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SOLID WASTE AS AN ENERGY SOURCE FOR THE NORTHEAST

P.M. Meier and T.H. McCoy

June 1976

POLICY ANALYSIS DIVISION
NATIONAL CENTER FOR ANALYSIS OF ENERGY SYSTEMS
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

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FOREWORD

This report is one of a number of issue papers prepared as part of the Brookhaven National Laboratory Northeast Energy Perspectives Study. The analyses in these papers were performed specifically to assist us in our first integrated study of the energy future of the northeastern United States.

Topics covered by the issue papers include the potential supply of energy to the Northeast from coal, oil, natural gas, liquefied natural gas (LNG), nuclear power, municipal waste, solar energy, and wind power, and the demand for energy in the Northeast from the industrial, transportation, and residential and commercial sectors. In each case a range of estimates of energy supply or demand was constructed to reflect not only a variety of possible policy and technological developments, but also the basic uncertainties of all such future projections. The integrative analysis which relates the supply and demand picture is presented in "A Perspective on the Energy Future of the Northeast United States."

The issue papers prepared for the Northeast Energy Perspectives Study and the summary report will be available from:

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The issue papers and summary report are listed below.

- H. Bronheim, "Future Oil Supply to the Northeast United States," BNL 50557 (June 1976).
- R. J. Goettle, IV, "Alternative Patterns of Industrial Energy Consumption in the Northeast," BNL 50555 (March 1976).
- R. N. Langlois, "Future Natural Gas Supply to the Northeast," BNL 50558 (April 1976).
- J. Lee, "Future Residential and Commercial Energy Demand in the Northeast," BNL 50552 (March 1976).
- P. M. Meier and T. H. McCoy, "Solid Waste as an Energy Source for the Northeast," BNL 50559 (June 1976).
- P. M. Meier, T. H. McCoy, and S. Rahman, "Issues in the Future Supply of Electricity to the Northeast," BNL 50553 (June 1976).
- B. S. Edelston and E. S. Rubin, "Current and Future Use of Coal in the Northeast," BNL 50560 (May 1976), Environmental Studies Institute, Carnegie-Mellon University, Pittsburgh, Penn.
- V. L. Sailor and F. J. Shore, "The Future of Nuclear Power in the Northeast," BNL 50551 (March 1976).
- G. R. Bray, S. K. Julin and J. A. Simmons, "Supply of Liquefied Natural Gas to the Northeast," BNL 50556 (April 1976), Science Applications, Inc., 1651 Old Meadow Road, McLean, Va.
- System Design Concepts, Inc., "Transportation Energy Consumption and Conservation Policy Options in the Northeast," BNL 50554 (April 1976), System Design Concepts, Inc., 9 Rector Street, New York, N.Y. 10006.
- J. Brainard et al., Editors, "A Perspective on the Energy Future of the Northeast United States," BNL 50550 (June 1976).

ABSTRACT

This report, one of a series prepared for the BNL study of the Energy Future of the Northeastern United States, presents an assessment of the potential contribution of energy recovery from municipal refuse to energy supply in the region. A brief review of the present and likely future quantity and composition of municipal refuse and the technologies available for energy recovery (Chapters II and III) is followed by a comparison of the potential contributions to energy supply of the various recovery options including direct firing in utility boilers, pyrolysis to oil or gas, and steam generation for industrial process heat or district space heating (Chapter IV). The relationship of refuse energy recovery to market conditions for alternative energy sources is considered in Chapter V, which also includes an analysis of the impact of haul costs, interest rates, and delivered prices of the major fuels. Institutional barriers to implementation of energy recovery are reviewed in Chapter VI, and the environmental implications of the concept are addressed in Chapter VII. In the concluding chapters scenarios of energy recovery are developed for 1985 and 2000, and the sensitivity of overall energy yield to projections and assumptions is examined.

Although even under the most optimistic assumptions, refuse energy recovery is found to contribute only some 5% of total regional consumption, the economic and environmental benefits, coupled with the increasing difficulty of finding other refuse disposal alternatives, make energy recovery a very attractive policy choice for helping to relieve future energy supply difficulties in the Northeast.

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CHAPTER I

INTRODUCTION

The problems of solid waste management have become increasingly severe over the past decade, but especially so in the densely populated metropolitan areas of the country, where the increasing difficulty of finding landfill sites, the restriction of incineration by implementation of air quality standards and the ever growing militance of sanitation labor unions have combined to make solid waste management not only more and more expensive, but, in many cases, an almost intractable political issue. In rural areas the situation is little better, as the cost of turning the traditional town dumps into properly operated sanitary landfills appears to face increasing resistance from property tax payers long accustomed to what is perceived as "free" solid waste disposal.

Under these conditions one might expect the climate for resource recovery to be rather favorable. Yet the Nation's experience with resource recovery from solid waste has, until only very recently, been uniformly disappointing. Chemical fertilizer has been so cheap in the U.S. that a substantial commercial market for compost, which determines the feasibility of composting plants, has simply not materialized.¹ Efforts at incineration of solid waste in waterwall boilers to recover the energy in the form of steam have similarly proven unsuccessful;² in part because of the lack of market for the resulting steam (due, historically, of course, to the very cheap cost of alternative energy supplies for both domestic heating and industrial process heat) and in part because of the difficulty of efficient combustion of refuse (which has also resulted in the failure of most

municipal refuse incinerators, especially with the imposition of air quality standards that almost double costs³).

Efforts at recovery of materials from municipal refuse have suffered a similar fate. Until very recently, separation of the components of mixed refuse was performed by hand, an increasingly costly and inefficient operation. But even with the development of sophisticated separation technology, exemplified by the development of air classification separation of the combustible fraction of refuse from the heavier, noncombustible fraction, resource recovery has been market limited.⁴ For a variety of reasons, the use of recovered materials from solid waste has been either uneconomic,⁵ or prohibited outright on grounds of public health;⁶ and thus resource recovery has proved successful only under special market circumstances. The most successful such operation is the fiber reclamation plant at Franklin, Ohio; but the recovered product is a rather low-grade fiber used in a nearby roofing felt plant.⁷

In the late 1960's the idea of using refuse as a supplementary fuel in utility boilers began to surface, and the results of an early demonstration project in St. Louis appeared very encouraging.⁸ The burning of refuse in highly efficient utility boilers bypasses the intractable problems of municipal incinerators, provides fuel savings for the utilities, and solves problems of marketing and distribution of the recovered energy.

Until the advent of the 1973 oil embargo, however, even this most promising resource recovery option was not pursued with any enthusiasm. The main issue appeared to be the apportionment of the savings; the utilities were prone to argue that since they were taking over the function of solid waste disposal, and thereby saving the municipality \$5 to \$20 per ton in disposal cost, they

should at least be given the solid waste free of charge, if not paid a disposal fee. The municipalities argued that they were in fact selling a fuel, and should be paid for it on the basis of Btu equivalent, just as utilities pay coal suppliers for that fuel. From the utilities viewpoint, there was the additional problem of making modifications to the generating facility, including the provision of storage and size reduction facilities, as well as the modification of the boilers and burners themselves.

Since the advent of the oil embargo, however, the significant increases in energy costs to the utilities have changed the situation somewhat. Since coal prices have climbed sharply, the value of refuse has risen also; and equitable compromises are perhaps easier to find. The recovery of metals from refuse, particularly aluminum, has also become more worthwhile.⁹ Over the past three years, many Northeastern states have now moved forward with statewide solid waste management plans focused on energy and resource recovery.¹⁰ Moreover, many utilities and municipalities are currently pursuing with renewed vigor the possibility of burning refuse in boilers, and within the next decade this concept will doubtless be implemented as a permanent feature of solid waste management and energy supply.

This report, then, presents an analysis of the potential contribution of solid waste as an energy source in the Northeastern United States. Discussion of the recovery of materials from solid waste is limited to an analysis of the trade-offs between material and energy recovery, although the importance of metals recovery is recognized in view of the current world political climate and the high probability that suppliers of commodities, and especially suppliers of metal ores, will succeed in organizing cartels similar to OPEC.¹¹ It will be seen, however, that recovery of

metals from refuse is little affected by energy recovery.

Besides the option of burning municipal refuse in utility boilers, we shall also consider the other important energy recovery options, which, although not currently regarded as proven concepts, appear to be on the verge of commercial feasibility (Figure 1). Thus, we shall also assess pyrolysis of refuse to yield either gas or a mix of liquid hydrocarbons; bioconversion by anaerobic microbial decomposition of the organic fraction to yield methane;¹² and combustion for steam generation using newly developed European technology. Low Btu gas hydrogasification and Brayton cycle power generation are also briefly reviewed.¹³

Figure 1. Options for energy recovery from solid waste.

NOTES TO CHAPTER I

1. Currently only two plants, one in Altoona, Pa., and the other in Brooklyn, N.Y., are known to be operating in the U.S. on a regular basis. The most celebrated failure is the plant built in Johnson City, Tenn., by the U.S. Public Health Service and TVA, which began operation in 1967 as a demonstration of the potential for composting. Apart from operational problems, the lack of a nearby market for the plant product led to the inevitable abandonment of the project. Note, however, that the European experience with composting has been altogether different, and largely successful. High population densities, smaller transportation distances and hence lower transportation costs, and the relatively higher cost of synthetic chemical fertilizer have resulted in a commercially exploitable market for compost.
2. For a review of the United States experience and the major facilities now operating, see e.g. "Resource Recovery: The State of Technology" Report by the Midwest Research Institute to CEQ, February 1973. One might again note that the European experience is again much more successful, and water-wall furnace technology has been developed in Germany and Switzerland. The advantage of waterwall furnaces over the conventional refractory furnaces in use in U.S. incinerators lies in the higher heat transfer efficiency, which results in lower excess air requirements and hence fewer air pollution problems (for further elaboration, see e.g. Drobny N.L. et al. "Recovery and Utilization of Municipal Solid Waste". U.S. Environmental Protection Agency, 1971, Report SW-loc.)
3. For a discussion of the problems of municipal incinerators from an air pollution standpoint, see e.g. A.G. Carotti and R.A. Smith, "Gaseous Emissions from Municipal Incinerators", U.S. Environmental Protection Agency, 1974, Report SW-18c.
4. The most comprehensive survey of the salvage markets for recovered materials from refuse is A. Darney and W.E. Franklin, "Salvage Markets for Materials in Solid Wastes", U.S. Environmental Protection Agency, 1972, Report SW-29c.
5. Interstate freight rates, for example, are lower for virgin than for recycled materials in almost all categories potentially recoverable from solid waste, a situation which significantly affects the economic competitiveness of recycled

products. Together with some institutional distortions, such as the depletion allowances available to mineral producers, this has historically made markets in recovered materials extremely limited.

6. Many public health regulations impose severe restrictions on fiber recycling; paperboard for food cartons, for example, especially for milk and other liquid foods, must be made of virgin fiber or clean scrap from the manufacturing process.
7. For a description and evaluation of this facility, see, e.g. N.T. Neff, "Solid Waste and Fiber Recovery Demonstration Plant for the City of Franklin, Ohio: An Interim Report", U.S. Environmental Protection Agency, Report SW-45d, 1972 (Published by NTIS, PB 213 646).
8. See e.g. Horner and Shifrin, Inc., "Solid Waste as a Fuel for Power Plants", Report to EPA, 1973 (Published by NTIS, PB 220 316).
9. Aluminum is one of the few metals for which the economics have traditionally favored secondary rather than primary sources. The production of primary aluminum requires high capital investments (\$700 to \$800 per ton of annual capacity) and large amounts of electric power, (15,000 to 16,000 kwh per ton of aluminum). Consequently, such smelters tend to be located near sources of low cost electricity; but these are usually remote from industrial centers, and, therefore, primary aluminum producers have high freight costs, (\$5 to \$30 per ton). Primary aluminum production costs, including freight to fabricators, range from \$306 to \$470 per ton. In contrast, secondary smelters can install capacity for \$100-\$120 per ton and can be located near scrap sources that are nearer the points of consumption, which in turn means lower freight costs. Operating costs are also cheaper because the major operation is scrap melting rather than electrolytic reduction of aluminum ores to aluminum. Secondary smelter total production costs range from \$375 to \$450 per ton. With the recent rises in electrical energy costs, and the higher world market price for bauxite, the advantage of secondary aluminum is becoming even greater. For further discussion, see Darnay and Franklin, note 4, supra, Chapter VI.
10. See e.g., "A Systems Evaluation of Alternate Statewide Resource Recovery Techniques for the disposal of Municipal Solid Waste", Report by A.D. Little to the Massachusetts Department of Public Works, December 1973 or "State of Vermont Agency of Environmental Conservation Agency - Solid Waste Mangement and

Resource Recovery Plan", January 1973 (Published by NTIS, PB 235 219).

11. See e.g., B. Varon and K. Takeuchi, "Developing Countries and Non-fuel Minerals", Foreign Affairs, Vol. 52, No. 3, p. 511 (April 1974), who conclude that Bauxite and Phosphate producers face the most favorable conditions for market manipulations by means of producer's cartels.
12. We shall refer to this process by the traditional, and somewhat less cumbersome, "anaerobic digestion".
13. For information on other options still in the conceptual study phase, section 6 of the Bibliography (Appendix G) contains some selected references. Possibilities include acid hydrolysis of cellulose to produce ethyl alcohol, enzymatic conversion to glucose, or conversion to Yeast.

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CHAPTER II

QUANTITIES AND COMPOSITION OF REFUSE

2.1 Quantities of Refuse

Modern society generates numerous categories of waste materials that have a significant content of organic matter, and therefore, offer some potential for energy recovery. The main categories, as noted by Anderson,¹ are animal manure, agricultural crop wastes, urban refuse, logging and wood manufacturing residues, sewage sludge solids, and industrial wastes. Table 1 gives some indication of the relative amounts involved in the United States:

Table 1

ESTIMATES OF ORGANIC WASTES, MILLION TONS PER YEAR

Manure	200
Urban refuse	129
Logging and wood manufacturing residues	55
Agriculture crops and food wastes	390
Industrial wastes	44
Municipal sewage solids	12
Miscellaneous organic wastes	<u>50</u>
Total	880

Source: Anderson, note 1, p. 2

Not all these categories are of interest as energy sources to the Northeast, and the present discussion is restricted to urban refuse and municipal sewage solids. Agricultural wastes and manure are generated primarily in the Midwest, and energy

recovery from agricultural wastes appears to be justified only in such areas of the U.S. where agriculture is organized in relatively large, consolidated units.² Although the recovery of energy on an individual farm basis in the Northeast is not precluded, agricultural wastes appear unsuited as a source of energy for the major energy consuming urban areas in the region. The paucity of information on industrial wastes justifies exclusion of that category from this analysis. However, the logging and wood manufacturing residue category does appear to be of interest to the Northern New England states, and is omitted here only because of the limited information on this subject at the time of writing.³

The organic waste listed under urban refuse in Table 1 is only a small fraction of the total urban refuse generated. The most frequently cited figure for total urban refuse generation is 5.72 pounds per capita per day, a figure derived in the first nationwide survey of solid waste problems in 1968.⁴ However, this total includes street sweepings, demolition and construction wastes, and some industrial wastes; in fact, the 1968 survey figure for residential and commercial refuse alone is 4.35 lb/cap/day. But even this latter figure has been criticized as being far too high.⁵ This 1968 survey relied on municipalities themselves to furnish quantitative estimates, yet in many cases these were speculations rather than measured facts, as historically there was little interest in expenditure for weighing and sampling refuse.

The problem of data in the solid waste field is formidable, and there is no comprehensive national or regional survey of adequate detail and reliability. To be sure, numerous studies and estimates exist for individual towns and cities, but quantitative comparisons are made difficult by the significant variations in reporting guidelines. For an estimate of solid waste generation

to be acceptable, it must include specific information about the following items, among others: the extent of garbage grinding in homes; whether bulky wastes are collected separately and whether they are included in the total; what fraction of commercial refuse is included in the total; and whether, if garbage is collected separately, it is included in the total (frequently it is not because its collection is privately contracted for delivery to piggeries, especially in the Northeast).⁶

Recognizing the inadequacies of the existing solid waste data base, the U.S. Environmental Protection Agency (EPA) commenced in 1973 a systematic, scientific data collection effort for a stratified random sample of Standard Metropolitan Statistical Areas (SMSA), the intent being to create a national data resource on solid waste quantities, composition, collection, and disposal costs.⁷ Unfortunately, this program has had its funding difficulties, and the fruits of the data collection effort are not yet apparent. However, preliminary data for the initial years of the program are available in unpublished EPA reports, and these data would appear to be the most reliable in existence.⁸

Figure 2. Residential refuse generation rates
(From Meier, note 5, p. 29).

Figure 2 shows the 1973 distribution of per capita refuse generation rates in a sample of SMSA's included within this EPA Program; a representative average value might be around 2.25 lb/cap/day.⁹ Unfortunately, the number of Northeastern SMSA's in the EPA sample is insufficient as a basis for a region-wide model, and information on per capita refuse generation was, therefore, assembled from a number of other sources. The regression analysis results shown on Table 2 show the refuse generation equation derived on the basis of the 19 SMSA-wide data sources that could be found; variables such as per capita income and population density were included so that the equation could be used to predict future refuse generation, since future per capita income and population projections are available from the OBERS projections that are the basis for the entire BNL Energy Futures Study.¹⁰ Table 3 shows the results of this model when applied to all SMSA's in the region for 1972, 1985, and 2000, but excluding industrial wastes (i.e. $X_2 = 0$).

Table 2

REGRESSION EQUATION FOR REFUSE GENERATION

Variables

- Y - lb/cap/day of refuse, 1972
- X_1 = commercial waste included ($X_1 = 1$) or excluded ($X_1 = 0$)
- X_2 = industrial waste included ($X_2 = 1$) or excluded ($X_2 = 0$)
- X_3 = July temp, °F
- X_4 = median school years
- X_5 = per capita income, 1000\$
- X_6 = mean precipitation, inches/year
- X_7 = population density, 1000 persons/sq.mi.

Regression Equation

$$\begin{aligned}
 Y &= 15.41 + 1.63X_1 + 1.31X_2 - 0.141X_3 \\
 &\quad t=3.43 \quad t=2.75 \quad t=-1.87 \\
 &\quad -0.247X_4 + 0.42X_5 - 0.055X_6 - 0.29X_7 \\
 &\quad t=1.515 \quad t=1.08 \quad t=-0.94 \quad t=-0.864 \\
 &\quad (R^2 = 0.94)
 \end{aligned}$$

These figures exclude street sweepings, and demolition and construction wastes, and only that fraction of commercial refuse normally picked up by municipal collection is included. This presents some problems, because cities vary widely in the degree to which they collect commercial refuse. In some, municipal crews collect all refuse as a matter of policy; in others, there are special commercial collections by city-owned trucks; and in yet others, commercial refuse is picked up under separate private contract. Indeed, all three options may coexist.¹¹ The figure excludes bulky wastes; these are domestic wastes not normally picked up by the collection crews for reasons of bulk or weight, and for which many cities organize special pick-up arrangements.¹² These bulky items are typically discarded domestic appliances, furniture, old car batteries and tires, house remodeling debris or even unusually large amounts of domestic debris (sometimes referred to as "attic wastes").

Finally, one should note that we make no allowance for seasonal variation in this analysis. This, again, is not because we believe seasonal variation to be unimportant, but because available estimates are so sketchy that no statistically meaningful quantitative relationships could be derived for incorporation into a regional-scale analysis.

The 1985 and 2000 results in Table 3 lie in the high range of current generation rate projections. One recent study on the use of refuse for power generation from the national perspective noted that the increase in per capita consumption of non-durable goods between 1950 and 1967 was 1.5 percent per year;¹³ applying this growth rate to our 1972 estimate results in generation rates of 4 to 5 lb/cap/day by 1985, and 5 to 6 lb/cap/day by 2000, substantially below the Table 3 estimates. Some planners expect no future increase in per capita refuse generation levels,

justified on the basis of a recent levelling off in generation rate in some cities, the likely impact of legislation banning no-return beverage containers or changing current wasteful packaging practices, and an increasing tendency to separate types of refuse at the source.

Therefore, the regression equation of Table 2 is used below for a high estimate of future refuse generation; growth at 1.5 %/yr. is used to calculate the median; and zero growth is assumed for the low estimate. Unless otherwise stated, the median estimate is used in the following sections and the impact of high and low estimates on overall energy yield is referred to Chapter VIII.

2.2. Refuse Composition

Predictions of refuse composition are probably even more speculative than projections of total amounts.¹⁴ It could be argued that each component should be individually projected to avoid separate specification of total amount and of fractional composition, the procedure adopted here. Unfortunately, independent quantitative projection of refuse categories is very difficult and can be done only for a few well-defined categories with reasonably reliable historical data. Thus, even if one or two categories are independently forecast, a total refuse projection still has to be made, with categories lacking independent projections obtained simply by difference.

In our judgement, the validity of the component projection equations in the literature is questionable. In particular, simple extrapolation of recent trends over long periods results in an unlikely mix of components. The nationwide paper content in municipal refuse, for example, has risen over the last decade from about 35% to 45%, and mere linear extrapolation of this trend leads to quite unrealistic results. Logistic and S-type

Table 3 PER CAPITA REFUSE GENERATION RATES, LB/CAP/DAY

	1975	1990	2020	
ALBN	4.15	5.53	9.92	ALBANY-SCHENECTADY-TROY
ALLN	3.42	4.68	8.83	ALLENTOWN-BETHLEHEM-EASTON
ALTO	3.44	4.63	8.51	ALTOONA
ATLA	3.56	4.78	8.81	ATLANTIC CITY
BALT	3.52	4.80	9.62	BALTIMORE
RING	3.96	5.28	9.62	BINGHAMTON
BOST	3.74	5.16	9.62	BOSTON
BRID	4.20	5.58	9.92	BRIDGEPORT
BRIS	4.14	5.61	10.21	BRISTOL
BROC	3.75	5.17	9.63	BROCKTON
BUFF	4.71	6.03	10.35	BUFFALO
DANB	3.97	5.36	9.70	DANBURY
FALL	3.98	5.24	9.26	FALL RIVER
ERIE	4.19	5.45	9.65	ERIE
FITC	3.56	4.86	9.01	FIRCHBURG-LEOMINSTER
HART	4.40	5.88	10.47	HARTFORD
HARR	3.41	4.73	8.69	HARRISBURG
JERS	3.85	5.22	9.47	JERSEY CITY
JOHN	3.13	4.26	8.21	JOHNSTOWN
LANC	3.52	4.73	8.79	LANCASTER
LAW*	3.86	5.28	9.74	LAWRENCE-HAVERHILL
LEWI	4.05	5.20	9.03	LEWIS-AUBURN
LOWE	3.93	5.35	9.60	LOWELL
MANC	4.08	5.32	9.37	MANCHESTER
MER I	3.32	5.36	9.79	MERIDEN
NASH	3.87	5.11	9.16	NASHUA
N.BE	4.30	5.56	9.53	NEW BEDFORD
N.BR	4.39	5.36	10.46	NEW BRITAIN
N.HA	3.90	5.33	9.76	NEW HAVEN
NEWA	4.08	5.50	9.88	NEWARK
N.LN	3.79	5.07	9.24	NEW LONDON-GROTON
NORW	3.79	5.17	9.51	NORWALK
N.YO	3.91	5.43	10.63	NEW YORK
PHIL	3.62	4.92	9.23	PHILADELPHIA
PTFS	3.81	5.30	9.74	PATTERSON-CLIFTON-PASSAIC
PITT	4.18	5.54	9.98	PITTSBURGH
PITT	4.21	5.53	9.86	PITTSFIELD
PORT	3.98	5.24	9.34	PORTLAND
PROV	3.47	5.21	9.39	PROVIDENCE
READ	3.54	4.85	9.05	READING
ROCH	4.95	6.32	10.82	ROCHESTER
SCFA	3.47	4.68	8.71	SCRANTON
STAM	3.77	5.15	9.49	STAMFORD
SPFO	3.24	4.52	8.65	SPRINGFIELD-HOLYOKE-CHICOPEE
SYFA	3.76	5.01	9.13	SYRACUSE
TREN	3.89	5.27	9.63	TRENTON
UTIC	3.88	5.05	9.69	UTICA
VINE	2.99	4.17	8.20	VINELAND
WATE	4.05	5.49	9.92	WATERBURY
WASH	3.43	4.83	9.35	WASHINGTON
WORC	3.81	5.11	9.26	WORCHESTER
WLKS	3.33	4.60	8.72	WILKES-BARRE-HAZELTON
WILM	3.69	5.15	9.73	WILMINGTON
YOFK	3.50	4.73	8.76	YORK
BUFL	4.47	5.80	11.44	BURLINGTON
NEWP	3.94	5.26	9.38	NEWPORT
NEWC	3.84	5.13	9.40	NEW CASTLE
STAT	2.40	3.67	7.79	STATE COLLEGE
WILL	3.30	4.56	8.76	WILLIAMSPORT
LEBA	3.16	4.41	8.46	LEBANON
JAME	3.06	5.12	9.32	JAMESTOWN
ITHA	3.77	5.11	9.37	ITHACA
ELHI	3.08	5.29	9.51	ELMIRA
AUBU	4.21	5.55	9.81	AUBURN
AMST	4.18	5.50	9.75	AMSTERDAM
WATE	3.76	5.01	9.12	WATERTOWN
KING	3.92	5.32	9.64	KINGSTON
NEWB	4.16	5.56	9.87	NEWBURGH
POUG	3.72	5.01	9.09	POUGHKEEPSIE
LONG	2.97	4.24	8.18	LONG BEACH
NOBP	3.83	5.20	9.43	NEW BRUNSWICK-PERTH AMBOY-SAYREVILLE
CONC	4.23	5.61	9.86	CONCORD
GLOU	3.78	5.19	9.65	GLOUCESTER
HAGE	3.49	4.73	8.81	HAGERSTOWN
CUMB	3.22	4.36	8.37	CUMBERLAND
BANG	3.70	4.71	8.76	BANGOR
TORR	4.05	5.46	9.87	TORRINGTON
MIDD	3.52	4.93	9.34	MIDDLETOWN
REGRESSION EQUATION COEFFICIENTS FOR PER CAPITA GENERATION RATES				
CONSTANT			15.41	
COMMERCIAL			1.32	
JULY TEMP.			-0.14	
MEAN PRECIP.			-0.66	
PER CAPITA INCOM			0.07	
POPULATION DENS			-0.29	
EMPLOYMENT			0.54	
INDUSTRIAL WASTE			0.00	
MEG. SCHOOL YRS			-0.24	

curves have been suggested to cope with this problem, but the point at which such a mathematical function levels off is quite arbitrary, and depends largely on each forecaster's choice.¹⁵

The difficulties of prediction are compounded by legislative constraints. Assumptions regarding glass and metal are strongly influenced by restriction or elimination of non-returnable beverage containers.¹⁶ The experience of the last decade suggests that such legislation is most likely in the most environmentally conscious states, but predictions based on this are speculative, at best. Similarly, estimates of organic refuse, particularly kitchen wastes, on the extent of garbage grinders; some cities presently ban grinders for reasons of inadequacies in sewage treatment facilities, whereas others mandate them in new construction. Yet, if energy recovery from the organic fraction of refuse becomes successful, garbage grinders may even be banned in order to maximize energy yields and lessen loads on sewage treatment facilities.

Figures 3 and 4 show typical judgemental forecasts of refuse composition.¹⁷ The significant differences between the two cities shown demonstrate the large variations encountered in refuse composition.

In view of the difficulties of making composition forecasts for each major metropolitan area in the Northeast, we shall use the composition forecast shown in Table 4, based on the widely quoted study by Niessen and Chamsky.¹⁸ The sensitivity of the solution to changes in the assumed composition mix will be established in Chapter VIII.¹⁹

The moisture content of refuse has special significance in energy recovery by combustion; and we have, therefore, chosen to specify it separately. Moisture content varies widely not only

Figure 3. Projected compositional changes in Cleveland refuse (from Hanson, note 17, p. III-9).

Figure 4. Projected compositional changes in Philadelphia refuse (from Hanson, note 17, p. II-10).

Table 4

REFUSE COMPOSITION ASSUMPTIONS, BASE CASE

BASE CASE SCENARIO, STANDARD METROPOLITAN STATISTICAL AREAS

REFUSE CATEGORY DESCRIPTION AND CODE I.D.

CODE CODE DESCRIPTION

PAPR PAPER
 GARB GARBAGE
 GARD GARDEN WASTE (GRASS, DIRT, WOOD)
 PLST PLASTICS
 METL METALS
 GLSS GLASS AND CERAMICS
 OTHR OTHER
 H2O MOISTURE

WET WEIGHT COMPOSITIONS, BY YEAR

YEAR	PAPR	GARB	GARD	PLST	METL	GLSS	OTHR	TOT
1970	40.0	20.5	13.5	1.5	8.9	9.5	6.1	100.0
1980	41.9	18.8	13.2	2.0	8.6	9.2	6.2	100.0
1990	43.9	17.1	12.8	2.6	8.3	8.9	6.3	100.0
2000	45.8	15.5	12.5	3.1	8.0	8.7	6.4	100.0
2010	47.8	13.8	12.1	3.7	7.7	8.4	6.6	100.0
2020	49.7	12.1	11.8	4.2	7.4	8.1	6.7	100.0

DRY WEIGHT COMPOSITIONS, BY YEAR

YEAR	PAPR	GARB	GARD	PLST	METL	GLSS	OTHR	H2O	TOT
1970	36.8	6.7	6.8	1.5	8.7	9.3	6.0	24.8	100.0
1980	38.6	5.6	6.6	2.0	8.4	9.0	6.1	23.6	100.0
1990	40.4	5.1	6.4	2.5	8.1	8.8	6.2	22.4	100.0
2000	42.2	4.6	6.2	3.1	7.8	8.5	6.3	21.3	100.0
2010	43.9	4.1	6.1	3.6	7.5	8.2	6.4	20.1	100.0
2020	45.7	3.6	5.9	4.1	7.3	7.9	6.4	18.9	100.0

MOISTURE CONTENT BY CATEGORY

PAPR .6800
 GARB .7000
 GARD .5000
 PLST .0200
 METL .0200
 GLSS .0200
 OTHR .0200

MOISTURE CONTENT MULTIPLIER 1.00

for reasons of variations in composition (refuse containing a high fraction of garden wastes, leaves, grass cuttings, and so forth, will obviously show a relatively high moisture content), but also with the weather - during periods of rainy weather moisture content rises significantly, due to the improper manner in which much urban refuse is stored awaiting collection.

The computer program used for making our computations, thus, makes two moisture content calculations. The first derives aggregate moisture content from the normal moisture content of each of the constituent components, as indicated on Table 4.²⁰ The second step adjusts for weather conditions using a simple multiplier of total moisture content - assumed in the base case computations to be equal to unity.

NOTES TO CHAPTER II

1. L.L. Anderson, "Energy Potential from Organic Wastes: Review of the Quantities and Sources", U.S. Bureau of Mines, Information Circular 8549, 1972 (Published by NTIS, PB 211 249).
2. Indeed, there seems to be some question as to whether energy recovery from even the largest commercial agricultural operations is a feasible proposition. See e.g., L.A. Schmid, "Feedlot Wastes to Useful Energy-Fact or Friction", Journal, Environmental Engineering Division, American Society of Civil Engineers, Vol. 101, No. EE5, October 1975.
3. Indeed, not only are wood and lumber wastes of interest to the Northern New England states, but the use of wood itself as a primary fuel for electricity generation is being considered. An evaluation of wood as an energy source in the Northeast is currently under study by the BNL Regional Energy Studies Program.
4. "The National Solid Wastes Survey", U.S. Department of Health, Education, and Welfare, Public Health Service, 1968.
5. For a discussion on this point, and some examples of studies that relied on the 5.72 lb/cap/day figure and whose conclusions were, therefore, suspect, see e.g., P. Meier, J. Kuhner, and C. Martel, "A Preliminary Assessment of wet systems for Residential Refuse Collection", U.S. Environmental Protection Agency, March 1974 (Published by NTIS, PB 234 496).
6. This is the case, for example, in the city of Springfield, Mass. One might note, however, that this practice is gradually becoming less frequent, because of increasing costs of maintaining a separate collection for garbage only. See e.g. P. Meier, "Wet Systems for Residential Refuse Collection: A Case Study of Springfield, Mass", U.S. Environmental Protection Agency, March 1974 (Published by NTIS, PB 234 499).
7. For a summary description of this data acquisition program, see, R.M. Clark, J.M. Sweeten, and D.G. Greathouse, "Basic Data for Solid Waste Pilot Study", Journal, Sanitary Engineering Division, ASCE, VOL. 98, No. SA6, p.897.

8. See e.g., "Data Acquisition and Analysis System, Quarterly Report, January-March 1972", Report by ACT Systems to the EPA Solid Waste Management Office, April 1972 (EPA Contracts 68-03-0034 and 68-03-0097).
9. Figure 2 is extracted from Meier, Note 5, supra, p.29.
10. The OBERS series E projections are being used as the basis for all of the analyses of the Energy Futures Study -- See, U.S. Water Resources Council: "1972 OBERS Projections, Series E Population", April 1974.
11. The city of Springfield, Mass. is quite typical in this respect. Commercial refuse is picked up by regular collection trucks provided it meets the city ordinance in terms of weight and bulk. A special commercial collection is also provided on Friday nights to service the downtown business area. However, most large commercial waste generators schedule additional refuse pick-up by private contract. (See Meier, Note 5, supra, Chapter III).
12. Again using Springfield as an example, the city provides a special by appointment bulk collection service - a resident who wishes to dispose of some large bulky item calls a special office number to arrange for a disposal day.
13. Envirogenics Company, "Systems Evaluation of Refuse as a Low Sulfur Fuel", Report to the U.S. Environmental Protection Agency, November, 1971 (Published by NTIS, PB 209 271), p. II-5.
14. There is, to be sure, no shortage of individual studies focused on a particular facet of generation for a particular local area. See e.g., "Socioeconomic Factors Affecting Demand for Municipal Collection of Household Refuse", Report to the U.S. Environmental Protection Agency by the Center for Urban Studies, University of Chicago, August 1973 (Published by NTIS, PB 225 020), which, as the title implies, analyses the Chicago metropolitan area -- or G.R. Davidson, "A Study of Residential Solid Waste Generated in Low Income Areas", U.S. Environmental Protection Agency, Report SE-83ts, 1972, which focuses on low-income areas in Cincinnati. The problem from the perspective of a regional scale analysis, however, is the absence of a synthesis of these individual studies and the consequent lack of a data base at the appropriate scale.

15. This is the procedure used by the Envirogenics Company Study in which equations were used to predict all major categories except paper, the latter being obtained by difference to the total amount projection. See Envirogenics Company, Note 13, supra, p. II-6 ff.
16. For a sophisticated analysis of the Beverage Container Problem, see T.H. Bingham and P.F. Mulligan, "The Beverage Container Problem - Analysis and Recommendations", U.S. Environmental Protection Agency, Environmental Protection Technology Series Report EPA-R2-72-059, September 1972.
17. R.C. Hanson, "Combined Firing Systems for Specific Metropolitan Areas", Report by the Envirogenics Company to the U.S. Environmental Protection Agency, November 1971 (Published by NTIS, PB 207 701).
18. W. Niessen and S.H. Chamsky, "The Nature of Solid Waste", Proceedings, American Society of Mechanical Engineers, Incinerator Division Convergence, 1969.
19. For a new approach to composition estimation based on production and marketing data, see F.L. Smith "A Solid Waste Estimation Procedure: A Material Flows Approach" EPA Report 530/SW-147, May 1975. However, this technique appears applicable only at the national level.
20. Based on Niessen and Chamsky, note 18, supra.

CHAPTER III

THE OPTIONS FOR ENERGY RECOVERY

3.1 Refuse Combustion in Electric Utility Boilers

The concept of using refuse as a supplementary fuel in utility boilers is almost deceptively simple. Shredded refuse has a heat value of some 4000 to 7000 Btu/lb, which, although significantly less than the heat value of coal, at around 12,000 to 13,000 Btu/lb, is nevertheless a fuel that can be burned in the suspension fired utility boilers of modern design with apparently minor modifications. The technical feasibility of the concept has been demonstrated at the Meramec generation facility of the Union Electric Company of St. Louis, Missouri. A comprehensive technical report on the pilot scale project published in 1973 concluded that the process is physically and technically feasible, under the premise that refuse would be milled to effect a particle size of about one inch, and that the milled refuse would replace approximately 10% of the heat value of the pulverized coal consumed in suspension fired furnaces.¹ This study also found that the process can be applied by adaptation of existing technology and commercially available mechanical equipment, with the probability that essentially no further development effort would be required. Modifications to suspension fired boilers normally would be minor.

The latter finding is particularly important in view of the status of other technologies for energy recovery from refuse such as pyrolysis, whose technical feasibility (and indeed economic feasibility) is far from assured. However, the long-term effects of refuse burning can be assessed only by full-scale testing over a reasonable period. On the basis of the pilot-scale St. Louis project, potential operating problems are

probably minimal, but potential long-term corrosion and bottomash handling problems have yet to be fully assessed.

Physical facilities are needed for size reduction of the raw refuse to about one-inch particle size, for removal of metals and other heavy materials by air density separation, for storage (since refuse is normally collected only on five weekdays, whereas boiler operation is continuous), and for modification of the boiler units and necessary ancillary conveyance facilities. The size reduction and ferrous metal removal could be done either at separate transfer facilities within the city or at the current disposal site, with truck haul to the boiler unit (the first option was used in St. Louis, as indicated schematically on Figures 5 and 6). If the boiler were located nearer the center of population, refuse collection trucks could deliver directly to it, and truck transfer would be eliminated. As noted in Section 5.4 this could bring considerable savings but would require sufficient land at the boiler site for additional equipment and storage areas. It would also be more likely to pose institutional problems, as discussed in Chapter VI.

By mid-1974, Union Electric concluded that the demonstration experiments were successful enough to warrant full-scale implementation. A program to burn some 8000 tons/day at the Meramec and Labadie generating stations is now being implemented, with the estimated \$70 million capital cost being financed by pollution control revenue bonds (which, not being subject to income taxes, carry somewhat lower interest rates). The utility will conduct the entire operation itself, and orders for the refuse processing, storage and haul equipment have been placed over the past year.

The success of the St. Louis experiments has led to wide interest in this concept. The EPA solid waste management program

Figure 5. Refuse processing facilities for refuse firing
(Source: Dille + Klumb, note 37, p. 2-11).

Figure 6. Refuse firing facilities at the Union Electric Meramec Plant (Source: Dille + Klumb, note 37, p. 2-10).

has been sponsoring studies in this area since 1970, including a major systems evaluation by the Envirogenics Company,² a survey of utility boilers in all states having significant amounts of fossil generation³, and detailed research analyses of the St. Louis project results focused on air pollution implications.⁴

In the Northeast, several statewide solid waste management plans are focused on use of the combustible fraction of refuse as a fuel. In Connecticut plans are currently being implemented for 1800 tpd plants in New Britain and Bridgeport. Other projects in the Northeast that anticipate the use of direct refuse firing in utility boilers include one sponsored by the Hackensack Meadows Development Commission in New Jersey; a 1500 tpd plant in Newton, Connecticut, that will supply the 22.5 Mw municipally

owned power plant in Wallingford; a 2000 tpd project in Monroe County, New York, to supply the Rochester Gas and Electric Company boilers; a 1200 tpd project in Montgomery County, Maryland, serving the Potomac Electric Power Company's Dickerson plant; and a 1500 tpd project in the City of New York at Consolidated Edison's Arthur Kill plant. Further details on these are given in Appendix F.

The use of refuse as a supplementary fuel at utility boilers raises three immediate questions of some importance to the Northeast. The first concerns the effect of low load factors on the economics of the concept; many Northeastern utilities have very little coal-fired generating capacity and what they do have is relatively old and inefficient and therefore of low plant load factor (See Appendix E). But, although obviously the utilization of the capital investment for modifying boilers for refuse burning is better at high than at low load factors, proper economic analysis takes this into account, as discussed in Chapter V. Note also that Commonwealth Edison in Chicago, which has one of the highest proportions of nuclear capacity in the country, plans to use refuse as a fuel at a coal plant with a load factor well below 50%.⁵

The second question relates to the use of refuse at oil-fired rather than coal-fired plants, the two obvious problems being particulate emissions and ash handling. Since refuse has a much higher ash content than oil, burning it in an oil boiler may require the installation of precipitators and bottom ash handling equipment besides burner modifications. Northeast Utilities is currently embarking on a two-year experimental project with the Connecticut Resource Recovery Authority to evaluate supplemental firing of refuse at its Devon Unit 7 and 8,⁶ which are 30 MW units built in 1955, currently using No. 6 fuel oil but

originally designed for coal. Consolidated Edison in New York City also plans to burn refuse at its oil-fired Arthur Kill facility.⁷ At present, however, the concept of refuse firing in oil boilers must be regarded as unproven.⁸

The third question concerns the use of refuse at industrial boilers other than utility plants. A.D. Little, in a detailed market survey on the potential use of refuse as a fuel supplement in Massachusetts in 1973,⁹ found that of 33 major industrial fuel users interviewed, 6 showed definite interest, 3 showed some interest, and 24 no interest, whereas, of 11 utilities interviewed, 6 showed definite interest, 2 some interest, and 2 no interest. The rated capacity of utilities with definite interest was $34,216 \times 10^6$ Btu/hr (or 18000 tons of refuse/day), but the industries with definite interest had a potential for only 968×10^6 Btu/hr (or 520 tons of refuse/day).¹⁰ These are 1973, pre-embargo data, and subsequent fuel cost increases may have changed the attitude of some industrial fuel users. Moreover, to what degree these relative results have regional generality remains somewhat questionable. Nevertheless, it does seem that the primary potential users of refuse as supplementary fuel are the electric utilities rather than industrial users.¹¹

Finally, it should be noted that Combustion Equipment Associates (CEA) and A.D. Little have developed a high density, high heat value fuel having a number of advantages over the type produced by conventional shredding and gross separation of refuse prior to combustion.¹² Called Eco-Fuel-II, it is a finely powdered substance with a bulk density 4 to 5 times that of shredded fuel. It can also be made into briquettes with handling characteristics similar to those of lump coal, or slurried with residual oil in amounts up to 40% by weight. CEA has been awarded two contracts for Eco-Fuel-II, in the greater Hartford region and in the Housatonic Valley region.¹³

3.2 Bioconversion Methods

Anaerobic decomposition of the organic fraction of solid waste to produce methane is the bioconversion method currently considered most promising.¹⁴ Optimal conditions require addition of nutrients, especially potassium and nitrogen, that do not occur in normal municipal refuse in sufficient quantities to maintain the appropriate microbial balances. It has been verified experimentally that sewage sludge represents the ideal additive in this respect, and several successful pilot demonstrations have confirmed the technological feasibility of the concept.¹⁵ Anaerobic digestion is a wet operation, and size reduction of the incoming refuse is done in hydropulpers to form a slurry of typically 4 to 6% solids concentration. After magnetic separation of ferrous metals and removal of glass, ceramics, and nonferrous metals by hydrocyclones, the slurry goes to anaerobic digesters similar to those now used in sewage treatment plants. The product gas is about 50% methane and 50% carbon dioxide¹⁶, and it has a heat value of 500 Btu per standard cubic foot (scf). This product gas might need some degree of further treatment, especially for removal of hydrogen sulfide, and, if it is to be sold for pipeline gas supply augmentation, the carbon dioxide would also need removal.¹⁷ Figure 7 indicates a possible process for such an energy recovery operation.

Figure 7. Process configuration for refuse bioconversion
(Source: Kispert et al, note 38, p. 15).

The attractiveness of the anaerobic digestion option rests primarily in its production of an energy source that is under increasingly severe supply constraints in the U.S., especially in the Northeast, which has no indigenous supply of natural gas. A number of pilot-scale projects have shown the technical feasibility of digestion, and plans are under way for a demonstration-scale facility.¹⁸ This option was also to have been a part of the NASA integrated utilities demonstration project at the Johnson, Texas, Space Center, but the project has been cancelled because of funding difficulties.

Interest has also been shown in obtaining methane from sanitary landfills, and the success of a demonstration project by the Los Angeles Department of Water and Power (LADWP) has led to plans for implementation of the concept. Engineering estimates suggest that a full scale project could recover 600×10^6 scf/year over 15 years, enough to produce 4 Mw at a neighboring LADWP-owned oil/gas fired plant some two miles from the dump.¹⁹ Pacific Gas and Electric is also experimenting with a landfill gas recovery system at Mountain View, California, but its aim is to serve interruptible gas customers rather than to generate electricity.

In the Northeast, the recovery of methane from landfills has little general potential, although it may be worthwhile in some instances.²⁰ Since landfill sites in our study area are increasingly difficult to find, conversion to methane at recovery facilities, and thus avoiding the need for landfilling, appears to be more promising.

3.3. Pyrolysis and Chemical Conversion Methods

Pyrolysis, or destructive distillation, is a process in which organic material is heated to high temperatures in an

xygen free or low oxygen atmosphere. Unlike combustion in an excess of air, which is highly exothermic, pyrolysis is endothermic. Pyrolysis of the organic fraction of refuse results in breakdown of the organic constituents into three major fractions: a gaseous fraction consisting primarily of hydrogen, methane, carbon monoxide and carbon dioxide; a liquid fraction (liquid at room temperatures), consisting of relatively volatile organic acids, acetones and alcohols (typically acetic acid, methanol and acetone); and a solid residue known as "char", consisting of almost pure carbon plus any inert materials present. Residence time, temperature, and pressure can be controlled in a pyrolysis reactor to produce various combinations of gas, liquids and char.

Although a number of pyrolysis systems are under investigation, this discussion is restricted to the three most fully developed: the Monsanto LANDGUARD system, the Garrett Process, and the Union Carbide PUROX system. For a good review of the state of the art of pyrolysis, and the various systems currently under investigation, see Baum & Parker.²¹

Figure 8. The Monsanto pyrolysis process (Source: Levy, note 22, p. 10).

The Monsanto system (Figure 8) is designed as a total resource system, with energy recovery as only one of its objectives.²² The shredded waste is pyrolyzed at temperatures of about 1800°F, to produce a low Btu gas (100 Btu/cf), which is burned in an afterburner to generate steam. A 35 tpd prototype facility demonstrated the feasibility of the process, and a 1000 tpd facility is now operating in Baltimore, with about 4.8 million pounds of steam per day being sold to the Baltimore Gas and Electric Company for use in its steam distribution system.

The Garrett process (Figure 9) requires a very finely shredded input to the pyrolysis reactor, which rapidly heats the one-eighth inch particles to as high as 1650°F.²³ Oil, gas, and char are collected from the reactor and all of the gas and one-third of the char are used to supply heat for the refuse dryer and the pyrolysis reactor. The net yield of oil is claimed to be about 1 barrel (or 4.78×10^6 Btu) per ton of raw refuse processed.

Figure 9. The Carrett pyrolysis process (Source: Levy, note 22, p. 19).

A desirable characteristic of this oil is its very low sulfur content, about 0.1 to 0.3 percent sulfur by weight. The oil (given the tradename Garboil) is suitable as a supplementary fuel in utility boilers for power generation, but its chemical properties are quite different from those of normal crude oil and it could not be refined in a typical oil refinery to produce, say, gasoline and lubricating oils.²⁴ The other distinctive property of this oil is its high viscosity, which requires warming to about 106°F for pumping. However, it has an atomization temperature of 240°F, only 20°F higher than normal fuel oils, so that it burns well in oil fired utility boilers.

A 4 tpd pilot plant at Laverne, California has proved the feasibility of the Garrett system, and a 200 tpd demonstration plant is now under construction for the San Diego County towns of Escondido and San Marcos, California.²⁵ The oil is to be sold at \$2.32 per barrel for power generation to the San Diego Gas and Electric Company.²⁶ The net operating cost of the facility is expected to be about \$8/ton, compared with the \$10/ton conventional disposal cost in the area. Garrett claims that a 2000 tpd plant would show a zero net disposal cost, and a 500 tpd plant, under municipal ownership a cost of about \$2.50/ton, competitive with almost all properly operated sanitary landfills.²⁷

Union carbide has developed a gas pyrolysis process known as the PUROX system, whose key element is a vertical shaft furnace, as shown on Figure 10. Refuse is fed into the top of the furnace. Oxygen entering at the base of the furnace reacts with the char that is one of the end products ultimately formed from the refuse. This reaction generates a temperature high enough to melt and fuse the ash, metal, and glass; this molten material drains continuously into a water-filled tank. where it solidifies as a hard granular material.²⁸ The hot gases formed by reaction of the

Figure 10. The Union Carbide pyrolysis process (Source: Levy, note 22, p. 11).

oxygen and char rise through the column pyrolyzing the refuse to gas and char, and in the upper portion of the furnace, serving to dry the incoming refuse. The gases leaving the furnace are at about 200°F, and they contain considerable water vapor, some oil mist, and minor amounts of other undesirable constituents, which are removed in a gas-cleaning system.

The resultant gas is a clean-burning fuel comparable to natural gas in combustion characteristics, but its heating value of about 300Btu per cubic foot is only 30 percent that of natural gas. The gas is essentially free of sulfur compounds and nitrogen oxides and burns at about the same temperature as natural gas. It can be substituted for natural gas in an existing facility; the only plant modification necessary would be

enlargement of the burner nozzle to increase the volumetric flow rate.

The feasibility of this process has been demonstrated at a 200 tpd facility in Charleston, West Virginia, and Mount Vernon, New York, plans to implement this system at a 400 tpd level to serve the Westchester County communities of Mt. Vernon, N. Pelham, Pelham, and Pelham Manor. The gas will be used to generate electricity, which will be sold to Consolidated Edison.

3.4 Steam Generation

Of all the options for energy recovery from refuse, steam generation as an adjunct to incineration has the longest history. The technology has been developed to very sophisticated levels in Europe, where historically higher energy costs, and urban development suited to district heating, have made energy recovery by so-called waterwall incinerators almost commonplace. But American technology in this area is quite undeveloped, and the few steam generation projects that have been built have either been plagued by operating problems, or encountered difficulties in marketing the steam. For example, a 240 tpd waterwall incinerator in Braintree, Massachusetts, which started operation in 1971, has only very recently been able to sell steam to nearby industries;²⁹ and the largest U.S. heat recovery incinerator, the Chicago Northwest Incinerator, had such severe reliability problems that even three years after start-up, it was unable to market steam to potential industrial customers.³⁰

Since the oil embargo, however, the sharp rise in the cost of fuel oil for industrial process heat has caused a resurgence of interest in steam generation from refuse to serve both large industries and urban district heating systems. The largest refuse-to-energy project in the Northeast, now under construction

in Saugus, Massachusetts, will burn 1200 tpd of refuse from 16 suburban Boston communities in Swiss designed Von Roll incinerators, and sell the entire steam output to an adjacent manufacturing facility of the General Electric Company.³¹

As noted in Chapter V, steam generation for industrial process heat use is more attractive economically than any pyrolysis process. However, even in the absence of detailed data on the extent of industrial use, the opportunities to implement this option appear rather limited in the Northeast. The distance between the steam generator and the user must be kept as short as possible, as the heat loss and transportation penalties are rather high.³²

The other major potential market for steam is for district heating, but here again the present opportunities are rather limited. In 1973, only eight cities in the Northeast had district heating systems, generally quite small systems in the downtown area: Allentown, Baltimore, Harrisburg, Hartford, Boston, New York, Philadelphia, and Pittsburgh.³³ Numerous other commercial and campus district heating systems do of course exist in the region, but these are typically too small to be candidates for major refuse-to-energy projects.

The paucity of existing markets notwithstanding, steam generation from refuse has undoubted merits under the existing energy price conditions. Indeed, a new district heating system in downtown Nashville,³⁴ using refuse as its major fuel, has recently been initiated, perhaps an encouraging precedent for a more widespread implementation of the concept in other parts of the Nation.

1.5 Other Energy Recovery Options

Two other energy recovery options deserve some attention, although they will not be discussed further in the analytical chapters of this report in view of their still rather experimental nature.

The first is the CPU-400 system, for generating electricity by the Brayton gas turbine cycle which has been under development with EPA funding for a number of years.³⁵ In this process, refuse is shredded and burned in a high temperature fluidized bed combustion chamber, and the hot exhaust gases are used to generate electricity in a gas-turbine generating unit. A demonstration scale, 80 tpd plant now operating is planned to be scaled up to 1000 tpd, but the design of several key systems has yet to be completed, and process economics are still uncertain.

The other possibility is to use solid waste as the raw material for low-Btu gas production by a process called hydro-gasification.³⁶ In this process, carbonaceous feed material is reacted with hydrogen to produce methane, but a portion of the feed material is used as an energy source for hydrogen manufacture. The composition of refuse (Table 5) is not altogether different from that of lignite and oil shale, and the proponents of the concept claim that it is economically attractive.

Table 5

TYPICAL ULTIMATE ANALYSES OF SOLID WASTES
AND SOME FOSSEL FUEL FEED STOCKS FOR
CONVERSION TO PIPELINE GAS

<u>Material</u> <u>Source</u>	<u>Lignite</u> <u>N. Dakota,</u> <u>Beulah</u> <u>Seam</u>	<u>Oil Shale</u> <u>Colorado</u> <u>Green River</u> <u>Deposit</u>	<u>Bituminous</u> <u>Coal,</u> <u>Pennsylvania</u> <u>Pgh. Seam</u>	<u>Subbituminous</u> <u>Coal,</u> <u>Wyoming</u> <u>Monarch Seam</u>	<u>Solid Waste</u> <u>Average</u> <u>Municipal</u> <u>Refuse</u>
Carbon	42.4	23.8 ^a	76.6	54.6	35.4
Hydrogen	6.7	2.6	5.2	6.4	4.4
Oxygen	43.3	12.3	6.2	33.8	28.2
Nitrogen	1.7	0.5	1.6	1.0	0.4
Sulfur	0.7	1.0	1.3	0.4	0.2
Ash	<u>6.2</u>	<u>59.8</u>	<u>9.1</u>	<u>3.8</u>	<u>31.4</u> ^b
	101.0(sic)	100.0	100.0	100.0	100.0
Moisture	34.8	0.2	2.6	23.2	20.7

a. Includes ash, metals, glass, and ceramics.

b. Includes 4.6% carbon as carbonate.

Source: Feldman, note 36, p. 128.

NOTES TO CHAPTER III

1. Horner and Shiffrin, "Solid Waste as a Fuel for Power Plants", U.S. Environmental Protection Agency, 1973 (Published by NTIS. PB 220 316). An interim report was published as EPA report SW-36d.i in 1972.
2. Envirogenics Company, "Systems Evaluation of Refuse as a Low Sulfur Fuel", Report to the U.S. Environmental Protection Agency, Nov. 1971 (Published by NTIS, PB 208 271).
3. Gordian Associates, Inc., "Where the Boilers Are: A Survey of Electric Utility Boilers with Potential Capacity for Burning Solid Waste as a Fuel", Report to the U.S. Environmental Protection Agency, 1974 (Published by NTIS, PB 239 392).
4. L.J. Shannon, et al, "St. Louis/Union Electric Refuse Firing Demonstration Air Pollution Test Report", Report by the Midwest Research Institute to the U.S. Environmental Protection Agency, August 1974 (Published by NTIS, PB 237 630).
5. J.J. McDonough "Solid Waste Management: A Metropolitan Viewpoint" A.I.Ch.E. Workshop on Industrial Process Design for Pollution Control, Chicago, Ill. Oct. 1973, p. 104.
6. Bechtel Corporation "Fuels from Municipal Refuse for Utilities: Technology Assessment" Report to Electric Power Research Institute, March 1975 (NTIS Report PB 242 413).
7. R.A. Low "Energy Conversion in New York" Proceedings, First International Conference on Conversion of Refuse to Energy, Montreux, Switzerland, Nov., 1975, p. 250.
8. It could be argued, of course, that since oil is the more expensive fuel than coal, supplementary firing of refuse at an oil fired plant would justify higher capital investment for plant modification than at coal fired plants.
9. A.D. Little, Inc. "A Systems Evaluation of Alternative Statewide Resource Recovery Techniques for the disposal of Municipal Solid Waste" Report to the Mass. Dept. of Public Works, Dec. 1973.
10. Even if all major industries were to have shown interest, the potential would be only 854 tons of refuse/day.

11. However, again that is not to say that refuse would not be used at small industrial facilities if local circumstances are favorable. For a discussion, see e.g. H.G. Rigo, S.A. Hathaway and F.C. Hildebrand "Preparation and use of refuse derived fuels in industrial scale applications". Proceedings, First International Conference on Refuse Conversion to Energy, Montreux, Switzerland, November 75, p.22.
12. R.M. Benningson, et.al. "Production of Eco-Fuel-II from Municipal Solid Waste" Proceedings, First International Conference on the Conversion of Refuse to Energy, Montreux, Switzerland, Nov. 1975, p. 14.
13. See Appendix F for further description of these projects.
14. A number of other possibilities have been suggested over the past years, including fermentation of cellulose to yield ethyl alcohol (based on the Madison wood sugar process developed during World War II at the U.S. Forest Products Laboratory in Wisconsin) See e.g. Drobney, et al, "Recovery and Utilization of Municipal Solid Waste:, U.S. Environmental Protection Agency, Report SW-loc, 1971, p. 81.
15. In 1973, NSF held a conference to review the state-of-the-art of anaerobic digestion of refuse -- see Proceedings of the Bioconversion Energy Research Conference, Institute for Man and Environment, University of Massachusetts, Amherst, Mass., 1973.
16. The exact ratio of CO_2 to CH_4 is determined by the pH of operation; CH_4 contents of more than 60% do not appear feasible. Scf is the abbreviation for standard cubic feet, the volume under standard pressure and temperature conditions.
17. The Dynatech Corporation suggests the use of monoethanolamine (MEA) scrubbers to effect the removal of acid gases.
18. See e.g., Klispert , note 38, *infra*, by Pfeffer at the University of Illinois and by Goulecke at the University of California (See C. Goulecke, "Bioconversion of Energy Studies at the University of California in Proceedings, Note 15, *supra*).
19. As reported in Electrical World, August 1, 1975, p. 27.
20. For example, the Town of Brookhaven on Long Island, New York, is investigating the possibility of collecting methane at its

Holtsville dump. Anticipated production is about 1.5×10^6 ft³/day, to be piped directly into the gas distribution system of The Long Island Lighting Company (as reported in the Three Village Herald, Feb. 11, 1976). Another project proposes to extract methane from the Fresh Hills landfill in New York City for sale to the Brooklyn Union Gas Company. (see R. A. Low "Energy Conversion in New York", PROCEEDINGS, First International Conference on Conversion of Refuse to Energy, Montreux, Switzerland, Nov. 1975, p. 254).

21. B. Baum, and C. H. Parker: "Solid Waste Disposal: Vol 2, Reuse/Recycle and Pyrolysis", Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1974.
22. See e.g., S. J. Levy, "Markets and Technology for Recovering Energy from Solid Waste", U.S. EPA Report SW-130, 1974.
23. See e.g., C. S. Finney and D.E. Garrett, "The Flash Pyrolysis of Solid Wastes", Energy Sources, Vol. 1, No. 1, p. 295 (1974).
24. The oil has a heat value of about 10,500 Btu/lb, lower than the 18,200 Btu/ lb for a typical No. 6 fuel oil because of its higher oxygen content. Since the specific gravity of the oil is about 1.3, as opposed to 0.98 for No. 6, its energy content by volume is about 75% that of No. 6.
25. Funding for 75% of the construction will come from EPA, and San Diego Gas and Electric will invest \$150,000 to handle the recovered fuel oil.
26. The selling price is based on the comparable cost of interruptible natural gas.
27. Finney & Garrett, Note 23, supra, at p. 313.
28. See Levy, Note 22, supra.
29. Levy, Note 22, supra.
30. Midwest Research Institute, "Resource Recovery: The State of Technology", Report to Council on Environmental Quality, (Feb. 1973, p. 7).
31. See e.g., "Refuse to Energy Plant Uses First Von Roll Incinerators in the U.S.", Environmental Science and Technology, Vol. 9, No. 5, p. 423 (May 1975).

32. A two mile maximum distance is a figure that often appears in the literature.
33. International District Heating Association, 1973 Rate Reference Book, cited in Levy, Note 22, supra, p. 15.
34. See below, Chapter VI.
35. See, Midwest Research Institute, Note 30, supra, p. 9-10.
36. H. F. Feldman, "Pipeline Gas from Solid Wastes", In A.E.Ch.E. Symposium Series, Vol. 68, 1972, "Chemical Engineering Applications in Solid Waste Treatment", No. 122, p. 125.
37. E. K. Dille and D. L. Klumb, "Recycling Solid Waste for Utility Fuel and Recovery of other Resources", PROCEEDINGS, 1973 Conference on Frontier of Power Technology, Oklahoma State University.
38. R. G. Kispert et al. "Fuel Gas Production from Solid Waste" Report to NSF, July 1974 (NTIS PB 238 068).

CHAPTER IV

THE POTENTIAL CONTRIBUTION TO ENERGY

SUPPLIES IN THE NORTHEAST

4.1 Energy Yield from Combustion

The energy yield from refuse combustion depends primarily on the composition of the refuse and its moisture content. Appendix A derives the relationship between refuse composition and Btu content per ton of raw refuse; the resultant values used in this study are given in Table 6. Note that the heat value of refuse is anticipated to rise as a result of expected increases in the combustible fraction, and that our values are consistent with the assumptions of other studies.

Table 6

HEAT CONTENT OF REFUSE, AS RECEIVED

<u>City</u>	<u>Btu/lb</u>		
	<u>1972</u>	<u>1985</u>	<u>2000</u>
St. Louis ^a	4500		
Philadelphia ^b	4300	4700	
Cleveland ^c	4200	5000	7300
National average ^d	5000		
This study	4500	5000	6000

^a Horner & Shifrin, Note 1, p. 8.

^b Roberts & Hanson, Note 2, p. II-12

^c Roberts & Hanson, Note 2, p. II-2

^d Envirogenics, Note 3, p. II-21

Although the heat value represents the available But content of refuse, not all of this is converted to useful heat. In fact, the experiments at the St. Louis demonstration project indicate that the combustion efficiency is a function of the percent of refuse fired, and varies little with moisture content, refuse composition or the output power of the boiler. At 9 percent firing, combustion efficiency was between 65 and 70%, rising to between 80 and 95% at an 18% firing rate and 98% at a 27% firing rate. Denoting refuse combustion efficiency as η_R , and h_c as the heat value of coal in Btu/lb then the potential coal saving, C_T , in 1000 tons per year, can be approximated by

$$C_T = \frac{10^{12}}{10^3} B_T \eta_R \frac{1}{h_c} \frac{1}{2000}$$

where B_T is the amount of refuse consumed per year (in 10^{12} Btu/yr). Expressed as the amount of energy, E_T (in Mwh/yr), that would be replaced by refuse, one obtains

$$E_T = \frac{10^{12}}{10^3} B_T \frac{1}{h_g}$$

where h_g is the average generation unit heat rate (in Btu/Kwh), Finally, the equivalent power level, P_T , (in Mw(e)) is given by

$$P_T = E_T \frac{1}{365 \times 24 \times LF}$$

where LF is the assumed load factor.

Table 7 shows for all urban areas in the study region the computed values of B_T , C_T , E_T , and P_T for the base case refuse generation rate and 1972 refuse composition as shown in Table 3.

Table 7

POTENTIAL YIELDS FROM REFUSE
COMBUSTION, 1970

	B _T	C _T	E _T	P _T
	10 ¹² BTU/YR	10 ³ tns/yr	MWH/YR	MW(E)
1 ALBANY SCHEN	3.91	138.27	311666.02	59.30
2 ALLNTWN SET	3.15	111.31	250907.85	47.74
3 ALTONA	.73	25.96	58518.27	11.13
4 ATLANTIC CIT	.96	34.08	76814.35	14.61
5 BALTIMORE	11.22	396.83	894500.06	170.19
6 BINGHAMPTON	1.54	57.96	130657.63	24.86
7 BOSTON	14.92	527.59	1189243.48	226.26
8 BRIDGEPORT	1.69	59.76	134697.09	25.63
9 BRISTOL	.36	12.61	28422.38	5.41
10 BROCKTON	1.03	36.35	81943.69	15.59
11 BUFFALO	7.31	258.42	582505.90	110.83
12 ERIE	1.08	38.16	86005.36	16.36
13 FALL RIVER	.42	15.00	33819.45	6.43
14 FITCH LEO	.53	18.63	41984.51	7.99
15 HARRISBURG	2.04	72.16	162665.76	30.95
16 HARTFORD	3.65	128.98	290738.63	55.32
17 JERSEY CITY	3.30	116.76	263192.48	50.07
18 JOHNSTOWN	1.43	50.50	113825.76	21.66
19 LANCASTER	1.77	62.62	141152.72	26.86
20 LAW#HAVERHIL	1.26	44.55	108407.31	19.10
21 LEWIS#AUBURN	.39	13.88	31280.51	5.95
22 LOWELL	1.15	40.77	91903.14	17.49
23 MANCHESTER	.63	22.12	49855.78	9.49
24 MERIDEN	.30	10.73	24178.06	4.60
25 NASHUA	.36	12.76	28754.62	5.47
26 N BEDFORD	.83	29.21	65838.74	12.53
27 N BRITAIN	.98	34.74	78317.30	14.90
28 N HAVEN	1.93	68.14	153583.80	29.22
29 N LNDN#GRTN#	1.13	39.91	89965.68	17.12
30 N YORK	62.66	2215.54	4994050.25	950.16
31 NEWARK	9.58	342.17	771278.12	146.74
32 NORWALK	.79	24.68	55631.25	10.58
33 PTRSN#CLIFT#	6.22	219.82	495497.39	94.27
34 PHILADELPHIA	26.10	922.96	2080440.95	395.82
35 PITTSBURG	13.03	460.67	1038389.30	197.56
36 PITTSFIELD	.43	15.27	34415.45	6.55
37 PORTLAND	.77	27.12	61134.58	11.63
38 PROVDC#PAW#	5.07	179.17	403862.37	76.84
39 READING	1.61	56.84	128115.01	24.38
40 ROCHESTER	4.78	169.10	381175.84	72.52
41 SCRANTON	1.66	58.53	131943.85	25.10
42 SPFD#HOL#CHI	2.87	101.48	228742.02	43.52
43 STAMFORD	1.12	39.59	89243.72	16.98
44 SYRACUSE	3.46	122.25	275554.18	52.43
45 TRENTON	1.69	58.24	131275.02	24.98
46 UTICA#ROME	1.95	68.84	155182.76	29.52
47 VINELAND	.66	23.31	52552.99	10.00
48 WASHINGTON	15.83	559.69	1261588.35	240.03
49 WATERBURY	1.13	39.99	90144.65	17.15
50 WLS#BA#HAZE	1.85	65.54	147727.87	28.11
51 WILMINGTON	2.49	88.02	198398.95	37.75
52 WORCESTER	1.87	66.00	148760.13	28.30
53 YORK	1.80	63.49	143105.32	27.23
54 BURLINGTON(*)	.43	15.29	34460.87	6.56
55 NEWPORT(*)	.42	14.81	33392.46	6.35
56 NEWCASTLE(*)	.58	20.57	46365.32	8.82
57 STATE COLLEG	.54	19.04	42911.16	8.16
58 WILLIAMSPORT	.62	21.87	49298.39	9.38
59 LEBANON(*)	.54	19.19	43248.91	8.23
60 DANBURY	.43	15.04	33892.46	6.45
61 JAMESTOWN(*)	.84	29.64	66804.01	12.71
62 EL#IRA(*)	.55	19.21	43974.99	8.37
63 ITHACA(*)	.42	14.73	33196.51	6.32
64 AUBURN(*)	.42	14.85	33470.86	6.37
65 AMSTERDAM(*)	.31	10.84	24427.35	4.65
66 WATERTOWN(*)	.48	16.96	38228.41	7.27
67 KINGSTON(*)	.90	31.72	71506.33	13.60
68 NEWBURGH(*)	1.66	58.78	132500.89	25.21
69 POUGHKEEPSIE	1.20	42.59	95991.97	18.26
70 LONG BRANCH	4.04	142.94	322191.09	61.30
71 NRP#PERTH#GAY	3.42	120.88	272469.53	51.84
72 CONCORD(*)	.45	15.83	35678.95	6.79
73 GLOUCESTER(*)	3.46	122.18	275409.69	52.40
74 HAGERSTOWN(*)	.63	22.38	50447.58	9.60
75 CUMBERLAND(*)	.49	17.26	38895.75	7.40
76 BANGOR(*)	1.04	36.66	82640.67	15.72
77 TORRINGTON(*)	.81	28.53	64307.86	12.24
78 MIDDLETOWN(*)	.93	33.03	74495.65	14.17
TOTAL	265.07	9372.12	21125724.31	4019.35

*BTU AS 10.12 BTU/YR
COAL AS 12.3 TONS/YEAR

ASSUMED REFUSE COMBUSTION EFFICIENCY .85

These computations assume a firing rate of 18 percent, and a combustion efficiency of $\eta_R = .85$. The overall efficiency of refuse to electricity conversion by direct combustion is given by the product

$$e_C = \eta_R \frac{3412.8}{h_g}$$

For $\eta_R = .85$ and a typical heat rate of 10665 Btu/Kwh, the Reference Energy System⁵ entry is

4.2 Energy Yield from Bioconversion

Calculation of the energy yield from bioconversion is considerably more difficult than in the case of combustion. Estimates of the methane yield based on experimental data vary widely, and an analytical derivation is not possible because of the complexity of the biochemical equilibria that govern the process.

Pfeffer⁶ estimated that one pound of organic solids destroyed in the digestion process would yield some 7.1 cubic feet (scf) methane. Assuming that one ton of raw refuse results in 0.6 tons of sludge solids, that the fraction of volatile solids is 0.6, that 0.8 of the volatile solids are destroyed, and that the heat content of methane is 1000 Btu/scf then one ton of refuse can be shown to yield 4.09×10^6 Btu/ton.

Dair⁷ estimated a methane yield of 6175 cu. ft. per ton of raw refuse, or 6.175×10^6 Btu/ton, whereas McFarland et al⁸ found gas production in a pilot scale digester to average 7.0 cu.ft. per pound of volatile solids added to the digester, with an equivalent Btu yield of 5.04×10^6 Btu/ton.

Taking an average yield of 5×10^6 Btu/ton and assuming the heat content of raw refuse to be 5000 Btu/lb and the heat content of sewage sludge to be 7300 Btu/lb of solids, then, if 1 part by weight of sewage sludge is added to 35 parts of refuse, the overall efficiency of bioconversion is computed as

$$\frac{5 \times 10^6}{\frac{35}{36} \times 5000 \times 2000 + \frac{1}{36} \times 7300 \times 2000} = 0.493$$

and thus the Reference Energy System entry is

4.3 Energy Yield from Pyrolysis

The energy yield of the Garrett process has been estimated to be 1 barrel of oil per ton of raw refuse or 4.87×10^6 Btu/ton of raw refuse.⁹ But, since this oil can be used only as a supplementary

fuel in oil-fired boilers, the electric energy yield would be $4.87 \times 10^6 \times 0.32 = 1.56 \times 10^6$ Btu/ton. Assuming the heat content of raw refuse to be 5000 Btu/lb or 10×10^6 Btu/ton, the entries of Reference Energy System are thus

This is equivalent to an overall efficiency of 0.155, less than half the refuse-to-power efficiency from direct firing in utility boilers.

The Union Carbide PUROX system energy yield is estimated at 5.5×10^6 Btu per ton of refuse in the form of gas.¹⁰ The Reference Energy System entry is thus

4.4 Energy Yield from Steam Generation

Energy yield from refuse via steam generation can be estimated by two methods that do not involve complicated thermodynamic computations. The first is simply to use boiler efficiency as a surrogate for conversion efficiency, but this neglects losses in transit, which may be substantial. A better method is based on consideration of the Btu content of the fuel being replaced by refuse.

The Saugus, Massachusetts, steam generation plant is estimated to save General Electric some 73,000 gallons of fuel oil per day.¹¹ At 18,200 Btu/lb and a specific gravity of 0.98, this equals an annual Btu savings of

$$300 \frac{\text{days}}{\text{yr}} \times 0.98 \times 8.34 \frac{\text{lb}}{\text{gal}} \times 73,000 \frac{\text{gal}}{\text{day}} \times 18,200 \frac{\text{Btu}}{\text{lb}} = 3.25 \times 10^{12} \frac{\text{Btu}}{\text{yr}} .$$

Given a refuse input of 440,000 tons/yr and a value of 5000 Btu/lb of refuse, the overall efficiency is

$$\frac{3.25 \times 10^{12}}{440,000 \times 5000 \times 2000} = 0.73 .$$

Hence, the Reference Energy System entry for a steam generation from refuse is

4.5 Comparative Assessment

The total 1972 energy consumption of the Northeast has been estimated at 15.6×10^{15} Btu.¹² Assuming a 1972 population of 54.27 million, a refuse generation rate of 3.3 lb per capita per day, and a refuse heat value of 4500 Btu/lb, the yearly heat content of the region's refuse is 294×10^{12} Btu, or 1.88% of total consumption. A more useful comparison, however, is by the specific resource that refuse would replace, and taking into account the appropriate conversion efficiencies. Table 8 shows the result of such

comparisons for each of the energy conversion options examined in this report; note, however, that each option listed assumes all the available refuse would be consumed by that particular option. Thus, for example, refuse could supply 6.1% of the region's natural gas consumption¹³ or, say, 18% of the coal used for utility electric generation.

Table 8

POTENTIAL ENERGY CONTRIBUTION: TO THE NORTHEAST U.S.
BASE YEAR 1972

Process	Efficiency	Potential Btu Yield 10^{12} Btu/year ^a	Resource Replaced	1972 Resource Use 10^{12} Btu/year ^b	Potential Percentage Replacement of Resource
Gas Pyrolysis	.55	161	Natural gas	2635	6.1
Bioconversion	.493	144			5.4
Oil Pyrolysis	.487	143	Fuel oil for steam electric	1630	8.7
Direct Firing	.272	80	Electricity	1239	6.4
	.85	250	Coal for steam electric	1335	18.7
Steam Generation	.73	214	Non-electric industrial process heat	1686	12.7

^aBased on 4500 Btu/lb refuse, a per capita generation rate of 3.3 lb/cap/day and 1972 estimated population of 54.27 million; equivalent to 294×10^{12} Btu/year.

^bFrom Lee, Note 12.

NOTES TO CHAPTER IV

1. Horner and Shiffrin, "Solid Waste as a Fuel for Power Plants" U.S. Environmental Protection Agency, Report SW-36, 1973 (Published by NTIS, PB 220 316).
2. R. M. Roberts and R. C. Hansen, "Combined Firing Systems for Specific Metropolitan Areas". U.S. Environmental Protection Agency, November 1971, (Published by NTIS, PB 207 701).
3. Environgenics Company, "Systems Evaluation of Refuse as a Low Sulfur Fuel, Volume 1", U.S. Environmental Protection Agency, November 1971 (Published by NTIS, PB 209 271).
4. L. J. Shannon et al, "St. Louis/Union Electric Refuse Firing Demonstration Air Pollution Test Report", Report by Midwest Research Institute to EPA, August 1974 (Published by NTIS, PB 237 630) P. 40. The explanation for this phenomenon was not addressed in any detail, and the authors of this study noted merely that ". . . while several factors may contribute to this behaviour . . . , the variations in fuel mixing patterns in the furnace probably can account for most of the effects".
5. For a description of the BNL Reference Energy System Model, and its application to the Northeastern U.S., See e.g. J. Lee, "Energy Supply and Demand in the Northeast United States," BNL Regional Energy Studies Program, Report 20427, September 1975.
6. J. Pfeffer, "Reclamation of Energy from Organic Waste", U.S. Environmental Protection Agency, 1974 (Published by NTIS, PB 231 176).
7. J. Dair, "Report on a Study of the Feasibility of Disposing of Rubbish into a Sewage Disposal System", Unpublished Memorandum, Los Angeles County Sanitation District, Sept. 13, 1963.
8. J. McFarland et al., "Comprehensive Studies of Solid Wastes Management, Final Report", University of California at Berkeley, Calif., 1972, Report No. SERL 72-3.
9. See above, Section 3.3.
10. Ibid.

1. "Refuse-to-Energy Plant Uses First Von Roll Incinerator in the U.S.", Environmental Science and Technology, Vol. 8, No. 8, p. 693, (August 1974).
12. Lee, Note 5, supra, p. 13.
13. This percentage matches well with that of Kispert et al "Fuel Gas Production from Solid Waste" Dynatech R/D Company, Report to NSF, Jan 75 (NTIS, PB 245 038), who examined the potential gas supply contribution on an SMSA basis. Extracting data for Northeastern SMSA's from their national survey one obtains a potential 1970 contribution of 6.5%.

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CHAPTER V

ECONOMIC ANALYSIS

5.1 A Framework for Analysis

The economic analysis of alternatives for energy recovery from waste in the Northeast presents a number of difficulties. To begin with, all the systematic comparative studies of energy recovery from solid waste have been conducted from the national perspective, using national averages in the economic analysis. Because of the marked regional variations in energy costs, however, these cannot be used directly in a study focused on the Northeast. In fact, because the delivered prices of fuels in the Northeast are among the highest in the country, the results of economic analyses conducted at the national level tend to be overly conservative from the Northeastern perspective. Also, rapid changes in energy prices since the 1973 oil embargo and the accelerating inflation in construction costs have caused early obsolescence of economic studies: indeed, the most comprehensive systematic economic analysis of resource recovery options, published in early 1973 for the Council on Environmental Quality, is based on pre-embargo fuel valuations, with conclusions that are pessimistic in light of post-embargo market conditions.¹ Unfortunately, because different resource recovery options produce different types of fuels, and because the relative prices of different fuels have shifted, simple extrapolation of the results of pre-embargo analyses is not possible.

Conventional economic analyses have generally been made from the viewpoint of solid waste management, with all costs expressed in terms of dollars per ton of raw refuse, and comparisons made on the basis of lowest overall cost of disposal. Such analyses rest on certain assumptions regarding credits for recovered materials

and energy, interest rates, depreciation, etc., integrated into the framework of conventional engineering economic analysis. The major shortcoming of this approach is its inflexibility. It reveals little about supply-demand relationships or about prices: yet a rational determination of the price for refuse, as sold by a municipality to an electric utility or privately owned resource recovery facility, is fundamental to reaching equitable agreements on implementing energy recovery projects.² Moreover, the relative conditions of the market for energy on the one hand and the price of refuse fuel on the other, set the framework for the entry of private capital into the energy recovery business. Obviously, therefore, a parametric approach with energy prices explicitly considered will be more useful in assessing the degree to which energy recovery from refuse will in fact be practiced in the future than the conventional engineering economics approach with fixed assumptions about energy prices.

A major problem in the economic analysis of new technologies concerns the extent of scale economies. Although most of the options considered in this report have been demonstrated at the 100 to 200-ton/day level, for which cost estimates are reasonably reliable, no large plants (1000 tpd and up) are yet operating, and reliable cost estimates are available for only two large projects, the Union Electric refuse burning project and the Saugus steam generating project, both still under construction. The proponents of the proprietary systems, such as the Garrett and Union Carbide pyrolysis systems, have made cost estimates for large projects, but these should be viewed with some scepticism.

As a pragmatic expedient a simple exponential rule is used here to scale up demonstration projects from the 100 to 200 tpd level to the 1000 tpd level that we shall use as the standard for comparison. This rule, widely used in chemical engineering process

economics,³ simply states that economies of scale are captured by the expression

$$C(x_1) = C(x_2) \left(\frac{x_1}{x_2} \right)^b \quad [1]$$

where $C(X_1)$, $C(X_2)$ are the capital costs of facilities of capacity X_1 , and X_2 , respectively, and the exponent b is typically around 0.7 for complete process plants.⁴

The rapid escalation in construction costs over the past few years necessitates use of an indexing procedure to convert all estimates to Mid-1975 prices. The Chemical Engineering Plant Cost Index seems to be the most appropriate to the type of facility needed for energy recovery from solid waste: values of this index over the past years are as follows:⁵

1970	125.7
1971	132.2
1972	137.2
1973	144.1
1974	165.4
Mid-1975	182.0

The economic analysis below rests on a computation of a breakeven refuse price for each energy recovery option, defined as that price for which the discounted present worth of annual returns equals the original investment.

i.e.

$$\sum_{t=1}^n \left(S - q_R(t) \cdot P_R(t) - O(t) \right) \frac{1}{(1+i)^t} = I$$

where i = opportunity cost of capital

n = recovery period, years

$q_R(t)$ = quantity of refuse purchased in period t , tons/year

$P_R(t)$ = breakeven price of refuse in period t , \$/ton

$O(t)$ = other operating costs in period t , \$/year

S = revenue for sale of recovered energy, \$/year

I = necessary investment, \$

To keep the analysis tractable, assume that refuse quantities, and prices and operating costs (in constant, mid-1975 dollars) remain constant with time.⁶ Then

$$S - q_R P_R - O = CRF(i, n) \cdot I$$

where $CRF(i, n)$ is the capital recovery factor at interest rate i and time horizon n . However, since the required investment is a function of the size of the facility, say in tons of refuse per year, the breakeven refuse price will also be a function of q_R . Hence, dividing by q_R yields

$$\frac{S}{q_R} - P_R - \frac{O}{q_R} = CRF(i, n) \cdot \frac{I(q_R)}{q_R}$$

but S/q_R is the revenue for sale of recovered energy per ton of refuse, and can also be written in the form

$$\frac{S}{q_R} = P_E E$$

where P_E is the price of energy (say in \$/10⁶ Btu) and E is the energy yield, (in 10⁶ Btu/ton) as derived, for example, in Chapter

IV above. O/q_R is the operating cost per ton, say O' . And, from Eq. [1],

$$\frac{I(q_R)}{q_R} = I'(q_O) \left(\frac{q_R}{q_O} \right)^{b-1} \quad [2]$$

where $I'(q_O)$ is the known capital cost per ton at capacity q_O , hence

$$P_R = P_E E - O' - CRF(i,n) I'(q_O) \left(\frac{q_R}{q_O} \right)^{b-1} \quad [3]$$

Note that this breakeven price, even though a function of q_R , is not strictly a demand function in the conventional sense.⁷ In particular, the assumption has been made that the price of energy is constant, and is unaffected by q_R -- an assumption that is valid only if the quantity of energy delivered by the new refuse conversion source is too small to affect market conditions.

5.2 Breakeven Prices for Refuse Fuel

Direct firing: consider first the case in which municipal refuse is directly fired in a utility boiler, and the municipality owns and operates the refuse processing facility, and sells the prepared refuse to the utility in a form ready for combustion. From the utility's viewpoint, the fuel savings (which equals the cost of coal that is replaced by the refuse, minus the cost of refuse) must at least offset capital and operating costs, in accordance with the foregoing discussion. Thus, the utility's breakeven cost is given by

$$q_C P_C - q_R P_R - O_u = CRF(i_u, n) I_u(q_R).$$

where q_c = Quantity of coal replaced by refuse, tons/year
 p_c = Price of coal, \$/ton
 q_R = Amount of refuse burned, tons/year
 p_R = Breakeven price of refuse, \$/ton
 O_u = Incremental operating costs, \$/year
 I_u = Capital cost of boiler modifications, \$

But one ton of coal is equivalent to h_c/nh_R tons of refuse, where n is the combustion efficiency of refuse, and h_c and h_R are the heat values of coal and refuse, respectively. If one sets $n = .85$, $h_c = 12020$ Btu/lb, $h_R = 5000$ Btu/lb, then $q_c = q_R/2.82$, and

$$\begin{aligned}
 p_R &= \frac{p_c \frac{q_R}{2.82} - O_u - I_u(q_R) \text{CRF}(i_u, n)}{q_R} & [4] \\
 &= \frac{p_c}{2.82} - O'_u - \text{CRF}(i_u, n) I'_u(q_R)
 \end{aligned}$$

where O'_u is the operating cost in \$/ton and I'_u is the capital cost in dollars per ton of yearly capacity, at capacity q_R .

Estimates of O'_u and I'_u are available from the 1972-1973 St. Louis Demonstration Project; namely $O'_u = 0.118$ and $I'_u = 3.55$.⁸ If one uses the 1972 coal cost at the St. Louis Meramec Plant of \$8.85/ton,⁹ and an interest rate of 10%, then

$$\begin{aligned}
 p_R &= \frac{8.85}{2.82} - .118 - 3.55 \times \text{CRF}(10\%, 20\text{yr}) \\
 &= \$2.60/\text{ton}
 \end{aligned}$$

where $\text{CRF}(10\%, 20\text{yr}) = 0.1175$

This implies that the utility would find it economic to invest in the necessary boiler modifications, and burn refuse as a supplementary fuel, at any refuse cost to the utility lower than \$2.60/ton. If the utility had to pay more than this, the conversion would be uneconomic, and presumably would not be undertaken. On the other hand, if the price to the utility is less, then the implied rate of return on investment would be higher than the interest rate assumed in Eq.[4]. This latter situation has some interesting interpretations, discussed further in section 5.5.

If it is assumed that delivery of municipal refuse to a utility boiler costs the same as delivery to an alternative disposal site, then the breakeven price for the municipality (which would justify investment in, and operation of, a facility that processes refuse for sale as a boiler fuel) is obtained by balancing the savings in disposal cost plus the revenue from sale of the refuse against the additional operating and capital recovery costs. Thus,

$$q_R (P_D + P_R) = O_m + CRF(i_m, n) I_m(q_R)$$

or

$$P_R = \frac{CRF(i_m, n) I_m(q_R) + O_m - q_R P_D}{q_R} \quad [5]$$

where I_m = Capital cost of the processing facility, \$

i_m = Interest rate to the municipality, say 6%/year

P_D = Alternative disposal cost (= \$5.17/ton in St. Louis in 1972-73)

O_m = Operating cost of the processing facility, \$/year

On the basis of the 1972-73 St. Louis cost data

$$P_R = 14.16 \times \text{CRF} (6\%, 20\text{yr}) + 3.65 - 5.17 = \$-0.28/\text{ton}$$

which implies that the breakeven price is a disposal fee to the utility of 28¢ per ton. A considerable difference between the two breakeven prices is evident. Union Electric (in St. Louis) was receiving the refuse free of charge, which clearly made the arrangement profitable to the municipality.

In view of this wide discrepancy, perhaps the proper valuation of the refuse should be such that the rate of return on investment for both municipality and utility is the same, say ρ . Then

$$q_R \left(\frac{P_C}{2.82} - P_R \right) - O_u = \rho I_u$$

and

$$q_R (P_D + P_R) - O_m = \rho I_m$$

solving for ρ

$$\begin{aligned} \rho &= \frac{q_R \frac{P_C}{2.82} - O_u + q_R P_D - O_m}{I_u + I_m} = \frac{\frac{P_C}{2.82} + P_D - O'_u - O'_m}{I'_u + I'_m} \\ &= \frac{3.13 + 5.17 - 3.76}{17.71} = 0.256 \end{aligned}$$

Inserting this into Eq.[5] yields

$$P_R = .256 \times 14.16 + 3.65 - 5.17 = \$2.10/\text{ton}$$

Note that this is not simply the average of the two previously

calculated breakeven prices, because the interest rate for the utility in Eq.[4], and that for the municipality as used in Eq.[5], are different.

In the case that the utility accepts raw refuse, so that the utility rather than the municipality owns and operates transfer stations and size reduction and inerts separation facilities, the fuel savings must again be at least equal to the investment costs:

$$\frac{q_R}{2.82} P_C - q_R P_R - (O_u + O_m) = CRF(i,n) (I_u + I_m)$$

hence

$$P_R = \frac{P_C}{2.82} - CRF(i,n) (I'_u + I'_m) - (O'_u + O'_m)$$

If the 1972-73 St. Louis data are used again, with an interest rate of 10% over 20 years, then

$$P_R = \frac{8.85}{2.82} - 0.1175 \times 17.71 - 3.768 = \$ -2.70/\text{ton}$$

suggesting that the utility must be paid a disposal fee of at least \$2.70/ton. Since the city would otherwise incur a \$5.71/ton cost for incineration, equity would suggest the utility be paid

$$\frac{5.71 + 2.70}{2} = \$4.20/\text{ton}$$

thereby giving both partners equal savings.

Figure 11. Coal prices, \$/ton, delivered to steam-electric plants.

An update to post-embargo coal prices in the Northeast shows a sharp rise in the breakeven price for refuse fuel. Figure 11 shows the average contract price for coal delivered to coal burning steam-electric plants in northeastern states having such plants.¹⁰ Note the wide variations: ranging from \$14 to \$32/ton in early 1974 to \$22 to \$42/ton in May 1975.¹¹ If one uses the Union Electric capital cost estimate of \$70 million for an 8000 tpd plant, and assumes utility ownership and operation of processing facilities and a coal cost of \$40/ton, then the breakeven refuse price to the utility is

$$P_R = \frac{40}{2.82} - 3.768 - \text{CRF}(10\%, 20 \text{ yr}) \times 23.97 = \$7.60/\text{ton}.$$

With the assumption of an 8000-tpd plant, no adjustment was made for scale effects because the cost of modifying boilers is not subject to the same scale economies as the cost of building an integrated process plant.

Figure 12. Breakeven refuse price.

Figure 12 illustrates the impact of delivered coal cost on the breakeven refuse price. Although P_R is a function of interest rate lowering the rate to 6% would make only a small difference (bringing P_R to \$8.32/ton for $P_C = \$40/\text{ton}$). The range of breakeven prices in the Northeast, based on May 1975 delivered coal costs, varies from \$1/ton to \$8/ton. Note, however, that these do not include any credit for sale by the utility of the ferrous metal or inert fraction, which would make the breakeven price somewhat higher.

The breakeven cost computed above is that of refuse delivered to the generating plant. However, a full economic analysis must also take account of the cost of bringing the refuse from its source to the plants, a haul cost that may be quite substantial if the plant is not near the center of population; the cost can also be high if refuse must be hauled over long distances for alternative disposal.

As noted in Section 5.4., the haul costs are typically in the range \$2 to \$10/ton, and they can be used to generate a set of curves (Figure 13) that parallel the breakeven price curve of Figure 12.

Figure 13 can best be explained by reference to some hypothetical examples. Consider first a municipality with a disposal cost of \$2/ton, say by sanitary landfill, located in Pennsylvania, where the delivered coal price is \$21/ton (point A in Figure 13). At this coal price, the utility's breakeven price is \$1/ton. If the municipality's haul cost for delivery to the utility is \$10/ton, then landfill remains cheaper than energy recovery, but if this haul cost is only \$2/ton, then energy recovery is preferable. At point B, typical for a municipality in Massachusetts, and faced with a disposal cost by incineration of \$8/ton, and a higher coal cost, energy recovery is economic if haul costs do not exceed \$13/ton.

Figure 13. Decision-diagram for direct refuse firing.

Gas Pyrolysis Consider next the options for converting refuse to gas. Here, the proceeds of gas sales must recover the investment costs, operating costs, and refuse fuel costs. Thus,

$$q_R \epsilon P_G - O_G - I_G(q_R) \text{ CRF}(i,n) - P_R q_R = 0$$

where P_G = Natural gas price, \$/million cubic feet (mcf)

ϵ = Gas yield, mcf/ton of refuse

O_G = Operating costs, \$/year

I_G = Capital costs at capacity q_R , \$

Converting this to the per ton form, and solving for P_R , then

$$P_R = \epsilon P_G - O'_G - I'_G \text{ CRF}(i,n)$$

With the use of Schulz's 1975 estimates, $I_G(200 \text{ tpd}) = \$4.74$ million and $O'_G = \$5.51/\text{ton}$,¹² application of Eq. [2] to the 1000 tpd (300 x 1000 tpd) level yields

$$\begin{aligned} I'_G(1000 \text{ tpd}) &= \frac{4.74 \times 10^6}{200 \times 300} \left(\frac{1000}{200} \right)^{-0.3} \\ &= \$48.75/\text{ton} \end{aligned}$$

hence, if the gas price is \$0.80/mcf (\$.080/10⁶ Btu) and the gas yield 5.5 x 10⁶ Btu/ton (see Section 4.3), then

$$P_R = 5.5 \times 0.80 - 5.51 - 48.75 \times \text{CRF}(10\%, 20 \text{ yr}) = \$-6.89/\text{ton}.$$

Figure 14. Decision diagram for gas pyrolysis.

Figure 14 shows the decision diagram for the Purox pyrolysis process, derived in the same way as that for direct firing. However, because this process is much more capital intensive and therefore the interest rate is more important, curves are shown for rates of both 6 and 10%. For this process, scale economies must also be considered explicitly; curves are therefore shown for capacities of 500, 1000, and 2000 tpd (corresponding, at a 3.5 lb/cap/day refuse generation rate, to cities with populations of about 286, 571, and 1143 thousand, respectively). Note that decreases in interest rates and increases in plant size result in upward, parallel shifts of the breakeven cost curve.

Current information on wholesale prices for natural gas is difficult to obtain on a regionally disaggregated basis, and the most recent regional data are for 1974.¹³ The FPC publishes, however, monthly reports on prices of gas delivered to electric generating plants, which may serve as a standard in estimating the value of gas recovered from refuse. FPC data for May 1975 show the following delivered prices in ¢/10⁶ Btu:¹⁴

	<u>Interruptible</u>	<u>Firm</u>
Massachusetts	126.2	--
Vermont	106.0	--
New Jersey	92.8	--
New York	99.3	--
Pennsylvania	---	173.0
Delaware	144.0	--
New Hampshire	101.1	--
Maryland	---	111.5

With gas prices in this range, the breakeven refuse price, say for a 1000-tpd facility, is between -5.75 and zero \$/ton, which is significantly lower than the current range of incineration costs in the Northeast (about \$15/ton for a new incinerator meeting strict air quality standards) even with haul costs added to it.

Oil Pyrolysis In contrast to delivered coal prices, the prices of No. 6 fuel oil delivered to steam electric plants in the Northeast shows relatively little variation, as seen from the May 1975 FPC statistics:¹⁵

	<u>\$/bbl</u>	<u>¢/10⁶ Btu</u>
Connecticut	12.48	206.5
Massachusetts	12.55	205.2
New Hampshire	11.35	183.8
New Jersey	12.78	214.8
New York	11.95	196.3
Pennsylvania	12.67	207.6
Delaware	11.37	182.0
District of Columbia	12.61	205.5
Maryland	11.21	181.3

Since oil produced by the Garrett pyrolysis process is suitable only as a fuel in utility boilers,¹⁶ the above prices can be used as a measure of energy recovery credits. Thus,

$$P_R = \lambda P_O - O'_P - I'_P \text{ CRF}(i,n)$$

where λ = oil yield, 10⁶ Btu/ton of raw refuse

P_O = fuel oil prices, \$/10⁶ Btu

O'_P = operating cost, \$/ton

I'_P = capital cost per ton of yearly capacity, \$/ton

hence, if one sets $\lambda = 4.87$, and $P_0 = \$2.00/10^6$ Btu, and uses the MRI¹⁷ 1972 cost estimate at the 1000 tpd level of \$12.34 million, then

$$P_R = 4.87 \times 2.0 - 5.78 - \frac{12.34 \times 10^6}{3 \times 10^5} \frac{182}{137.2} \text{CRF}(10\%, 20 \text{ yr})$$

$$= \$-2.63/\text{ton}$$

The breakeven refuse price curve for this process is shown in Figure 15.

The best basis for an economic analysis of steam generation from refuse is the 440,000 ton/year plant now under construction in Saugus, Massachusetts. This facility has an equivalent energy recovery value (see Section 4.4) of 3.95×10^{12} Btu/yr. Hence, the yield per ton, in 10^6 Btu/ton of raw refuse, is

$$\frac{3.95 \times 10^6}{440,000} = 8.97$$

The total capital cost has been estimated at \$30 million.¹⁸ Using Eq. [1] to scale the project down to 1000 tpd yields a capital cost of

$$30 \times 10^6 \left(\frac{1000}{1200} \right)^{0.7} = \$26.3 \text{ million.}$$

Hence, the cost in \$/ton of yearly capacity is \$93.66,¹⁹ and the breakeven refuse price computes to

$$P_R = 8.97 \times 2.0 - 5.78 - 93.66 \times \text{CRF}(10\%, 20 \text{ yr})$$

$$= \$2.12/\text{ton}$$

The breakeven price curve for steam generation using the Von Roll process is also shown in Figure 15.

5.3 Process Comparisons

Figure 16 summarizes the above results, showing the breakeven refuse prices for each of the energy recovery options: 1000-tpd plant size and 10% interest rate are assumed, and all fuel prices have been converted to $\$/10^6$ Btu.

Several conclusions can be drawn at this point. The most striking is that direct firing in utility boilers is by far the best energy recovery option. It presupposes, however, that coal-fired boilers are available for conversion, which is not true for all SMSAs. The next best option is steam generation for industrial process heat, but this is not universally applicable either, as it presupposes a large industrial process steam user reasonably near a sizable population concentration and having an adjacent site for the energy conversion facility (so that heat losses and steam transmission costs can be kept to economic levels).

The data in Figure 16 imply that a municipality forced to incineration, which is likely to cost \$15 to \$20/ton because of air pollution standards, will almost certainly elect to use some energy recovery process.²⁰ Even if neither direct firing nor steam generation is possible, one of the pyrolysis technologies will still result in a lower disposal cost than incineration.

In the absence of a coal-fired plant that can be converted to refuse firing or a large industrial process steam user, the economic advantage for a city projecting continued disposal by sanitary landfill will probably depend on the incremental haul cost. A city with, say a \$3/ton landfill cost, and an incremental haul penalty of

Figure 15. Breakeven refuse price for oil pyrolysis and steam generation.

Figure 16. Process comparisons.

\$2/ton, would find neither pyrolysis process attractive at current energy prices. If there were no haul penalty, however, then the situation would be changed somewhat. Moreover, depending on the interest rate and capacity size, the breakeven refuse price curves shift vertically, which means that the decision problem may be quite complex.

If it is assumed that oil and coal prices will stay at their current levels (in constant dollars) but gas will be deregulated, then a significant rise in gas prices would be expected, particularly in the face of supply shortages in the Northeast. A scenario with gas prices rising to \$2 to \$3 per 10^6 Btu would thus appear quite reasonable, and at this point gas pyrolysis or bioconversion would be economic for all but the most severe haul cost penalty.

Likely energy conversion scenarios are further discussed in Chapter IX.

5.4 Haul Costs

Haul cost differentials are due to locational factors: if a refuse-burning utility boiler is further away from the center of population than the alternative disposal site, then an additional haul cost will be incurred. But the haul cost differential favors the energy recovery method if the utility boiler is in or near the center of the city so that it is cheaper for the collection trucks to deliver there than to a landfill, typically on the outskirts of the city.

The problem is complicated by alternative methods of bringing refuse to the energy recovery facility or alternative disposal site. The simplest procedure is for the collection vehicles to be driven directly to the disposal site (leaving all crew but the driver in the collection area, where they might typically be assigned to clean lots or sweep streets until the empty truck returns to continue collection). Alternatively, the collection vehicles are driven to

--- or more centrally located transfer stations, and large tractor-ailers are used for the trip to the disposal site; this is preferable if the disposal site is far from the central city. Generalized cost functions for these two alternatives are derived in Appendix C.

If one assumes a radially symmetric city with an exponential population density gradient, then direct haul in collection vehicles to a site at distance ℓ from the city center, results in an average haul cost per ton that is a function of the radius, R , to which refuse is collected, namely²¹

$$C_s(R) = \frac{\gamma_h}{t} \frac{1}{s} \frac{4\alpha^2}{\pi} \frac{\int_0^R r(r + \ell) e^{-\alpha r} E\left(\frac{2\sqrt{r\ell}}{r + \ell}\right) dr}{1 - (1 + \alpha R) e^{-\alpha R}} + \frac{\gamma_{h_u}}{t} \quad [6]$$

where $C_s(R)$ = average haul cost, \$/ton, in a city of radius R

γ_h = hourly cost of operation of collection vehicle, \$/hour

t = truck capacity, tons

s = average truck speed, mph

α = density gradient of SMSA, mile⁻¹

u = unloading time, in hours

$E(x)$ = a complete elliptical integral of the second kind

In the special case of a destination at the city center this can be shown to reduce to²²

$$C_s(R) = \frac{\gamma_h}{t} \frac{1}{s} \frac{2}{\alpha} \left[\frac{2 - (2 + 2\alpha R + \alpha^2 R^2) e^{-\alpha R}}{1 - (1 + \alpha R) e^{-\alpha R}} \right] + \frac{\gamma_{h_u}}{t}$$

The assumption that population distribution in an urban area is adequately characterized by an exponential decline with distance from the city center is discussed elsewhere.²³

Alternatively, if a transfer station at a distance ℓ from the city center is used, and with the disposal destination at distance h from the center, the average cost per ton can be shown to be given by²⁴

$$C_s(R) = \frac{\gamma_h}{t} \frac{1}{s} \frac{4\alpha^2}{\pi} \frac{\int_0^R r(r + \ell) e^{-\alpha r} E\left(\frac{2\sqrt{r\ell}}{r + \ell}\right) dr}{1 - (1 + \alpha R) e^{-\alpha R}} + \frac{\gamma_h}{t} u$$

$$+ \frac{\gamma^*}{t^*} \left[\frac{2(h - \ell)}{s^*} + u^* \right] + \frac{33.4}{\left[\frac{2\pi\alpha}{260\alpha^2} [1 - (1 + \alpha R) e^{-\alpha R}] \right]^{0.55}} \quad [7]$$

where γ^* = hourly cost of operating transfer vehicle, \$/hr

t^* = transfer vehicle capacity, tons

s^* = transfer vehicle speed, mph

u^* = loading and unloading time, hours

For a given disposal site, Eq. [7] can be used to determine the optimal transfer station location simply by solving for a series of values of ℓ . The cost of the optimal transfer system can then be compared with that of the optimal direct haul system computed from Eq. [6], and the lower of the two determines which system is chosen. By carrying out this procedure for hauling both to the energy recovery site and to the conventional disposal site, the haul penalty is easily determined.

Two points need to be stressed. First, haul cost as defined here includes all costs incurred by the collection vehicles except that during actual house-to-house collection; it thus comprises the costs of travel from the end of a collection route (when the truck is full), to the disposal (or transfer station) site, unloading time, and travel back to the beginning of the next collection route.

cond, the procedure outlined above for the determination of haul cost penalty assumes that R is known: in the general case one simply sets R equal to the average radius of the urban area in question, from which the average costs can be computed directly with the above equations. The amount of refuse collected within the radius R is derived in Appendix B, and can be shown to equal²⁵

$$Q(R) = \frac{.1825 q_o d_o^{1+\beta} \theta}{\alpha^2} \left(1 - (1 + \alpha R) e^{-\alpha R} \right)$$

where q_o = per capita waste generation, lbs/cap/day

d_o = population density at the city center, persons/sq. mi.

β = parameter characteristic of the variation of waste generation with population density

θ = sector angle (defined in Meier & McCoy, Note 22)

At this point the breakeven refuse price can be reconsidered. Assume that an urban area has no coal-fired plants and no potential industrial user of process steam. Further, let the price of gas be $80¢/10^6$ Btu and of oil $200¢/10^6$ Btu, and let the alternative disposal cost be \$5/ton, say by sanitary landfill. These two points are shown as X and Y in Figure 16. Since Y lies above the gas pyrolysis curve, the alternative disposal method (landfilling) will be cheaper unless it costs less (by at least \$1.84/ton) to haul refuse to the gas pyrolysis facility than to the landfill. Similarly, oil pyrolysis will be economic only if the haul cost differential is less than about \$2.55/ton.

However, Eqs. [6] and [7] show that the haul cost differential is a function of R (and hence of the amount of refuse delivered to the facility); the average haul cost will increase as refuse is brought in from greater distances. The question is, how much

refuse in any given area will in fact be converted to energy in that area? It is shown in Appendix D that R is the distance for which the breakeven refuse price plus the alternative disposal cost equals the haul cost; in the simplest case, namely, an energy conversion facility at the city center with direct delivery of refuse in collection vehicles, the optimal distance R^* is given by

$$R^* = \frac{ts(P_R + P_D)}{2\gamma_h} - \frac{us}{2} \quad [8]$$

and the corresponding quantity of refuse converted to energy is given by

$$Q(R^*) = \frac{.1825q_o d_o^{1+\beta}}{\alpha^2} \left(1 - (1 + \alpha R^*)e^{-\alpha R^*} \right) \quad [9]$$

For typical values of the parameters of Eq. [8], R^* can be expressed as a function of P_R and P_D ; for example, if $t = 5.5$ tons, $s = 15$ mph, $u = .25$ hrs, and $\gamma_h = \$20/\text{hour}$

$$\begin{aligned} R^* &= \frac{5.5 \times 15}{2 \times 20} P_R + \frac{5.5 \times 15}{2 \times 20} P_D - \frac{.25 \times 15}{2} \\ &= 2.06 P_R + 2.06 P_D - 1.875 \end{aligned}$$

In the decision diagram of Figure 16, point X is given by $P_R = -2.5$, $P_D = 5.0$; hence for gas pyrolysis

$$\begin{aligned} R^* &= -5.15 + 10.3 - 1.875 \\ &= 3.27 \text{ miles} \end{aligned}$$

This is a rather small distance, implying that it would be worthwhile to collect the refuse for energy recovery only from the very central part of the city where the population concentration is high. But if the same town had a coal fired utility boiler, for which P_R is \$6/ton, then R^* computes to

$$R^* = 12.36 + 10.3 - 1.875 = 20.78 \text{ miles}$$

implying that it would be worthwhile to go well out to suburbia to collect refuse for burning at a centrally located utility boiler.

5.5 Results for Northeastern SMSA's

The preceding analysis has been considerably simplified in order to illustrate the principles involved. Two major simplifications need be addressed. First, it was assumed in Eq. [9] that P_R is constant; but it was stated previously that P_R is a function of scale economies. In fact, Eq. [3] should be substituted into Eq. [8] to yield

$$R^* = \frac{ts}{2r_h} \left\{ P_E^E - 0' - CRF(i,n) \left[\frac{I'(q_o)}{q_o^{b-1}} \right] Q(R^*)^{b-1} \right\} + \frac{ts}{2r_h} P_D - \frac{us}{2}$$

which must be solved simultaneously with Eq. [9].

The second assumption, implicit in the derivation of Eq. [8] in Appendix D, is that there is no haul cost for refuse not delivered to the energy recovery facility, i.e., for refuse generated beyond the distance R^* . This assumption is not unrealistic if R^* is larger than the radius of the central city. In the typical urban area of the Northeast, municipal house-to-house collection exists only in the central city; in the suburbs disposal is by individuals

delivering to a landfill or by private contractors on an ad hoc basis. Since the disposal sites in the typical suburb tend to lie within that suburb, haul costs (as defined here) tend to be low.

Since efficient refuse collection exists primarily in urban areas, the SMSA (standard metropolitan statistical area) is used here as the basis for detailed estimates of parameters of refuse-to-energy conversion. Tables 9 through 12 show the optimum collection radius R^* for all Northeastern SMSAs and all non-SMSA urbanized areas of more than 25,000 population. Tables 9 and 10 show the 1972 base year results for direct refuse firing in a centrally located utility boiler, for an alternative disposal cost of \$5 and \$15/ton, respectively, corresponding to landfill and incineration disposal. Tables 11 and 12 give similar data for gas conversion (pyrolysis or bioconversion).

Several conclusions can be drawn from these tables. Note, first, that the optimal radius exceeds the SMSA radius in all cases for direct firing at an alternative disposal cost of \$15.00/ton (Table 10). This implies that it would be worth while to burn all of the refuse generated in these areas. If the alternative disposal cost falls to \$5.00/ton (Table 9) the optimal recovery radius for some SMSA's (marked with an X) is less than the SMSA radius which implies that only part of the SMSA would be included in an energy recovery project. Note that the optimal radius is greater than the central city radius (R_{CC}), as indicated in the earlier discussion.

Table 11 shows that gas pyrolysis would not be economic in any SMSA if the alternative disposal cost is \$5.00/ton. However, if it rises to \$15.00/ton (Table 12), only those SMSAs (marked X) for which the optimum radius is less than the SMSA radius would not include all refuse in a recovery system.

Table 9

OPTIMUM RADIUS FOR ALTERNATIVE
DISPOSAL AT \$5.00/TON

DIRECT FIRING IN UTILITY BOILERS, PE=GOAL PRICE,\$/TON					
SMSA	R*	R-SMSA	R-CC	PR	PE
ALBANY SCHEN	20.5X	26.6	3.6	3.3	28.0
ALLNTWN BET	14.6X	18.6	3.7	1.2	22.0
ALTOONA	14.6	13.0	1.7	1.2	22.0
ATLANTIC CIT	33.1	19.0	2.8	8.0	41.0
BALTIMORE	10.7X	35.1	6.5	6.9	38.0
BINGHAMPTON	20.5X	25.7	1.9	3.3	28.0
BOSTON	24.4	19.9	4.3	4.8	32.0
BRIDGEPORT	24.4	11.1	2.3	4.8	32.0
BRISTOL	24.4	4.0	2.9	4.8	32.0
BROCKTON	24.4	7.2	2.6	4.8	32.0
BUFFALO	20.5X	26.0	4.2	3.3	28.0
ERIE	14.6X	22.8	2.5	1.2	22.0
FALL RIVER	24.4	13.5	3.2	4.8	32.0
FITCH LEO	24.4	7.3	4.2	4.8	32.0
HARRISBURG	14.6X	32.2	1.6	1.2	22.0
HARTFORD	24.4	14.6	2.4	4.8	32.0
JERSEY CITY	33.1	5.5	3.1	8.0	41.0
JOHNSTOWN	14.6X	23.8	1.4	1.2	22.0
LANCASTER	14.6X	17.4	1.5	1.2	22.0
LAW#HAVERHIL	24.4	8.1	3.5	4.8	32.0
LEWIS#AUBURN	24.4	6.1	3.3	4.8	32.0
LOWELL	24.4	7.0	2.1	4.8	32.0
MANCHESTER	24.4	6.7	3.2	4.8	32.0
MERIDEN	2.8	2.8	2.8	4.8	32.0
NASHUA	3.3	3.3	3.2	4.8	32.0
N.BEDFORD	24.4	6.7	2.5	4.8	32.0
N.BRITAIN	24.4	5.3	2.1	4.8	32.0
N.HAVEN	24.4	9.1	2.5	4.8	32.0
N.LNDON#GRNT#	24.4	10.9	3.2	6.8	32.0
N.YORK	20.5X	16.9	13.8	3.3	28.0
NEWARK	33.1	14.9	2.7	8.0	41.0
NORWALK	24.4	6.6	3.7	4.8	32.0
PTRSN#CLIFT#	33.1	23.3	2.7	8.0	41.0
PHILADELPHIA	14.6X	33.6	6.4	1.2	22.0
PITTSBURG	14.6X	31.2	4.2	1.2	22.0
PITTSFIELD	24.4	6.7	3.6	4.8	32.0
PORTLAND	24.4	10.6	3.2	4.8	32.0
PROVONCEPAN#	24.4	15.1	4.6	4.8	32.0
READING	14.6X	16.6	1.8	1.2	22.0
ROCHESTER	20.5X	36.4	4.6	3.3	28.0
SCRANTON	14.6	12.0	2.9	1.2	22.0
SPFD#HOL#CHI	24.4	13.0	4.9	4.8	32.0
STAMFORD	24.4	6.8	4.9	4.8	32.0
SYRACUSE	20.5X	27.8	2.9	3.3	28.0
TRENTON	33.1	12.1	2.2	8.0	41.0
UTICA#ROME	20.5X	29.1	5.3	3.3	28.0
VINELAND	33.1	12.6	4.7	8.0	41.0
WASHINGTON	22.4X	27.4	4.4	4.1	30.0
WATERBURY	24.4	8.3	3.0	4.8	32.0
WLS#BA#HAZE	14.6X	16.8	2.0	1.2	22.0
WILMINGTON	15.6X	27.2	2.0	1.6	23.0
WORCESTER	24.4	12.3	3.5	4.8	32.0
YORK	14.6X	21.4	1.3	1.2	22.0
BURLINGTON(*)	24.4	18.4	1.8	4.8	32.0
NEWPORT(*)	24.4	12.1	2.2	4.8	32.0
NEWCASTLE(*)	14.6	10.8	1.6	1.2	22.0
STATE COLLEG	14.6X	18.8	1.2	1.2	22.0
WILLIAMSPORT	14.6X	19.7	1.7	1.2	22.0
LEBANON(*)	14.6	10.8	1.2	1.2	22.0
DANBURY	4.4	4.4	3.7	4.8	32.0
JAMESTOWN(*)	20.5	18.6	1.7	3.3	28.0
ELMIRA(*)	20.5	11.5	1.5	3.3	28.0
ITHACA(*)	20.5	12.4	1.3	3.3	28.0
AUBURN(*)	20.5	14.9	1.6	3.3	28.0
AMSTERDAM(*)	20.5	11.4	1.4	3.3	28.0
WATERTOWN(*)	20.5	26.3	1.7	3.3	28.0
KINGSTON(*)	20.5	19.1	1.6	3.3	28.0
NEWBURGH(*)	20.5	16.3	1.1	3.3	28.0
POUGHKEEPSIE	20.5X	22.8	1.8	3.3	28.0
LONG BRANCH	33.1	12.3	1.3	8.0	41.0
NE#PERTH#SAY	33.1	10.0	2.9	8.0	41.0
CONCORD(*)	24.4	17.2	4.5	4.8	32.0
GLoucester(*)	43.4	43.4	9.7	4.8	32.0
HAGERSTOWN(*)	30.2	12.0	1.6	6.9	38.0
CUMBERLAND(*)	30.2	16.5	2.3	6.9	38.0
BANGOR(*)	24.4X	32.9	3.3	4.8	32.0
TORRINGTON(*)	24.4	17.2	3.6	4.8	32.0
MIDDLETON(*)	24.4	10.9	3.7	4.8	32.0

Haul Cost Parameters

Truck size, tons (t) = 5.50
 Unload time, hr (u) = 0.25
 Average speed mph (s) = 20.00
 Optimum cost, \$/hr (γ_h) = 20.00

Table 10

OPTIMUM RADIUS FOR ALTERNATIVE
DISPOSAL AT \$15.00/TON

DIRECT FIRING IN UTILITY BOILERS, PE=COAL PRICE,\$/TON					
SMSA	R*	R-SMSA	R-CC	PR	PE
ALBANY SCHEN	48.0	26.6	3.6	3.3	28.0
ALLUTOWN RET	42.1	18.6	3.7	1.2	22.0
ALTONVA	42.1	13.0	1.7	1.2	22.0
ATLANTIC CIT	60.6	19.0	2.8	8.0	41.0
BALTIMORE	57.7	35.1	6.5	6.9	38.0
BINGHAMPTON	48.0	25.7	1.9	3.3	28.0
BOSTON	51.9	19.9	4.3	4.8	32.0
BRIDGEPORT	51.9	11.1	2.3	4.8	32.0
BRISTOL	51.9	4.0	2.9	4.8	32.0
BROCKTON	51.9	7.2	2.6	4.8	32.0
BUFFALO	48.0	26.0	4.2	3.3	28.0
ERIE	42.1	22.8	2.5	1.2	22.0
FALL RIVER	51.9	13.5	3.2	4.8	32.0
FITCH LEO	51.9	7.3	4.2	4.8	32.0
HARRISBURG	42.1	32.2	1.6	1.2	22.0
HARTFORD	51.9	14.6	2.4	4.8	32.0
JERSEY CITY	60.6	5.5	3.1	8.0	41.0
JONESTOWN	42.1	33.0	1.1	1.2	22.0
LANCASTER	42.1	17.1	1.6	1.2	22.0
LAWRENCEHIL	51.9	8.1	3.5	4.8	32.0
LEWIS & AUBURN	51.9	6.1	3.3	4.8	32.0
LOWELL	51.9	7.0	2.1	4.8	32.0
MANCHESTER	51.9	6.7	3.2	4.8	32.0
MERIDEN	2.8	2.8	2.8	4.8	32.0
NASHUA	3.3	3.3	3.2	4.8	32.0
N. REDFORD	51.9	6.7	2.5	4.8	32.0
N. BRITAIN	51.9	5.3	2.1	4.8	32.0
N. HAVEN	51.9	9.1	2.5	4.8	32.0
N. LONDON & GRTN	31.9	10.9	3.2	4.8	32.0
N. YORK	48.0	36.9	13.8	3.3	28.0
NEWARK	60.6	14.9	1.7	8.0	41.0
NORWALK	51.9	6.6	3.7	4.8	32.0
PATRICK CLIFT	60.6	23.3	2.7	8.0	41.0
PHILADELPHIA	42.1	33.6	6.4	1.2	22.0
PITTSBURG	42.1	31.2	4.2	1.2	22.0
PITTSFIELD	51.9	6.7	3.6	4.8	32.0
PORTLAND	51.9	10.6	3.2	4.8	32.0
PROVIDENCE & PAN	51.9	15.1	4.6	4.8	32.0
READING	42.1	16.6	1.8	1.2	22.0
ROCHESTER	48.0	36.4	4.6	3.3	28.0
SCRANTON	42.1	12.0	2.9	1.2	22.0
SPRINGHOL & CHI	51.9	13.0	4.9	4.8	32.0
STAMFORD	51.9	8.8	4.9	4.8	32.0
SYRACUSE	48.0	27.8	2.9	3.3	28.0
TRENTON	60.6	12.1	2.2	8.0	41.0
UTICA & PONE	48.0	29.1	5.3	3.3	28.0
VINELAND	60.6	12.6	4.7	8.0	41.0
WASHINGTON	49.9	27.4	4.4	4.1	30.0
WATERBURY	51.9	8.3	3.0	4.8	32.0
WILKES & WARE	42.1	16.8	2.0	1.2	22.0
WILMINGTON	43.1	27.2	2.0	1.6	23.0
WORCESTER	51.9	12.3	3.5	4.8	32.0
YORK	42.1	21.4	1.3	1.2	22.0
BURLINGTON(*)	51.9	18.4	1.8	4.8	32.0
NEWPORT(*)	51.9	12.1	2.2	4.8	32.0
NEWCASTLE(*)	42.1	10.8	1.6	1.2	22.0
STATE COLLEGE	42.1	18.8	1.2	1.2	22.0
WILLIAMSPORT	42.1	19.7	1.7	1.2	22.0
LEBANON(*)	42.1	16.8	1.2	1.2	22.0
DANBURY	4.4	4.4	3.7	4.8	32.0
JAMESTOWN(*)	48.0	18.6	1.7	3.3	28.0
ELMIRA(*)	48.0	11.5	1.5	3.3	28.0
ITHACA(*)	48.0	12.4	1.3	3.3	28.0
AUBURN(*)	48.0	14.9	1.6	3.3	28.0
AMSTERDAM(*)	48.0	11.4	1.4	3.3	28.0
HATFIELD(*)	40.0	20.3	1.7	3.3	28.0
KINGSTON(*)	48.0	19.1	1.6	3.3	28.0
NEWBURGH(*)	48.0	16.3	1.1	3.3	28.0
POUGHKEEPSIE	48.0	22.8	1.8	3.3	28.0
LONG BRANCH	60.6	12.3	1.3	8.0	41.0
NEW PETERHAY	60.6	10.0	2.9	8.0	41.0
CONCORD(*)	51.9	17.2	4.8	1.0	32.0
GLOUCESTER(*)	43.4	43.4	6.7	4.8	32.0
HAGERSTOWN(*)	57.7	12.0	1.6	6.9	38.0
CUMBERLAND(*)	57.7	16.5	2.3	6.9	38.0
RANDOLPH(*)	51.9	32.9	3.3	4.8	32.0
TORRINGTON(*)	51.9	17.2	3.6	4.8	32.0
MIDDLETOWN(*)	51.9	10.9	3.7	4.8	32.0

Note: For haul cost parameters
see Table 9.

Table 11

OPTIMUM RADIUS FOR ALTERNATIVE
DISPOSAL AT \$5.00/TON

GAS PYROLYSIS, PE=GAS PRICE, \$/MCF					
SMSA	R*	R-SMSA	R-CC	PR	PE
ALBANY SCHEN	0.0	26.6	3.6	-5.8	100.0
ALLNTWN BET	0.0	18.6	3.7	-5.8	100.0
ALTOONA	0.0	13.0	1.7	-5.8	100.0
ATLANTIC CIT	0.0	19.0	2.8	-6.2	93.0
BALTIMORE	0.0	35.1	6.5	-5.8	100.0
BINGHAMPTON	0.0	25.7	1.9	-5.8	100.0
BOSTON	0.0	19.9	4.3	-4.3	126.0
BRIDGEPORT	0.0	11.1	2.3	-4.3	126.0
BRISTOL	0.0	4.0	2.9	-4.3	126.0
BROCKTON	0.0	7.2	2.6	-4.3	126.0
BUFFALO	0.0	26.0	4.2	-5.8	100.0
ERIE	0.0	22.8	2.5	-5.8	100.0
FALL RIVER	0.0	13.5	3.2	-4.3	126.0
FITCH LEO	0.0	7.3	4.2	-4.3	126.0
HARRISBURG	0.0	32.2	1.6	-5.8	100.0
HARTFORD	0.0	14.6	2.4	-4.3	126.0
JERSEY CITY	0.0	5.5	3.1	-6.2	93.0
JOHNSTOWN	0.0	23.8	1.4	-5.8	100.0
LANCASTER	0.0	17.4	1.5	-5.8	100.0
LAW#HAVERHIL	0.0	8.1	3.5	-4.3	126.0
LEWIS#AUBURN	0.0	6.1	3.3	-4.3	126.0
LOWELL	0.0	7.0	2.1	-4.3	126.0
MANCHESTER	0.0	6.7	3.2	-5.4	106.0
MERIDEN	2.8	2.8	2.8	-4.3	126.0
NASHUA	3.3	3.3	3.2	-5.4	106.0
N.BEDFORD	0.0	-6.7	2.5	-4.3	126.0
N.BRITAIN	0.0	5.3	2.1	-4.3	126.0
N.HAVEN	0.0	9.1	2.5	-4.3	126.0
N.LNDN#ORTN#	0.0	10.9	3.2	-4.3	126.0
N.YORK	0.0	36.9	3.8	-5.8	100.0
NEWARK	0.0	14.9	2.7	-6.2	93.0
NORWALK	0.0	6.6	3.7	-4.3	126.0
PTRSN#CLIFT#	0.0	23.3	2.7	-6.2	93.0
PHILADELPHIA	0.0	33.6	6.4	-5.8	100.0
PITTSBURG	0.0	31.2	4.2	-5.8	100.0
PITTSFIELD	0.0	6.7	3.6	-4.3	126.0
PORTLAND	0.0	10.6	3.2	-4.3	126.0
PROVDNC#PAW#	0.0	15.1	4.6	-4.3	126.0
READING	0.0	16.6	1.8	-5.8	100.0
ROCHESTER	0.0	36.4	4.6	-5.8	100.0
SCRANTON	0.0	12.0	2.9	-5.8	100.0
SPFD#WOL#CHI	0.0	13.0	4.9	-4.3	126.0
STAMFORD	0.0	8.8	4.9	-4.3	126.0
SYRACUSE	0.0	27.8	2.9	-5.8	100.0
TRENTON	0.0	12.1	2.2	-6.2	93.0
UTICA#PHONE	0.0	29.1	5.3	-5.8	100.0
VINELAND	0.0	12.6	4.7	-6.2	93.0
WASHINGTON	0.0	27.4	4.4	-5.8	100.0
WATERBURY	0.0	8.3	3.0	-4.3	126.0
WLS#BA#HAZE	0.0	16.8	2.3	-5.8	100.0
WILMINGTON	2.0	27.2	2.3	-3.4	144.0
WORCESTER	0.0	12.3	3.5	-4.3	126.0
YORK	0.0	21.4	1.3	-5.8	100.0
BURLINGTON(*)	0.0	18.4	1.8	-5.4	106.0
NEWPORT(*)	0.0	12.1	2.2	-4.3	126.0
NEWCASTLE(*)	0.0	10.8	1.6	-5.8	100.0
STATE COLLEG	0.0	16.8	1.2	-5.8	100.0
WILLIAMSPORT	0.0	19.7	1.7	-5.8	100.0
LERANON(*)	0.0	10.8	1.2	-5.8	100.0
DANBURY	4.4	4.4	3.7	-4.3	126.0
JAMESTOWN(*)	0.0	18.6	1.7	-5.8	100.0
ELMIRA(*)	0.0	11.5	1.5	-5.8	100.0
ITHACA(*)	0.0	12.4	1.3	-5.8	100.0
AUBURN(*)	0.0	14.9	1.6	-5.8	100.0
AMSTERDAM(*)	0.0	11.4	1.4	-5.8	100.0
WATERTOWN(*)	0.0	20.3	1.7	-5.8	100.0
KINGSTON(*)	0.0	19.1	1.6	-5.8	100.0
NEWBURGH(*)	0.0	16.3	1.1	-5.8	100.0
POUGHKEEPSIE	0.0	22.8	1.8	-5.8	100.0
LONG BRANCH	0.0	12.3	1.3	-6.2	93.0
NB#PERTH#SAY	0.0	10.0	2.9	-6.2	93.0
CONCORN(*)	0.0	17.2	4.5	-5.4	106.0
GLOUCESTER(*)	43.4	43.4	9.7	-4.3	126.0
HAGERSTOWN(*)	0.0	12.0	1.6	-5.8	100.0
CUMBERLAND(*)	0.0	16.5	2.3	-5.8	100.0
BANGOR(*)	0.0	32.9	3.3	-4.3	126.0
TORRINGTON(*)	0.0	17.2	3.6	-4.3	126.0
MIDDLETOWN(*)	0.0	10.9	3.7	-4.3	126.0

Note: See Table 9 for haul cost parameters.

Table 12

OPTIMUM RADIUS FOR ALTERNATIVE
DISPOSAL AT \$15.00/TON

GAS PYROLYSIS, PE=GAS PRICE, \$/MCF

SMSA	P*	P-SMSA	P-CC	PR	PE
ALBANY SCHEN	22.9 X	26.6	3.6	-5.8	100.0
ALLNTNN BET	22.9	18.6	3.7	-5.8	100.0
ALTOONA	22.9	13.0	1.7	-5.8	100.0
ATLANTIC CIT	21.8	19.0	2.8	-6.2	93.0
BALTIMORE	22.9 X	35.1	6.5	-5.8	100.0
BINGHAMPTON	22.9 X	25.7	1.9	-5.8	100.0
BOSTON	26.8	19.9	4.3	-4.3	126.0
BRIDGEPORT	26.8	11.1	2.3	-4.3	126.0
BRISTOL	26.8	4.0	2.9	-4.3	126.0
BROCKTON	26.8	7.2	2.6	-4.3	126.0
BUFFALO	22.9 X	26.0	4.2	-5.8	100.0
ERIE	22.9	22.8	2.5	-5.8	100.0
FALL RIVER	26.8	13.5	3.2	-4.3	126.0
FITCH LEO	26.8	7.3	4.2	-4.3	126.0
HARRISBURG	22.9 X	32.2	1.6	-5.8	100.0
HARTFORD	26.8	14.6	2.4	-4.3	126.0
JEKSEY CITY	21.8	5.5	3.1	-6.2	93.0
JOHNSTOWN	22.9 X	23.8	1.4	-5.8	100.0
LANCASTER	22.9	17.4	1.5	-5.8	100.0
LAW#HAVERPHIL	26.8	8.1	3.5	-4.3	126.0
LEWIS#AUBURN	26.8	6.1	3.3	-4.3	126.0
LOWELL	26.8	7.0	2.1	-5.8	126.0
MANCHESTER	21.8	6.7	3.2	-5.8	100.0
MERIDEN	26.8	2.8	2.8	-4.3	126.0
NASHUA	3.3	3.3	3.2	-5.8	100.0
N. BEDFORD	26.8	6.7	2.5	-4.3	126.0
N. BRITAIN	26.8	5.3	2.1	-4.3	126.0
N. HAVEN	26.8	9.1	2.9	-4.3	126.0
N. LUNenburg	26.8	10.9	3.2	-4.3	126.0
N. YORP	22.9 X	36.9	13.8	-5.8	100.0
NEWARK	21.8	14.9	2.7	-6.2	93.0
NORWALK	26.8	6.6	3.7	-4.3	126.0
PATRICKLIFT#	21.8 X	23.3	2.7	-6.2	93.0
PHILADELPHIA	22.9 X	33.6	6.4	-5.8	100.0
PITTSBURG	22.9 X	31.2	4.2	-5.8	100.0
PITTSFIELD	26.8	6.7	3.6	-4.3	126.0
PORTLAND	26.8	10.6	3.2	-4.3	126.0
PROVINCETOWN	26.8	15.1	4.6	-4.3	126.0
READING	22.9	16.6	1.8	-5.8	100.0
ROCHESTER	22.9 X	36.4	4.5	-5.8	100.0
SCRANTON	22.9	12.0	2.9	-5.8	100.0
SPEO#HOL#CHI	26.8	13.0	4.9	-4.3	126.0
STAMFORD	26.8	8.8	4.9	-4.3	126.0
SYRACUSE	22.9 X	27.8	2.9	-5.8	100.0
TRENTON	21.8	12.1	2.2	-6.2	93.0
UTICA#ROME	22.9 X	29.1	5.3	-5.8	100.0
VINELAND	21.8	12.6	4.7	-6.2	93.0
WASHINGTON	22.9 X	27.4	4.4	-5.8	100.0
WATERBURY	26.8	8.3	3.0	-4.3	126.0
WILKS#BA#HAZE	22.9	16.8	2.0	-5.8	100.0
WILMINGTON	22.9 X	27.2	2.0	-3.4	144.0
WORCESTER	26.8	12.3	3.5	-4.3	126.0
YORK	22.9	21.4	1.3	-5.8	100.0
BURLINGTON(*)	23.6	18.4	1.8	-5.8	100.0
NEWPORT(*)	26.8	12.1	2.2	-4.3	126.0
NEWCASTLE(*)	22.9	10.8	1.6	-5.8	100.0
STATE COLLEGE	22.9	18.8	4.2	-5.8	100.0
WILLIAMSPORT	22.9	19.7	1.7	-5.8	100.0
LEBANON(*)	22.9	10.8	1.2	-5.8	100.0
DANBURY	4.4	4.4	3.7	-4.3	126.0
JAMESTOWN(*)	22.9	18.6	1.7	-5.8	100.0
ELMHURST(*)	22.9	11.5	1.5	-5.8	100.0
ITHACA(*)	22.9	12.4	1.3	-5.8	100.0
AUBURN(*)	22.9	14.9	1.4	-5.8	100.0
AMSTERDAM(*)	22.9	11.4	1.4	-5.8	100.0
WATERTOWN(*)	22.9	20.3	1.7	-5.8	100.0
KINGSTON(*)	22.9	19.1	1.6	-5.8	100.0
NEWBURGH(*)	22.9	16.3	1.1	-5.8	100.0
POUGHKEEPSIE	22.9	22.8	1.8	-5.8	100.0
LONG BRANCH	21.8	12.3	1.3	-6.2	93.0
NE#PE#TH#SAY	21.8	10.0	2.9	-6.2	93.0
CONCORD(*)	23.8	17.2	4.5	-5.8	100.0
GLOUCESTER(*)	43.4	43.4	9.7	-4.3	126.0
HAGERSTOWN(*)	22.9	12.0	1.8	-5.8	100.0
CUMBERLAND(*)	22.9	16.5	2.3	-5.8	100.0
BANGOR(*)	26.8 X	37.9	3.7	-4.3	126.0
TORRINGTON(*)	26.8	17.2	3.6	-4.3	126.0
MIDDLETOWN(*)	26.8	16.9	3.7	-4.3	126.0

Note: See Table 9 for haul cost parameters.

In summary, any urban area that has a coal-fired utility boiler within its radius should find it economic to dispose of its refuse by direct firing. If the alternative disposal method is sanitary landfill, some cities would find it economic to burn only part of their refuse at a utility boiler, but in all cases it appears that some part of urban refuse could be fired economically. Gas pyrolysis by either bioconversion or the Garrett process appears economic only if incineration is the alternative disposal method.

5.6 A Caveat

The results of this section, whatever their validity at a regional scale, must obviously be interpreted with some caution at the local level. The conclusion, for example, that firing of refuse as a supplementary fuel at coal-firing boilers appears on the basis of a strictly economic analysis to be the optimal choice does not imply that every utility would or should take this course. Obviously, some Northeastern utilities currently have no coal-fired plants nor have they plans to convert from oil to coal;²⁶ and surely our conclusion should not be taken as a recommendation that such utilities immediately make radical changes in their generation mix in order to utilize any available refuse. By the same token, many mine-mouth plants in western Pennsylvania are quite remote from the urban areas where most refuse is generated, and again we do not imply that refuse should be hauled uneconomic distances. The type of regional assessment undertaken here obviously is no substitute for case-by-case engineering analysis; yet, in the absence of such studies for each locality, regional analysis demands that certain generalizations be made if the effort of analysis is to be kept within reasonable bounds.

NOTES TO CHAPTER V

1. Midwest Research Institute, "Resource Recovery: The State of Technology", Report to the Council on Environmental Quality, Feb. 1973.
2. See below, Chapter VI.
3. See e.g., F. A. Holland, F. A. Watson, and J. K. Wilkinson, "How to Estimate Capital Costs", Chemical Engineering, April 1, 1974, p. 71.
4. Ibid, p. 73-74
5. As tabulated in recent issues of Chemical Engineering.
6. This assumption is not as unreasonable as may appear, because the agreements between entrepreneur and municipality typically span 15 to 25 years, guaranteeing supply arrangements and delivery prices over that time span. (See also Chapter VI, below).
7. In fact, a plot of P_R against Q_R would slope upwards rather than downwards.
8. See e.g., Horner & Shifrin, "Solid Waste as a fuel for Power Plants". U. S. EPA, 1973 (Published by NTIS, PB 220 316).
9. FPC, "Steam-Electric Plant Construction Cost & Annual Production Expenses", 25th Annual Suppl. - 1972, p. 84.
10. FPC News, Vol. 8, No. 37, (Sept. 12, 1975), p. 11.
11. Spot prices for the same period were between \$2 and \$4/ton higher.
12. H. W. Schulz, "Cost/Benefits of Solid Waste Refuse", Environmental Science & Technology, Vol. 9, No. 5, p. 423 (May 1975).
13. R. N. Langlois, A Perspective on the Energy Future of the Northeast: Natural Gas Supply, BNL 50558, Sept. 1975.
14. FPC News, Vol. 8, No. 38, p. 24, 32.
15. Ibid, p. 18.
16. See above, Section 3.3

7. Midwest Research Institute, Note 1, supra, at p. 40.
18. "Refuse to Energy Plant Uses First Von Roll Incinerators in U. S.", Environmental Science & Technology, Vol. 8, No. 8, p. 693 (Aug. 1974).
19. Assuming a standard industrial work week of six 24 hour days, as used, for example, in Midwest Research Institute, Note 1, supra.
20. The validity of this figure is evident also from Figure 16; if one assumes no energy recovery from the Von Roll incinerator equivalent to a zero fuel price, then the applicable breakeven refuse price is seen to lie at around \$17/ton, namely the intercept of the steam generation breakeven price curve.
21. Appendix C, Eq. [21].
22. Appendix C, Eq. [18].
23. P. M. Meier and T. H. McCoy, "An Analytical Approach to the Determination of Urban Population Density Gradients and its application to Energy Planning Problems," BNL 20916 (Jan. 1976), Policy Analysis Division, Brookhaven National Laboratory.
24. Appendix C, Equation [22].
25. Appendix B, Equation [14].
26. Long Island Lighting Company, for example, has no coal fired generating facility.

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CHAPTER VI

INSTITUTIONAL CONSTRAINTS

A number of institutional constraints hinder implementation of energy recovery from solid waste, particularly statutory provisions that impede a desired course of resource recovery. However, a municipality that can demonstrate resource recovery to be economically and environmentally attractive in solid waste management can generally muster the political support necessary to remove statutory obstacles. A good example is Nashville, Tennessee: preliminary investigation of the district heating concept for publicly owned downtown buildings showed that local gas and electric utilities did not have authority under the metropolitan charter to build or operate such a facility; therefore, a new organization, the Nashville Thermal Transfer Corporation, was chartered under Tennessee law in May 1970¹ and given the power to issue revenue bonds for construction.

A major difficulty is that in many cases municipal and county authorities are constrained by law from negotiating contracts that extend beyond the term of the incumbent administration. Yet private enterprise cannot be expected to assume the risk of investing its capital without the protection of long-term contracts to recover the investment and earn a reasonable profit. Utilities, for example, are accustomed to long-term contracts with their fuel suppliers. However, such obstacles can be easily bypassed, as witnessed by recent legislation in Connecticut which established a Resources Recovery Authority expressly empowered to negotiate long-term contracts for the entrepreneurial management of publicly owned resource recovery facilities.²

Other difficulties are less easily overcome. A utility, before it modifies its boilers for supplementary refuse burning, needs some assurance of guaranteed supply, particularly in view of the prolonged sanitation men's strikes that have occurred in several large cities in the recent years. One solution may be a State agency guaranteeing the refuse supply and providing cash payments or covering the haul cost from a more distant location in the event of a major disruption of refuse supply. Scheduling also poses problems as refuse is normally collected only five days/week whereas power generation is usually a continuous seven-day/week operation. Storage facilities to cover weekend periods could be provided, or refuse could be burned only on weekdays (but the latter incurs a penalty due to underutilization of the modifications to the boilers and feeding equipment). On the other hand, in a number of large cities the electricity (or steam) demand is considerably lower on weekends than on weekdays.³

Most of the resource recovery options require some prior processing of the refuse, at least shredding and removal of magnetic materials. The question is who should build, own, and operate the facilities for this. In the case of direct burning of refuse in utility boilers, the consensus is that it should be the municipality which could then offer the utility a fuel ready for burning.

Recent developments suggest that the most promising approach may involve a private-sector middleman. For example, Jersey Central Power and Light (JCP&L) recently announced an agreement with Energy Systems, a division of Wheelabrator-Frye that holds the U.S. rights to the Swiss developed Von Roll incinerator design.⁴ Under the 25-year agreement, Energy Systems will design, build, own, and operate the refuse-to-energy facility; and JCP&L will build a nearby substation and guarantees to purchase the power at a "price competitive with the utility's alternative generating sources." The

445 million facility will have a design capacity of 110 MW, with initial daily refuse capacity of 2000 tons/day rising to 4000 tons/day. Energy Systems will make agreements with local municipalities to obtain the necessary refuse.

Private industry is attracted to such a brokerage position between utility and municipality for a number of reasons, but mainly because under existing and expected energy prices the anticipated rate of return on the energy-recovery conversion is sufficient to attract the necessary capital. Many utilities prefer to deal with such private sector operators, with whom they can enter into long-term contracts as with other fuel or bulk power suppliers, and thus avoid the problems of negotiating with municipalities. Moreover, utilities thus circumvent the need to "get into the refuse business," since they can simply buy the power from the entrepreneur or, in the case of supplementary refuse firing, buy a fuel ready for burning rather than getting involved with resource recovery operations.

The intent of many statewide solid waste management plans in the Northeast is to obtain private sector involvement in the recovery operations. In Massachusetts, for example, it is hoped that the so-called primary resource recovery centers, whose function is to separate combustible and magnetic fractions from the remainder, would be financed, built, owned, and operated by the private sector,⁵ with the State acting only to guarantee delivery of refuse to the recovery center at a certain cost.⁶ In fact, the State can exert significant leverage merely by strict enforcement of current sanitary landfill and air quality regulations.⁷ For most urban areas in the Northeast, a disposal cost (whether for landfill or for incineration) lower than that for economic energy recovery can be achieved only at significant environmental penalty. Few incinerators meeting current air quality requirements can be operated at

less than \$10/ton, a cost that would in most cases make delivery to an energy-recovery facility very attractive.⁸

From the municipalities' viewpoint, the entry of private industry into the energy recovery and disposal business offers the significant advantage of relieving them of the burden of capital financing for disposal facilities, which, under existing municipal bond market conditions, is both difficult and expensive. Moreover, many municipalities are long accustomed to dealing with private industry in the collection of solid waste, and thus extension to disposal and resource recovery appears quite logical.⁹

The ability of municipal electric utilities to internalize the entire operation remains somewhat questionable. Many of these are relatively small, inefficient producers of electric power, operating old generating plants far too small to exploit the scale economies available at unit sizes of 600 MW and beyond.¹⁰ Few small municipal utilities are likely to find modification of their boilers to burn refuse an economic proposition (although there are significant exceptions).¹¹ Nevertheless, from an institutional viewpoint, cities with their own generating plants appear to be in a good position to exploit the solid waste resource, and the question warrants further study.

The situation is similar for steam generation from refuse, whether for industrial use or district heating. Indeed, the Saugus facility, providing steam to the General Electric plant in Lynn, was originally planned as a GE owned operation,¹² but difficulties in reaching an operating agreement and organizing a regional solid waste district to supply the refuse led to construction of the plant by the Refuse Energy Systems Company (a joint venture of the D. Matteo Construction Company and Wheelabrator-Frye).¹³

A number of analyses point out that the cost of capital is much higher to private than to municipal borrowers because of the tax exemption on municipal bond interests,¹⁴ which may increase

the costs by as much as a \$2.00 to \$3.00/ton.¹⁵ Note, however, that public ownership does not lower the opportunity cost of capital to the economy as a whole because the lower costs to the government owning the facility are offset by higher costs to others in the economy resulting from the subsidies that allow the municipal bond rate to be below the opportunity cost of capital. Moreover, recent increases in interest rates on municipal borrowing, which some observers feel may persist for some time, make this advantage less compelling.¹⁶

In assessing the importance and possible means of redressing institutional problems, the experience of New York, especially New York City, is illuminating. As noted by Low,¹⁷ existing legislation to protect the consumer may offset even a strong economic advantage offered by the use of refuse-derived fuels. Since New York utilities must pass any savings due to fuel economy on to their consumers (since additional fuel costs are also passed on directly), a utility has no direct profit incentive to accept refuse fuels. However, since fossil fuels have as much as tripled in cost over the past few years,¹⁸ some utilities (in New York, especially Consolidated Edison) have been faced with severe customer resistance to price increases, which makes the use of cheaper fuels more attractive to them. Indeed, plans are now moving forward to burn 1000 tons/day of refuse at Consolidated Edison's oil-fired Arthur Kill plant on Staten Island.¹⁹

In an analysis of the statewide problems in New York, Axelrod²⁰ noted that, despite the optimism of many municipalities regarding the feasibility and economics of energy recovery, utilities were resisting the use of solid waste as fuel because of two fears: that the municipalities would not commit themselves to long-term agreements necessary for recovery of capital expenses, and that they might be tempted to use the utilities as a revenue source by

future increases in the solid waste price. To allay these fears, the New York Public Service Commission issued a statement of policy on burning municipal wastes in February 1974 which called for the electric utilities to cooperate with the municipalities in disposing solid wastes but recognized the responsibility of the electric utilities to maintain high quality service at a reasonable cost and the responsibility of the public authorities for disposal of general municipal wastes. The Commission limited the utilities' financial participation to expenditures for modifications of or additions to boiler equipment and the purchase cost of processed solid waste fuel, and it restricted the utilities from expending funds on solid waste processing facilities or financing facilities for collection and processing. These activities are limited to the community, which is financially supported by the Environmental Bond Act. Overall, the Commission defined the utilities' financial participation as not exceeding the costs of alternative boiler fuel systems. As noted by Axelrod, this policy appears restrictive but, in effect, it set clear guidelines for utility participation and eliminated the fear of the utilities that they might end up footing the entire bill in the name of community relations.²¹

The response has been positive: during 1974 each of the electric utilities in the State met with many local communities to discuss cooperative programs. As a result, four utilities agreed to assist communities with four separate engineering and economic studies to determine the feasibility of a solid waste reclamation center in conjunction with a steam electric plant. To date three of the four studies are complete, and two utilities, Long Island Lighting Company and Rochester Gas and Electric, have formally agreed to purchase a solid waste fuel from the communities.²²

One can thus conclude that, whatever the apparent difficulties presented by prevailing institutional conditions, sufficient resolve

on the part of a municipality or the State to opt for solid waste resource recovery is readily translated into the political measures necessary to surmount them. In view of the recent continuing rise in energy prices, which makes it possible for private industry to set an adequate rate of return on investment in resource recovery facilities and makes utilities anxious to find substitutes for increasingly expensive fossil fuels, institutional problems should not prove to be insurmountable in implementing energy recovery from solid waste.

NOTES TO CHAPTER VI

1. "Local Trash Cuts Downtown Fuel Bills", Environmental Science and Technology, September 1972, p. 780.
2. See e.g., "Connecticut's Energy Outlook: 1975-1995", Connecticut Energy Advisory Board, January 1975.
3. For a good review of the financial and contractual problems from the utility perspective see e.g. Bechtel Corporation. "Fuels from Municipal Refuse for Utilities - Technology Assessment" Report to the Electric Power Research Institute, March 1975 (NTIS PB 242 413).
4. As reported in Electrical World, June 15, 1975.
5. A. D. Little Inc., "A Systems Evaluation of Alternative State-wide Resource Recovery Options for the Disposal of Municipal Solid Waste" Report to the Massachusetts Department of Public Works, December 1973.
6. And, if necessary, provide residual landfill sites during the transition period before operation of the two secondary facilities for recovery of non-ferrous glass from the residual fraction produced at the primary facility.
7. Passage of a Tennessee law requiring all sanitary landfills to use daily earth cover provided the impetus for organization of the Nashville district heating scheme. (Not only does the law raise the cost, but also the site capacity is sharply reduced by the earth cover).
8. A recent analysis for Connecticut estimated the cost of new incinerator capacity as \$17 to \$25/ton. (see note 2, supra, p. D-124).
9. Some municipalities, too, would prefer "to stay out of the energy business." The Commissioner of Streets and Sanitation of Chicago, at a conference at which he outlined plans for burning refuse at a Commonwealth Edison coal plant, noted, in response to a question as to why the city did not itself burn its refuse and sell the utility steam, "...we did not want to get into actual energy production." (A.I.Ch.E. Workshop on industrial Process Design For Pollution Control", Vol. 6, Chicago, Ill, October 1973, p. 106).

10. For a discussion of this point, see e.g., R. L. Wallace and P. E. Junk, "Economic Inefficiency of Small Municipal Generating Systems", Land Economics, XLVI, 1, p. 98 (February 1970).
11. One example frequently cited is Ames, Iowa, which operates its own municipal electric generating plant, a 33-MW coal/gas-fired unit plus a 20-MW oil-fired gas turbine. Refuse will be burned in one of the three steam boilers at 10 to 20%. Since the generating plant runs directly under the supervision of the mayor and council, through the city manager, cooperation within a single city administration was relatively easy to achieve. For further details on the Ames project, see A. O. Chantland. "Making Kilowatts out of Refuse" The American City, September 1974.
12. Metcalf & Eddy, Inc., "Generation of Steam from Solid Wastes", U.S. Environmental Protection Agency, 1972 (Published by NTIS PB 214 166).
13. "Refuse to Energy Plant Uses first Von Roll Incinerators in the U.S.", Environmental Science & Technology, Vol. 8, No. 8, p. 693, (August 1974).
14. See e.g., J. G. Abert, H. Alter, and J. F. Bernheisel, "The Economics of Resource Recovery from Municipal Solid Waste", Science 183, 1052-1058 (1974) or H. W. Schulz, "Cost/Benefits of Solid Waste Reuse, " Environmental Science & Technology, Vol. 9, No. 5, p. 423, (May 1975).
15. Midwest Research Institute, "Resource Recovery - The State of Technology Report to the Council on Environmental Quality," February 1973.
16. Unfortunately, there is some doubt as to whether the pollution control bond, a variant of the tax-free industrial development bond, might be a suitable way of financing the capital costs. These bonds are issued by local governments to buy or build capital facilities, which are then leased to private corporations. Although the 1968 Industrial Revenue Bond Act stipulated that no individual offering could be larger than \$5 million, the financing of pollution control equipment was specifically exempted from this requirement. Electric utilities were early beneficiaries of this provision. In April 1974, the Internal Revenue Service approved such bonds for the financing of solid waste recycling facilities, but with restrictions; to qualify, the processed material must be of no value to the producer and cannot be used or sold by the producer at the location of processing. (see Albert et. al. note 14, supra).

17. R. A. Low "Energy Conversion in New York" Proceedings, First International Conference on Conversion of refuse to energy, Montreux, Switzerland, November 1975, p. 250.
18. The cost of No. 6 fuel oil with 0.3% sulfur used by Consolidated Edison has tripled since 1973.
19. Originally the city assumed the cost of the feasibility studies. But in recognition of the contribution the refuse-derived energy would make to the Project Independence strategy, a \$5,000 Federal grant was also made, since almost all of Consolidated Edison's oil is from foreign sources. It is estimated that the refuse used at Arthur Kill would replace about 1400 barrels of imported oil per day. See Low, note 17, supra.
20. H. J. Axelrod "Utilization of solid waste in New York: A State Government's Positive Action Program". Proceedings, First International Conference on Refuse to Energy, Montreux, Switzerland, November 1975, p. 447
21. Ibid, p. 480.
22. Rochester Gas and Electric will purchase a briquette derived from solid waste to burn in a coal-fired plant, and Long Island Lighting has agreed to purchase a 32-MW turbine generator to be installed at the Town of Hempstead's resource recovery site, where the Town will produce steam from burning solid waste. The Hempstead facility will be in service by mid-1977.

CHAPTER VII

SECONDARY IMPACTS

7.1 Environmental Ramifications

The conversion of the organic fraction of refuse into energy has a number of potential impacts on the environment, ranging from direct affects on air quality due to pollutant emissions to indirect effects on land use; on balance, the net environmental impact is clearly positive.

Regardless of which conversion option is chosen, if the alternative refuse disposal method is landfilling, the major environmental impacts are the substantial reduction of land required for disposal and the elimination of concomitant secondary effects such as water pollution from landfill leachates.¹ Since incinerators achieve average volume reductions of 95%,² disposal of the residue should use only 5% of the area needed for raw refuse landfill and in fact uses less because the residue is inert and does not require daily earth cover; hence a given fill area lasts longer. Since the energy recovery options discussed in this report all produce the same volume and weight reduction as does incineration, they provide a substantial saving in land area.

The impact of direct refuse firing on pollution emissions and air quality is difficult to assess. Refuse typically has a sulfur content of some 0.1%, substantially below that of even so-called low-sulfur coals. Sulfur limitations in fuel in the Northeast vary widely, from a low of 0.2% by weight to a high of 2.5% in parts of Maine and Pennsylvania.³ The 0.1% sulfur content of refuse should be adjusted for the lower Btu content: the sulfur content of refuse can be expressed as $0.22 \text{ lb}/10^6 \text{ Btu}$; whereas a 1% sulfur coal of 12,020 Btu/lb has a sulfur content of $0.83 \text{ lb}/10^6 \text{ Btu}$. Hence a power plant burning 1% sulfur coal, if it used refuse

to supply 20% of its heat input, would decrease its sulfur emission by 15%, from 0.83 to 0.71 lb/10⁶ Btu.

Burning refuse at a firing rate of 10 to 30% in a plant using high-sulfur coal would not eliminate the need for a flue gas desulfurization (FGD) system. Even if refuse had zero sulfur content, the maximum possible reduction in SO_x emissions would be equal to the firing rate, which probably will not exceed 30%. Burning high-sulfur coal, however, requires SO_x removal efficiencies of 80% and higher, significantly above the 15 to 30% reduction due to burning partly refuse. Conversely, however, with an FGD system of given efficiency, the sulfur content of the coal could be raised by the corresponding percentage without affecting SO_x emissions. For example, a plant burning 3% sulfur coal, with a FGD system of 80% efficiency, could, if burning 20% refuse, use 3.75% sulfur coal with no increase in SO_x levels. The ability to burn higher-sulfur coal is a further economic advantage, not considered in Section V, since the price of coal is significantly affected by its sulfur content.

How do these expectations match reality? Unfortunately, the few tests conducted in St. Louis show little evidence of significant decreases in gaseous pollution levels, and a statistically significant decrease in SO_x emission levels has yet to be established.⁴ It is unlikely, however, that SO_x emissions would increase.

Another major air pollutant is particulate emission. Since refuse has a higher ash content than coal, higher particulate loadings at the inlet to electrostatic precipitators, as observed at the St. Louis project, are not expected. Even though the precipitator efficiency decreased when refuse was fired (so that particulate emission levels increased), it was assumed that this could be corrected by adjustment and optimization of precipitator operation.

The loss of efficiency was thought to be due to the higher moisture content of the emissions affecting the performance of the precipitators.⁵

The direct firing of refuse in coal-fired boilers has some interesting secondary impacts on human health. Sanitationmen who collect refuse have one of the highest occupational injury rates (higher than coal miners or construction workers⁶), but collection work is largely unaffected by the disposal option. However, the partial replacement of coal by refuse results in a proportional reduction in occupational injuries in coal mining; also, x% substitution of refuse for coal results in x% reduction in the environmental impacts associated with coal mining, processing, and transport for power generation. Hamilton and Morris⁷ have estimated that supplying the coal to support a 1000-MW power plant results in 0.6 accidental deaths and 30 disabling injuries (with a mean time loss of 50 days) per year of operation. Since coal-fired power generation in the Northeast now amounts to some 28,000 MW,⁸ the benefit to occupational health from substituting refuse at an 18% firing rate would be avoidance of 3.02 deaths and 7560 man-days of disablement per year.

Both pyrolysis and waterwall incineration would have the same air pollution impacts as conventional incineration because the emission standards would be the same. Landfill disposal of the residues would also be the same as in the conventional case.

A major advantage of bioconversion is the simultaneous handling of municipal sewage sludge, (see Section 3.2.) the addition of which is almost mandatory because it is the cheapest source of phosphorous and nitrogen nutrients essential to successful microbial conversion. The disposal of sewage sludge is one of the thorniest issues in municipal waste treatment, with total processing and disposal costs currently in the range of \$30 to 50 per ton of dry solids. Since

the generation rate of sewage sludge solids is about 0.1 lb/cap/day a 1000-tpd refuse-to-energy facility, serving some 571,000 persons, would simultaneously dispose of the 28.5 tons of sludge solids generated by the same population. The conversion facility would thus be credited \$1.14 per ton of sludge solids (\$416,000 per year). The environmental benefit is elimination of the need for sewage sludge landfill or incineration.

7.2 Relationship to Materials Recovery Options

The recovery of materials from the noncombustible fraction of refuse is largely unaffected by the recovery of energy from the combustible fraction. Indeed, to the extent that the separation of metals and glass before burning or conversion is desirable, it would be stimulated by energy costs recovery because its costs would be shared.

The use of refuse for energy precludes recovery of materials from the combustible fraction, particularly paper fiber. Present and anticipated market conditions for paper fiber recycling, make fiber recovery uneconomic except in special circumstances.⁹ In contrast to the consistent upward trend in energy prices, the market for recyclable paper products exhibits wide and rapid fluctuations. In 1972-1973, for example, used cardboard sold for \$70/ton and newsprint for nearly \$50/ton, but by mid-1975 the former brought little over \$20/ton and the latter only \$10/ton--if a market could be found.¹⁰ Such swings discourage private industry, which seeks stable and assured returns on capital. None of the statewide solid waste management plans in the Northeast envisages the recovery of paper fiber from mixed municipal refuse, and all consider the optimum use of the combustible fraction to be energy recovery. Since most of these plans were completed before the post-embargo increases in energy prices, their conclusions remain sound.¹¹

A small market for recyclable waste paper does exist in the Northeast, estimated at no more than 15% of the total wastepaper content of municipal refuse. In Massachusetts in 1975 the estimated market for recyclable wastepaper was 566,000 tons, while in municipal refuse the total wastepaper was 3,375,000 tons and the total combustible material 4,693,000 tons¹² so that even satisfying the entire market for recyclable newsprint by source separation would have diverted only 12% of the combustible waste stream.

The breakeven price of refuse as a coal substitute is in the range \$3 to 8/ton (see Figure 12, Section 5.2). Since paper contributes some 75% of the total Btu but constitutes only some 40% of the weight, wastepaper has a fuel value of \$5.60 to 15/ton and must fetch at least this price in the recycling market for that use to be competitive; this may have happened in 1972-1973 but seldom does under normal market conditions. The wastepaper market can probably be adequately served by continuing current source separation methods such as Boy Scout paper drives and local recycling centers typical of middle-class suburbs, which do not significantly affect energy recovery from refuse.

NOTES TO CHAPTER VII

1. The problem of landfill leachates has recently become prominent because of efforts to eliminate sources of water pollution. Direct groundwater contamination can be avoided by lining the landfill and treating the leachate, but such measures are very expensive.
2. See e.g., R. A. Colonna and C. McLaren, "Decision-makers Guide in Solid Waste Management", U.S. Environmental Protection Agency, Report SW-127, 1974.
3. See B. S. Edelston and E. S. Rubin, "Current and Future Use of Coal in the Northeast," BNL 50560 (May 1976), Environmental Studies Institute, Carnegie-Mellon University, Pittsburgh, Pennsylvania.
4. L. J. Shannon, et al, "St. Louis/Union Electric Refuse Firing Demonstration Air Pollution Test Report", U.S. Environmental Protection Agency, August 1974, (Published by NTIS PB 237 630).
5. Ibid, p. 74.
6. In 1970, there were 63.9 injuries and 2598 days of disability per million man-hours worked in sanitation; the corresponding figures for coal mining were 41.6 and 7792, and for the construction industry, 28.0 and 2100. (see P.M. Meier) Kuhner, and R. E. Bolton, "Wet Systems for Residential Refuse Collection: A Case Study for Springfield, Mass.", U.S. Environmental Protection Agency, March 1974 (Published by NTIS PB 234 496).
7. L. D. Hamilton and S. C. Morris, "Health Effects of Fossil Fuel Power Plants", Proceedings, 8th Midyear Topical Symposium of the Health Physics Society, Knoxville, Tenn., October 1974 (Published by NTIS CONF 741 018), p. 305-316.
8. Based on S. Rahman, "Issue Paper on the Electrical Sector, 1950-2000", BNL Regional Energy Studies Program, Draft Report, September, 1975, Tables 19 and 20.
9. The recovery plant in Franklin, Ohio, noted in Chapter I, is such an exception, but here the recovery fiber is delivered to an adjacent roofing felt mill.
10. Environmental Science and Technology, Vol. 9, No. 12, p. 1015, November 1975.

.. The essential features of these plans are outlined in the latter pages of Appendix F.

12. A. D. Little, "A Systems Evaluation of Alternative Statewide Resource Recovery Techniques for the Disposal of Municipal Solid Waste, "Massachusetts Department of Public Works, December 1973, p. 12.

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CHAPTER VIII

SENSITIVITY ANALYSIS

8.1 Sensitivity to Per Capita Refuse Generation Rates

In Chapter II, we discussed a number of different predictions of per capita refuse generation rates: a low case, in which we assumed no change in current per capita generation rates; a median case, in which we assumed that current generation rates would increase by 1.5% per year in accordance with trends in consumption of non-durable goods;¹ and a high case based on extrapolation of the regression equation used to characterize 1975 rates into the future. In subsequent computations the median generation level has been used as the base case, and here we review the sensitivity of energy yield to this assumption.

Using the computer model, one can readily compute the quantity of refuse economically deliverable to a central conversion facility in each SMSA, assuming for purposes of comparison that all such refuse would be used as a boiler fuel to generate electricity. From another Issue Paper in this study, one can obtain a range of electric energy demands in the Northeast,² and thus a useful analysis is to examine the percentage of electric demand that could be supplied by refuse under different combinations of per capita refuse generation and total electric demand.

The results of such an analysis for 1985 and 2000 are displayed on Tables 13 and 14, respectively. These show that even under the most favorable circumstances (low electricity demand, high refuse generation), at most 13% of the demand could be satisfied; but since, as noted elsewhere, not all SMSA's have sufficient coal fired generating capacity to use the refuse, the actual percentage contribution is likely to be much lower. Conversely, under the most unfavorable circumstances (low refuse generation,

Table 13

PERCENTAGE OF 1985 REGIONAL ELECTRIC DEMAND POTENTIALLY CONTRIBUTED BY REFUSE

		<u>1985 Electricity Demand^a</u>		
		<u>Low₆</u> <u>(480 x 10⁶ Mwh)</u>	<u>Median</u> <u>(555 x 10⁶ Mwh)</u>	<u>High</u> <u>(638 x 10⁶ Mwh)</u>
1985 Refuse Generation	Low (28.5 x 10 ⁶ Mwh)	5.9%	5.1%	4.5%
	Median (33.1 x 10 ⁶ Mwh)	6.9%	5.9%	5.2%
	High (38.9 x 10 ⁶ Mwh)	8.1%	7.0%	6.0%

^aSource: Meier, et al, Note 2, Chapter III.

Table 14

PERCENTAGE OF 2000 REGIONAL ELECTRIC DEMAND POTENTIALLY CONTRIBUED BY REFUSE

		<u>2000 Electricity Demand^a</u>		
		<u>Low</u> <u>(681 x 10⁶ Mwh)</u>	<u>Median</u> <u>(900 x 10⁶ Mwh)</u>	<u>High</u> <u>(1158 x 10⁶ Mwh)</u>
	Low (36.0 x 10 ⁶ Mwh)	5.2%	4.0%	3.1%
	Median (52.0 x 10 ⁶ Mwh)	7.6%	5.7%	4.5%
	High (90.7 x 10 ⁶ Mwh)	13.3%	10.1%	7.8%

Source: Meier et al, Note 2, Chapter III.

igh electricity demand), only some 3% could be contributed by refuse. The overall contribution, then, is likely to be around 6%, with the uncertainty in per capita refuse generation assumption resulting in a deviation of a few percent in either direction.

8.2 Sensitivity to Population Density Gradient Assumptions

In Chapter V we noted that haul costs were a function of population density, postulated as declining exponentially from the city center. Thus, the equations for cost and refuse quantity derived in that Chapter incorporated the density gradient α and central density d_0 (see e.g. Eq. [7] or [9]), the parameters of the model describing the exponential density relationship as³

$$d(r) = d_0 e^{-\alpha r} \quad [10]$$

where $d(r)$ is the population density at distance r from the center.

In making projections for the future cost and refuse quantity functions, which determine how much refuse is economically delivered to an energy conversion facility, one must go beyond total future population (which, for each SMSA, is given for purposes of the BNL futures study as the OBERS Series E projection), but consider also the future values of central density and density gradient. Indeed, by integrating Eq. [10], one obtains⁴

$$P(R) = \frac{\theta d_0}{\alpha^2} \left[1 - (1 + \alpha R) e^{-\alpha R} \right] \quad [11]$$

where $P(R)$ is the total population within a radius R and θ is the sector angle.⁵ Thus, as $P(R)$, the SMSA population, changes through time, α and d_0 must change also. As American cities have grown over the past few decades, a decrease in density gradient has occurred, characteristic of urban sprawl.

For the base case computations, it is assumed that SMSAs in the region will continue current trends of urban sprawl over the next 25 years. Thus, the decline in density gradient from 1960 to 1970 has been extrapolated linearly, with future values of α as shown in Table 15. Using these values with the corresponding OBERS projection for $P(R)$, one can determine a value of $d_0(t)$ from Eq. [11]. The d_0 values obtained this way are also shown in Table 15; and, as expected, d_0 values also decrease with continued urban sprawl.⁶

Alternatively, assume a scenario characterized by revitalization of the city center with central densities remaining at 1970 levels. Inserting constant d_0 and increasing population into Eq. [10] again results in changing values of α with time, although, as evident from Table 16, the decrease in density gradient is much less than in the urban sprawl case. An iterative method must be used, however, because with given values for $P(R)$ and d_0 , one cannot solve Eq. [11] for d_0 .

Comparing the results of the revitalization case with those for the base case shows the former to yield 15% greater Btu yield economically recoverable by the year 2000. However, many of the smaller SMSAs show little or no increase⁷ with this scenario, whereas the larger SMSAs show a much higher increase.⁸ The reason is that in the smaller SMSAs, all or most of the refuse would be economically hauled to the central facility, even in the base case, whereas in the larger ones, the optimal collection radius does not encompass the entire population and hence concentration of the population results in a greater proportion of the total refuse being economically recoverable.

0.3 Sensitivity to Refuse Composition Assumptions

In order to establish an upper limit for subsequent scenario development, the sensitivity of energy conversion to refuse composition was evaluated in conjunction with the urban revitalization

Table 15

URBAN GROWTH SCENARIO 1 - CONTINUED URBAN SPRAWL

LINEAR EXTRAPOLATION OF 1960-1970 DENSITY GRADIENT TREND

	ALPHA			DZERO X100.3			THETA	SMSA RADIUS
	1975	1990	2000	1975	1990	2000		
ALBN	.340	.280	.220	13.7	10.7	7.7	360.0	26.6
ALLN	.350	.310	.270	11.3	10.0	8.7	360.0	18.6
ALTO	.920	.650	.780	18.3	15.0	11.7	360.0	13.0
ATLA	.360	.260	.160	7.4	3.9	.5	180.0	19.0
BALT	.230	.190	.150	29.1	23.3	17.4	210.0	35.1
BING	.460	.330	.360	10.1	7.1	4.0	360.0	25.7
COST	.200	.180	.160	24.1	26.1	16.1	285.0	19.9
BRID	.410	.350	.290	17.6	15.9	14.2	180.0	11.1
BFIS	.890	.930	.970	9.6	11.7	13.8	360.0	4.0
BPOC	.960	.930	.900	10.4	12.0	13.8	360.0	7.2
BUFF	.290	.250	.210	24.1	17.3	10.5	270.0	26.0
CANB	.110	.040	.030	.9	1.4	2.0	360.0	4.4
FALL	.330	.250	.170	5.8	4.7	3.5	90.0	13.5
ERIE	.470	.400	.330	10.3	11.7	9.2	180.0	22.6
FITC	.620	.620	.620	6.3	6.7	7.1	360.0	7.3
HART	.380	.310	.240	16.2	14.0	11.5	360.0	14.6
HARR	.320	.260	.200	12.4	9.4	6.4	180.0	32.2
JEFS	.200	.180	.120	25.6	21.8	18.0	180.0	5.5
JOHN	.530	.460	.390	11.8	7.8	3.8	360.0	23.8
LANC	.500	.430	.360	13.0	11.3	9.5	360.0	17.4
LAWY	.390	.260	.130	6.9	4.6	2.4	360.0	8.1
LEWI	.440	.430	.420	3.9	3.1	3.1	360.0	6.1
LOWE	.690	.490	.290	17.0	13.0	9.0	360.0	7.0
MENC	.830	.700	.570	12.9	9.9	6.5	360.0	6.7
MERI	-0.000	0.000	0.000	-0.0	0.0	0.0	360.0	2.8
NASH	.160	.240	.300	1.2	1.4	1.7	360.0	3.3
N.BE	.900	.800	.700	20.1	17.3	14.4	360.0	6.7
N.BR	.670	.550	.430	14.8	12.6	10.4	360.0	5.3
N.HA	.510	.390	.270	16.8	11.8	6.7	340.0	9.1
NEWA	.190	.150	.130	26.0	22.5	19.0	180.0	14.9
N.LN	.360	.290	.220	4.7	4.0	3.3	360.0	10.9
NORN	.430	.370	.310	9.8	10.0	10.1	180.0	6.6
N.YO	.170	.160	.150	104.8	93.5	82.1	180.0	36.9
PHIL	.220	.200	.180	36.0	31.3	26.5	360.0	32.6
PTRS	.130	.110	.090	15.2	14.9	14.6	90.0	23.3
PITT	.210	.190	.170	16.4	12.6	8.8	360.0	31.2
PITT	.630	.560	.490	5.5	4.6	3.8	360.0	6.7
PORT	.470	.410	.350	7.6	5.6	3.6	240.0	10.6
PROV	.250	.210	.170	11.2	9.2	7.2	340.0	15.1
READ	.810	.510	.410	17.6	13.4	9.2	360.0	16.6
ROCH	.260	.200	.140	17.2	12.5	7.9	200.0	36.4
SCRA	.410	.380	.350	8.4	7.2	6.0	360.0	12.0
STAM	.240	.250	.260	6.0	7.0	8.0	180.0	8.8
SPPO	.340	.300	.260	10.3	8.6	6.9	360.0	13.0
SYRA	.390	.320	.250	15.6	11.9	8.2	360.0	27.8
TREN	.550	.430	.310	29.9	22.2	14.6	180.0	12.1
UTIC	.260	.240	.220	3.7	3.1	2.5	360.0	29.1
VINE	.240	.270	.300	1.4	1.8	2.2	360.0	12.6
WATE	.550	.470	.390	10.8	9.4	8.0	360.0	8.3
WASH	.220	.150	.080	23.0	18.2	13.4	360.0	27.4
WORC	.490	.430	.370	13.4	11.0	8.6	360.0	12.3
WLSK	.490	.470	.450	13.3	12.0	10.7	360.0	16.8
WILM	.240	.170	.100	8.6	6.0	3.4	180.0	27.2
YORK	.530	.450	.370	14.8	12.6	10.4	360.0	21.4
BURL	.520	.410	.300	7.0	6.7	6.5	180.0	18.4
NEWP	.400	.160	.080	5.2	1.2	-5.8	90.0	12.1
NEWC	.800	.730	.660	11.1	8.5	5.8	360.0	10.8
STAT	1.030	1.160	1.290	16.8	23.5	30.1	360.0	18.8
HILL	.700	.620	.540	8.8	7.1	5.3	360.0	19.7
LEBR	.870	.770	.670	12.2	10.6	9.0	360.0	10.8
JAME	.560	.530	.500	7.8	7.2	6.5	360.0	18.6
ITMA	.910	.710	.510	10.1	7.2	4.3	360.0	12.4
ELMI	.890	.740	.590	12.8	8.6	4.3	360.0	11.5
AUBU	.920	.870	.820	10.4	9.7	8.9	360.0	14.9
AMST	1.120	1.010	.900	11.4	8.8	6.2	360.0	11.4
WATE	.720	.670	.620	7.3	6.3	5.2	360.0	20.3
KING	.440	.310	.180	5.2	3.7	2.2	360.0	19.1
KEWB	.430	.290	.150	9.2	6.5	3.7	360.0	16.3
POUG	.780	.260	.140	10.3	8.6	2.9	180.0	22.8
LONG	.220	.200	.180	7.5	6.7	5.3	360.0	12.3
NBXP	.180	.130	.080	6.0	6.1	6.3	360.0	10.0
CONC	.770	.230	.190	1.1	.9	.9	360.0	17.2
GLOU	-0.000	0.000	0.000	-0.0	0.0	0.0	30.0	43.4
HAGE	.680	.580	.480	8.6	7.4	6.1	360.0	12.0
CLIMB	.520	.460	.400	7.9	6.1	4.4	180.0	16.5
BANG	.230	.200	.170	1.6	1.2	.8	360.0	32.9
TORR	.230	.210	.190	1.4	1.4	1.4	360.0	17.2
MILD	.140	.110	.080	1.2	1.2	1.2	360.0	11.9

* Full names of cities appear in Table 3.

Table 16

URBAN GROWTH SCENARIO 2 - LIMITED SPATIAL GROWTH

POPULATION GROWTH ACCOMMODATED BY DECREASE IN GRADIENT ONLY

	ALPHA			DZERO X10 ^{11.3}			THETA	SMMA RADIUS
	1975	1990	2000	1975	1990	2020		
ALBN	.340	.322	.300	13.7	13.7	13.7	360.0	26.6
ALLN	.350	.346	.335	11.3	11.3	11.3	360.0	18.6
ALTO	.920	.883	.846	18.3	18.3	18.3	360.0	13.0
ATLA	.380	.344	.334	7.4	7.4	7.4	180.0	19.0
EALT	.230	.216	.207	29.1	29.1	29.1	210.0	35.1
FINO	.480	.445	.430	10.1	10.1	10.1	360.0	25.7
BOST	.200	.181	.164	24.1	24.1	24.1	285.0	19.9
ERID	.410	.325	.292	17.6	17.6	17.6	180.0	11.1
BRIS	.890	.805	.726	9.6	9.6	9.6	360.0	4.0
ERCC	.580	.510	.462	10.4	10.4	10.4	360.0	7.2
BUFF	.290	.286	.278	24.1	24.1	24.1	270.0	26.0
LAKE	0.000	0.000	0.000	.9	.9	.9	360.0	4.4
FALL	.330	.213	.204	5.8	5.8	5.8	90.0	13.5
ERIE	.470	.376	.356	14.3	14.3	14.3	180.0	22.8
FITC	.620	.576	.536	6.3	6.3	6.3	360.0	7.3
HART	.370	.357	.329	16.2	16.2	16.2	360.0	14.6
HARR	.320	.282	.261	12.4	12.4	12.4	100.0	32.2
HERS	.200	.197	.171	25.6	25.6	25.6	180.0	5.5
JOHN	.530	.540	.547	11.8	11.8	11.8	360.0	23.8
LAAC	.500	.464	.444	13.0	13.0	13.0	360.0	17.4
LANE	.390	.352	.314	6.9	6.9	6.9	360.0	8.1
LEW	.440	.447	.446	3.0	3.0	3.0	360.0	6.1
LOWE	.690	.635	.575	17.0	17.0	17.0	360.0	7.0
PANC	.830	.762	.695	12.9	12.9	12.9	360.0	6.7
PERI	0.000	0.000	0.000	0.0	0.0	0.0	360.0	2.8
NASH	0.000	0.000	0.000	1.2	1.2	1.2	360.0	3.3
N.BE	.600	.677	.692	20.1	20.1	20.1	360.0	6.7
N.BR	.670	.695	.632	14.8	14.8	14.8	360.0	5.3
N.HA	.530	.476	.436	16.8	16.8	16.8	340.0	9.1
KEWA	.190	.161	.141	26.0	26.0	26.0	180.0	14.9
N.LN	.360	.331	.302	4.7	4.7	4.7	360.0	10.9
NORM	.430	.403	.357	9.8	9.8	9.8	180.0	6.6
N.YO	.170	.159	.146	104.8	104.8	104.8	180.0	36.9
PHIL	.220	.203	.193	36.0	36.0	36.0	360.0	33.6
PTAS	.130	.097	.080	15.2	15.2	15.2	90.0	23.3
FITT	.210	.202	.200	16.4	16.4	16.4	360.0	31.2
FITT	.630	.583	.536	5.5	5.5	5.5	360.0	6.7
PORT	.470	.447	.425	7.6	7.6	7.6	240.0	10.6
PRCV	.250	.239	.224	11.2	11.2	11.2	340.0	15.1
READ	.610	.585	.569	17.6	17.6	17.6	360.0	16.6
ROCH	.260	.225	.206	17.2	17.2	17.2	200.0	36.4
SORA	.410	.432	.412	8.4	8.4	8.4	360.0	12.0
STAM	.240	.203	.171	6.0	6.0	6.0	180.0	8.8
SPFD	.340	.324	.311	10.3	10.3	10.3	340.0	13.8
SVRA	.390	.370	.353	15.6	15.6	15.6	360.0	27.8
TREN	.890	.495	.444	29.9	29.9	29.9	180.0	12.1
UTIC	.260	.256	.256	3.7	3.7	3.7	360.0	29.1
VINE	.240	.207	.187	1.4	1.4	1.4	360.0	12.6
WATE	.550	.511	.470	10.8	10.8	10.8	360.0	8.3
WASH	.220	.187	.157	23.0	23.0	23.0	360.0	29.4
WORC	.490	.458	.400	13.4	13.4	13.4	360.0	12.3
WLMK	.470	.454	.432	13.3	13.3	13.3	360.0	10.8
WILM	.240	.209	.190	8.6	8.6	8.6	180.0	27.2
YORK	.530	.489	.462	14.8	14.8	14.8	360.0	21.4
YURL	.520	.410	.371	7.0	7.0	7.0	180.0	18.4
KEWP	.400	.329	.302	8.2	8.2	8.2	90.0	12.1
KENC	.600	.777	.767	11.1	11.1	11.1	360.0	10.8
STAT	1.030	.998	.975	16.8	16.8	16.8	360.0	18.8
HILL	.700	.686	.685	8.8	8.8	8.8	360.0	19.7
LEBA	.870	.817	.772	12.2	12.2	12.2	360.0	10.8
JAME	.560	.551	.532	7.8	7.8	7.8	360.0	18.6
ITWA	.630	.635	.626	10.1	10.1	10.1	360.0	12.4
ELVI	.890	.861	.826	12.8	12.8	12.8	360.0	11.5
AUGU	.920	.846	.791	10.4	10.4	10.4	360.0	14.9
AMST	1.120	1.082	1.035	11.4	11.4	11.4	360.0	11.4
KATE	.720	.698	.672	7.3	7.3	7.3	600.0	20.3
HINO	.440	.444	.407	5.2	5.2	5.2	350.0	19.1
KEWB	.430	.471	.436	9.2	9.2	9.2	360.0	16.3
POLG	.380	.337	.296	10.3	10.3	10.3	190.0	22.8
LONG	.220	.265	.240	7.5	7.5	7.5	360.0	12.1
KSP	.180	.347	.304	6.0	6.0	6.0	360.0	10.0
CONC	.270	.247	.221	1.0	1.0	1.0	360.0	17.2
OLCU	0.000	0.000	0.000	0.0	0.0	0.0	30.0	43.4
MAGE	.680	.693	.676	8.6	8.6	8.6	360.0	12.0
CUMB	.570	.542	.546	7.9	7.9	7.9	180.0	16.5
BAKO	.230	.286	.287	1.6	1.6	1.6	360.0	32.9
TORR	.230	.212	.194	1.4	1.4	1.4	360.0	17.2
YILD	.140	.178	.156	1.2	1.2	1.2	360.0	10.9

* Full names of cities appear in Table 3.

ario for population density distribution. Besides the base case refuse composition (Table 4, Section II), for which a modest increase in combustible materials was assumed, two others were considered; one remaining unchanged at the current mix and one containing a much higher fraction of combustibles (especially paper and plastic) because of assumed widespread use of home garbage grinders and returnable beverage containers (see Table 17).

Results of computer analysis show remarkably little sensitivity to composition, as indicated by Figure 17, which shows the potential yield in 10^{12} Btu coal equivalent economically delivered to energy conversion facilities. Most of the rise in energy yield by 2000 is seen to be due to increases in population and in per capita refuse generation (a rise of 300%, from 287 to 1020×10^{12} Btu/yr). For the lowest case examined, i.e., base case composition and low per capita generation (no increase over present levels), the yield increases only to 460×10^{12} Btu/yr. Clearly, the assumption that introduces the greatest degree of uncertainty is that for per capita generation rates.

Table 17

REFUSE COMPOSITION (% OF WET WEIGHT) FOR THREE CASES:
BASE CASE, CONSTANT COMPOSITION, AND HIGH CUMBUSTIBLES

	Current	1985			2000		
		Base	Const.	High	Base	Const.	High
Paper	40.0	44.9	40.0	47.5	49.7	40.0	55.0
Garbage	20.5	16.3	20.5	12.8	12.1	20.5	5.0
Garden waste	13.5	12.7	13.5	11.8	11.8	13.5	10.0
Plastic	1.5	2.9	1.5	5.8	4.2	1.5	10.0
Metal	8.9	8.2	8.9	7.8	7.4	8.9	6.7
Glass	9.5	8.8	9.5	8.1	8.1	9.5	6.7
Other	6.1	6.4	6.1	6.4	6.7	6.1	6.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Av. Btu/lb	4500	5000	4500	5663	6000	4500	6937

Figure 17. Energy yield as a function of refuse composition.

NOTES ON CHAPTER VIII

1. See Section 2.1.
2. P. M. Meier, T. H. McCoy and S. P. Rahman, "Perspectives on the Energy Future of the Northeast: The Electric Sector", BNL - 50553, Brookhaven National Laboratory, Upton, NY, April 1976.
3. This is the classic model of C. Clark, "Urban Population Densities", Journal of the Royal Statistical Society, Series A, Vol. 114, No. 4, p. 490 (1951). For further discussion, particularly in connection with energy planning problems, see P. Meier and T. H. McCoy, "An Analytical Approach to the Determination of Urban Population Density Gradients and Its Application to Energy Planning Problems", BNL - 20196, Brookhaven National Laboratory, Upton, NY, January 1976.
4. Meier and McCoy, Note 3, supra, p. 12.
5. For a circular city, $\theta = 360$ degrees or 2π radians.
6. Those SMSAs shown on Tables 15 and 16 as having zero α and d_0 in fact have computed values of density gradients that are negative (implying population density increases with distance from the center). These are all small SMSAa, and clearly do not fit our model; in subsequent computations for these SMSAs the program inserts constant population density throughout the SMSA.
7. *Reading, Scranton and Waterbury, for example, show increases of 1.78, 4.0, and 0.6%, respectively.
8. New York and Boston, for example, show increases of 29 and 44%, respectively.

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CHAPTER IX

SCENARIOS

9.1 Introduction

Alternative scenarios can now be posited for energy recovery from refuse. In view of the conclusions of Chapter V, the alternatives can probably be limited to direct firing in utility boilers, steam generation for industrial process heat, or gas generation by pyrolysis. Other technologies (such as bioconversion or Garrett pyrolysis) still may be introduced in the Northeast within the time period of interest but are likely to have a limited contribution in comparison with the first three.

The basic assumptions are recapitulated in Table 18. From the OBERS population projections¹ and the base case estimates for heat value of refuse and per capita refuse generation derived in Sections III and IV, one can readily compute the total quantity of refuse in the region and its energy content since one of the more attractive choices for energy recovery is to burn refuse as a supplementary fuel, an obvious initial step is to correlate projected coal use with refuse availability. Projections for coal use at utility boilers are available from another report,² which gives low, medium, and high projections for coal use (Table 19). Assuming that refuse would be fired at 20% by heat value, one can derive a potential demand for refuse; as shown in Table 19, this corresponds quite well with the available refuse resource in 1985, independent of the coal scenario. By the year 2000, however, the potential demand ranges from 0.6 of the available resource in the low coal use case to 2.61 of the available resource in the high coal use case.³

9.2 Low Case

In this scenario, it is assumed that by 1985, only projects presently planned will have been implemented, and that in the interval 1985 to 2000, the rate of implementation will be double

Table 18

PROJECTIONS FOR THE NORTHEAST

	<u>1970</u>	<u>1985</u>	<u>2000</u>
Total population (millions)	54.27	61.45	68.82
Refuse generation (lb/cap/day)	3.3	4.13	5.16
Heat value (Btu/lb refuse)	4500	5000	6000
Total refuse (10 ⁶ tons/year)	32.68	46.3	64.80
Total refuse energy Resource (10 ¹² Btu/year)	294	463	777

Table 19

REFUSE DEMAND AT COAL-BURNING BOILERS

	<u>1985</u>			<u>2000</u>		
	<u>Low</u>	<u>Medium</u>	<u>High</u>	<u>Low</u>	<u>Medium</u>	<u>High</u>
Coal use (10 ¹² Btu) ²	1975	1975	2227	1975	3733	8648
Refuse demand						
As coal (10 ¹² Btu)	395	395	445	395	748	1729
As refuse (10 ¹² Btu)	464	464	524	464	1289	2034
As fraction of available resource:						
460 x 10 ¹² Btu	1.002	1.002	1.131	-	-	-
784 x 10 ¹² Btu	-	-	-	0.59	1.65	2.61

²From Edelston and Rubin, Note 2.

in the first interval. Currently planned projects are detailed in the Appendix F, and summarized on Table 20. Planned usage totals 56.5×10^{12} Btu/yr, representing some 12% of the available 1985 refuse resource. By 2000, with 170×10^{12} Btu/yr of refuse converted, some 22% of the resource is utilized. Table 19 also shows that these refuse utilization levels represent only a very small fraction of the potential demand, which implies that only relatively few coal burning plants will have been converted; in the low coal case, the 2000 refuse demand with all facilities converted would be 464×10^{12} Btu, as compared with 170×10^{12} actually supplied, which implies conversion of only about one third of coal burning plants in the region be converted to supplementary refuse firing.

Figure 18 summarizes the low case scenario. Note that the proportion of refuse going into gas pyrolysis and steam generation is assumed to remain at the current level; if, however, natural gas becomes deregulated, the economics of gas pyrolysis would become more favorable, and this might result in a higher proportion of conversion to gas.⁴

Figure 18. The low case.

Table 20

SUMMARY OF CURRENT ENERGY CONVERSION PROJECTS

<u>Type</u>	<u>Location</u>	<u>Tcns/day</u>	<u>Etu/yr</u>	<u>Total Btu/yr</u>
Direct Firing	Bridgeport	1800	5.4×10^{12}	} 47.7×10^{12} Btu/yr as Refuse.
	E. Brigewater	600	1.8×10^{12}	
	Hackersack	1000	3×10^{12}	
	Hempstead	2000	6×10^{12}	
	Housatonic Valley	1500	4.5×10^{12}	
	Rochester	2000	6×10^{12}	
	Montgomery Cty., MD	1200	3.6×10^{12}	
	N. Britain, CN	1800	5.4×10^{12}	
	New Ycrk	1500	4.5×10^{12}	
	Onodaga Cty., NY	1000	3×10^{12}	
	Washington	1000	3×10^{12}	
	Willington	500	1.5×10^{12}	
Steam Generation	Braintree, MA	240	$.72 \times 10^{12}$	} 7.32×10^{12} Btu/yr as Refuse.
	Saugus, MA	1200	3.6×10^{12}	
	Onondaga Cty., NY	1300	3×10^{12}	
Pyrolysis	Baltimore	1000	3×10^{12}	} 4.20×10^{12} Btu/yr as Refuse.
	Mt. Vernon, NY	400	1.2×10^{12}	

3 High Case

This case assumes, for every state in the region, complete implementation of statewide solid waste management plans as currently underway for Massachusetts and Connecticut.⁵ To be sure, such an assumption depends on political, financial, and environmental policy at the State level, as discussed in Chapter VI; and particularly on strict enforcement of sanitary landfill regulations and air quality standards, which will make incineration without energy recovery less attractive than with it in urban areas, and will preclude open dumps in rural areas. The data in Figure 19 are based on such statewide plans being 50% complete by 1985, and 100% complete by 2000.

Figure 19. The high case.

9.4 Contribution to Regional Energy Supply

What contribution, then, would energy recovery from refuse make to the future energy supply of the Northeast? Because of the complexity of interlocking alternatives, this question is not easily answered.

The base case 1985 and 2000 resource requirements, as derived in the integrated analysis report of the BNL, Perspectives Study⁶ are 20.35×10^{15} Btu/yr, and 31.28×10^{15} Btu/yr, respectively. To these totals, refuse could contribute a maximum of $.231 \times 10^{15}$ Btu in 1985, or $.77 \times 10^{15}$ Btu by 2000, or 1.1% and 2.5%, respectively. That, to be sure, is a very small contribution.

But when expressed as a contribution to specific sectors, the result is more encouraging. If all the refuse were converted by pyrolysis to augment natural gas supply, refuse could provide $0.231 \times 10^{15} \times .55 = 0.12 \times 10^{15}$ Btu of natural gas by 1985, or 5% of the 2.36×10^{15} Btus of expected base case consumption. By 2000, the contribution is $.42 \times 10^{15}$ Btu, or 22% of the total regional gas requirement of 1.85×10^{15} Btu.⁷

Similarly, if all the refuse were directly fired in utility boilers, the 1985 base case regional coal requirement would be reduced from 3.50×10^{15} Btu to 3.27, or 6.6%; and by 2000 from 8.13×10^{15} Btu to 7.36×10^{15} Btu, or 9.5 percent.

It can be concluded, therefore, that recovery of energy from refuse can make a significant contribution to the regional energy supply; and, coupled with its environmental, economic and solid waste management benefits, certainly represents an attractive policy option.

NOTES TO CHAPTER IX

1. OBERS Projection, Series E population; U.S. Water Resources Council, Washington, DC, April 1974.
2. B. S. Edelston and E. S. Rubin, "Current and Future Use of Coal in the Northeast," BNL 50560 (May 1976), Environmental Studies Institute, Carnegie-Mellon University, Pittsburgh, Pennsylvania
3. Edelston and Rubin, Note 2, supra, Tables IV-11 and IV-1B.
4. For further discussion, see R. N. Langlois, " A Perspective on the Energy Future of the Northeast: Natural Gas", Brookhaven National Laboratory, Energy Policy Analysis Division, BNL - 50558, May 1976.
5. Appendix F for status of these plans.
6. As given in J. Brainard, et al., " A Perspective on the Future of the Northeast United States," BNL - 50550, Energy Policy Analysis Division, Brookhaven National Laboratory, May 1976, Appendix B, "Scenario 1"
7. Ibid .

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CHAPTER X

SUMMARY AND CONCLUSIONS

The conclusions of this study can be summarized as follows.

1. The contribution of energy recovered from municipal refuse to the future energy supply of the Northeastern United States, even though representing only 1 to 2% of total Btu consumption, is significant in terms of potential contribution to particular sectors; by 2000, refuse could supply as much as 22% of the total regional demand for natural gas or 9.5% of that for coal.

2. The high hauling cost of refuse over long distances makes it unlikely that significant quantities of rural waste will be converted to energy because disposal by sanitary landfill will usually be cheaper; therefore at most 90 to 95% of the total regional refuse energy resource will be economically recoverable.

3. The most attractive energy conversion option is direct firing of refuse in coal-fired utility boilers. Regardless of alternative disposal cost, most urban areas in the Northeast having coal-fired plants would find it economically attractive to burn refuse in it.

4. The generation of steam for industrial process heat in waterwall incinerators is economically attractive if a large industrial user is nearby. Although this condition will doubtless be met in many cases over the next 25 years, this option is unlikely to make a major contribution. Plans for direct firing of municipal refuse in the Northeast already outnumber process steam projects by about 7 to 1, even though the first major refuse-to-energy project in New England is of the latter type.

5. The options for converting refuse to gas, by either gas pyrolysis or anaerobic digestion with sewage sludge, are economically competitive only under rather special circumstances. Deregulation

of interstate natural gas prices will make gas conversion more attractive relative to steam generation and direct firing, but the price would have to exceed 300¢/mcf for the gas option to become more widespread.

6. Given that direct firing in utility boilers is the most attractive option, the extent to which this will in fact be used over the next 25 years depends on two factors. First, the availability of refuse fuel in the urban areas suggests that new coal capacity should also be located in these areas; yet additional mine-mouth plants in Western Pennsylvania are too distant for supplementary refuse firing. Second, the cost of coal to the utilities stands in direct relationship to the amount and price of refuse demanded by utilities; and return to pre-embargo coal prices would invalidate the conclusions reached in this study.

APPENDIX A: THE ENERGY YIELD FROM COMBUSTION

The energy yield from combustion is readily computed by means of a series of matrix transformations. We assume that the refuse composition does not vary throughout the whole region. Let Column matrix C , of dimension $(m \times 1)$, represent the fractional composition of m categories of refuse. Let W be a row matrix, of dimension $(1 \times n)$, whose j -th element represents the annual gross amount of refuse generated in the j -th subregion, in tons/year. Hence the matrix product

$$\begin{matrix} C & \times & W \\ (m \times 1) & & (1 \times n) \end{matrix} = \begin{matrix} C^* \\ (m \times n) \end{matrix}$$

gives the annual amount (in tons/year) of refuse in each of the m categories for each of the n subregions. For example, $C_{ij}^* = C_i W_j$ is the tons of refuse generated each year of i -th category in the j -th subregion.

Now let T be a $k \times m$ matrix corresponding to the transformation from m refuse categories to k ultimate analysis categories. The element T_{ij} thus represents the amount of element i contained in refuse category j .¹ In this study, we shall use the 7 ultimate analysis categories and matrix T shown in Table 21. For example, $T_{23} = 0.059$ means that hydrogen forms 5.9% of garden component of refuse.

Thus, the matrix product

$$\begin{matrix} T & \times & C^* \\ (k \times m) & & (m \times n) \end{matrix} = \begin{matrix} U \\ (k \times n) \end{matrix}$$

represents the annual amount (in tons/year) of each element of k ultimate analysis categories in each of the n subregions. Table 22 shows some typical values of u for the Northeast.

The heat value of refuse may be computed directly from ultimate analysis using an equation derived by Wilson.² Using basic thermochemical principles, and assuming complete combustion, the heat content, in Btu/lb, may be given as

$$= 14096 C + 64678 H - 5950 O + 3982 S + 1040 N$$

where C, O, H, N, and S are the fractions of total carbon, total oxygen, total hydrogen, total nitrogen, and total sulfur found on ultimate analysis. However, this heat value will be reduced due to moisture in the refuse; if h_v is the energy required to heat and vaporize moisture, in Btu/lb, then the net value, per lb of refuse as received, is

$$= 14096 C + 64678 H - 5959 O + 1040 N + 3982 S - k_v H_2O$$

Table 21
ASSUMPTIONS

ULTIMATE ANALYSIS CATEGORIES	
C	CARBON
H	HYDROGEN
O	OXYGEN
N	NITROGEN
S	SULFUR
INRT	INERTS
H2O	MOISTURE

ULTIMATE ANALYSIS TRANSFORMATION MATRIX								
	PAPR	GARB	GARD	PLST	MTL	GLS	OTHR	H2O
C	.4400	.4700	.4800	.4700	.0450	.0090	0.0000	0.0000
H	.0610	.0970	.0990	.0400	.0063	.0007	0.0000	0.0000
O	.4160	.2760	.4240	.2400	.0420	.0036	0.0000	0.0000
N	.0043	.0279	.0029	.0190	.0045	.0063	0.0000	0.0000
S	.0012	.0025	.0011	.0055	.0031	0.0000	0.0000	0.0000
INRT	.0765	.2167	.0209	.1970	.9040	.9962	1.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
TOT	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

GAMMA VECTOR	
C	14096.0
H	64678.0
O	-5950.0
N	1040.0
S	3982.0
INRT	0.0
H2O	-1120.0

HEAT VALUE OF COAL	12020.0, BTU/LB
HEAT RATE	10665.0, BTU/KWHR
AVE. LOAD FACTOR	.600

Table 22

ULTIMATE ANALYSIS, TONS/YR

	C	H	O	N	S	INRT	H2O	TOT
ALBN	33.7	4.6	30.1	.6	.1	40.5	36.2	145.7
ALLN	27.5	3.7	24.6	.5	.1	33.1	29.6	119.1
ALTO	20.1	2.7	18.0	.3	.1	24.2	21.6	87.0
ATLA	14.0	1.9	12.5	.2	.0	16.8	15.0	60.5
BALT	21.4	2.9	19.1	.4	.1	25.7	23.0	92.6
BING	33.2	4.5	29.7	.6	.1	39.9	35.7	143.6
BOST	22.9	3.1	20.4	.4	.1	27.5	24.6	98.9
BRID	8.5	1.2	7.6	.1	.0	10.2	9.1	36.5
BRIS	3.8	.5	3.4	.1	.0	4.6	4.1	16.7
BROC	9.7	1.3	8.7	.2	.0	11.7	10.4	42.0
BUFF	25.0	3.4	22.4	.4	.1	30.1	26.9	108.3
ERIE	15.6	2.1	14.0	.3	.1	18.8	16.8	67.6
FALL	5.2	.7	4.7	.1	.0	6.3	5.6	22.6
FITC	9.9	1.4	8.9	.2	.0	11.9	10.7	42.9
HARR	18.0	2.4	16.0	.3	.1	21.6	19.3	77.7
HART	22.6	3.1	20.2	.4	.1	27.1	24.3	97.7
JERS	3.2	.4	2.9	.1	.0	3.9	3.5	14.0
JOHN	37.0	4.4	28.6	.5	.1	38.5	34.4	138.5
LANC	26.1	3.6	23.3	.4	.1	31.4	28.1	113.1
LAW#	11.5	1.6	10.3	.2	.0	13.9	12.4	49.9
LEWI	7.6	1.0	6.8	.1	.0	9.2	8.2	33.0
LOWE	9.3	1.3	8.3	.2	.0	11.2	10.0	40.2
MANC	8.8	1.2	7.8	.1	.0	10.5	9.4	37.9
MERI	5.3	.7	4.7	.1	.0	6.4	5.7	23.0
NASH	6.3	.9	5.6	.1	.0	7.6	6.8	27.3
N,BE	8.8	1.2	7.9	.1	.0	10.6	9.5	38.2
N,BR	6.1	.8	5.5	.1	.0	7.3	6.6	26.4
N,HA	12.6	1.7	11.2	.2	.0	15.1	13.5	54.5
N,LN	16.5	2.3	14.8	.3	.1	19.9	17.8	71.5
N,YO	18.5	2.5	16.5	.3	.1	22.2	19.9	80.1
NEWA	11.5	1.6	10.3	.2	.0	13.8	12.4	49.8
NORW	4.3	.6	3.9	.1	.0	5.2	4.7	19.7
PTRS	7.9	1.1	7.1	.1	.0	9.5	8.5	34.3
PHIL	36.3	4.9	32.5	.6	.1	43.6	39.1	157.2
PITT	35.6	4.8	31.8	.6	.1	42.8	38.3	154.0
PITT	8.8	1.2	7.8	.1	.0	10.5	9.4	37.9
PORT	10.8	1.5	9.6	.2	.0	12.9	11.6	46.5
PROV	22.0	3.0	19.7	.4	.1	26.4	23.7	95.2
READ	25.2	3.4	22.5	.4	.1	30.2	27.1	105.9
ROGM	28.5	3.8	18.3	.3	.1	24.7	22.1	88.8
SCRA	18.5	2.5	16.6	.3	.1	22.3	19.9	80.2
SPFD	20.2	2.8	18.0	.3	.1	24.3	21.7	87.4
STAM	6.4	.9	5.7	.1	.0	7.7	6.9	27.6
SVRA	34.3	4.7	30.6	.6	.1	41.2	36.8	145.2
TREN	9.3	1.3	8.3	.2	.0	11.2	10.0	40.2
UTIC	34.9	4.7	31.1	.6	.1	41.9	37.5	150.5
VINE	19.5	2.7	17.4	.3	.1	23.5	21.0	84.5
WASH	34.1	4.6	30.4	.6	.1	40.9	36.6	147.4
WATE	11.9	1.4	10.6	.2	.0	14.2	12.8	51.3
WLKS	25.5	3.5	22.8	.4	.1	30.6	27.4	110.2
WJLM	17.0	2.3	15.2	.3	.1	20.4	18.3	73.6
WORC	19.0	2.6	16.9	.3	.1	22.8	20.4	82.1
YORK	30.2	4.1	27.0	.5	.1	36.2	32.4	130.5
BUKL	13.7	1.9	12.2	.2	.0	16.4	14.7	59.1
NEWP	4.7	.6	4.2	.1	.0	5.6	5.0	20.2
NEWC	16.5	2.2	14.7	.3	.1	19.8	17.7	71.2
STAT	27.8	3.8	24.8	.5	.1	33.4	29.9	120.2
WILL	28.6	3.9	25.6	.5	.1	34.4	30.8	123.9
LEBA	16.4	2.2	14.6	.3	.1	19.6	17.6	70.5
DANB	7.4	1.0	6.6	.1	.0	8.9	8.0	32.2
JAME	27.5	3.7	24.6	.5	.1	33.0	29.6	115.9
ELMI	17.6	2.4	15.8	.3	.1	21.2	19.0	76.3
ITMA	19.2	2.6	17.1	.3	.1	23.0	20.6	82.9
AUBU	23.8	3.1	20.5	.4	.1	27.6	24.7	99.4
ANST	17.5	2.4	15.6	.3	.1	21.0	18.8	75.7
WATE	24.2	4.0	26.1	.5	.1	35.1	31.4	126.4
KING	28.0	3.8	25.0	.5	.1	33.7	30.1	121.2
NEWS	24.8	3.4	22.2	.4	.1	29.8	26.7	107.4
POUG	15.6	2.1	14.0	.3	.1	18.8	16.8	67.6
LOHG	19.0	2.6	17.0	.3	.1	22.8	20.5	82.3
NB#P	15.0	2.0	13.4	.2	.0	18.0	16.1	64.7
CONC	26.0	3.5	23.2	.4	.1	31.2	27.9	112.3
GLOU	60.5	8.2	54.0	1.0	.2	72.6	65.0	261.6
HAGE	18.6	2.5	16.6	.3	.1	22.3	20.0	80.3
CUMR	12.6	1.7	11.2	.2	.0	15.1	13.5	54.3
BAHA	36.1	4.9	32.3	.6	.1	43.4	38.8	156.3
TORR	25.9	3.5	23.1	.4	.1	31.1	27.9	112.1
MIDD	16.6	2.3	14.8	.3	.1	19.9	17.8	71.8
TOT	1475.2	200.9	1317.8	24.6	4.9	1771.9	1586.2	6381.4

One may thus compute the annual energy yield

$$B_T = \frac{2000}{10^{12}} \times \gamma \times u$$

(1 x n) (1 x 1) (1 x k) (k x n)

where

$$\gamma = [14096, 64678, -5950, 1040, 3982, 0.0, -k_v]$$

and B_T is an (1 x n) matrix. Each element of B_T represents the annual energy yield in 10^{12} Btu/year, of each of the n subregions. Inserting a value of $k = -1120$,³ the full γ -vector, as used in the computer model, is shown in Table 21.

Since refuse composition varies from year to year, as indicated by historical trend, the heat content of raw refuse (in Btu/lb) for a particular year is also of interest. Let V be a (1 x t) matrix whose j-th element is the heat content of raw refuse in year j. Let matrix D, of dimension (m x t) whose transpose is shown in Table 4, represent the dry weight composition of t years. Thus

$$V = \gamma \times T \times D$$

(1 x t) (1 x k) (k x m) (m x t)

and elements of V are sometimes referred to as "As received heat values."

NOTES TO APPENDIX A

1. Clearly, this definition results in column sums of unity, i.e.,

$$\sum_{j=1}^k t_{ji} = 1$$

2. D. L. Wilson, "Prediction of Heat of Combustion of Solid Wastes from Ultimate Analysis", Environmental Science and Technology, Vol. 6, No. 13, p. 1119 (December 1972).
3. See e.g., Envirogenics Company, "Systems Evaluation of Refuse as a Low Sulfur Fuel", Vol. 1, p. II-48.

APPENDIX B. DERIVATION OF SOLID WASTE GENERATION EQUATION

Let the amount of refuse $q'(r)$, in lb capita/day, generated at distance r from the center of the city be a function of population density at that point, i.e.

$$q'(r) = q_0 [d(r)]^\beta$$

where q_0 and β are constants, and $d(r)$ is the population density (persons/sq.mi.) at distance r from the city center. According to the exponential model for urban population density,²

$$d(r) = d_0 e^{-\alpha r}$$

where d_0 is the population density at the center of the city, α the density gradient (mile⁻¹), and thus

$$q'(r) = q_0 d_0^\beta e^{-\alpha\beta r}$$

It follows that $q(r)$, the amount of refuse generated per square mile per year at distance r from the city center, is given by

$$\begin{aligned} q(r) &= \frac{365}{2000} q'(r) d(r) \\ &= 0.1825 q_0 d_0^{1+\beta} e^{-\alpha(1+\beta)r} \end{aligned} \quad [12]$$

where $q(r)$ is in tons/sq.mi./year.

Hence, if

$$\alpha' = \alpha(1 + \beta)$$

$$a = 0.1825 q_o d_o^{1+\beta}$$

Eq. [12] can be written as

$$q(r) = ae^{-\alpha' r} \quad [13]$$

To obtain the total quantity of solid waste generated in a city of sector angle θ ,³ one must integrate Eq. [13] over appropriate limits. The quantity $Q(R)$ (tons/year), generated in a city of radius R , can be stated as⁴

$$\begin{aligned} Q(R) &= \int_{r=0}^R \int_{\theta=0}^{\theta} q(r) r dr d\theta \\ &= a\theta \int_0^R e^{-\alpha' r} r dr \\ &= \frac{a\theta}{\alpha'^2} \left[1 - (1 + \alpha' R) e^{-\alpha' R} \right] \end{aligned} \quad [14]$$

NOTES TO APPENDIX B

1. Refuse generation may of course be a function of more variables than only population density, but for a given city population density is the best explanatory variable for describing intra-city variations in generation rate. Evidently population density is a good surrogate for other important variables such as household income.
2. The exponential model for urban population density is discussed in detail in P. M. Meier and T. H. McCoy, "An Analytical Approach to the Determination of Urban Population Density Gradients and its Application to Energy Planning Problems", BNL - 20916, Policy Analysis Division, Brookhaven National Laboratory, January 1976.
3. Ibid., Chapter III.
4. Ibid.

APPENDIX C. DERIVATION OF HAUL COST EQUATIONS

Case 1. Destination at Center of City, Haul in Collection Vehicle

Transportation costs for house-to-house refuse collection vehicles are generally given in terms of \$/hour to operate a truck of given capacity. The haul cost per trip is thus

$$\gamma_h \left(\frac{2r}{s} + u \right) \quad [15]$$

where γ_h = cost, \$/hour

r = haul distance, miles

s = average truck speed, miles/hour

u = unloading time, hours

and hence the cost per ton, as a function of haul distance, is

$$\frac{\gamma_h \left(\frac{2r}{s} + u \right)}{t}$$

where t is the truck capacity in tons.

Therefore, with Eq. [13] used to obtain the amount of refuse generated (tons/sq.mi./yr), the haul cost in \$/sq.mi./year at distance r from the center is

$$\begin{aligned} c(r) &= \frac{\gamma_h \left(\frac{2r}{s} + u \right)}{t} q(r) \\ &= \frac{\gamma_h \left(\frac{2r}{s} + u \right)}{t} a e^{-\alpha' r} \\ &= \frac{2a\gamma_h}{ts} r e^{-\alpha' r} + \frac{au\gamma_h}{t} e^{-\alpha' r} \end{aligned}$$

If one assumes a circular city of sector angle θ ,¹ then the total haul cost per year for the area within radius R is

$$C(R) = \int_0^R c(r) r \theta dr \quad [16]$$

Substitution of Eq. [15] into Eq. [16] gives

$$\begin{aligned} C(R) &= \int_0^R \left[\left(\frac{2a\gamma_h}{ts} \right) r e^{-\alpha' r} + \left(\frac{au\gamma_h}{t} \right) e^{-\alpha' r} \right] r \theta dr \\ &= \frac{2a\theta\gamma_h}{ts} \int_0^R r^2 e^{-\alpha' r} dr + \frac{au\theta\gamma_h}{t} \int_0^R r e^{-\alpha' r} dr \quad [17] \end{aligned}$$

By further algebra omitted here, this integral can be shown to yield

$$\begin{aligned} C(R) &= \frac{2a\theta\gamma_h}{ts\alpha'} \left[2 - \left(2 + 2\alpha'R + \alpha'^2 R^2 \right) e^{-\alpha'R} \right] \\ &+ \frac{au\theta\gamma_h}{t\alpha'^2} \left[1 - \left(1 + \alpha'R \right) e^{-\alpha'R} \right] \end{aligned}$$

the systemwide cost per ton, C_s , of collecting all refuse within radius R and delivering it to the center of the city, is given by

$$C_s(R) = \frac{C(R)}{Q(R)}$$

hence

$$C_s(R) = \frac{\frac{2a\theta\gamma_h}{st\alpha'^3} \left[2 - \left(2 + 2\alpha'R + \alpha'^2 R^2 \right) e^{-\alpha'R} \right] + \frac{au\theta\gamma_h}{t\alpha'^2} \left[1 - \left(1 + \alpha'R \right) e^{-\alpha'R} \right]}{\frac{a\theta}{\alpha'^2} \left[1 - \left(1 + \alpha'R \right) e^{-\alpha'R} \right]}$$

Which simplifies to

$$C_s(R) = \frac{\gamma_h}{t} \left[\frac{2}{\alpha' s} \cdot \frac{2 - \left(2 + 2\alpha'R + \alpha'^2 R^2 \right) e^{-\alpha'R}}{1 - \left(1 + \alpha'R \right) e^{-\alpha'R}} + u \right] \quad [18]$$

Case 2. Arbitrary Destination: Haul in Collection Vehicle

Consider destination P, a distance ℓ from the center of a circular SMSA, as shown in Figure 18. Note that

$$r'^2 = r^2 + \ell^2 - 2r\ell\cos\theta$$

The amount of refuse generated per unit area is given by Eq. [13] as

$$q(r) = ae^{-\alpha'r}$$

hence the haul cost per unit area at point (r, θ) is²

$$\begin{aligned} c(r, \theta) &= \frac{\gamma_h}{t} \left(\frac{2r'}{s} + u \right) q(r) \\ &= \frac{\gamma_h}{t} \left[\frac{2}{s} \left(r^2 + \ell^2 - 2r\ell\cos\theta \right)^{\frac{1}{2}} + u \right] q(r) \end{aligned}$$

Figure 18. Definition sketch for an arbitrary destination.

The total average system haul cost is given by

$$C_s(R) = \frac{\int_{r=0}^R \int_{\theta=0}^{2\pi} c(r, \theta) r dr d\theta}{\int_{r=0}^R \int_{\theta=0}^{2\pi} q(r) r dr d\theta}$$

$$= \frac{2\gamma_h}{ts} \cdot \frac{\int_{r=0}^R \int_{\theta=0}^{2\pi} \left(r^2 + l^2 - 2rl \cos \theta \right)^{\frac{1}{2}} q(r) r dr d\theta}{\int_{r=0}^R \int_{\theta=0}^{2\pi} q(r) r dr d\theta} + \frac{\gamma_h}{t} u$$

but, from Eq. [13],

$$q(r) = ae^{-\alpha' r}$$

hence

$$\int_{r=0}^R \int_{\theta=0}^{2\pi} q(r) r dr d\theta = \frac{2\pi a}{\alpha'^2} \left[1 - \left(1 + \alpha' R \right) e^{-\alpha' R} \right]$$

and

$$\begin{aligned} & \int_{r=0}^R \int_{\theta=0}^{2\pi} \left(r^2 + \ell^2 - 2r\ell \cos\theta \right)^{\frac{1}{2}} q(r) r dr d\theta \\ &= 2a \int_0^R r e^{-\alpha' r} dr \int_0^\pi \left(r^2 + \ell^2 - 2r\ell \cos\theta \right)^{\frac{1}{2}} d\theta \end{aligned} \quad [18a]$$

the integral

$$I = \int_0^\pi \left(r^2 + \ell^2 - 2r\ell \cos\theta \right)^{\frac{1}{2}} d\theta \quad [19]$$

can be solved by introducing the change of variable

$$\xi = \frac{\pi}{2} - \frac{\theta}{2} \quad [20]$$

It can be shown that Eq. [19] reduces to

$$\begin{aligned} I &= 2(r + \ell) \int_0^{\pi/2} \left(1 - \frac{4r\ell}{(r + \ell)^2} \sin^2\zeta \right)^{\frac{1}{2}} d\zeta \\ &= 2(r + \ell) E\left(\frac{2\sqrt{r\ell}}{r + \ell} \right) \end{aligned}$$

where $E[2\sqrt{rl}/(r+l)]$ is a complete elliptical integral of the second kind,³ for which numerical integration routines are available at most large scientific computer facilities. Thus Eq. [18a] can be written

$$I = 4a \int_0^R r(r+l) e^{-\alpha' r} E\left(\frac{2\sqrt{rl}}{r+l}\right) dr$$

which can be solved numerically. Hence

$$\begin{aligned} C_s(R) &= \frac{2\gamma_h}{ts} \cdot \frac{4a \int_0^R r(r+l) e^{-\alpha' r} E\left(\frac{2\sqrt{rl}}{r+l}\right) dr}{\frac{2\pi a}{\alpha'^2} \left[1 - (1 + \alpha' R) e^{-\alpha' R}\right]} + \frac{\gamma_h}{t} u \\ &= \frac{4\gamma_h \alpha'^2}{\pi ts} \cdot \frac{\int_0^R r(r+l) e^{-\alpha' r} E\left(\frac{2\sqrt{rl}}{r+l}\right) dr}{1 - (1 + \alpha' R) e^{-\alpha' R}} + \frac{\gamma_h}{t} u \quad [21] \end{aligned}$$

Note that for the special case $l = 0$, this reduces to Eq. [18], and that Eq. [21] is valid for any l , within or outside R_A .

Case 3. Transfer Station Case

As the distance from population center to haul destination increases, the cost of transporting refuse in the vehicle used for house-to-house collection increases. At some break-even distances, it becomes cheaper to build a transfer facility near the population center and to haul refuse from there to the disposal (or energy recovery) site in large tractor-trailers.

Such a system is diagrammed in Figure 19. Haul cost to the transfer station in collection vehicles is given by Eq. [21]. To this must be added the haul cost from transfer station to disposal

Figure 19. Definition sketch, transfer station case.

site, given by

$$\frac{\gamma^*}{t^*} \left[\frac{2(h-l)}{s^*} + u^* \right]$$

where γ^* = cost, \$/hour

t^* = truck capacity, tons

s^* = speed, miles/hour

u^* = loading and unloading time, hours

This is analogous to Eq. [15], with the asterisk indicating reference to a transfer vehicle rather than a collection vehicle

that u^* includes both loading and unloading time whereas u included only unloading time).

The capital cost of the transfer facility must also be considered. The cost of processing a ton of refuse at a transfer station, C_T , can be expressed⁴

$$C_T = b/T^m$$

where b and m are constants characteristic of the station design and construction costs, and T is the transfer station capacity in tons/day. If T is in the range 100 to 1500, then $b = 33.4$ and $m = 0.55$,⁵ and hence the average cost per ton for a transfer station serving a city of radius R is

$$C_T = \frac{33.4}{[Q(R)/260]^{0.55}}$$

where $Q(R)$, in tons/year, is given by Eq. [14] and 260 represents working days per year. The total cost for delivering refuse to the transfer station, transferring it, and hauling it to the destination point is given by

$$C_g(R) = \frac{4\gamma_h \alpha'^2}{\pi t \alpha} \cdot \frac{\int_0^R r(r + \ell) e^{-\alpha' r} E\left(\frac{2\sqrt{r\ell}}{r + \ell}\right) dr}{1 - (1 + \alpha'R) e^{-\alpha'R}} + \frac{\gamma_h}{t} u$$

$$+ \frac{\gamma^*}{t^*} \left[\frac{2(h - \ell)}{s^*} + u^* \right] + \frac{33.4}{\left\{ \frac{a\theta}{260\alpha'^2} + [1 - (1 + \alpha'R) e^{-\alpha'R}] \right\}^{0.55}}$$

[22]

NOTES TO APPENDIX C

1. For an explanation of this assumption, see P. Meier and T. n. McCoy, "An Analytical Approach to the Determination of Urban Population Density Gradients and its Application to Ener Planning Problems", BNL 20916 , Policy Analysis Division, Brookhaven National Laboratory.
2. Ibid, Chapter III.
3. An Elliptical integral of the second kind is defined as the general form
$$E(X) = \int_0^{\varphi_0} \left(1 - x^2 \sin^2 \varphi\right)^{\frac{1}{2}} d\varphi$$
if $\varphi_0 = \pi/2$, $E(X)$ is called a complete elliptical integral (of the second kind).
4. A. D. Little, Inc. "A Systems Evaluation of Alternative State-wide Resource Recovery Techniques for the disposal of Municipal Solid Waste" Report to the Massachusetts Department of Public Works, December 1973, p. 118.
5. Ibid, p. 119.

APPENDIX D: DETERMINATION OF THE OPTIMAL DELIVERY
DISTANCE TO AN ENERGY RECOVERY FACILITY

Let the total annual cost of refuse haul, disposal, and energy conversion be given by

$$Y = -Q(R)P_R + \left[Q_T - Q(R) \right] P_D + C(R) \quad [23]$$

where the first term represents revenue from energy conversion, the second, cost of disposing of the residual refuse; and the third, haul cost to the energy facility; and

$Q(R)$ = refuse converted to energy, tons/year

Q_T = total refuse in the region, tons/year

P_R = breakeven refuse price, \$/ton

P_D = alternative refuse disposal cost, \$/ton

$C(R)$ = cost of refuse delivery to conversion facility
\$/ton

Since minimization of y is the objective, differentiating Eq. [22] with respect to R , setting the result to zero, and solving for R will yield the optimum distance (and hence, the amount of refuse optimally converted):

$$\frac{dy}{dR} = -P_R \frac{dQ(R)}{dR} - P_D \frac{dQ(R)}{dR} + \frac{dC(R)}{dR} = 0$$

[24]

$$\left(P_R + P_D \right) \frac{dQ(R)}{dR} = \frac{dC(R)}{dR}$$

From Appendix B

$$\frac{dQ(R)}{dR} = a\theta Re^{-\alpha' R}$$

and from Appendix C

$$\frac{dC(R)}{dR} = a\theta Re^{-\alpha' R} \cdot \frac{\gamma}{t} h \left(\frac{2R}{s} + u \right)$$

Substituting into Eq. [23] gives

$$\left(P_R + P_D \right) a\theta Re^{-\alpha' R} = a\theta Re^{-\alpha' R} \cdot \frac{\gamma}{t} h \left(\frac{2R}{s} + u \right)$$

hence

$$P_R + P_D = \frac{\gamma}{t} h \left(\frac{2R}{s} + u \right)$$

Thus, R is the distance for which the haul cost equals alternative disposal cost plus breakeven refuse price and can be written as

$$R = \frac{ts \left(P_R + P_D \right)}{2\gamma_h} - \frac{us}{2} \quad [25]$$

Appendix E

FOSSIL FUELED UNITS IN THE NORTHEAST

BNL REGIONAL ENERGY STUDIES PROGRAM - - POWER PLANT DATA BASE

FOSSIL-FUELED UNITS, NORTHEAST U.S.

STATE	SMSA	STATION	UTILITY	MAF(E)	LF	10 ¹² Btu/yr	FUEL MIX COAL OIL GAS	DESIGN COAL
CONNECTICUT	BRIDGEPORT	STEEL POINT	UNITED ILL.	155.5	.5	11.5	0.0 100.0	0.0 1.0
		BRIDGEPORT HAPBO	UNITED ILL.	660.5	.7	41.8	0.0 100.0	0.0 1.0
		DERBY	UNITED ILL.	20.0	.1	.2	0.0 100.0	0.0 0.0
		DEVON	CONNECTICUT L+P	454.0	.5	24.1	46.0 54.0	0.0 1.0
				1290.0		77.5		
HARTFORD	SOUTH MEADOW MIDDLETOWN MIDDLETOWN 4	HARTFORD ELECTRI	216.8	-.5	12.2	0.0 100.0	0.0 1.0	
		HARTFORD ELECTRI	422.0	.7	25.3	12.0 88.0	0.0 1.0	
		HARTFORD ELECTRI	400.0	-0.0	-0.0	0.0 100.0	0.0 0.0	
			1038.8		37.5			
NEW HAVEN	ENGLISH COKEWORKS 1	UNITED ILL.	146.3	.3	6.5	0.0 100.0	0.0 1.0	
		UNITED ILL.	445.0	-0.0	-0.0	0.0 100.0	0.0 0.0	
			591.3		6.5			
N.LNDON-GFTN-NFMC	MONTVILLE GREENVILLE	CONNECTICUT L+P	545.5	.4	23.4	17.0 83.0	0.0 1.0	
		NORWICH	14.3	.1	.1	0.0 100.0	0.0 0.0	
			559.8		23.5			
NORWALK	NORWALK HARBOUR	CONNECTICUT L+P	326.4	.6	16.8	93.0 7.0	0.0 1.0	
			326.4		16.8			
STAMFORD	STAMFORD	HARTFORD ELECTRI	52.5	.3	2.6	3.0 95.0	2.0 1.0	
			52.5		2.6			
NEW HAVEN(*)	PIEPCE	WALLINGFORD DPU	22.5	.1	.3	100.0 -0.0 -0.0	1.0	
			22.5		.3			
				3881.3		164.8		

BNL REGIONAL ENERGY STUDIES PROGRAM - - POWER PLANT DATA BASE

FOSSIL-FUELED UNITS, NORTHEAST U.S.

STATE	SMSA	STATION	UTILITY	MW(E)	LF	10 ¹² Btu/yr	FUEL MIX COAL OIL	GAS DESIGN	COAL
DELAWARE	WILMINGTON	EDGEWOOD	DELMARVA P&L	390.0	.7	30.9	60.0 32.0	8.0	1.0
		DELAWARE CITY	DELMARVA P&L	129.4	.3	4.5	0.0 54.0	46.0	1.0
		DEEPWATER	ATLANTIC CITY EL	308.3	.6	18.2	0.0 83.0	17.0	1.0
				827.7		53.5			
				827.7		53.5			

BNL REGIONAL ENERGY STUDIES PROGRAM - - POWER PLANT DATA BASE

FOSSIL-FUELED UNITS, NORTHEAST U.S.

STATE	SMSA	STATION	UTILITY	MW(E)	LF	10 ¹² Btu/yr	FUEL MIX COAL OIL	GAS DESIGN	COAL
MARYLAND	BALTIMORE	LEANE	BALTIMORE G&E	399.8	.8	26.0	50.0 50.0	0.0	1.0
		GOULD STREET	BALTIMORE G&E	173.5	.4	8.5	73.0 71.0	1.0	1.0
		RIVERSIDE	BALTIMORE G&E	333.5	.5	20.0	0.0 100.0	0.0	0.0
		WAGNER	BALTIMORE G&E	527.0	.7	37.7	93.0 2.0	0.0	1.0
		WESTPORT	BALTIMORE G&E	194.0	.5	10.5	1.0 99.0	0.0	1.0
		PRATT STREET	BALTIMORE G&E	20.0	.5	1.3	100.0 0.0	0.0	1.0
				1747.8		104.9			
	CHARLES (*)	MORGANTOWN	POTOMAC ELECTRIC	1251.0	.8	83.2	21.0 79.0	0.0	1.0
				1251.0		83.2			
	NO-CHESTER (*)	VIRGINIA	DELMARVA P&L	256.5	.2	6.9	88.0 12.0	0.0	1.0
				256.5		6.9			
	WASHINGTON (*)	HAGERSTOWN	HAGERSTOWN ELECT	38.8	.1	.3	48.0 52.0	0.0	1.0
		SMITH	POTOMAC EDISON	109.5	.6	6.3	100.0 0.0	0.0	1.0
				148.3		6.7			
				3483.6		201.6			

BNL REGIONAL ENERGY STUDIES PROGRAM - POWER PLANT DATA BASE

FOSSIL-FUELED UNITS, NORTHEAST U.S.

STATE	SMSA	STATION	UTILITY	10 ¹²		FUEL MIX			COAL
				MW(E)	LF	Btu/yr	COAL	OIL	GAS DESIGN
MASSACHUSETTS	BARNSTABLE(*)	CANAL	CANAL ELECTRIC CO.	542.0	.8	32.0	0.0	100.0	0.0
				542.0		32.0			
BOSTON	MYSTIC 1	BOSTON EDISON		150.0	.4	7.4	0.0	100.0	0.0
	MYSTIC 2	BOSTON EDISON		468.8	.5	19.3	0.0	100.0	0.0
	NEW BOSTON	BOSTON EDISON		760.0	.7	72.3	0.0	100.0	0.0
	L-STREET	BOSTON EDISON		153.8	.2	5.5	0.0	100.0	0.0
	EDGAR 2	BOSTON EDISON		261.3	.5	14.6	0.0	100.0	0.0
	ALLEN STREET	BRAINTREE E.C.		21.0	.4	.8	0.0	100.0	0.0
	POTTER	BRAINTREE E.C.		12.5	.7	1.0	0.0	100.0	0.0
	KENDALL SQUARE	CAMBRIDGE E.L.		67.5	.6	3.6	0.0	70.0	30.0
	BLACKSTONE ST.	CAMBRIDGE E.L.		24.8	.3	.8	0.0	55.0	45.0
	LYNWAY	MASS. ELECTRIC		49.0	.4	2.1	0.0	100.0	0.0
	SALEM HARBOR	NEPC		319.8	.5	15.7	0.0	100.0	0.0
				2288.5		143.7			
BRISTOL(*)	WEST WATER STREET	TAUNTON MUN.L.		49.0	.3	2.0	0.0	100.0	0.0
	CLEARY	REE TAUNTON MUN.L.		28.3	.6	1.9	0.0	100.0	0.0
				77.3		3.9			
BROCKTON	EAST BRIDGEWATER	BROCKTON EDISON		20.0	.1	.2	0.0	100.0	0.0
				20.0		.2			
FALL RIVER	HATHAWAY ST.	FALL RIVER E.O.		14.3	.1	.1	0.0	100.0	0.0
	SOMERSET	MONTAUP		329.0	.6	19.4	14.0	86.0	0.0
	BRAYTON POINT	NEPC		1124.7	.7	66.1	0.0	100.0	0.0
				1468.0		85.7			
FITCHBURG-LEOMIN	FITCHBURG	G+E		61.4	.4	2.5	1.0	73.0	26.0
				61.4		2.5			
NEW BEDFORD	CANNON STREET	NEW BEDFORD G+E		93.0	.6	7.4	0.0	76.0	24.0
				93.0		7.4			
SPRINGFIELD-HOLYOKE	HOUNT TOM	HOLYOKE W&P		136.0	.6	7.0	0.0	100.0	0.0
	RIVERSIDE	HOLYOKE W&P		44.8	.2	.9	0.0	100.0	0.0
	HOLYOKE	HOLYOKE G+E		30.0	.5	1.3	7.0	61.0	32.0
	WEST SPRINGFIELD	WMCO		209.6	.6	13.7	14.0	67.0	24.0
				420.4		22.4			
WORCESTER	WEBSTER STREET	MASS. ELECTRIC		34.5	.5	1.7	91.6	9.0	0.0
				34.5		1.7			
				5085.1		299.4			

BNL REGIONAL ENERGY STUDIES PROGRAM - - POWER PLANT DATA BASE

FOSSIL-FUELED UNITS, NORTHEAST U.S.

STATE	SMSA	STATION	UTILITY	MW(E)	LF	10^{12} Btu/yr	FUEL MIX COAL OIL	COAL GAS DESIGN
NEW HAMPSHIRE	MANCHESTER	MERRIMACK	PSNH	459.2	.6	23.9	100.0 0.0	0.0 1.0
				459.2		23.9		
	ROCKINGHAM(*)	SCHILPE	PSNH	178.8	.7	12.4	0.0 100.0	0.0 1.0
				178.8		12.4		
				638.0		36.4		

STATE	SMSA	STATION	UTILITY	MW(E)	LF	10^{12} Btu/yr	FUEL MIX COAL OIL	COAL GAS DESIGN
MAINE	LINCOLN(*)	MASON	CENTRAL MAINE PO	146.5	.2	0.0	-0.0 -0.0	-0.0 -0.0
				146.5		0.0		
	PENOBSCOT(*)	GFAHAN	BANGOR HYDRO	57.5	.6	-0.0	-0.0 -0.0	-0.0 -0.0
				57.5		0.0		
	PORTLAND	WYMAN	CENTRAL MAINE PO	217.0	7814.0	*****	151.0 .8	3.1 1.0
				217.0		24184.0		
				421.0		24184.0		

BNL REGIONAL ENERGY STUDIES PROGRAM - - POWER PLANT DATA BASE

FOSSIL-FUELED UNITS, NORTHEAST U.S.

STATE	SMSA	STATION	UTILITY	MW(E)	10 ¹² Btu/yr		FUEL MIX			COAL DESIGN
					LF		COAL	OIL	GAS	
NEW JERSEY	ATLANTIC CITY	ENGLAND MISSOURI AVE.	ATLANTIC CITY EL	299.2	.7	17.7	92.0	8.0	0.0	1.0
			ATLANTIC CITY EL	52.5	.6	3.5	100.0	0.0	0.0	1.0
				351.7		21.2				
	JERSEY CITY	HUDSON MARION	PSE+G	1114.5	.5	45.0	38.0	40.0	22.0	1.0
			PSE+G	125.0	.4	6.5	0.0	100.0	0.0	1.0
				1239.5		51.5				
	MIDDLESEX(*)	WERNER SAYREVILLE SEWAREN	JERSEY CENTRAL P	116.3	.5	6.8	0.0	100.0	0.0	1.0
			JERSEY CENTRAL P	346.8	.7	23.3	0.0	82.0	18.0	1.0
			PSE+G	820.0	.6	46.8	0.0	97.0	3.0	1.0
				1283.1		76.9				
	NEWARK	ESSEX KEAFNY LINDON	PSE+G	336.8	.4	17.1	0.0	97.0	3.0	1.0
			PSE+G	598.6	.5	33.5	0.0	100.0	0.0	1.0
			PSE+G	519.4	.5	25.7	0.0	100.0	0.0	0.0
				1454.8		76.3				
	PATERSON-CLIFT-	BERGEN	PSE+G	650.4	.5	27.9	60.0	27.0	13.0	1.0
				650.4		27.9				
	TRENTON	MURCEP	PSE+G	652.0	.6	32.0	91.0	0.0	9.0	1.0
				652.0		32.0				
	VINELAND	VINELAND	VINELAND ELEC. DE	82.0	.4	3.9	21.0	79.0	0.0	1.0
				82.0		3.9				
			5713.5		289.6					

BNL REGIONAL ENERGY STUDIES PROGRAM - - POWER PLANT DATA BASE

FOSSIL-FUELED UNITS, NORTHEAST U.S.

STATE	SMSA	STATION	UTILITY	MW(E)	10 ¹² Btu/yr		FUEL MIX		COAL DESIGN	
					LF		COAL	OIL	GAS	
NEW YORK	ALBANY-SCHENECTADY	ALBANY	NIAGARA MOHAWK	400.0	.7	25.0	0.0	100.0	0.0	1.0
				400.0		25.0				
	RINGHAMPTON	GOUDFY	NYSG+E	145.8	.6	8.3	100.0	0.0	0.0	1.0
				145.8		8.3				
	BUFFALO	HUNTLEY	NIAGARA MOHAWK	828.0	.5	38.3	100.0	0.0	0.0	1.0
				828.0		38.3				
	CHAUTAUQUA (*)	CARLSON DUNKIRK	JAMESTOWN B.P.U. NIAGARA MOHAWK	80.5 628.0	.3 .5	3.2 28.6	100.0 100.0	0.0 0.0	0.0 0.0	1.0 1.0
				708.5		31.8				
	CHEMANGO (*)	JENNISON	NYSG+E	60.0	.6	4.9	100.0	0.0	0.0	1.0
				60.0		4.9				
NEW YORK	59-TH STREET	CON.ED.		184.5	.4	5.9	0.0	100.0	0.0	0.0
	ASTORIA	CON.ED.		1720.0	.5	66.6	16.0	61.0	71.0	1.0
	FAST RIVER	CON.ED.		834.0	.4	39.0	0.0	38.0	62.0	0.0
	HELLGATE	CON.ED.		511.0	.4	28.6	0.0	91.0	9.0	0.0
	SHEPMAN CREEK	CON.ED.		216.5	.1	4.0	0.0	97.0	3.0	0.0
	FAVENWOOD	CON.ED.		1828.0	.5	78.3	0.0	92.0	8.0	1.0
	ARTHUR KILL	CON.ED.		911.0	.4	34.7	56.0	44.0	0.0	1.0
	HUDSON AVENUE	CON.ED.		945.0	.3	30.7	0.0	100.0	0.0	0.0
	KENT AVENUE	CON.ED.		108.0	.1	19.3	0.0	0.0	100.0	0.0
	74-TH STREET	CON.ED.		269.1	.2	5.7	0.0	100.0	0.0	0.0
	WATERSIDE	CON.ED.		712.3	.3	30.2	0.0	61.0	39.0	0.0
	FAR ROCKAWAY	LILCO		113.6	.6	6.1	0.0	85.0	15.0	1.0
	GLENWOOD	LILCO		380.3	.4	17.2	0.0	75.0	25.0	1.0
	PORT JEFFERSON	LILCO		467.0	.7	28.3	0.0	100.0	0.0	1.0
	PARFETT	LILCO		375.0	.7	22.5	-0.0	85.0	15.0	1.0
	NORTHPOFT	LILCO		1151.3	.7	42.2	-0.0	100.0	-0.0	0.0
	LOVETT	ORANGE+ROCKLAND		495.1	.6	29.0	-0.0	64.0	36.0	1.0
				10961.7		488.8				
	ORANGE (*)	GENSKAMMEL	HUDSON G+E	537.4	.6	30.2	12.0	84.0	4.0	1.0
				537.4		30.2				
	ROCHESTER	ROCHESTER	ROCHESTER G+E	206.0	.6	8.1	38.0	0.0	2.0	1.0
	ROCHESTER	ROCHESTER	ROCHESTER G+E	252.6	.6	16.9	99.0	0.0	1.0	1.0
				458.6		25.0				
	STEUBEN-CHEM. (*)	HICKLING	NYSE+G	70.0	1.0	8.7	100.0	0.0	0.0	1.0
				70.0		8.7				
	SYRACUSE	OSWEGO	NIAGARA MOHAWK	376.0	.6	19.9	100.0	0.0	0.0	1.0
				376.0		19.9				
	TOMPKINS (*)	HILLIKEN	NYSE+G	270.0	.4	18.5	100.0	0.0	0.0	1.0
				270.0		18.5				
	YATES (*)	GREENIDGE	NYSE+G	160.0	.7	10.8	100.0	0.0	0.0	1.0
				160.0		10.8				
				14976.0		710.0				

PUL REGIONAL ENERGY STUDIES PROGRAM - POWER PLANT DATA BASE

Fossil-Fueled Units, Northeast U.S.

STATE	SMSA	STATION	UTILITY	10 ¹² Btu/yr						
				MW(E)	LF	FUEL MIX	COAL	CAC	DECISION	
PENNSYLVANIA	ALLENTOWN-BETH-	PORTLAND	METROP. EDISON	426.7	.7	25.3	99.0	1.0	0.0	1.0
		GILBERT	NJP&L	126.1	.7	9.8	4.0	65.0	31.0	1.0
		HAFINS CREEK	PENN. P&L	312.5	.7	20.5	100.0	0.0	0.0	1.0
				865.3		55.6				
	ALTOONA	WILLIAMSBURG	P.E.C.	30.0	.7	3.6	100.0	0.0	0.0	1.0
				30.0		3.6				
	ARMSTRONG (*)	KEYSTONE	PENN. P.L.	1872.0	.5	80.5	99.0	1.0	0.0	1.0
				1872.0		80.5				
	ARMSTRONG (*)	ARMSTRONG	WEST PENN. P.C.	325.4	.7	22.4	100.0	0.0	0.0	1.0
				325.4		22.4				
	BERKSHIRE (*)	SAXTON	P.E.C.	40.9	.1	1.0	100.0	0.0	0.0	1.0
				40.9		1.0				
	CENTER (*)	MILLSBURG	WEST PENN. P.C.	46.0	.7	3.5	100.0	0.0	0.0	1.0
				46.0		3.5				
	CLARIFIELD (*)	SHANVILLE	P.E.C.	640.0	.7	43.7	99.0	1.0	0.0	1.0
				640.0		43.7				
	ELIC	FRONT STREET	P.E.C.	118.0	.5	7.5	99.0	1.0	0.0	1.0
				118.0		7.5				
	FAYETTE (*)	HATSFIELD FERRY	WEST PENN. P.C.	1728.0	.4	58.9	100.0	0.0	0.0	1.0
				1728.0		58.9				
	FRANKLIN (*)	CHAMBERSBURG	CHAMBERSBURG E.O.	19.1	.4	.9	52.0	0.0	48.0	1.0
				19.1		.9				
	HARRISBURG	CRANFORD	METR. EDISON	117.0	.3	4.8	52.0	38.0	0.0	1.0
				117.0		4.8				
	INDIANA (*)	SEWARD	PENN. E.C.	262.2	.6	16.3	97.0	3.0	0.0	1.0
		HOMER CITY	PENN. E.C.	1319.0	.4	43.3	98.0	2.0	0.0	1.0
				1581.2		59.6				
	LANCASTER	LANCASTER	PPL	105.0	.7	8.5	100.0	0.0	0.0	1.0
				105.0		8.5				
	LAWRENCE (*)	LANCASTER	PENN. P.C.	425.8	.5	22.4	100.0	0.0	0.0	1.0
				425.8		22.4				
	PHILADELPHIA	GIBBSTOWN	A.C.E.	11.5	.5	.6	0.0	100.0	0.0	1.0
		LANSDALE	LANSDALE EL. DEP.	25.5	.3	.7	94.0	0.0	0.0	1.0
		SCHWILL	PHIL. E.P.	325.0	.7	18.2	0.0	100.0	0.0	0.0
		CHESTER	PHIL. E.P.	256.0	.4	11.8	1.0	73.0	26.0	1.0
		RICHMOND	PHIL. E.C.	474.0	.5	29.0	0.0	100.0	0.0	1.0
		DELMAR	PHIL. E.C.	439.3	.5	20.8	0.0	100.0	0.0	1.0
		LODYSTONE	PHIL. E.C.	707.2	.7	37.5	99.0	1.0	0.0	1.0
		CRONBY	PHIL. E.C.	417.5	.7	26.1	22.0	78.0	0.0	1.0
		BRADDOCK	PHIL. E.C.	155.0	.6	10.1	9.0	49.0	42.0	1.0
		SCUTHAM	PHIL. E.C.	345.0	.7	26.2	0.0	100.0	0.0	1.0
		PUNLINGTON	PSE&G	501.0	.5	24.2	0.0	100.0	0.0	1.0
				3659.0		205.4				
	PITTSBURGH	COLFAX	DUQUESNE	262.5	.2	9.4	100.0	0.0	0.0	1.0
		CHESWICK	DUQUESNE	355.3	.6	27.3	99.0	1.0	0.0	1.0
		ELFAMA	DUQUESNE	510.3	.6	30.3	100.0	0.0	0.0	1.0
		REED	DUQUESNE	170.0	.4	10.4	100.0	0.0	0.0	1.0
		PHILLIPS	DUQUESNE	411.0	.6	24.7	100.0	0.0	0.0	1.0
		CONHAUGH	PENN. P.L.	1064.0	.5	70.1	99.0	2.0	0.0	1.0
		MITCHELL	WEST PENN. P.C.	440.7	.6	26.4	100.0	0.0	0.0	1.0
		SPRINGDALE	WEST PENN. P.C.	416.1	.4	17.3	100.0	0.0	0.0	1.0
				4777.9		218.9				
	READING	TITUS	METROP. EDISON	225.0	.7	14.9	98.0	2.0	0.0	1.0
		RYLER	METROP. EDISON	84.0	.1	1.3	67.0	33.0	0.0	1.0
				309.0		16.2				
	SNYDER-UNION (*)	SUNRISE	PENN. P.L.	409.8	.7	31.4	100.0	0.0	0.0	1.0
				409.8		31.4				
	WARREN (*)	WARREN	P.E.C.	84.6	.6	7.1	100.0	0.0	0.0	1.0
				84.6		7.1				
	WILKES-BARRE-HAZ	STANTON	PENN. P.L.	146.0	.6	8.3	100.0	0.0	0.0	1.0
		HUMLOCK	J.G.I.	93.0	.5	6.9	99.0	1.0	0.0	1.0
				239.0		15.2				
	YORK	DEUNNEP ISLAND	PENN. P.L.	1558.7	.6	84.1	100.0	0.0	0.0	1.0
				1558.7		84.1				
				18658.7		948.6				

BNL REGIONAL ENERGY STUDIES PROGRAM - POWER PLANT DATA BASE

FOSSIL-FUELED UNITS, NORTHEAST U.S.

STATE	SMVA	STATION	UTILITY	MW(E)	LP	FUEL MIX COAL OIL GAS DESIGN	COAL
10 ¹² Btu/yr							
WASHINGTON D.C.	WASHINGTON D.C.	POTOMAC RIVER	POTOMAC ELECTRIC	514.8	.6	26.0 99.0	1.0
		DICKERSON	POTOMAC ELECTRIC	346.5	.5	28.0 92.0	0.0
		MUZZEY'S POINT	POTOMAC ELECTRIC	270.0	.5	15.7 48.0	60.0
		SETHING	POTOMAC ELECTRIC	553.5	.3	27.5 24.0	76.0
		CHALK POINT	POTOMAC ELECTRIC	727.6	.5	32.1 98.0	2.0
		POSSUM POINT	VIRGINIA E&P	491.0	.7	17.7 0.0	100.0
				3143.4		167.3	
				3143.4		167.4	

BNL REGIONAL ENERGY STUDIES PROGRAM - POWER PLANT DATA BASE

FOSSIL-FUELED UNITS, NORTHEAST U.S.

STATE	SMVA	STATION	UTILITY	MW(E)	LP	FUEL MIX COAL OIL GAS DESIGN	COAL
10 ¹² Btu/yr							
MAINE ISLAND	PROVIDENCE	SOUTH STREET	NARRAGANSETT EL.	145.9	.4	10.0 100.0	0.0
		MANCHESTER STREET	NARRAGANSETT EL.	112.0	.5	-0.0 -0.0	-0.0
				277.9		10.5	
				277.9		10.6	

BNL REGIONAL ENERGY STUDIES PROGRAM - POWER PLANT DATA BASE

FOSSIL-FUELED UNITS, NORTHEAST U.S.

STATE	SMVA	STATION	UTILITY	MW(E)	LP	FUEL MIX COAL OIL GAS DESIGN	COAL
10 ¹² Btu/yr							
VERMONT	RUFLINGTON	HOFAN	BURLINGTON ELEC.	30.0	0.0	0.0 0.0	0.0
				30.0		0.0	
				30.0		0.0	

APPENDIX F: SUMMARY OF REFUSE-TO-ENERGY
PROJECTS IN THE NORTHEAST*

Project Description

LOCATION: Baltimore, Maryland

EPA CONTACT: David Sussman

PROJECT CONTACT: Elliot Zulver
Project Director
Pyrolysis Plant
1801 Annapolis Road
Baltimore, Maryland 21330
(301) 396-3499

PROJECT TYPE: Pyrolysis

TONS/DAY: 1000

CAPITAL COST: \$16 million.

METHOD OF FINANCING: EPA grant - \$6 million.
State loan - \$4 million.
City funds - \$6 million.

CONTRACTOR: Monsanto Enviro-Chem Systems, Inc.

Project Status

Baltimore will own and operate a 1,000 ton per day solid waste pyrolysis plant developed by Monsanto Enviro-Chem Systems, Inc. The LANDGARD system will be designed and constructed by Monsanto under a turnkey contract with moneyback performance guarantee provisions. Monsanto is guaranteeing plant availability at 85 percent, particulate emissions to meet local and Federal standards, and the residue putrescible content to be less than 0.2 percent.

The plant is being designed to handle mixed municipal solid waste, including tires and white goods. All incoming waste will be shredded to a 4-inch particle size and then conveyed to a rotary pyrolysis kiln.

The pyrolysis gases leave the kiln and will then be combusted in an afterburner. The hot afterburner exhaust gases will pass through waste heat boilers that generate 200,000 pounds of steam per hour for sale to the Baltimore Gas and Electric Company. The steam will be used for downtown heating and cooling. Boiler exhaust gases will be scrubbed, dehumidified, and released to the atmosphere.

* Extracted from R.E. Hopper. "A Nationwide Survey of Resource Recovery Activities" U.S. Environmental Protection Agency, Report SW-142, Jan. 1975.

Baltimore, Maryland
(continued)

Construction is complete and the plant is now in a shake-down phase.

The pyrolysis residue will be water quenched and ferrous metals will be separated. Water flotation and screening processes will separate the char residue, which must be landfilled (16 tons, with 50 percent moisture, for every 100 tons of solid waste input), from a glassy aggregate fraction, which will be used as aggregate for city asphalt concrete street construction.

For additional information, see: Baltimore Demonstrates Gas Pyrolysis (SW-75d.i), David B. Sussman, U.S. Environmental Protection Agency, 1974.

Project Description

LOCATION: Braintree, Massachusetts

EPA CONTACT: Steven Levy

PROJECT CONTACT: John Griffith, Superintendant
Braintree Thermal Waste Reduction Center
Ivory Street
Braintree, Massachusetts 02184
(617) 843-6209

PROJECT TYPE: Waterwall incineration.

TONS/DAY: 240

CAPITAL COST: \$2.5 million.

METHOD OF FINANCING: General obligation bonds.

CONTRACTOR: Designed by Camp, Dresser and McKee.

Project Status

Plant has been operational since 1971, but until recently no steam was being sold. Community is now developing a market for steam. Recently, however, Braintree has begun to sell steam to the Weymouth Art and Leather Company (20,000 - 25,000 lbs./hr. or 400,000 lbs./day) and is also negotiating with Michigan Abrasives, Inc. for an equal supply of steam. Initially, the plant's net operating costs were \$30/ton, but today the plant's net operating costs are \$5/ton. The plant is presently processing 150-175 tons of waste per day on a 3 shift, 5 day per week basis.

Project Description

LOCATION: Bridgeport, Connecticut

EPA CONTACT: Robert Randol

PROJECT CONTACT: Richard P. Chase
CRRA; Connecticut Resources Recovery Authority
60 Washington Street
Suite 1305
Hartford, Connecticut 06106
(203) 549-6390

PROJECT TYPE: Prepared waste as a supplementary fuel;
materials recovery.

TONS/DAY: 1800

CAPITAL COST: \$29 million.

METHOD OF FINANCING: Connecticut Resources Recovery Authority

CONTRACTOR: Garrett Research and Development

Project Status

The system will process eighteen hundred tons of solid waste a day. The dry shredded fuel fraction will be sold to United Illuminating, a subsidiary of Northeast Utilities. United Illuminating is a new market for the fuel. Previously Connecticut Light and Power had been the designated user. Groundbreaking ceremonies were held on December 10, 1974.

As of February 1, 1975 a final contract between The Connecticut Resources Recovery Authority and Garrett Research and Development had not been signed. However, a letter of intent to design, construct and operate a system was signed in September, 1974. Delays in the signing of the final contract stem from the reluctance of the contracting parties to assume different levels of risk.

Bridgeport will be the first system built in Connecticut. The interlocal agreement for delivery of solid waste (negotiated between CRRA and the communities) and the system's construction and operation contract (negotiated between CRRA and Garrett) will serve as models for future implementations.

Project Description

LOCATION: East Bridgewater, Massachusetts

EPA CONTACT: Robert Holloway

PROJECT CONTACT: John Reilly
CEA (Combustion Equipment Associates, Inc.)
555 Madison Avenue
New York, New York 10022
(212) 980-3700

PROJECT TYPE: Prepared waste as a supplementary fuel.

TONS/DAY: 600 (Two shifts)

CAPITAL COST:

METHOD OF FINANCING: Private capital.

CONTRACTOR: CEA

Project Status

Plant shakedown started Winter, 1973-74. Shakedown is continuing thru Summer, 1974. No fuel product has been sold because no coal boilers are nearby. Plant is not operating except for experimentation because there is no market for the product.

In addition, CEA is basing future contracts on Eco-Fuel II, a chemically treated, pulverized solid fuel derived from waste. The East Bridgewater plant was designed to produce Eco-Fuel I, the feed material to an Eco-Fuel II system. The East Bridgewater plant is to be modified in the future to produce Eco-Fuel II.

CEA plans Eco-Fuel II trial firings with fuel produced from a pilot plant at Weyerhaeuser Corp. (close to Brockton) and at Public Services Gas and Electric, Elizabeth, New Jersey.

Project Description

LOCATION: Hackensack Meadowlands, New Jersey

EPA CONTACT: Robert Holloway

PROJECT CONTACT: George Casino
Chief Engineer
Hackensack Meadowlands Development Commission
1099 Wall Street, West
Lyndhurst, New Jersey 07071
(201) 935-3250

PROJECT TYPE: Prepared waste as a supplementary fuel.

TONS/DAY: N/A

CAPITAL COST: N/A

METHOD OF FINANCING: N/A

CONTRACTOR: N/A

Project Status

HMDC received 8 proposals in Fall 1973 as result of RFP. HMDC asked Stevens Institute and Fairleigh Dickinson University to review proposals. CEA was recommended.

No action was taken because of change in State administration.

HMDC has now contracted with First Boston Corporation, Sullivan & Cromwell, and Hawkins, Delafield & Wood to pursue negotiations with several of the original bidders to implement a fuel system.

Public Service Electric and Gas has expressed interest in waste fuel. PSEG signed a contract in August 1974 with CEA to burn 200 tons per day of Eco-Fuel II on a trial basis. CEA hopes to start preliminary tests with pellets within 2 months at PSEG and Weyerhaeuser (near CEA's East Bridgewater plant). Eco-Fuel II for the early burns will be produced by the pilot plant. Additional PSEG tests will be run in 1-2 years with fuel produced from a plant to be built in New Jersey.

Project Description

LOCATION: Hempstead, New York

EPA CONTACT: Alan Shilepsky

PROJECT CONTACT: William Landman
Commissioner of Sanitation
1600 Merrick Road
Merrick, New York 11566
(516) 378-4210

PROJECT TYPE: Wet-pulping of waste for materials and energy recovery.

TONS/DAY: 2000

CAPITAL COST: \$55 million.

METHOD OF FINANCING: Exact form is undetermined until a contract is signed, but will probably be corporate revenue bonds.

CONTRACTOR: Hempstead Resource Recovery Corp.
(a subsidiary of Black Clawson Co.)

Project Status

A contract was signed on December 12, 1974 between Hempstead and Hempstead Resource Recovery Corporation, a subsidiary of Black Clawson Corporation. The contract stipulates that the City "put or pay" to the recovery system at least 6000 tons of solid waste per week. The contract also requires the corporation to be capable of processing 11,000 tons per week with a maximum of 3 percent residue by volume. The system will recover ferrous, aluminum and glass (if economically feasible) and produce electricity. Revenues will be shared between the corporation and the City. Dump service fees, depending on tonnages, will range between \$14.05 to \$12.37 per ton.

Project Description

LOCATION:	Housatonic Valley, Connecticut
EPA CONTACT:	Robert Randol
PROJECT CONTACT:	Robert Schulz The Fourth Sink Management Group, Inc. P.O. Box 75 Kattskill Bay, New York 12844 (518) 656-9253
PROJECT TYPE:	Prepared waste as a supplementary fuel; materials recovery.
TONS/DAY:	1500
CAPITAL COST:	\$35 million.
METHOD OF FINANCING:	CRRA funding requested (See State of Conn.)
CONTRACTOR:	CEA (Combustion Equipment Associates, Inc.)

Project Status

Twenty two million dollar processing plant to be located in Newtown, Conn. to prepare Eco-Fuel II. Fuel will be shipped by rail to the Pierce Power Plant in Wallingford, Conn., where a \$10 million high-pressure steam generating facility will be designed and constructed by CEA.

CRRA limited to \$100 million funding through FY75. Therefore, with funding of New Britain and Bridgeport, CRRA cannot now fund entire Housatonic project. CRRA likely to fund just transfer station portion, with landfilling of waste until authority extended.

Project Description

LOCATION: Monroe County, New York

EPA CONTACT: Alan Shilepsky

PROJECT CONTACT: Harold Christensen
Director of Solid Waste
Department of Public Works
200 County Office Building
Rochester, New York 14614
(716) 454-7200

PROJECT TYPE: Shredded fuel for supplementary burning
in Rochester Gas and Electric Boilers.

TONS/DAY: 2000

CAPITAL COST: \$25 million, not including retrofitting
and storage facilities.

METHOD OF FINANCING: Public improvement bonds plus at least
\$9 million from the State.

CONTRACTOR: Raytheon Service Corporation

Project Status

Monroe County's request for proposals was prepared by the consulting engineering firm of Black, Crow and Eidsness and drew upon a market analysis and feasibility study done by Black, Crow and Eidsness's parent company, Hercules. County officials have evaluated the proposals with the assistance of Black, Crow and Eidsness and have tentatively chosen Raytheon. A contract has been negotiated with Raytheon and the County legislature has authorized the County executive to execute the contract.

The proposed design involves two stages of shredding, air classification, and the recovery of ferrous and non-ferrous metals.

Project Description

LOCATION: Montgomery County, Maryland

EPA CONTACT: Robert Holloway

PROJECT CONTACT: F.K. Erickson
Office of Environmental Planning
Montgomery County Office Building
Rockville, Maryland 20850
(301) 279-1316

PROJECT TYPE: Prepared waste as a supplementary fuel
to be used in local utility boiler.

TONS/DAY: 1200

CAPITAL COST: \$16 million.

METHOD OF FINANCING: General obligation bonds.

CONTRACTOR: Pope, Evans, and Robbins Consulting Engineers.

Project Status

Based on a feasibility study by Pope, Evans and Robbins, Consulting Engineers, New York, the County Executive recommended and the County Council approved a ten year solid waste management plan calling for a 1200 ton per day county-owned and operated resource recovery system, producing magnetic metals and shredded waste fuel to be used as a supplement to coal in Potomac Electric Power Company's (PEPCO) Dickerson, Maryland plant.

The \$16 million for the central processing facility has been approved in the county's budget and will probably be obtained by general obligation bonds. Funding for the \$4 million receiving and firing facility at Dickerson has not been yet arranged.

A site selection study identified five candidate sites. The site selection process began with hearings in September, and ended with the selection of a site in November, 1974. This site is now being acquired. Meanwhile, the County is also negotiating with PEPCO as to the details of their contract. PEPCO's boiler that will accept the waste fuel is a new 800 megawatt unit that is scheduled to go into operation in 1982.

Project Description

LOCATION:	Mt. Vernon, New York
EPA CONTACT:	Steven Levy
PROJECT CONTACT:	Seymour Lefkowitz Intergovernmental Coordinator City Hall Mt. Vernon, New York (914) 668-0737
PROJECT TYPE:	Gas Pyrolysis
TONS/DAY:	400
CAPITAL COST:	N/A
METHOD OF FINANCING:	N/A
CONTRACTOR:	Union Carbide (Proposed)

Project Status

Mt. Vernon, as part of the Westchester County, New York plan, intends to build a 400 ton per day Union Carbide Purox system which will serve Mt. Vernon and the communities of North Pelham, Pelham and Pelham Manor. The gas produced will be used to generate electricity which will be sold to Consolidated Edison Company.

Project Description

LOCATION:	New Britain, Connecticut
EPA CONTACT:	Robert Randol
PROJECT CONTACT:	Richard Chase CRRRA; Connecticut Resources Recovery Authority 60 Washington Street Suite 1305 Hartford, Connecticut 06106 (203) 549-6390
PROJECT TYPE:	Prepared waste as a supplementary fuel.
TONS/DAY:	1800
CAPITAL COST:	\$22 million.
METHOD OF FINANCING:	Revenue bonds.
CONTRACTOR:	CEA (Combustion Equipment Associates, Inc.)

Project Status

CEA proposes to produce Eco-Fuel II for the Wallingford power plant (city owned). The waste fuel will reportedly be mixed with fuel oil and fired in combination into the existing boiler. (Ability of Wallingford plant to accept large amounts of fuel unknown to EPA). A contract has not yet been signed between any of the parties. After Bridgeport, New Britain will be the second project to be implemented by the Connecticut Resources Recovery Authority.

Project Description

LOCATION: New York, New York

EPA CONTACT: David Sussman

PROJECT CONTACT: Leonard F. O'Reilly
Director, Solid Waste Task Force
51 Chambers Street
New York, New York
(212) 566-0922

PROJECT TYPE: Shredded fuel.

TONS/DAY: 1500

CAPITAL COST:

METHOD OF FINANCING: 50 percent State funds.
50 percent City funds.
Consolidated Edison finances their
plant modifications.

CONTRACTOR: Horner & Shifrin, Inc. for feasibility
study.

Project Status

City is finalizing contract with Horner & Shifrin to design a 1500 ton per day shredded fuel plant in conjunction with Con Ed's Arthur Kill plant, unit #20. The plant will be similar to the St. Louis demonstration plant. Construction will not begin until Con Ed is financially able to pay for the required modifications to its boilers. The plant will demonstrate the feasibility of shredded fuel in the New York City area.

Plans for a new 700 megawatt plant in the City that will burn 1600 tons per day are being formulated by the New York Power Authority. Implementation date for the plan is unknown.

Project Description

LOCATION: Onondaga County, New York

EPA CONTACT: Richard Hopper

PROJECT CONTACT: Charles R. Stoffel
Federal Aid Representative
Onondaga County, New York
Box 23324
L'Enfant Plaza Station
Washington, D.C. 20024
(202) 554-2494

PROJECT TYPE: Waterwall incineration to produce steam for district heating and cooling.

TONS/DAY: 1000

CAPITAL COST: \$21,503,900

METHOD OF FINANCING: Municipal bonds; bond anticipation notes; State grant.

CONTRACTOR: Carrier Corporation.

Project Status

Onondaga County owns and operates a mid-town district heating and cooling plant which supplies steam and chilled water to various County and City buildings in Syracuse. A few blocks away is a district heating and cooling plant owned by Syracuse University serving many campus buildings, several hospitals, and a housing project. In May 1974, the County and University entered into a contract with Carrier Corporation to conduct a feasibility study of the possibilities of converting the two plants to the use of municipal solid waste as a fuel.

To assist in the study, Carrier Corporation engaged the services of Roisson and Woese, Consulting Engineers; J.C. Thomasson & Associates, Consulting Engineers; and Edward Joe Company, Mechanical Contractors. The completed study recommended that the existing county steam plant be phased out and that a new steam plant using solid waste as a fuel be built adjacent to the existing university steam plant site. The facility would have the capacity to incinerate most of the 1,200 tons of solid waste produced by Onondaga County's half million residents each day and would recover energy from this waste in the form of steam. The existing university steam plant would be retained as a standby unit, while the new plant would be designed to burn waste as delivered or to burn fuel that may be produced in the future by a pyrolysis system that would convert waste into gas or oil. The proposed plant will produce 270,000 pounds of steam per hour.

Project Description

LOCATION:	Saugus, Massachusetts
EPA CONTACT:	Steven Levy
PROJECT CONTACT:	W.C. Stephens Energy Systems Division Wheelabrator-Frye, Inc. 299 Park Avenue New York, New York 10017
PROJECT TYPE:	Waterwall incineration.
TONS/DAY:	1200
CAPITAL COST:	\$30 million.
METHOD OF FINANCING:	Private.
CONTRACTOR:	RESCO

Project Status

RESCO (Refuse Energy Systems Company), a joint venture of De Matteo Construction Company and Wheelabrator-Frye, is constructing a water-wall incinerator in Saugus, Massachusetts. The steam generated will be sold to the General Electric Company plant at Lynn, Massachusetts, across the Saugus River. The plant's input refuse will come from some 16 communities north of Boston. The twenty year contract between RESCO and the communities provides for an initial disposal fee of \$13 per ton of solid waste.

Project Description

LOCATION:	Washington, D.C.
EPA CONTACT:	Robert Holloway
PROJECT CONTACT:	Clark W. Hand Environmental Planning Metropolitan Washington Council of Governments 1225 Connecticut Avenue, N.W. Washington, D.C. (202) 223-6800 Ext. 330.
PROJECT TYPE:	Waste as fuel - probably to EMPCO, but looking for other fuel users.
TONS/DAY:	650-1300
CAPITAL COST:	N/A
METHOD OF FINANCING:	N/A
CONTRACTOR:	N/A

Project Status

Washington, D.C., and Fairfax, Arlington, and Alexandria counties in Northern Virginia are pursuing a regional approach to resource recovery. The project is being conducted by the Metropolitan Council of Governments (COG). The COG has contracted with the National Center for Resource Recovery to evaluate markets for recovered materials and to conduct a feasibility study of a facility for materials recovery and the processing of solid waste into a supplementary fuel. The COG is also in the preliminary stages of negotiation with the Potomac and Electric Power Company to purchase the fuel.

The National Center for Resource Recovery's report was delivered to the COG in January. The District of Columbia plans to prepare a budget request for fiscal year 1976 funds to develop an engineering design and recommend equipment specifications.

Project Description

LOCATION:	Westchester County, New York
EPA CONTACT:	Steven Levy
PROJECT CONTACT:	Robert Dennison Commissioner of Public Works County Office Building White Plains, New York (914) 682-2537
PROJECT TYPE:	County-wide.
TONS/DAY:	400
CAPITAL COST:	\$105 million.
METHOD OF FINANCING:	N/A
CONTRACTOR:	N/A

Project Status

County Plan calls for upgrading 3 or 4 existing incinerators and installing a Bureau of Mines incinerator recovery system, for building a thermal reduction facility at the County's Grasslands Reservation, for closing the Croton Landfills and for building a 400 ton per day Union Carbide Purox System in Mt. Vernon. Under the plan, the County is divided into eight waste sheds for solid waste management and resource recovery, and the County assumes responsibility for solid waste disposal.

Project Description

LOCATION: Wilmington, Delaware

EPA CONTACT: Robert Holloway

PROJECT CONTACT: Pasquale S. Canzano
Department of Natural Resources and
Environmental Control
State of Delaware
Dover, Delaware 19901
(302) 678-4781

PROJECT TYPE: Prepared solid waste as a supplementary fuel to be used in oil fired utility boiler; sewage sludge will be processed; subsystems will include composting, pyrolysis, and materials recovery (ferrous, aluminum, glass).

TONS/DAY: 500 (One shift).

CAPITAL COST: \$20 million.

METHOD OF FINANCING: State general obligation bonds; EPA grant.

CONTRACTOR: Full-service contract to be bid competitively with RFP.

Project Status

EPA awarded a \$9 million resource recovery demonstration grant to the State of Delaware in October, 1972. As a result of negotiations between EPA and Delaware over conditions of the grant agreement, Delaware accepted EPA's recommendation not to compost the waste fuel to be burned in a Delmarva Power and Light Co. oil-fired boiler. Resolution of conditions and paper work required to amend project have delayed project about two years.

Delaware will apply for an EPA Step III Water Construction Grant for those facilities that handle sludge. Delaware plans to ask for \$4-5 million in EPA water funds.

Delaware hopes to develop an RFP package by early 1975. A contract should be signed by January, 1976 to design, construct, and operate the facility.

Project Description

LOCATION: State of Connecticut

EPA CONTACT: Robert Randol

PROJECT CONTACT: Mr. Joseph L. Boren, Director
Solid Waste Management Programs
Department of Environmental Protection
State of Connecticut
State Office Building, Room 248
Hartford, Connecticut 06115
(203) 566-3672

PROJECT TYPE: Development of State authority.

TONS/DAY:

CAPITAL COST:

METHOD OF FINANCING: Revenue bonds.

CONTRACTOR: Garrett Research and Development Company
(Bridgeport facility)

Combustion Equipment Associates
(Greater Hartford facility)

Project Status

As a result of a comprehensive State plan developed by the Connecticut Department of Environmental Protection, the State legislature created the Connecticut Resources Recovery Authority (CRRA). The Authority is carrying out implementation of the plan, which calls for the construction by 1985 of 10 resource recovery facilities which will process 84 percent of the State's waste. CRRA has been given \$250 million bonding authority for facility construction. During formulation of the plan, the U.S. Environmental Protection Agency funded a study which gave the State an independent commentary on the proposed legislation, gave a framework for evaluation of proposed projects, and made recommendations for the organization and management of the Authority as well as on aspects of financing and system incentives. Contracts for the first two facilities have been awarded to Garrett Research and Development Company for a resource recovery plant in Bridgeport and to Combustion Equipment Associates for a plant in New Britain, which will serve several communities in the Greater Hartford area. Unique features of the Connecticut plan include:

Voluntary Participation. Communities are not required to utilize the services of the CRRA facilities, but instead may decide to do so on an economical basis.

Rate Setting. There is no regulation of the rates charged to the communities. However, since the system is voluntary, CRRA is forced to be competitive with other means of disposal.

Private Sector Involvement. Since CRRA is limited to 30 employees, the private sector will be utilized for design, construction, and operation of facilities.

Project Description

LOCATION: State of Maryland

EPA CONTACT: Harry Butler

PROJECT CONTACT: Cliff Willey
Chief of Solid Waste Services
Maryland Environmental Services
Tawes State Office Building
Annapolis, Maryland 21401
(301) 267-5666

PROJECT TYPE: State grant and loan program.

TONS/DAY: N/A

CAPITAL COST: N/A

METHOD OF FINANCING: State appropriation.

CONTRACTOR: N/A

Project Status

The Maryland Environmental Services (MES) can provide both grants and loans for resource recovery facilities. Four million dollars of the matching funds for the U.S. Environmental Protection Agency's \$16 million demonstration in Baltimore was provided by MES. In addition, MES is funding, in a joint venture with Baltimore County, the Baltimore County Solid Waste Disposal System and Reclamation Project. Phase I of this project will consist of shredding followed by magnetic separation. The ferrous fraction recovered will be sold to the detinning market. The remainder is to be landfilled. MES is spending \$300,000 on market and product development. Phase II of the project will consist of recovery of the fiber (either as fuel or fiberboard), glass and other heavy fraction as their markets develop.

Project Description

LOCATION: Commonwealth of Massachusetts

EPA CONTACT: Yvonne Garbe

PROJECT CONTACT: Alden Cousins, Director
Bureau of Solid Waste Disposal
Massachusetts Department of Public Works
100 Nashua Street
Boston, Massachusetts 02114
(617) 727-4293

PROJECT TYPE: Development of State plan.

TONS/DAY: N/A

CAPITAL COST: N/A

METHOD OF FINANCING: N/A

CONTRACTOR: N/A

Project Status

The Commonwealth of Massachusetts is implementing a state-wide resource recovery plan. The plan features a system of privately financed, privately owned, State controlled resource recovery facilities. The State has issued a "Request for Proposals" as a first step towards implementing a resource recovery facility in the Greater Lawrence area.

A bidders conference was held on January 11, 1975 with proposals to be returned for review by March 18, 1975.

Project Description

LOCATION: State of New York

EPA CONTACT: Harry Butler

PROJECT CONTACT: David Mafrizi, Director
Bureau of Resource Recovery
Division of Solid Waste Management
New York State Department of Environmental
Conservation
50 Wolf Road
Albany, New York 12201
(518) 457-3199

PROJECT TYPE: State grant program.

TONS/DAY: N/A

CAPITAL COST: \$175 million for solid waste disposal and
resource recovery grants to local govern-
ment.

METHOD OF FINANCING: General obligation bond.

CONTRACTOR: N/A

Project Status

New York State voters have approved a \$1.1 billion Environmental Bond, which includes \$175 million for solid waste disposal and resource recovery facilities. The regulations provide up to 25 percent State funding for disposal projects and up to 50 percent for resource recovery projects, thus increasing the incentive for resource recovery. In addition, the regulations provide that to be eligible for State assistance, a project must be consistent with a comprehensive solid waste management plan. Comprehensive plans must: (1) assure that all municipalities within a region will be served by a solid waste recovery and management system; (2) provide for intermunicipal cooperation; (3) define solid waste collection service areas and the type of service to be provided; (4) utilize modern technology to best meet local needs and optimize opportunities for resource recovery; and (5) provide for phased implementation of proposed systems to meet short range and long range needs. To date, \$116 million has been set aside for specific resource recovery projects. Actual grant awards will be made to the specific communities upon State approval of the contractor's bid price for a facility.

Project Description

LOCATION: Commonwealth of Pennsylvania

EPA CONTACT: Richard Hopper

PROJECT CONTACT: William C. Bucciarelli, Director
Division of Solid Waste Management
Department of Environmental Resources
8th Floor Fulton Building
P.O. Box 2063
Harrisburg, Pennsylvania 17120
(717) 787-7381

PROJECT TYPE: State loan program.

TONS/DAY: N/A

CAPITAL COST: N/A

METHOD OF FINANCING: N/A

CONTRACTOR: N/A

Project Status

In 1974 the Pennsylvania State Legislature enacted the Pennsylvania Solid Waste Resource Recovery Development Act creating a State loan program for local resource recovery projects. Requirements of the Act are that in reviewing applications for loans, the Department of Environmental Resources shall: (1) consider the amounts of polluting substances treated and/or eliminated; (2) the overall environmental benefits to be accrued as a result of the projects; (3) the amount of populations served; and (4) the extent of resource recovery to be included. Furthermore, the law requires that no loan shall be made to any local government which is not a part of a department approved local solid waste management plan. Twenty million dollars was appropriated for the purposes of the Act. At present, the Department of Environmental Resources is drafting rules and regulations to implement the loan program.

Project Description

LOCATION:	State of Rhode Island
EPA CONTACT:	David Sussman
PROJECT CONTACT:	John Quinn, Jr., Chief Division of Solid Waste Management State Health Department 204 Health Building Davis Street Providence, Rhode Island 02908 (401) 277-2808
PROJECT TYPE:	Development of State plan.
TONS/DAY:	N/A
CAPITAL COST:	N/A
METHOD OF FINANCING:	N/A
CONTRACTOR:	N/A

Project Status

The Rhode Island legislature has created the Rhode Island Solid Waste Management Corporation. The legislation which created the Corporation is a result of the State Solid Waste Management Plan and is modeled after the Connecticut Resource Recovery legislation. Environmental Protection Agency, through a grant to Rhode Island, assisted in the preparation of the State Plan.

As outlined in the legislation, details of the State program are:

- (1) The corporation will prepare and implement a functional level plan for an integrated statewide system of solid waste management facilities;
- (2) Municipal participation in the statewide system of solid waste management facilities that will be developed by the corporation will be on a voluntary basis.
- (3) The corporation will make its waste management facilities available under contract to any municipality, institution, or person at reasonable fees established by the corporation; and,

- (4) Any revenues received by the corporation shall be used by said corporation to provide the financial support that is required to maintain financial solvency.

Since a bond referendum to fund the corporation failed in last year's elections, the State is presently exploring other alternatives for providing the necessary start-up funding for the corporation.

Although there is no funding for the corporation, the Advisory Board has been appointed and is operating, with the expectation that staff will be hired this Spring.

Project Description

LOCATION:	State of Vermont
EPA CONTACT:	Yvonne Garbe
PROJECT CONTACT:	Richard Valentinetti Air & Solid Waste Programs Protection Division Agency of Environmental Conservation P.O. Box 489 Montpelier, Vermont 05602 (802) 828-3395
PROJECT TYPE:	Development of State plan.
TONS/DAY:	N/A
CAPITAL COST:	N/A
METHOD OF FINANCING:	N/A
CONTRACTOR:	N/A

Project Status

The State solid waste plan calls for mandatory separation of wastes by the householder and for the construction of four regional resource recovery facilities. The proposed legislation to put this plan into effect failed to pass in 1973, and again in 1974. The State is currently drafting more general legislation to be introduced in the legislature in 1975 that would respond to criticisms of previous legislation by being less specific, and giving greater flexibility to the Agency of Environmental Conservation to develop the details.

APPENDIX G: BIBLIOGRAPHY

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The Brookhaven National Laboratory Regional Energy Studies Program is part of a national effort supported by the U.S. Energy Research and Development Administration (ERDA) to create an energy assessment capability which is sensitive to regional conditions, perceptions, and impacts. Within ERDA, this program is supported by the Division of Biomedical and Environmental Research and includes, in addition to a concern for health and environmental impacts of energy systems, analysis of the complex trade-offs between economics, environmental quality, technical considerations, national security, social impacts, and institutional questions. The Brookhaven Program focuses on the Northeast, including the New England states, New York, Pennsylvania, New Jersey, Maryland, Delaware, and the District of Columbia. The content of the program is determined through an identification of the major energy planning issues of the region and in consultation with state and regional agencies. A major component of the program in 1976 is the Northeast Energy Perspectives Study which examines the implications of alternative energy supply-demand possibilities for the region.