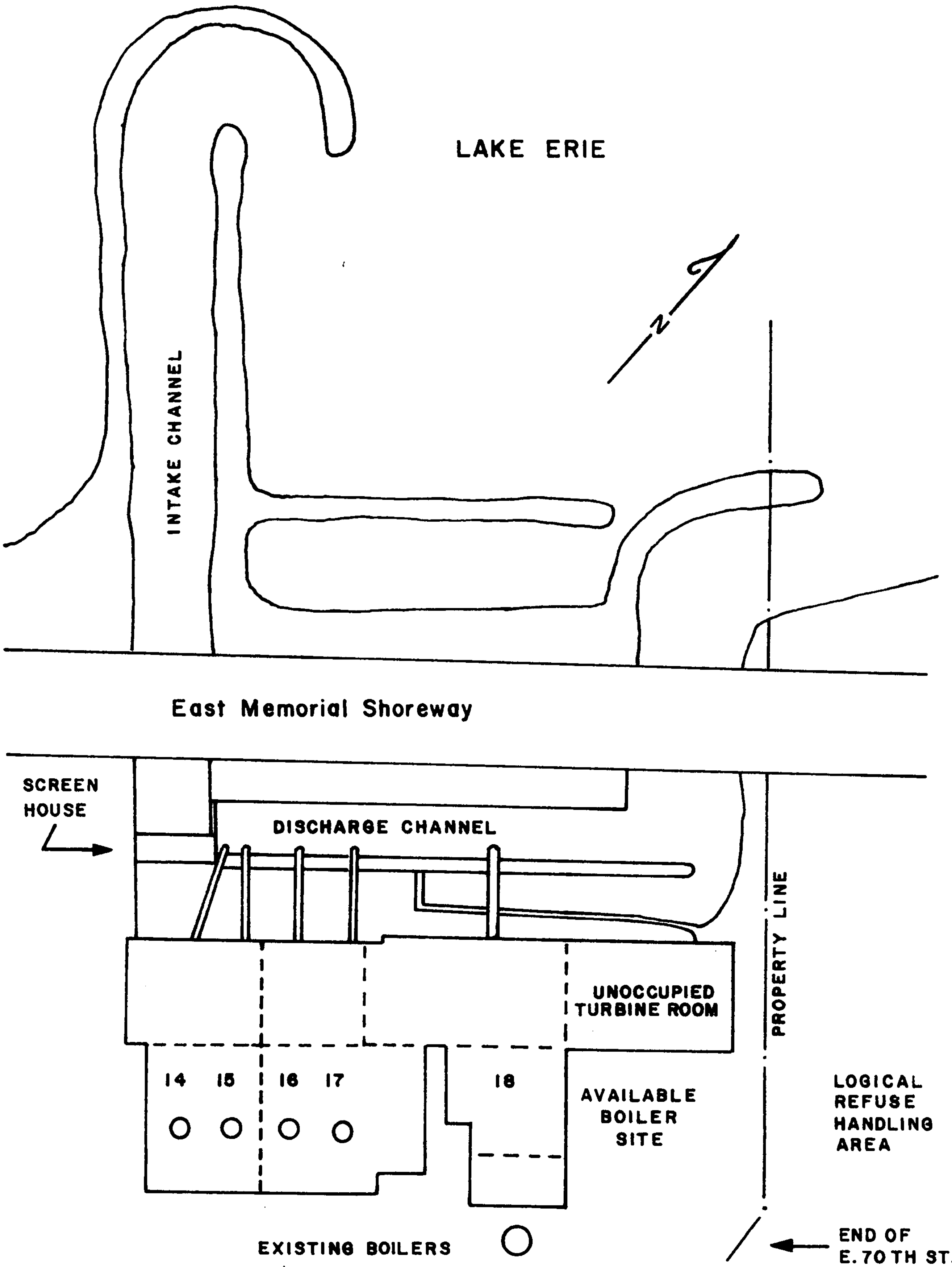
c. System Characteristics

A 200 MW version would be comprised of one coal-fired steam generator and one refuse-fired economizer. The tipping pit would be 150 ft long, 40 ft wide, and 60 ft deep. Two cranes mounted on 60 ft bridges and equipped with 5 cu yd grapples would be provided. One crane would be used for standby service except during the day shift on week days, when it would be manned and used to mix and arrange the pit contents.

The general design and operational characteristics of the system would be very similar to those described in Section II E, 3, a. Specific descriptive information on the present system is itemized in Table 19.

Because of its more accessible location, the Lake Shore system would be assigned the task of shredding and firing oversized refuse. A single 700 h. p. hammermill could reduce such items at a rate of at least 30 tph. The city's entire output of such refuse is only about 50 tpd at the present time and would probably increase to only 75 tpd by 1980. Thus the mill would only be used a few days each week.

A special design requirement for this proposed plant would be low stack height. The present Lake Shore site is situated in an aircraft lane and CEI has already been requested to shorten the boiler stacks already erected on the property. There is, in fact, a possibility that the site may be condemned for the above reason.



LAKE SHORE PLANT LAYOUT

Figure 20

TABLE 19

CHARACTERISTICS OF 200 MW, COMBINATION-FIRED SYSTEM FOR THE LAKE SHORE PLANT

Item	Economizer	Steam Generator
Fuel Rate, tpd	936 (Refuse)	1,752 (Coal)
Excess Air, %	50	18
Flue Gas Exit Temperature, °F	575	300
Flue Gas Volume, ACFM	195,000	570,000
Unit Efficiency, %	67.3	87.0
Design Fuel Value, Btu/lb	4,750	12,022
Duty, 10^9 Btu/hr	0.249	1.527
Feedwater Temperature, °F	440	620 (1960 psig
Steam Conditions, psig/°F/°F	-	1800/1000/1000
Steam Flow, 10^6 lb/hr	-	1.430
Number of Turbines	-	1
Plant Factor, %	80	80

The addition of a combination-fired system would not, however, complicate the stack hazard problem. Being equipped with high efficiency gas cleaning systems, there would be no need to rely on high stacks to disperse pollutants. The wet scrubber system on the coal-fired steam generator would be sized to handle the 570,000 ACFM of flue gas calculated for this boiler based on an exit flue gas temperature of 300° F. The wet scrubber would remove both fly ash and SO_x. The latter removal would be accomplished by liming the scrubber liquor in accordance with the Mitsubishi process. Gypsum recovery would not be attempted, however. The separated calcium sulfate would instead be discarded. Because of the inclusion of this system, use of a low sulfur coal would be unnecessary.

The refuse-fired economizer would be equipped with an electrostatic precipitator having a dust-removal efficiency of 99%. It would be sized to handle a gas throughput of 195,000 ACFM based on an inlet gas temperature of 575° F. Following the gas cleaning stages, the exit gases from the two furnaces would be blended and discharged through a common stack. Because of the comparatively high temperature of the economizer flue gas, it would be unnecessary to reheat the flue gas exiting the wet scrubber of the steam generator.

Using the same emission factors observed for the Philadelphia analysis (Section II, E, 3), the following emission estimates can be tabulated:

ESTIMATED STACK EMISSIONS OF 200 MW
CASE 3 POWER SYSTEM

	Fly Ash		SO_2	
Source	lb/day	gr/SCF	lb/day	Vol-%
Steam Generator	3154	0.039	18,922	0.020
Economizer	224	0.012	1,872	0.008
Combined Stack	3378	0.033	20,794	0.017

Costs for this system have been derived as shown in Table 20 and in accordance with the procedures described earlier in this report. In computing the annual credit for power generated, a parallel costing was performed for a conventionally-fired, 200 MW unit to determine annual costs and, thus, production costs for electricity, based on today's capital and operating expenses. Unlike Philadelphia, considerable amounts of coal are being fired in Cleveland such that fuel costs are more stable. Because of this, a fixed fuel cost of $\$0.31/10^6$ Btu could be used in the calculations. It can be seen from the cost data that the disposal cost for refuse, exclusive of transportation, is considerably more attractive than those derived for the district heating plant.

TABLE 20

ESTIMATED COSTS FOR REFUSE-FIRED, TURBO-ELECTRIC SYSTEM INSTALLED AT THE LAKESHORE STATION

CAPITAL COSTS

FPC Codes	Description	Cost, 10^6 $
310	Land and Land Rights	1.040
311	Structures and Improvements	3.343
312	Boiler Plant Equipment	23.663
314	Turbine-Generator Equipment	10.582
315	Accessory Electrical Equipment	1.682
316	Misc. Power Plant Equipment	0.384
	Air Pollution Control Equipment	2.550
	Waste Handling Equipment	1.362
	Engineering and Inspection	2.268
	Total Capital Cost	46.874

ANNUAL COSTS

	Annual Capital Cost, 10^6 $ (Effective Annualization Rate = 14.6%)	6.844
	Operating Labor, 10^6 $	0.551
	Maintenance, 10^6 $	1.107
	Coal Cost, 10^6 $	3.813
	Residue Disposal, 10^6 $	0.249
	Total Annual Costs, 10^6 $	12.564
	Annual Credit for Power Generated, 10^6 $	11.849
	Quantity of Waste Burned, 10^3 ton/yr	273
	Disposal Cost, $/ton	2.62

4. Transportation Costs

a. Overview

An important cost element in disposing of refuse is that associated with the movement of packer trucks, once they are loaded, from their collection routes to the disposal site. If this cost increases in shifting from present disposal methods to the steam generator approach, appropriate operating adjustments will be required. Either the rolling stock and the number of collection routes must be increased or transfer stations will have to be incorporated within the system.

In performing the cost analysis, a number of assumptions were necessarily made. These are discussed in the following sections.

b. Tonnage Hauled

It was assumed that the amount of collected refuse generated daily would be that projected for 1980 (1375 tpd). It was further assumed that the relative distribution of this production among the five collection districts would be the same as that recorded for the year 1969. The values thus derived are shown in the following table.

CLEVELAND REFUSE PRODUCTION
PROJECTED FOR 1980 BY DISTRICTS

Collection District	Collected Refuse Generation Rate, tpd	Percentage of Total
1. West Side	439	31.9
2. 24th and Rockwell	161	11.7
3. West 3rd	231	16.8
4. Harvard	286	20.8
5. Glenville	258	18.8
Total	1375	100.0

It was also assumed that the refuse production densitites within each district would be uniform.

c. Disposal Sites

In attempting to compare transportation costs of the present methods of disposal with those associated with steam plant operation, the disposal sites must be identified. This is difficult to do in that the landfill areas now in use will doubtless be exhausted before the end of the decade and other sites, probably more distant from the collection system, will have been put into operation. Because the location of future landfill sites is unknown at the present time, it was necessary to assume that the Rockside landfill would still be in use in 1980. Thus the transportation costs derived for landfill disposal are probably low.

The other disposal sites were assumed to be the Ridge Road Incinerator, and refuse-firing boilers at the Canal Road steam plant and the Lakeshore power station. The areas assumed to be served by these facilities are itemized in Table 21.

d. Travel Distance Derivations

Weight-distance vectors were derived as explained in Section II, E, 2, d.

e. Results

Using a base cost of $0.20/ton-mile, it was found that haulage to the existing disposal sites would average out at $2.58/ton. The information used to derive this value is shown in Table 22. The cost would be somewhat lower if current refuse production quantities were used, since then the fraction of the total refuse handled at the more centralized Ridge Road incinerator would arithmetically increase. Regardless of which base year is observed, however, the cost would be high enough to warrant serious consideration of the use of transfer stations, as is now being done.

Costs were similarly derived for transporting refuse to the proposed steam generators. The data are summarized in Table 23. The cost of $2.17/ton is significantly lower than that associated with haulage to the existing system ($2.58/ton) and would become even more favorable as new, more distant landfill sites are brought into operation.

By way of breakdown, transportation cost to the proposed Canal Road plant would be $2.80/ton, while that to the Lakeshore Station would be only $1.91/ton. This would suggest that transfer stations also be considered in connection with the operation of the refuse-fired boiler at Canal Road. Referring to Figure 12, the most westerly plus one of the two other transfer station sites proposed for District 1 would appear to be suitable.

TABLE 21

REFUSE INPUT AREAS ASSUMED FOR TRANSPORTATION COST ANALYSIS

Disposal Site	Area Served	Refuse Input, tpd
Present Disposal Methods:		
Ridge Road Incinerator	District 1 east of West 117th Street	350
Rockside Landfill	District 1 west of West 117th Street, plus all other districts	1025
Disposal in Steam Generators:		
Canal Road Plant	District 1 and District 2 south of Denison Avenue	400
Lakeshore Plant	District 2 north of Denison Avenue plus Districts 3, 4 and 5	975*

*This is slightly higher than the actual capacity (936 tpd) of the plant. This was done to permit direct transportation cost comparisons of the two disposal methods. This adjustment does not bias the results.

TABLE 22

REFUSE TRANSPORTATION COST FACTORS FOR EXISTING CLEVELAND DISPOSAL SITES

Site	Avg. Direct Haul Distance, Mi.	Refuse Transported, tpd	Average Round trip mileage*	Ton-miles
Ridge Avenue Incinerator:				
District 1, east of West 117th Street	1.3	350	3.3	1,138
Rockside Landfill:				
District 1, west of West 117th Street	9.0	89	22.5	2,003
District 2	5.8	161	14.5	2,335
District 3	5.1	231	12.8	2,957
District 4	4.8	286	12.0	3,432
District 5	9.1	258	22.8	5,882
Total		1,375		17,747

$$\text{Transportation cost} = \frac{\$0.20 \times 17,747}{1,375} = \$2.58/\text{ton}$$

*Includes 25% increase for indirect travel patterns.

TABLE 23

REFUSE TRANSPORTATION COST FACTORS FOR PROPOSED STEAM GENERATORS

Site	Avg. Direct Haul Distance, Mi.	Refuse Transported, tpd	Average Round trip mileage*	Ton-miles
Canal Road Plant:				
District 1 and District 2 south of Denison Avenue	5.6	400	14.0	5,600
Lakeshore Plant:				
District 2, north of Denison Avenue	4.5	200	11.3	2,260
District 3	4.2	231	10.5	2,426
District 4	5.2	286	13.0	3,718
District 5, SW of 140th Street	1.2	173	3.0	519
District 5, NE of 140th Street	1.9	85	4.8	408
Total		1,375		14,931

$$\text{Transportation cost} = \frac{\$0.20 \times 14,931}{1,375} = \$2.17/\text{ton}$$

*Includes 25% increase for indirect travel patterns.

5. Conclusions Regarding the Cleveland Study

At the present time, the City of Cleveland is considering proposals for the operation of new landfill sites under arrangements with private contractors. The new approach will include the use of transfer stations to reduce transportation costs. Including an estimated cost of $0.50/ton for hauling to the transfer stations, it appears likely from recent bidding that net disposal costs will increase to about $7.00/ton.

In comparison, the below summarized costs for disposal with energy recovery in refuse-fired boilers can be considered.

ESTIMATED COSTS FOR CLEVELAND'S WASTE-FIRED STEAM GENERATING SYSTEMS

	District Heating Plant (On-Site Version)		Turbo-electric Facility
Total Capital Cost, 10^6 $	5.331		46.874
Total Annual Cost, 10^6 $	1.455		12.564
	A	B	
Annual Credit, 10^6 $	0.552	0.519	11.849
Refuse Disposal Cost, $/ton	7.72	8.00	2.62
Transportation Cost, $/ton	2.80	2.80	1.88
Total Net Disposal Cost, $/ton	10.52	10.80	4.50

A Based on revenues for steam generated.

B Based on displaced coal, labor, and maintenance costs for operating existing, conventional steam generator of equivalent capacity.

It is clear that operation of the combustion-fired power plant would provide considerable cost savings to the City of Cleveland. This is not immediately true in the case of the district heating plant. Assuming that the proposed steam plant were operated in connection with transfer stations, total net disposal costs would still be higher (about $9.75 and $10.00 per ton by costing methods A and B, respectively) than for landfilling. This comparison, however, is based on today's fossil fuel and disposal costs.

As both of these increase, the cost-effectiveness of the proposed heating plant will rapidly change. In terms of fuel cost variations, for example, this sensitivity was demonstrated in Figure 11. Another factor that would serve to reduce disposal costs would be an increase in steam sales. This would put the plant on a more attractive (Method A) costing basis and the required increase in the refuse rate would result in a more cost-effective system design.

An alternate plan that can be considered is to construct two smaller turbo-electric stations. From the cost model developed on the earlier program, this arrangement can be shown to be non-optimum and to result in very high disposal costs. It has been concluded, therefore, that the system recommended is the proper approach. To trade off nicely the factors that influence an area case study of this type, it is virtually impossible to realize a perfect balance of system cost benefits in the face of local constraints.

ACKNOWLEDGEMENTS

The present program was conducted under the technical guidance of EPA's Robert C. Lorentz, who also served as project officer on the previous program. The insight and understanding he provided on both programs have been much appreciated. The authors also wish to acknowledge the inputs and guidance supplied by their department head, Mr. E. M. Wilson.

Accomplishment of the work described in the present report obviously required a considerable amount of assistance and cooperation by city and utility officials in the two municipalities studied. What is noteworthy is that this support was given in such a friendly and open manner.

The authors particularly extend their thanks to Mr. Elwood A. Clymer of Philadelphia Electric Co. and Mr. Howard Mayerhofer of Cleveland Electric Illuminating Co. These men not only provided much of the needed working data and their review talents, but generally smoothed the way. Acknowledgement should also be made of the following other officials who lent their support, in one form or another, to the present study.

Individual	Title
City of Philadelphia	
David Damiano*	Chief Sanitation Engineer Department of Streets-Sanitation
Leo Goldstein	Commissioner Department of Streets
Glenn Smith	Chief Sanitation Engineer Department of Streets-Sanitation
Philadelphia Electric Co.	
Vincent S. Boyer	Vice President Engineering and Research
John S. Kemper	Manager Engineering and Research Division
Edward C. Kistner	Chief Mechanical Engineer

*Now with New York City.

Individual	Title
Charles W. McQuiston	Sales Engineer, Government Sales Division
Frederick A. Pyecroft	Manager Government Sales Division
City of Cleveland	
Robert Beasley	Commissioner Division of Waste Collection and Disposal
O. N. Bergman, Jr.	Commissioner Division of Light and Power
Cleveland Electric Illuminating Co.	
R. G. Schuerger	Manager Civil and Mechanical Engineering
John A. Bostic	General Supervising Engineer

REFERENCES

1. Roberts, R. M., et al, "Systems Evaluation of Refuse as a Low Sulfur Fuel," Envirogenics Co. Final Report No. F-1295 for EPA Contract CPA 22-69-22, November 1971.

2. Federal Power Commission Staff Report, Air Pollution and the Regulated Electric Power and Natural Gas Industries, September 1968.

3. Solid Waste Management, Department of Public Service Report to City Council of Cleveland, 10 June 1968.

4. Beasley, R., Functions and Activities, Department of Public Service, Division of Waste Collection and Disposal, City of Cleveland Internal Report, December 1, 1968.

5. Kaiser, E. R., "The Incineration of Bulky Refuse," Proc. 1966 Nat. Incin. Conf., New York, 1-4 May 1966, pp 39-48.

6. Governmental Facts, No. 125, Governmental Research Institute Cleveland, Ohio, 8 August 1967.

APPENDIX A

COSTS OF OPERATING PLANTS OF OVERSIZED REFUSE CAPACITY

I. INTRODUCTION

The sizing of refuse-fired steam generators should logically conform to the collection rates of the area served. During the life expectancy of the boiler, which should be at least 20 years, both the quantity and fuel value of refuse will increase. An enhancement in heating value would likely necessitate a cut-back in the refuse firing rate of waste fueled plants. The net effect would be that alternate methods of disposal would have to be sought for the refuse in excess of plant capacity. A possible solution to this problem would be to construct plants that are of greater capacities than the refuse available. As the design refuse rate approached fulfillment, lead time would thus be provided for planning new starts on additional units. An obvious drawback to operating oversized plants would be the higher initial capital outlay and, in all probability, a substantial increase in disposal costs over those that would be realized when firing at rated capacity. The purpose of the analysis described in this appendix was to examine the effect of oversizing on disposal costs and to compare two different approaches for operating oversized plants.

II. COST ANALYSIS

A. SYSTEM OPTIONS

The cost analysis was performed for system conditions that were initially expected to have applicability for the Philadelphia case study. This did not prove to be the case. Thus the systems subjected to the cost modeling described here are somewhat different from those detailed in the main part of the report. The general conclusions reached, however, are qualitatively valid regardless of which system conditions are actually observed.

For the purpose of the present analysis, a 500 MW Case 3 plant firing 5500 Btu refuse was analyzed. Two modalities of under-capacity operation were considered. These are referred to here as the expandable plant and the fixed design plant.

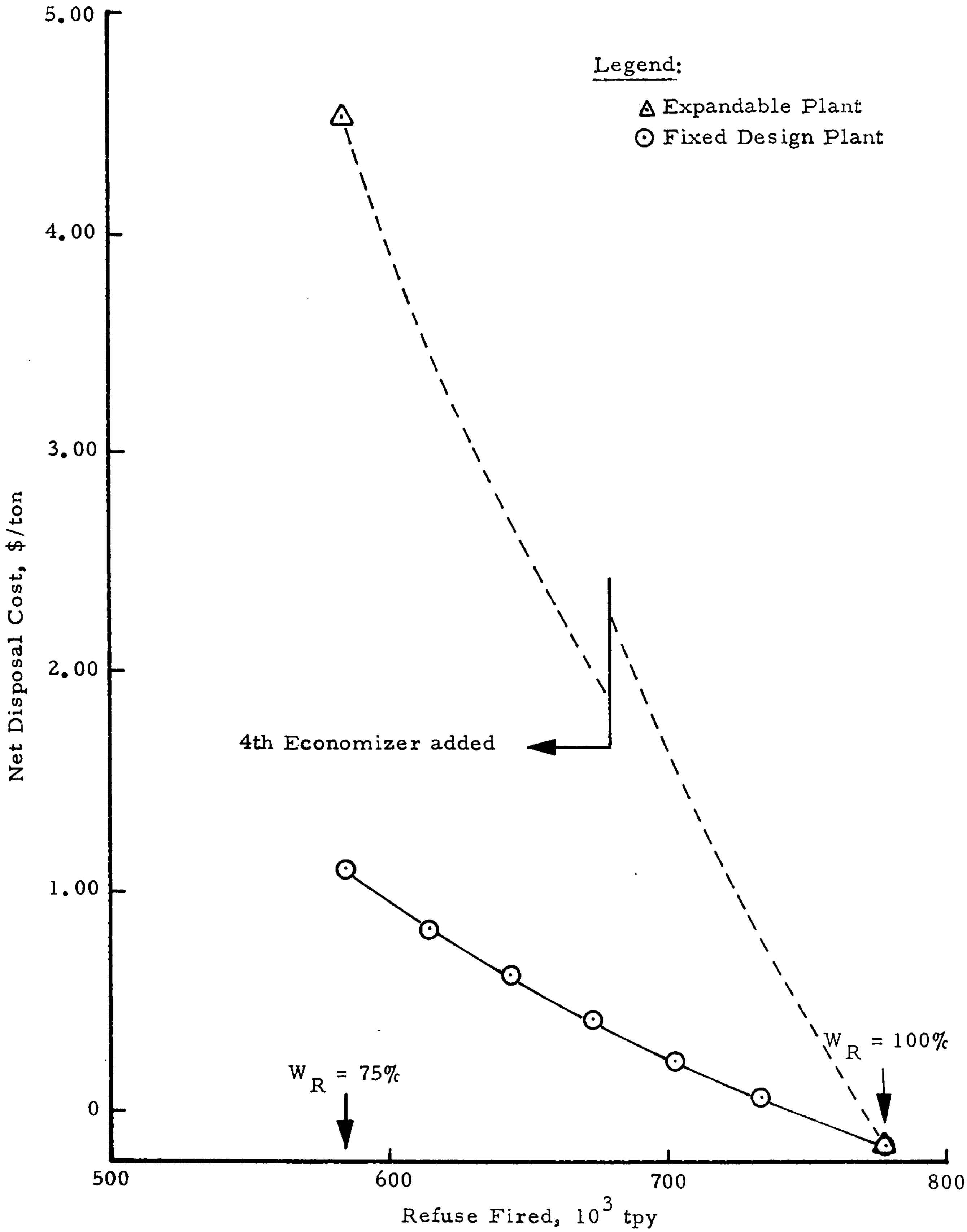
The expandable plant would be a full-sized, Case 3 system in all respects except that it would be equipped with only three of the four waste-fueled economizers specified on the initial program. It would thus operate at something less than the 75% refuse rate. The shortage of energy input would be compensated for by reducing the fossil fuel input to the steam generator. The turndown of the steam generator would not necessarily have to be directly proportional to the shortage of refuse energy input. There would be very definite limits, however, as to the flow of extra steam that could be achieved by firing higher than proportional quantities of fossil fuel in the steam generator. For the present analysis, therefore, it was assumed that the fuel rates would be at a fixed ratio regardless of the plant duty. This would mean that when the three economizers achieve full refuse input rates the plant capacity would be at 75% of nameplate rating, or 375 MW. Beyond this point a fourth economizer could then be installed when convenient and the steam generator turn-down slowly decreased until the design refuse rate and full plant capacity of 500 MW is attained.

The alternative approach is the fixed design plant. This would be essentially identical to the design described on the initial program and, thus, to the system discussed above, after it had been expanded. The notable difference in the operation of the two plants would be in the fueling of the economizers. In the fixed design plant, the fossil fuel burners normally used in the economizers for trimming and start-up purposes would be continuously fired. Their function of course would be to make up for the refuse energy shortage. Thus the plant would operate at full nameplate rating regardless of the quantities of refuse that are available for the plant.

B. COST ANALYSIS RESULTS

The two systems described were analyzed using the previously developed cost model. The range of the analysis was from 75% to 100% of refuse rate (W_R). The results are shown in Figure A-1. Because of the comparatively poor cost effectiveness of the expandable plant approach, only a single data point was derived. The connecting dashed line is therefore only illustrative, as is the cost jump shown (at an arbitrary point) when the plant is expanded by adding a fourth economizer.

It is obvious from Figure A-1 that the use of make-up fossil fuel is the preferred approach to take if a plant is to be operated at less than full refuse rate. It is also interesting to note that, in this mode of operation, disposal costs are not increased to unacceptable levels under conditions of substantial fossil fuel substitutions. It should be borne in mind, however, that system conditions used for the modeling were those stipulated on the original program. Thus the fuel cost of $0.31/$10^6$ Btu observed may be seriously inappropriate in terms of the more recent fuel cost trends. At higher fuel costs, the analytical results would have proved less favorable toward the fixed design plant.



DISPOSAL COSTS FOR PLANTS OPERATING AT LESS THAN FULL REFUSE INPUT RATING

Figure A-1