POTENTIAL FOR SOLID WASTE USE AS AN ENERGY SOURCE IN TEXAS

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ERRATA

Page No.	Line No.	Correction
4	5	... Power Research ...
5	3	... and research-development...
5	7	... be researched because....
5	20	... difference or the...
6	17	... or approximately 40 MM...
7	1	... 8-10% of this total...
9	10	... an over-all multiplication factor of 2.4; a factor of 2.0 was used for ASW excluding the waste from feed-lot cattle which was directly added to give the over-all factor of 2.4.
14	12	... supported research is ...
35	15	... through research experience...
37	17	... Garrett Research and ...
39	6	... to reclaim materials...
39	18	... complete combustion...
45	1	... visit, a plant, ...
51	3	... current research program...
57	18	... of the research program...
57	23	... Garrett Research and ...
64	16	... to be competitive with ...
67	8	... Garrett Research and ...
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INTRODUCTION

The recent dramatic changes in the price and supply of energy have made a new set of options economically feasible with regard to the disposal of municipal and agricultural solid wastes (MSW, ASW). In many ways, these changes were a welcome development, because the disposal of solid wastes now has the potential to provide a net income for Texas cities and the agricultural industry. For example, ugly landfills and enormous piles of cattle feedlot manure can probably be replaced with energy and/or chemical producing plants. An increase in the recycled fraction of metals may also be expected as a result of the application of this technology.

Due to the fact that our national as well as state energy consumption is so large, the recovery of all the direct energy available in MSW will not have a dramatic impact on the total energy supply. The potential is, however, significant, because the national energy value of MSW is approximately one/half million barrels per day without accounting for the recoverable energy in ASW (1).

In addition to the direct energy recovery indicated above, the potential energy savings from reclamation or recycling of metals in MSW has considerable potential. Producing 1000 tons of steel reinforcing bars from scrap only requires approximately 25 per cent of the energy of that required for production from virgin ore; the reprocessing of aluminum requires approximately 5 per cent of the energy needed to win this material from the original ore (2, 3). On the average, 7 per cent of the iron, 8 per cent of the aluminum, 20 per cent of the tin, and 14 per cent of the paper consumed annually could be obtained from MSW (4).

OBJECTIVES

On the basis of the indicated national potential, the broad objective of this project was to assess the potential for solid waste as an energy source in Texas. Specific sub-objectives were to:

(1) Summarize the municipal and agricultural production rates in Texas.

(2) Assess the technology of solid waste conversion processes.

(3) Determine those locations in Texas where these conservation processes would be feasible.

(4) Recommend the research-development and legislative actions required to realize the full potential of energy recovery from solid wastes.

SUMMARY AND CONCLUSIONS: TECHNOLOGY ASSESSMENT

A. Direct Energy Conversion Processes

Although there are at least twenty different designs currently being marketed in the U.S., there are only four basic conversion processes for achieving direct energy recovery from solid wastes. These processes are (1) combustion or incineration with heat recovery, (2) pyrolysis or cracking, (3) partial oxidation or combined pyrolysis-combustion, and (4) biochemical methane production. The technology for these basic processes certainly exists, but only the first and third types have been evaluated in a demonstration-sized plant (100-200 ton MSW per day) or greater. A significant protion of this technology is European, but little experience exists for the scale of use being contemplated in the U.S. For example, one privately sponsored facility for steam generation being built in the U.S. will use incinerators two to three times the size normally employed in Europe (5, 6, 7). A demonstration plant utilizing pyrolysis for production of an oil similar to No. 6 fuel oil is now being built near San Diego, California, and evaluation data will probably become available in late 1975. Two or more commercial partial-oxidation designs (1000 ton MSW per day) are being built for production of low Btu gas and steam. Process designs for production of petrochemical feedstocks (e.g. ammonia) are still in the pilot plant stage (8). Biochemical processing is also limited to pilot plant experience (9).

In general, we conclude that MSW, or solid waste conversion process technology is equivalent to or not as advanced as that for coal utilization. Thus, any venture undertaken by Texas within the next three years for conversion of municipal or agricultural solid waste must be considered a developmental project. This conclusion excludes any proprietary processes developed for conversion of a specific industrial solid waste.

The most economical process innovation for the U.S. would appear to be the combined combustion of pulverized coal and MSW (St. Louis project, 10). A detailed assessment of this attractive process will be made available by the Electrical Power Reserach Institute and the Bechtel Corporation by December 1974 and will be transmitted to the Council. This technology is, however, not generally adaptable to Texas because there are only a few coal-fired boilers in the state. Most utilities are reluctant to invest in the ash-handling, ash-disposal facilities, and the technology required to obtain the expected energy equivalent (10-20% of the total boiler load). If, in the future, the State's lignite reserves are exploited for intra-state generation of electrical power, lignite-MSW firing processes might become highly attractive. The location of the plants could, in large measure, determine the feasibility of a mixed-fuel boiler. Technology for combined lignite-solid waste combustion is not available and is recommended for further study.

It should also be noted that there has been considerable discussion at the national level of converting the nation's base-load electrical generating system to coal within the next five years. If this program is undertaken, the retrofitting program for boilers near large cities should incorporate the capability to fire coal-MSW mixtures.

Due to the current lack of boilers with ash removal capability in Texas, the preceeding technology assessment has led us to conclude that pyrolysis processing for production of fuel oil (6) and a partial oxidation process for production of petrochemical feedstocks such as ammonia synthesis gas (11) are attractive alternatives for the State. This technology is, as noted above, still being developed. Thus, a continuing technology assessment and reserach-development program is recommended for state support. The two processes should be investigated for utilization of both MSW and ASW. Finally, little technology has been published on the combination of industrial wastes with either municipal or agricultural wastes. This possibility should also be research because such a combination may make energy conversion processes economically attractive in marginal, low population density areas.

B. Indirect Energy Recovery Processes

This type of processing has received considerable attention in the U.S. because there appears to be "gold-in-garbage". In fact, the American Iron and Steel Institute has estimated that $4.5 billion a year is spent in the U.S. to dispose of MSW containing $5.0 billion of reuseable metals. The technology associated with the magnetic separation of ferrous materials is well developed and suitable devices can be purchased on the open market.

Although can recycling by concerned individuals has received considerable promotional consideration, the technology needed to remove non-ferrous metals (primarily aluminum) from a shredded MSW stream is still in the developmental stage. The two basic processes involve either flotation due to a density difference on the induction of an eddy current and subsequent ejection from a magnetic field. Currently, neither of these approaches has achieved the desired selectivity and recovery factors. Nevertheless, the economic potential is considerable and private industry appears to have sufficient initiation that a satisfactory system development is highly probable without additional state or national support.

SUMMARY AND CONCLUSIONS: POTENTIAL FOR SOLID WASTE

The relative potential for solid waste as an energy source in Texas is estimated to be equivalent to or greater than that of the nation as a whole. This conclusion is based upon the general range of generation rates of solid waste (2.5-6.24 lb solid waste per day) determined in our survey of 33 municipalities. The average rate of generation for Texas localities with populations greater than 10,000 was 4.7 lb/person-day (ppd) which compares favorably with the oft-quoted national value of 4.8 ppd (14). Texas also has a large volume, highly mechanized agricultural industry which may provide a more concentrated supply of ASW than other localities in the nation. Concentration of ASW is needed to minimize transportation costs and to make energy conversion economically viable (See below for a more thorough summary of this data base).

Within Texas, a realistic estimate indicates the 1974 energy equivalent of 38,266 barrels per day (approximately 14 MM barrels per year) can be generated from 9 metropolitan centers and 2.4 million cattle located on the High Plains. The total ASW-MSW potential in 1974 is estimated to be approximately 110,000 barrels per day or 27 MM barrels per year. These estimates indicate a combined MSW-ASW energy production equivalent of only 1-3% of the refinery capacity in the State (approximately 3.5 MM barrels per day (12)). Thus, MSW-ASW energy conversion would have only a very small impact on the total state energy production-consumption.

A better prespective of the MSW-ASW energy impact is to note that the total MSW-ASW potential is 25-28 per cent of the total energy needed for electrical power production in Texas on a typical winter day in January-February 1974. The MSW-ASW energy potential in the 9 metro centers and in cattle waste is equivalent to 8-10% of the total state electrical power consumption (a 40% electric power-Btu conversion factor was used in making these comparisons). These latter two comparisons suggest that solid waste energy conversion can provide a significant part of basic human and industrial energy needs in Texas.

Finally, we note that one should not ignore the importance of, even though it cannot be calculated, the potential impact of MSW-ASW resource recovery on reduction of environmental pollution and energy conservation psychology.

SUMMARY AND CONCLUSIONS: GENERATIONS RATES OF MSW AND ASW IN TEXAS

As noted above, the generation rate of MSW in Texas appears to be equivalent to the national value of 4.8 ppd. Within this value, 2.5-3.0 ppd may be expected from households and 1.5-2.0 ppd from commercial establishments (13). These data confirm the generation rates reported by Melina and Smith (1968) for Austin, Ft. Worth, Dallas, Waco, and Corpus Christi.

As part of the study for G.E.A.C., a survey was made across the State through the Council of Governments to obtain municipal solid waste generation rates. The range of rates reported in this survey were 0.71 ppd to 10.41 ppd and the average value was 4.4 ± 1.8 ppd for 33 localities with populations from 997 and up. For cities over 10,000 the reported generation rate was 4.7 ± 1.2. There appeared to be a slight trend with larger municipalities reporting an average rate of 5.1 ppd ± 1.2. In general, the data must be used cautiously because many locations were able to report only estimated values. We do conclude that the average generation rates are reasonable because the results do agree with more exhaustive studies (13).

An attempt was also made to obtain agricultural and industrial solid waste generation rates. These data are essentially non-existent and we have had to rely on national data, even though these data, by definition, must also be considered suspect. The potential amounts in Texas must, however, be quite large because the meager data available are equivalent to major population centers. On the High Plains of Texas alone, there are approximately 2.4 MM cattle fed per day. At a generation rate of 8 lb per cow-day, with a heat content of 6000 Btu per pound, these cattle alone produce the solid waste energy equivalent of approximately 4,800,000 people.

With regard to industrial solid waste, one estimate from the Houston area suggests that 46-152 tons per day of organic solid wastes are produced which is equivalent to a population of 66,000-218,880 (14). This estimate includes only hydrocarbon polymer and chlorinated hydrocarbons; general rubbish and office collection is not included in the value. Thus, ASW and industrial solid waste are probably significant because these two estimates alone are equivalent to 40-45% of the 1970 state population. Such an estimate confirms national projections that ASW amounts to 4 times the tonnages produced as MSW. For our calculations, we have employed a multiplication factor of 2. It is recommended that a state-wide survey be immediately initiated to collect the necessary data to make better estimates of the energy potential in the industrial and agricultural sectors.

SUMMARY AND CONCLUSIONS: ENERGY CONVERSION SITES IN TEXAS

At this time, there are nine sites in Texas which have potential of supporting an energy conversion process using MSW. These locations are Austin, Beaumont-Port Arthur-Orange, Corpus Christi, Dallas, El Paso, Fort Worth, Houston, Lubbock, and San Antonio. These were selected on the basis that all commercially available processes become uneconomical for volumes less than those generated by a population of 150,000 and/or densities less than that served by a single incorporated municipality ($\geq$ 150,000 population per 12-14 square miles based upon Lubbock, Texas). At volumes less than the 150,000 population equivalent or for larger transportation distances, the investment and daily charges become prohibitive (7, 15, 16,17).

Because the potential impact of solid waste resources on energy needs in Texas can be significant, we recommend that the State and one or more specific municipalities begin a detailed assessment of a solid waste resource recovery process. This process might be an energy production unit and/or a materials recycle center depending upon the needs and opportunities of the specific locality. We recommend that at least one energy and one material recycle plant be contracted in the state no later than December 1976 for operation in 1978. The responsibility and sponsorship of such processes should probably be legislated as outlined in the last section of this summary. We note that Houston, El Paso, and Amarillo have already initiated limited recycle of some materials.

SUMMARY AND CONCLUSIONS: ESTIMATED INVESTMENTS AND COSTS

Most of the processes for direct energy recovery from solid wastes (7, 10, 15, 26) indicate that capital investment costs for most energy generation plants will be $15,000-20,000 per daily ton of MSW, depending upon the volume of throughput and location (1974 dollars). The net cost to a municipality is called a dump charge and is projected to be about $4-$6 per ton (1974 dollars) with full recovery of both energy and materials. The net dump cost is that fee required in addition to collection costs and includes all operating costs as well as debt retirement over a 15-20 year period. The net dump charge with either energy recovery or materials recovery alone ranges from $3-$11 per ton depending upon the location and potential market, but appears to generally range from $5-$7 per ton.

Utilizing the $15,000-$20,000 per daily ton investment projections, an estimated investment of $575 to $1,534 MM (depending upon size of plants and inflation) would be required in Texas over the next ten years to recover the realistic energy potential estimated above. This investment or debt would be recovered within a 15-20 year period. The cost to a typical family of four in a Texas community participating in full recovery of materials and energy would be $9-$13 per family per year (1974 dollars). This is a relatively small incremental cost and provides some insight to the actual effect and impact of energy recovery from solid waste on the citizens of Texas.

RECOMMENDATIONS FOR RESEARCH-DEVELOPMENT AND LEGISLATIVE ACTION

If ultimately implemented, we believe the programs outlines below will minimize the chances of failure or the possibility of wasted effort experienced by other states. To realize the fullest benefit and to insure a successful program result, we recommend that the state government of Texas consider the following items:

1. Resource Recovery Authority

Six states are actively considering or have established state-wide Resource Recovery Authorities (38) to facilitate planning, data gathering, economic and marketing analysis, and bonding authority for solid waste processing centers. Connecticut has had such an authority in existence since 1972. We recommend that Texas review such programs, assess the advisability of establishing such an authority in the state, and propose proper legislation, if any is deemed desirable. We personally recommend such an authority be established to provide, at the least, a final review board which will insure that (1) reliable markets exist in a given locale, (2) the best available technology is utilized, (3) adequate bonding can be obtained, and (4) equitable financial contracts are obtained.

2. Existing Legislation

Solicited comments from various resource recovery system designers and marketers, and the Environmental Protection Agency have shown that current Texas laws will have to be enforced or changed before significant recovery ventures can be organized. Specifically, it is known that 70 per cent of Texas landfills are not in compliance with existing Department of Health requirements (1973). Thus, as long as the state does not enforce the laws in this area, there will be little incentive to develop recovery programs.

Resource recovery centers would also have minor problems in complying with "Municipal Solid Waste Rules, Standards and Regulations" published by the State Board of Health. In particular, article D-1.6 indicates MSW may not be stored more than 24 hours awaiting processing and D-2.1b requires that a plant stop receiving MSW if a mechanical breakdown will require more than 24 hours to correct. We conclude that these may be unnecessarily restrictive, especially when current technology in both Europe (5,7) and the U.S. (e.g. Nashville, Tennessee) indicate that MSW may be stored 2-7 days without adverse effects.

We therefore recommend that existing laws and enforcement procedures be reviewed and possibly be modified to insure a positive atmosphere for development of resource recovery programs.

3. Development of a Data Base

Data gathering or development of a data base would be one of the functions of a Resource Authority cited above. This aspect is so very important that a separate recommendation is made here.

Texas is one of the leading industrial and agricultural states in the nation. In spite of this, the data on the amount and type of solid waste being generated by these two sectors are woefully inadequate. Furthermore, the reliability of the meager data now available has been seriously questioned by both the governmental and the industrial personnel that have been contacted during this review. An extended study is therefore recommended to obtain these needed data. All sectors should be reviewed, but the acquisition of an agricultural and industrial solid waste generation data base should be emphasized.

4. Development of a Technological Data Base

The state has several unique features with regard to solid waste resource recovery. The features are: (1) few coal-fired utility boilers, (2) significant reserves of lignite, and (3) highly developed agricultural and petrochemical industries. Each one is discussed below in terms of technological needs.

We anticipate that the number of coal-fired boilers within the state will increase within the next ten years and that lignite may well be the primary coal supply. Since this new investment will be justified on its own merits, as well as energy need, the state has a unique opportunity to utilize solid waste as a supplemental fuel in boilers designed specifically for this purpose. Utilities cannot, however, be expected to develop the necessary technology on its own and some state supported reserach is needed. Of all the known technical problems, we conclude that boiler tube corrosion is a key variable and the lack of adequate data could severely retard the acceptance of solid waste combustion. Thus, we recommend that the state support research on the corrosion aspects of combined firing of coal and solid wastes.

The state's agricultural industry will always require significant quantities of ammonia. The production of this primary chemical currently utilizes natural gas as a feedstock which can be supplemented using various solid wastes. Ammonia synthesis from feedlot cattle manure has been demonstrated on a small pilot plant scale (11), and other solid wastes could probably be employed. We recommend that such a project be supported by the state to provide a supplemental source of ammonia. This type of project could create an economic and pollution control advantage for the agri-business of the entire state, and would provide immediate support for the cattlemen of Texas.

A continuing technological review of solid waste conversion by pyrolysis processing is also recommended. This type of processing has not been fully demonstrated, but has been shown to produce approximately one barrel of oil (high oxygen) from one ton of municipal waste which can be fired with No. 6 fuel oil in a utility boiler. Since many electric utilities in Texas do not have ash removal capability, this second generation gasification or liquefaction process has significance with respect to their operation and utilization of solid waste. Alternately, pyrolysis processing could provide a supplemental feedstock for the petrochemical industry utilizing the highly developed pipeline network already available.

There are other research needs in this area but they are not as critical as those mentioned here. We strongly recommend that the state consider support for research projects which address the problems of boiler tube corrosion, ammonia production, and pyrolysis process development.

DISCUSSION OF STUDY AND RESULTS

BACKGROUND OF PROJECT

The original scope and objectives of this project are given in Appendix I. The material included in this Appendix is testimony given January, 1974, the project proposed to G.E.A.C. in February, 1974, and the approved research project.

Key comments made during this formulative stage indicated that (1) immediate action is required if resource recovery is to supplement the availability of our natural resources and energy; (2) disposal and/or recycling of solid waste is a significant engineering problem which will require time, money, and patience to solve; (3) pyrolysis and/or partial oxidation of solid waste offers an attractive alternative to landfill; and, (4) truly sophisticated resource recovery processes will always be designed to exploit locational advantages. We reviewed these items at the end of the project and conclude the study not only confirms but demands that these ideas and comments be emphasized.

POTENTIAL AND PROJECTIONS OF SOLID WASTE AS AN ENERGY SOURCE

Assessing and projecting the potential of solid waste as an energy source within Texas is a difficult task, as any such assessment is, but this subject has its own particular problems due to the lack of a reliable and adequate data base. During this study, we attempted to secure data in the municipal, agricultural, and industrial sectors as described below. The municipal data appeared to form a reliable base but the industrial and agricultural data proved to be inadequate. The projections made below recognize these limitations. We have made estimates on the basis of cited national projections and have attempted to be conservative. All calculations are given in Appendix II.

A summary of the estimates are given in Table I. This table illustrates the relative magnitude of energy potential from the three expected sources as well as the total potential for solid wastes. The most important values would appear to be the 1985 estimate because this is the value which defines an immediate goal. The realistic value of 1.4×10^{14} Btu/yr indicates that Texas could realize about 1/3 of the maximum potential by this date. In the year 2000, a 40% utilization of the maximum value is projected.

To gain some perspective on the impact of solid waste on the Texas economy, the maximum and realistic values of energy from solid waste have been compared to the state's electrical power consumption. This calculation is also given in Appendix II. The results show that the maximum potential energy from solid waste is approximately 30% of the total energy consumed in generating electrical power in the State in January-February, 1974. The energy from only 9-metro centers and the manure from cattle

TABLE I

POTENTIAL AND PROJECTIONS OF SOLID WASTE AS AN ENERGY SOURCE IN TEXAS[c]

Type of Waste	CURRENT YEAR (1970)			Year 1985 ESTIMATE[a]		Year 2000 ESTIMATE[a]		
	Maximum BTU/YR	Realistic BTU/YR	Realistic BBL Oil/Yr	Maximum BTU/YR	Realistic BTU/YR	Maximum BTU/YR	Realistic BTU/YR	Realistic BBL/YR
Municipal	7.9×10^{13}	0	0	12.3×10^{13}	4.7×10^{13}	19.1×10^{13}	7.6×10^{13}	12.9×10^{6}
Agricultural[b]	19.3×10^{13}	0	0	30.0×10^{13}	9.4×10^{13}	47.0×10^{13}	19.3×10^{13}	26.2×10^{6}
Industrial	0.2×10^{13}	0	0	0.3×10^{13}	0.1×10^{13}	0.5×10^{13}	0.2×10^{13}	0.3×10^{6}
TOTALS	2.7×10^{14} BTU/YR			4.3×10^{14}	1.4×10^{14}	6.7×10^{14}	2.7×10^{14}	39.4×10^{6}

(a) A growth of 3% per year has been used for 1985 and 2000 estimates.

(b) Agricultural Waste = 19.3/7.90 = 2.4 times MSW. National estimates indicate that ASW may be 4 times MSW. This adjustment has been made to account for the diffuse nature of ASW.

(c) All calculations are given in text of the report.

on the High Plains is equivalent to 11% of the electric power energy consumption.

These values are subject to revision pending the development of a reliable data base for agricultural and industrial solid wastes as well as development of new technology.

BASIC DATA AND GENERATION RATES

In order to make realistic projections concerning the direct and indirect energy which can be recovered, it is essential to know the average composition, heat content, and amount of solid waste being generated. The most recent study made on this aspect with respect to Texas was the Smith and Melina report of 1968 on MSW (19).

Municipal Solid Waste

Reasonable projections of MSW composition can be made on the basis of data obtained on the national level. The average MSW composition reported in Table II has been compiled by the National Center for Resource Recovery, Incorporated (13). These data indicate that on a dry basis approximately 79 weight percent of MSW is composed of combustible material. Although the metallic portion of the dry material is nominally only 9 percent, at $50 per ton for ferrous and $300 per ton for non-ferrous materials, the income from metal recovery processes can be considerable.

The energy content of the incoming organic or combustible fraction can vary considerably but it appears that 5000 Btu per pound is a reasonable value. Combustion Engineering Associates indicate that they can produce a saleable organic product with the characteristics listed in Table III while recovering about 8 million Btu's from a ton of MSW containing 10 million Btu's (20). As the data indicate, the "new" fuel has a heat content approaching that of many coals in Wyoming.

The design of an engineering system also requires a knowledge of the rate of generation or the pounds of solid waste that can be produced by a given population. In order to obtain some data relative to cities in Texas, a letter was sent to the Executive Director of all the regional Councils of

TABLE II

NOMINAL MSW COMPOSITION

Composition	Composition (% of dry weight)*	
	Range	Nominal
Metallics	7 to 10	9.0
Ferrous	6 to 8	7.5
Non-ferrous	1 to 2	1.5
Glass	6 to 12	9.0
Paper	37 to 60	55.0
Newsprint	7 to 15	12.0
Cardboard	4 to 18	11.0
Other	26 5o 37	32.0
Food	12 to 18	14.0
Yard	4 to 10	5.0
Wood	1 to 4	4.0
Plastic	1 to 3	1.0
Miscellaneous	> 5	

*Moisture Content: range, 20 to 40 percent; nominal, 30 percent.

TABLE III

ECO-FUEL^{TM} - II CHARACTERISTICS

Particle Size	1/4 inch to 100 mesh
Higher Heating Volume	7500 - 8000 Btu/lb
Moisture Content	<2% by weight
Inorganic Content	Approximately 5% by weight
Storage Life	Indefinite
Bulk Density	Approximately 30 lbs/ft^3

Government. Reports were received from approximately 50 percent of the Texas Councils of Governments. The survey results confirm the Melina and Smith study of 1968 (19) in which 4.5-5.0 lbs solid waste/person/day were generated in the larger metropolitan areas. The limited data obtained indicate that the average output for a given Texan is 4.4 lb/per day which agrees well with the oft-quoted value of 4.8 lb/person/day. The data compiled from the survey are given in Table IV.

Our analysis of the data is given in Table V and shows a possible increase in the rate of generation with increasing population of a given locality. For example, a generation rate of 4.8 ± 1.8 lb/person/day was obtained for population centers greater than 5000 versus 5.2 lb/person/day when the population exceeds 50,000. In using these data, we have chosen to use a conservative estimate of 4.8 lb/person/day for cities with populations > 100,000. This value also agrees with the 1968 data (19) reported for Dallas, Ft. Worth, Corpus Christi, Waco, and Austin, as mentioned above, 4.5-5.0 lb/person/day. It should be noted that recent data from a new survey for Dallas-Ft. Worth area (21) indicates that total solid waste may be generated at rates exceeding 8.0 lb/person/day for dense urban areas. Thus, overall we consider the value 4.8 lb/person/day to be quite reasonable and effectively confirms the more detailed survey.

The preceding values include both residential and commerical wastes, but no industrial disposables. For this study, no attempt was made to identify the individual residential and commercial contributions. If needed, individual values can probably be estimated from the known national surveys which indicate 2.5-3.0 lb/person/day from households (residential) and 2.0-2.5 lb/person/day from commercial establishments.

TABLE IV

SOLID WASTE GENERATION RATES FOR VARIOUS CITIES IN TEXAS

City	Year	Population	Tons	Tons per Year/Person	Pounds per Day/Person
Abilene	70	93,600	100,000	1.068	5.852
West Central C of G	71	93,600	105,000	1.122	6.1468
	72	93,600	110,000	1.1752	6.439
	73	93,600	120,450	1.2868	7.0512
	74	93,600	130,000	1.383	7.6102
Amarillo	12/71	125,284	100,574	.8027	4.39
Potter & Randal C.	12/72	127,010	108,004	.8503	4.659
	12/73	131,535	11,780	.8956	4.90
	74	134,576	36,388	.8111	4.44
Alice Jim Wells County Coastal Bend C of G	12/73	21,000	27,698	1.318	7.22
Athens Henderson County East Texas C of G	72	9,582	8,680	.9058	4.963
Beaumont Jefferson County	74	120,000	122,824	1.023	5.608
Brownfield Terry County South Plains Assoc. of Govt.	74	10,000	9,124	.9125	5.0

TABLE IV (continued) ....

City	Year	Population	Tons	Tons per Year/Person	Pounds per Day/Person
Carthage	72	5,392	3,640	.6750	3.699
Panola County					
East Texas C of G					
Clarksville City	72	398	312	.7839	4.295
Greg County					
Corpus Christi	71	215,000	191,190	.8892	4.872
Nueces County	72	215,000	192,500	.8953	4.906
Coastal Bend C of G	73	215,000	193,325	.8991	4.927
	74	215,000	207,500	.9651	5.28
Denison	73	25,000	21,632	.8652	4.741
Grayson County					
Texoma					
Edgewood	72	1,176	416	.3537	1.938
Van Zandt County					
Elkhart	72	997	130	.130	.7144
Anderson County					
El Paso (County)	12/71	350,000	224,129	.6403	3.50
West Texas C of G	12/72	350,000	229,850	.6567	3.59
	12/73	360,000	251,723	.6992	3.83
	12/74	365,000	269,070	.7371	4.039

TABLE IV (continued) ....

City	Year	Population	Tons	Tons per Year/Person	Pounds per Day/Person
Gilmer-Upsur C.	72	4,196	3,276	.7807	4.278
Henderson Rusk County	72	10,187	7,000	.6871	3.765
Jacksonville Cherokee County	72	9,734	9,125	.9374	5.13
Lindale-Smith C.	72	1,631	3,100	1.900	10.41
Longview-Gregg C.	72	46,742	21,000	.4492	2.461
Lubbock	74	159,000	196,000	1.232	6.75
Malakoff Henderson	72	2,095	832	.4074	2.232
Marshall Harrison County	72	22,937	19,500	.850	4.65
Mineola Wood County East Texas C of G	72	3,926	4,000	1.018	5.582
Palestine Anderson County East Texas C of G	72	14,525	8,968	.6174	3.383

TABLE IV (continued) ....

City	Year	Population	Tons	Tons per Year/Person	Pounds per Day/Person
Quitman Wood County	72	1,494	1,106	.7402	4.056
Rusk Cherokee County East Texas C of G	72	4,914	1,248	.2539	1.391
San Angelo Tom Green County Concho Valley C of G	6/71 6/72 6/73 6/74	63,884 63,884 63,884 63,884	50,000 53,000 56,000 59,000	.7826 .829 .8765 .923	4.28 4.54 4.8 5.057
Sherman Grayson County Texoma	73	30,000	21,450	.7044	3.859
Tyler-Smith County	72	57,770	56,628	.9785	5.36
Victoria Golden Cresent C of G		43,000	47,450	1.103	6.043
Wasom Harrison County	72	1,460	660	.4561	2.49
Wichita Falls Nortex Regional Planning Commission	12/73	97,564	71,967	.7376	4.04

TABLE IV (continued) ....

City	Year	Population	Tons	Tons per Year/Person	Pounds per Day/Person
Wills Point Van Zandt County	72	1,494	1,106	.7402	4.056
Winsboro Woods County	72	3,064	2,390	.7800	4.274

TABLE V

SUMMARY OF 1971-1973 MSW GENERATION DATA FOR TEXAS

MSW = Municipal Solid Waste, including residential and commercial waste. Industrial and Agricultural Wastes excluded.

No. Location = 33

Population Range = 997 - 365,000

Average Generation Rate	Number Data Points	Population Range
4.44 ± 1.8	33	997 - 365,000
4.8 ± 1.2	21	> 5,000
4.7 ± 1.2	17	> 10,000
5.2 ± 1.1	10	> 50,000
5.1 ± 1.2	5	> 100,000

Industrial Solid Waste

Generation data on industrial solid waste are essentially non-existent, but preliminary information on industrial solid wastes indicate that sizeable quantities are being generated. One estimate from the Houston area suggests that 46-152 tons per day of organic solid waste (18,000 BTU/lb) is produced which is equivalent on a BTU basis to a population 66,000-218,880 (14). Most of this waste is hydrocarbon polymer but 10 or more tons per day may also include chlorinated hydrocarbons, a very difficult waste to process due to corrosive HCl which may be generated during disposal operations. These data do not include office and general rubbish collection figures.

One informed source* has indicated, however that such numbers may be completely unreliable because (1) most industrial management is currently unaware of what their actual volume and type of waste products are (2) such information is generally considered to be proprietary, and (3) material balances between the industrial and disposal sites are notoriously bad. Thus, either legislation must be passed or the industrial sector must recognize their public duty if reliable, industrial solid waste data are to be obtained. We do note, however, most firms appear to be willing to cooperate with municipalities and supply technical expertise where or when needed. They just do not want to divulge knowledge which may be related to process capacity or technology.

Agricultural Solid Waste

As with industrial solid waste, rate of generation data for agricultural solid wastes are also meager except for one case: the cattle manure

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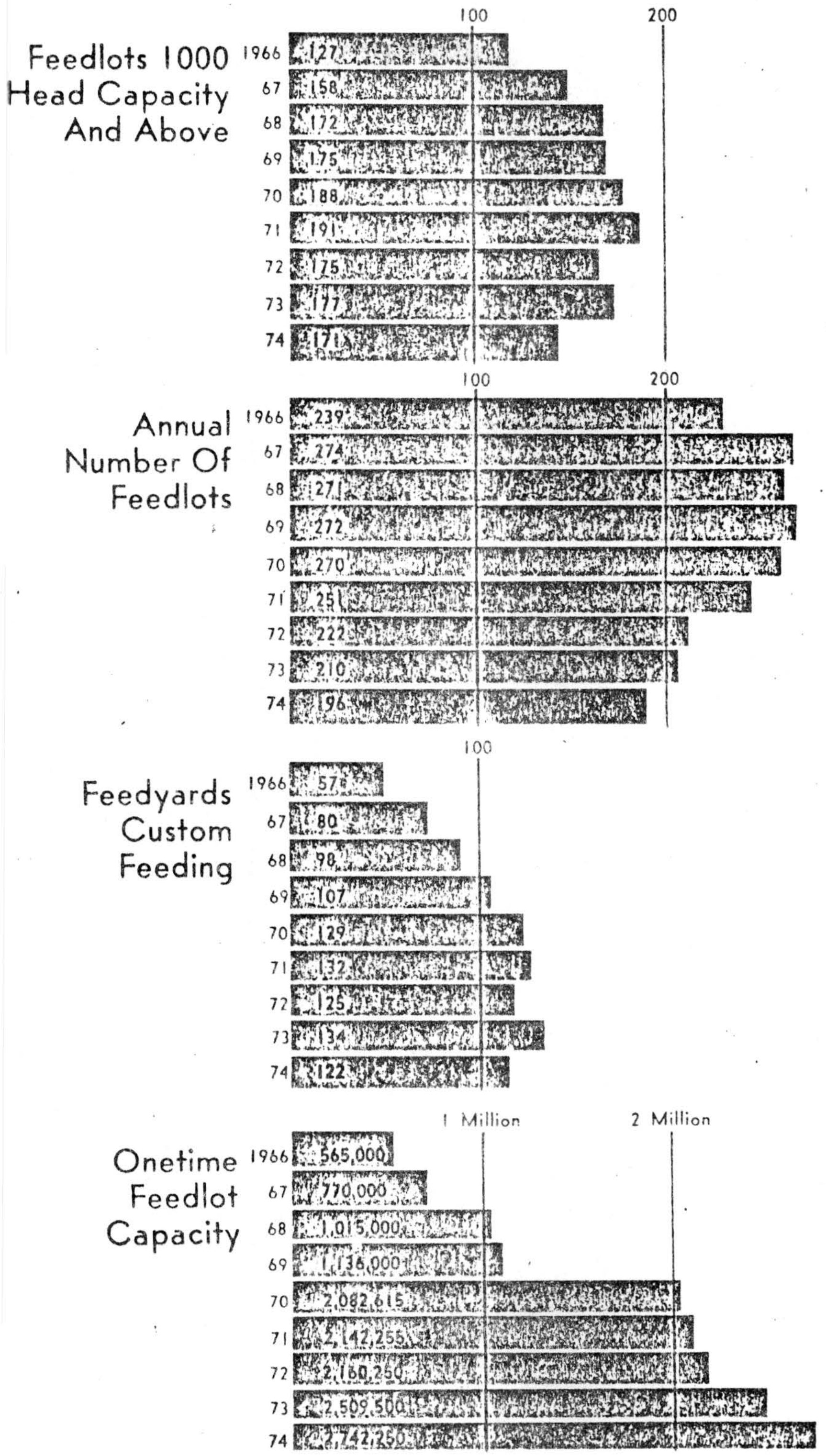
*One major study has been summarized as "based on inconclusive and in some cases inaccurate sampling information." The source of this information has requested anonymity.

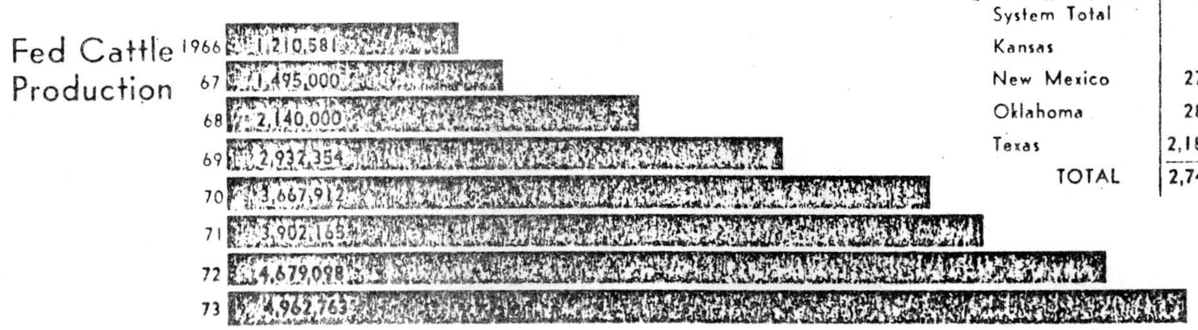
being generated on the High Plains of Texas. Even the casual observer will note that considerable agricultural solid waste exists in Texas (e.g., cotton, forestry, fruit, food processing, etc.), but the Texas Department of Agriculture could not supply any estimates. Obviously, a significant survey must be undertaken to determine these data to assess the energy potential from the agricultural sector.

National surveys, which must be considered suspect, indicate that agricultural solid waste is 4 times the amount of municipal. The potential energy supply from such a resource is not as significant as the raw material values indicate because ASW is quite diffuse or scattered. This diffuse nature leads to high transportation costs which will often negate economical energy processing of enormous stockpiles of ASW. We suspect, however, that the potential energy supply from ASW in Texas will, nevertheless, be significant due to the high mechanization and volumes involved. Such potential is suggested by the cattle feedlot manure discussed below.

Approximately 25% of the cattle in the U.S. or 2.5 MM head in 1974 are fed on the High Plains of Texas. Current estimates (11) indicate a generation rate of 8 lb of manure/day/cow. Thus, the stockpile of manure is tremendous, i.e., $8 \times 2.5 \times 10^6 = 20 \times 10^6$ lb/day. Significantly, approximately 97 percent of this waste is concentrated in only 225 feedlots as shown in Figure 1 (22). This high concentration of feedlot cattle allows recovery schemes to be considered which would not be feasible at lower cattle densities.

The composition of a typical feedlot manure is given in Table VI. The data indicate that manure is low in sulfur, but high is ash. As with most fuels, both desirable and undesirable properties exist. For example, in





STATE & COUNTY	Lot Capacity Now	No. Fed in 1973
KANSAS		
Morton	1,000	2,000
NEW MEXICO		
Chaves	134,900	168,691
Curry	79,500	116,050
Eddy	26,800	50,937
Roosevelt	32,850	60,711
TOTAL	274,050	396,389
OKLAHOMA		
Beaver	22,000	47,306
Cimarron	53,000	76,100
Texas	207,100	424,700
TOTAL	282,100	548,106
TEXAS		
Armstrong	9,600	21,300
Bailey	46,200	80,300
Briscoe	1,400	1,300
Carson	24,000	43,500
Castro	221,200	388,500
Cochran	40,000	100,000
Crosby	NONE	REPORTED
Dallam	72,900	83,900
Deaf Smith	299,000	602,889
Floyd	30,600	55,800
Gaines	10,700	21,000
Garza	2,500	2,250
Gray	85,000	135,700
Hale	90,100	190,100
Hansford	166,500	315,680
Hartley	82,500	194,499
Hockley	15,500	31,100
Hutchinson	10,000	7,500
Lamb	61,000	118,800
Lubbock	61,000	112,000
Moore	105,500	187,750
Oldham	33,400	90,221
Parmer	289,000	437,000
Potter	21,000	42,000
Randall	132,200	228,584
Sherman	116,300	212,700
Swisher	118,000	231,895
Wheeler	40,000	80,000
TOTAL	2,185,100	4,016,268
System Total		
Kansas	1,000	2,000
New Mexico	274,050	396,389
Oklahoma	282,100	548,106
Texas	2,185,100	4,016,268
TOTAL	2,742,250	4,962,763

Figure 1
1974 Fed Cattle Report (22)

TABLE VI

Commercial Feedlot Manure, Typical Values(11)

Quantity	Weight Percent
Moisture	15-37
Carbon*	35-40
Hydrogen	5.3-5.9
Nitrogen	2.5-3.1
Sulfur	0.4-0.6
Ash	24-30
Gross heating value, BTU/lb	5750-6730

*All measurements are on a dry basis except for the moisture which was on an as-received basis.

combustion low sulfur is desirable but the high ash content may cause serious problems with electrostatic precipitators. Due to the arid climate of the locale, the moisture content of manure can frequently be as low as 15 percent. This is a very important parameter because of the large amount of energy required to vaporize water. Water content above 50% may negate the potential recovery of energy for any solid waste.

As indicated in Table VI, the gross heating value of commercial feedlot manure ranges from 5750-6730 Btu/lb with an average value of 6250 Btu/lb (11). For comparison, MSW has approximately 5000 Btu/lb and a quality coal would contain about 12,000 Btu/lb.

These data indicate that cattle feedlot manure may provide a significant supplement to fossil fuels. To this end, a sustained research program has been undertaken to develop the data base needed to assess the economics of such processing (11). We conclude that other such agriculture sources exist in Texas and recommend a significant research program to define the potential. Data similar to that shown in Figure 1 and Table VI are the minimum data needed.

TECHNOLOGY ASSESSMENT OF ENERGY AND RESOURCE RECOVERY PROCESSES

Energy and resource plants using solid wastes are generally divided into front-end and back-end processes. The front-end of a plant incorporates the processing for classification and separation of non-combustible material from the organic or combustible matter. The back-end of the total process is the phase normally associated with direct-energy recovery such as combustion or pyrolysis. The other major back-end processing technology may be classified as biochemical in which the organics are converted to methane or other products (e.g., protein) by microorganisms.

The discussion in this section will concentrate on front-end processing and back-end processing for direct energy recovery; biochemical technology is treated briefly. There are many excellent summaries on processing of solids, particularly MSW, and the reader is referred to the papers of Glysson, et al., (23), Levy (8), Jackson (24), and Wilson (25) for additional data and processes. This review will present only those processes that the writers have assessed through site visits or are familiar with through reserach experience. This limitation is not, however, a severe one because the required technology is common to most all of the processes. Furthermore, the authors do not intend to slight any commercial process. To circumvent this latter point, the review will be discussed in terms of the basic technology of back-end processing; combustion, partial oxidation, pyrolysis, and biochemical treatment.

Front-end Processing of MSW

In the front-end of the plant the incoming municipal solid waste is normally weighed before dumping onto a holding platform. This procedure allows the operators of front-end loaders to be somewhat discriminatory concerning the nature of the material that is pushed onto a conveyor belt for transfer to the shredding operation. If an engine block or some other unusually large object were detected then it could be pushed to one side for special disposal. An operator is frequently positioned over the conveyor belt to provide a second check to insure that the shredder can process the material on the belt.

The shredding operation is the most difficult operation in the front end sequence. Erosion of the swinging hammers is so high that it is not unusual for a plant to set aside 8 hours out of 24 for shredder maintenance. In the initial shredding step the average particle size of the MSW is normally reduced to approximately 1- to 1-1/2 inches.

From the shredder the material is transported by a conveyor belt to an air classifier where the MSW is fed into the middle of a column of rising air. By varying the velocity of the air, a separation can be made on the basis of the density of the material. Unfortunately, due to interparticle collisions and agglomeration this separation is far from perfect. However, the lighter stream will be predominately the organic fraction and the heavier stream will contain most of the metals. Glass appears in both streams and some metal can lids will leave in the light stream perhaps due to the "frisbee" effect. These materials can lead to serious erosion problems in pipes and burner nozzles when the organic fraction is subsequently transferred to the boilers by air conveyance.

The heavy stream is then passed by a magnetic drum to remove the ferrous materials. In order to have a viable scrap market for this iron it is frequently necessary to process the product from the magnetic drum through a nuggetizer in order to increase its bulk density and reduce its particle size.

The portion of the stream that was not attracted to the belt contains aluminum, copper, glass, dirt and small amounts of organics. Considerable research and developmental effort will be needed to fully exploit the potential of this stream. However, it appears that the aluminum content is sufficiently high to make recovery economically attractive (3).

The establishment of viable, non-volatile markets for recycled materials can substantially assist in the establishment of economic resource recovery plants. Recycled ferrous materials and aluminum is generally considered a saleable product (St. Louis, G.C., Allis-Chalmers, American Can, etc.) but other non-ferrous metals and paper products are generally unreliable due to impurities. Most vendors who supply shredders, conveying, air classifiers, etc. for a recycle system do not quote an end-use of glass other than as highway fill, highway asphalt mixture, or bricks.

An exception to the end-use of glass is the Garrett Reserach and Development process for a pure, saleable glass. The process uses a linear motor to separate aluminum and a froth floatation scheme for obtaining a pure glass. The process is being incorporated in the facility being built for the Connecticut Resource Recovery Authority in Bridgeport, Conn. This process will also produce a dry-fuel similar to that indicated in Table III and the over-all cost to the community is estimated to be approximately \$3.70 as shown in Table VII (26). The next maximum cost to the community is approximately \$9.90 per ton.

TABLE VII

SUMMARY OF NET PLANT OPERATING COST FOR

FRONT-END PROCESSING OF MSW(26)

Basis: (a) 10,000 ton per week; 520,000 ton per year

(b) 20% moisture

(c) Dry fuel = $1.50 per MM BTU

(d) 1974 Letters of intent for sale of ferrous, non-ferrous, and glass products, FOB destination

(e) 4.8 lb/person/day = 0.88 ton/person/year

	$/TON	$/PERSON/YR
Debt Service at 6% and 20 years	4.32	3.78
Utilities	3.74	3.28
Labor	4.17	3.65
Maintenance and Supplies	1.24	1.09
Other	2.64	2.31
Disposal of Residuals	0.62	0.54
Total cost	16.73	14.66
Minimum Revenue	6.84	5.99
Net Maximum Cost to Community	9.89	8.66
Additional Revenue based on 1974 Letters of Intent	6.18	5.41
Net Potential Cost to Community	3.71	3.25

Table VII also illustrates the cost of front-end processing person per year. The most interesting value the potential cost of \$3.25 to \$8.66 per person per year to dispose of MSW and obtain energy. We, the authors, view this as the incremental cost to a community and believe that most individuals would be willing to pay \$3.25 ÷ 12 = \$0.25 per month extra to recliam materials and eliminate sanitary landfills. Most front-end costs are similar to these values.

For Texas, the highly volatile nature of the paper/fiber market may ultimately limit recycle of such materials (27). We have discussed these problems with Browning-Ferris Industries of Houston. At this time, we suspect that legislation may be needed to reduce the burden of recycle industries, perhaps, in the form of (1) tax incentives or (2) a reconsideration of the freight rates charged on recycle materials relative to those associated with virgin materials.

Organic Fraction or Direct Energy Utilization

There are basically four different schemes which have been proposed to utilize the energy available in the organic fraction of municipal waste. These are complete combusion, partial oxidation, pyrolysis, and biochemical treatment. With the exception of the latter process, the others differ principally in the amount of air admitted to a reactor. Combustion normally uses more than enough air to convert all of the carbon present to CO_2, partial oxidation uses a controlled amount of air to produce a low Btu synthesis gas, and finally pyrolysis involves heating in the absence of air. This latter procedure is used to produce a high Btu gas which may be subsequently upgraded to pipeline quality. The pyrolysis conditions may also be varied to produce a low grade oil similar to a number six fuel oil.

Combustion: Coal + MSW Mixtures

This first generation of energy from MSW processes emphasize direct combustion. The St. Louis project which is a joint effort of Union Electric Company, the Environmental Protection Agency, and the City of St. Louis is an outstanding example of such a separation sequence. It is our opinion at this time that this process has considerable potential for transferral to several locations in Texas, assuming solid fuel boilers become available within the state. Currently, there are only 2 coal or lignite boilers within the state operated by public utilities (28).

As shown in Figure 2 (16) the front end sequence is typical in that the incoming MSW is fed to a conveyor belt which dumps into a hammermill in order to shed the material and thereby reduce the average particle size to approximately one inch. The organic and inorganic fractions of this material are then separated by air classification. The organic fraction is then fired to a conventional boiler using pneumatic transport. At present the MSW is carrying 10-20 percent of the boiler heat load with the remainder being supplied conventionally with pulverized coal. The steam produced by this combustion is used to generate electricity using a typical turbine generator.

In order to use the organic fraction of the MSW as boiler fuel, it is essential to have ash handling capability at the bottom of the boiler. Unfortunately, there are not many boilers which have this capability in Texas because of the ready availability in the past of natural gas. Utilities which have generation stations located near major cities should be encouraged to include this capability in a portion of all new boilers.

The most encouraging aspect of the St. Louis project is that Union Electric is sufficiently confident of the economic and technical viability

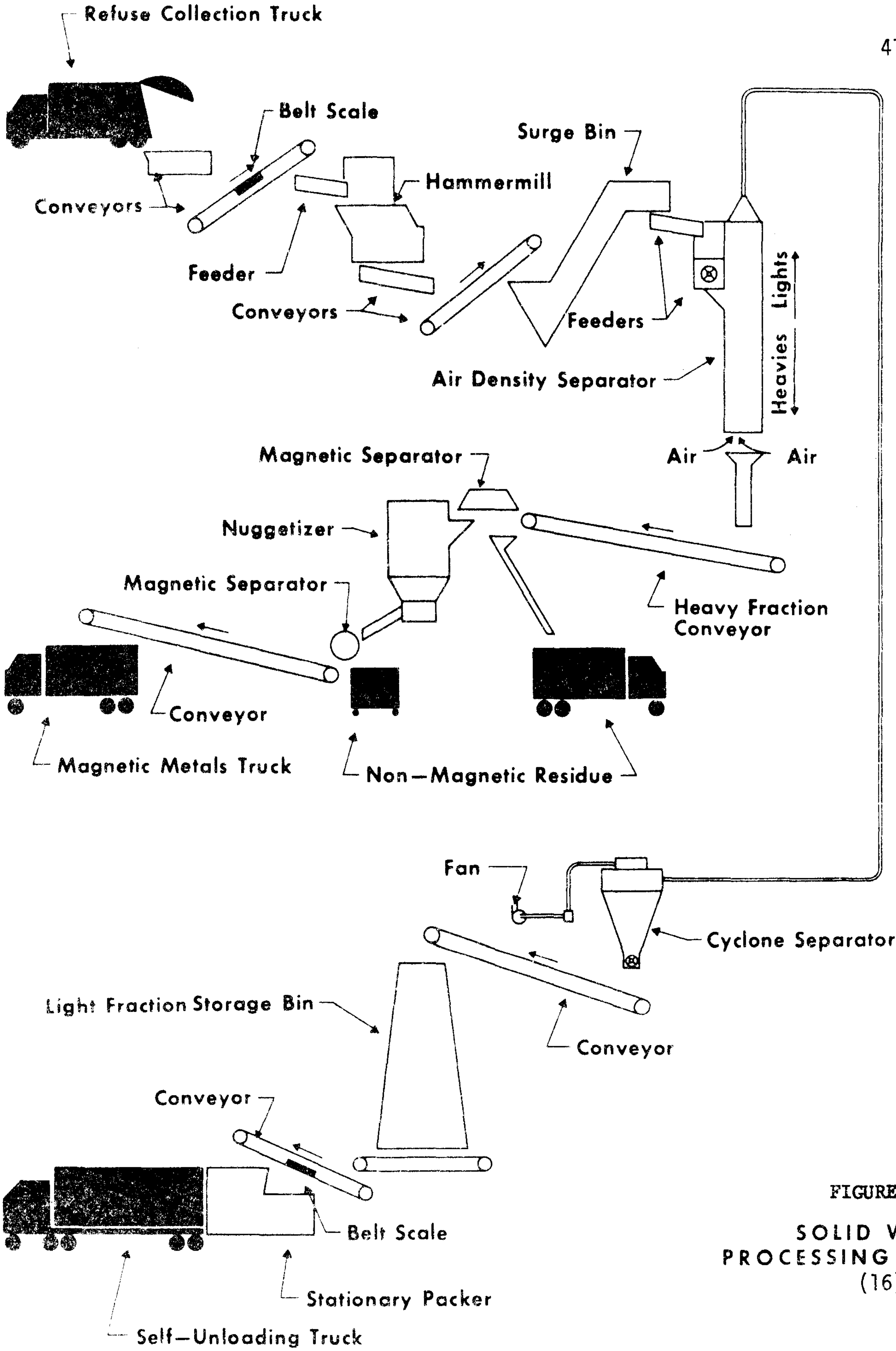
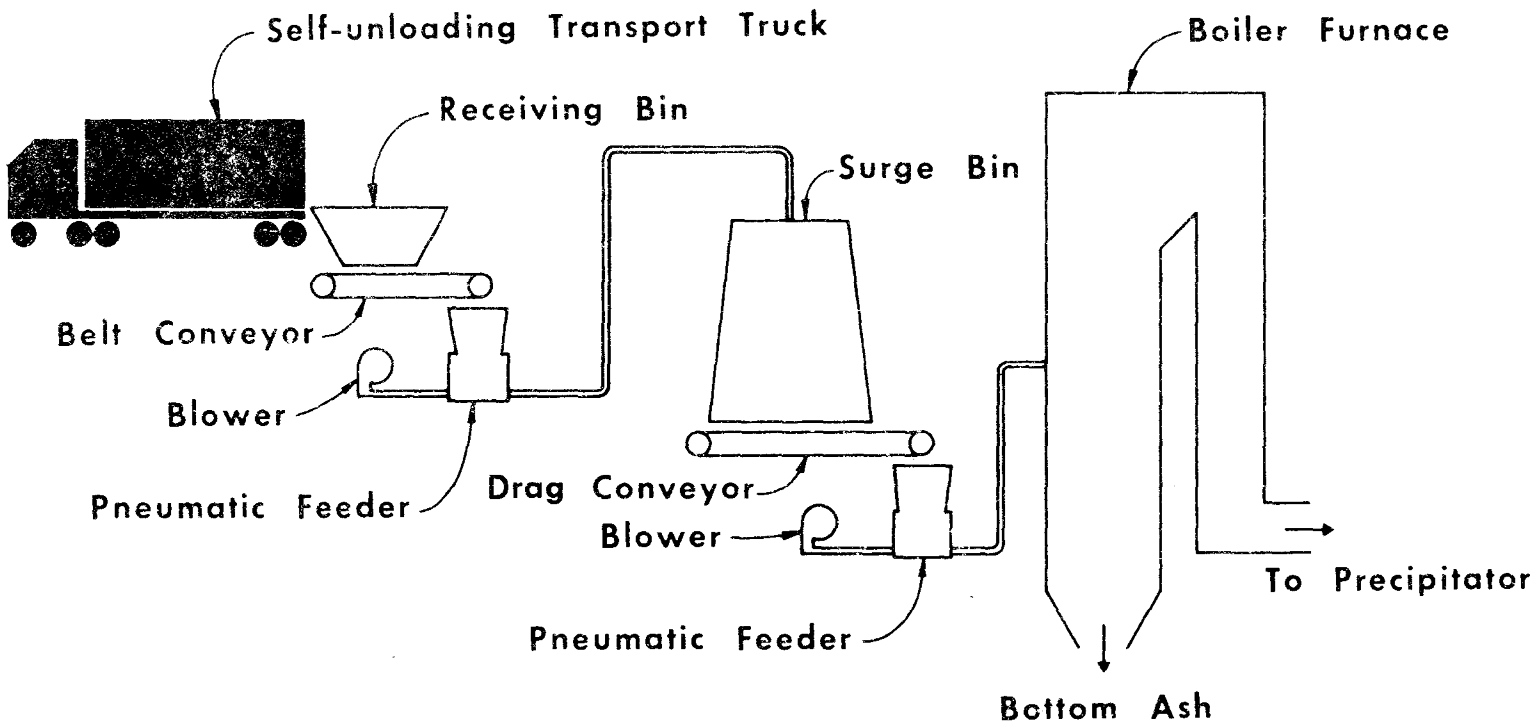


FIGURE 2a

SOLID WASTE PROCESSING FACILITIES (16)



SUPPLEMENTARY FUEL RECEIVING AND FIRING FACILITIES (16)

FIGURE 2b

of the project that they have proposed a plant to invest $70 million of their money in capital costs for a system capable of handling essentially all of the municipal solid waste generated in the metropolitan St. Louis region. Under the plan, Union Electric will establish and operate five to seven strategically located collection-transfer centers capable of handling a total of 2.5 to 3 million tons of waste annually. Refuse will be received from private and public haulers at these centers and transferred to closed containers for rail shipment to processing facilities at power plants.

The Union Electric system will encompass the City of St. Louis and six adjacent counties in Missouri and Illinois. In a private communication, an engineer-analyst associated with the project indicated that the economics suggested that MSW could be economically moved 100 miles to the processing center (10). Although the dumping fee charge has not been firmly established, it was estimated that a fee of $5 would accrue to Union Electric for each ton accepted from the City or private haulers. It should be recognized that the regional collection centers will allow the city significant savings in transportation costs due to the decrease in distance of the average haul and increased efficiency of the pickup crews.

The commitment by Union Electric is contingent upon the establishment of realistic environmental regulations for refuse burning boilers and the assurance of a supply of solid waste for a duration that will justify the required capital investment. The first restriction points out a problem in MSW combustion, in that boilers which are fired with coal-MSW mixtures have difficulty meeting current EPA stack gas emission standards with regard to particulates.

Another significant problem with the firing of MSW has been with boiler-tube corrosion due to sulfates or chlorides attacking on the fire side of the tubes (16). Union Electric is aware of this problem and has installed several probes to attempt to measure the corrosion rate. However, when questioned in detail, it was obvious that the company really had little or no program underway to try to assess the magnitude or to develop possible solutions to this problem. One of the recommendations of this report is to begin research on the kinetics and stack gas compositions associated with the combustion of coal-MSW mixtures. Our review of the literature has not yielded any studies of this type with respect to such mixtures. An interim report on this potential is given in Appendix III.

Combustion: Incineration of MSW with Heat Recovery

Incineration of MSW with heat recovery is probably the most advanced technology for solid waste because this technology has been in use in Europe for the last 20-25 years. There are, however, operating problems which require serious attention before implementation is considered. As suggested above, corrosion is a key problem and is summarized in Appendix III. The discussion given below outlines other problems and gives some estimates of the cost of incineration.

One of the major sites for incineration with heat recovery is the Saugus Plant, RESCO North Shore Facility, being designed to supply 890 psig, 875°F steam to a General Electric plant. Approximately, 1200 tons per day of MSW will be processed to generate 185,000 lb steam per hour. Energy recovery for the plant is estimated to be 70% (thermal efficiency). The refuse will be collected from 15-20 cities within a 10-15 mile radius (7, 29).

Operating cost of the plant without the energy credit or any metal recovery is expected to be $22-25/ton; this value includes debt reduction of $30 MM over a 15-year period. Such a cost depends upon volume; operating costs without allowances generally range from $30/ton to $11/ton as the scale of plant changes from 500 ton/day to 4000 ton/day, respectively. With the steam or energy credit, this plant is expected to require a $10-$12/ton dumping fee (dump fee is the cost any city must pay the plant; this fee is a bargin in the Northeast where costs can run as high as $50/ton) and the cost over the above volume range is $30 per ton to $1/ton (7). The plant will employ 50 personnel including 4 administrative positions. Engineering support will be supplied by the engineering contractor. These costs, efficiencies, and personnel requirements reflect the general economics of most any incineration-heat recovery process (7). The values appear to be high compared to the costs given earlier for materials recovery alone as cited in Table VII; however, adding the revenue included in Table VII for materials recovery, the net dumping charge for this facility could be as low as $2-4/ton. We note that the RESCO facility engineering contractor does not think materials recovery is economical and does not plan to install such facilities initially.

Our discussions with the engineering contractor (Rust Engineering, 7) indicate that the site should not be compared to the usual European facility. For example, in Paris a similar sized plant employs an additional 45 administrative personnel. Furthermore, most European plants are operated with less stringent demands, compared to General Electric's needs. General Electric's demand is for their turbine fabricating facilities and the required steam will be purchased instead of replacing old, obsolete boilers.

During one European visit, the plant, operating with 4, 200 tpd units, had 3 units down at one time and maintenance was only scheduled during the day shift. One European plant does appear to operate with demand and 5-7% is the demonstrated downtime (La Zahn, Switzerland).

The heart of the RESCO facility includes two, 750 tpd (design) Von Roll incinerators. These units are two times the size of any other plants. It should be noted that multiple units are normally built instead of a single train plant. The multiplicity appears to be needed to insure continuous processing during individual unit turn-arounds and to smooth-out production in spite of the MSW variability. Only 10-12% of the MSW is shredded for feed to the plant. Shredding will be accomplished with a 1000 HP (40 HPhr/ ton) hammermill, which can probably handle most anything. MSW is brought to the site, weighed, and dumped immediately into a trough capable of holding 5.6 days capacity. Odor problems will be minimized by drawing combustion air-through the dumping doors. It should be noted that many European incinerators are located in or near "respectable" residence areas. Problems with fires during storage are expected to be minimal. All MSW will be moved to the feed chute using overhead cranes. Bulky items will be shredded at the operator's discretion. Even if bulky items enter the combustion chamber, no problems are expected due to the size of the units.

Residence time in the combustors will range form 30-43 minutes depending upon throughput. The MSW enters the combustion chamber through a chute with a MSW seal and drops onto a reciprocating grate. Four inclined grates are used with a 3-4 foot drop between each one. The drop is incorporated to break-up clinkers and thick combustibles (e.g., telephone books, logs, cushions). Heated air is blown up thru the grates with secondary air admitted at a high velocity to insure intimate mixing and complete combustion. The ash is finally dumped onto a conveyor under a water seal where it is quenched. Two conveyors are provided to insure continuous operation.

Combustion gases at 1600 °F rise to the superheaters, economizers, and through electrostatic precipitators and vents. Water-walls are employed before the superheater and are coated with Silicone Carbide. Current water walls do not start at the grate but will in new designs. Refractory walls are 12-14" thick near the grates and 6-8" in the superheater.

The superheater consists of vertically hung tubes which are continuously cleaned using a "rapper". The rapper is simply a hammer which knocks off scale approximately 1/2" thick but still leaves a thin protective coating to minimize corrosion. Operating time between turnarounds to remove scale and replace tubes has been increased from 3 months to 1 year with these rappers.

An attractive alternative to steam production alone is the development of a central heating and cooling plant similar to that being built in Nashville, Tenn. This plant (30) employs a conventional incinerator for combustion of MSW but also incorporates a natural gas burner. The plant economics are based upon supplying a central source of heating and cooling to downtown Nashville; the incineration or combustion of MSW was chosen for an auxilary fuel. The technology is clearly not new but the concept is; however, we must, again, express reservations on corrosion problems. The major problem noted in detailed discussions (31) is control of particulates as noted for the St. Louis project.

The key economical factor in this process is that the dumping fee charged to the city is zero. All operating costs are charged to the customer.

Even with the cost involved, old buildings are expected to save 15-25% of their normal heating/cooling bills and new buildings will save 25% or more. For the plant itself, cooling or chilled water revenues account for approximately 60% of the total. This result comes about because most major buildings require cooling <u>all</u> year and chilled water or cooling can be sold for four (4) times the cost of electricity ($4/ton•hr). The facility can serve that part of the community within a three mile radius, the general limit for central heating and cooling plants. A summary of this facility is given in Appendix IV.

Pyrolysis and Partial Oxidation

Since most of the boilers currently in use in Texas do not have ash handling capability, new facilities or an option other than that proposed for the St. Louis metroplex will be needed. What is called "the second generation" of waste processing systems will be able to fill this need in an environmentally acceptable manner (24). In general, these processes gasify the refuse in the absence of or reduced air to produce an oil or gas product or a fuel burnable in a conventional boiler. By including the intermediate gas producing step prior to combustion, the options of gas cleanup and particulate removal become available. In contrast to the St. Louis project, this permits the total MSW-to-energy conversion sequence to be in compliance with existing EPA stack gas emission standards. It also should eliminate boiler tube corrosion problems by removing the attacking gas constituents. Of course, the intermediate processing will incur additional costs, but exact economic comparisons are not yet available.

Two such processes have been developed for municipal solid waste and agricultural solid waste. These are discussed below. The reader should keep in mind that either, or a combination of the two, feedstocks could be utilized in either one of the two processes. Such technology does not, however, exist other than exploratory studies (11, 36).

A. Partial Oxidation of Agricultrual Solid Waste

Data with regard to the generation rates, compositions, and energy content of solid wastes are very difficult to obtain. The Texas Department of Agriculture was contacted but no significant waste generation data are contained in their reports. Several educators have recommended that a significant survey be undertaken to determine the basic data needed to make an assessment of the energy potential of the wastes generated by this sector.

Due to their economic importance, the special problems associated with the solid residues from cattle feedlots have received special attention. Animal wastes can lead to pollution and economic problems when they are produced in such high concentrations that they cannot be readily assimilated by the surrounding ecosystem. Such situations frequently exist where large numbers of animals are fed in confinement. In Texas about 2.3 million tons of dry manure must be disposed of or recycled from confined cattle feeding operations. Approximately 97 percent of these wastes are produced in only 225 feedlots (22).

The development of a concentrated cattle feeding industry has been a rather recent development on the High Plains of Texas. During the period 1966-1971 the fed cattle production in this area increased by almost a factor of four from 1.1 to 4.3 million head (32). In the Hereford-Dimmitt area, there is a one-time capacity for over 600,000 cattle within a circle of radius 15 miles. This high concentration of feedlot cattle allows disposal schemes to be considered which would not be feasible at lower cattle densities.

Thermochemical calculations have been made to assess the feasibility of producing natural gas, oil, and anhydrous ammonia from cattle feedlot manure (11). Due to its consistency with the local economy and the lack of a requirement for an oxygen plant, the anhydrous ammonia option was deemed to have the most potential. To this end, a sustained research effort (33, 34) has been underway to develop the data base needed to assess the economic viability of this option of energy recovery from solid waste.

A1. Compositional Data

Before any detailed process analysis can be conducted, it is essential to know the chemical composition of a typical feedlot manure. Although it will be a function of the practices of the feedlot operator, it is not unusual for a lot to be cleaned only about every 120 days in West Texas. Due to the aridity of the local cliamte, the moisture content of the manure can frequently be as low as 15 percent. This is a very important parameter with regard to chemical processing because of the large energy requirement to vaporize substantial amounts of water.

As indicated in Table VI, the gross heating value of a typical commercial feedlot manure ranges in value from 5750 to 6730 BTU/lb (11). For comparison, municipal solid waste has approximately 5000 BTU/lb while a quality coal would contain about 12,000 BTU/lb. As long as the price of energy was very low, there was little incentive to recover the energy in this material. However, the energy crisis has brought about renewed interest in disposing of municipal solid waste by using it as a fuel. This strongly suggests that energy recovery from manure may also be feasible.

The chemical composition listed in Table VI indicates that the manure is low in sulfur content but that it is high in ash. The latter material may cause serious problems with electrostatic precipitators, if a conventional combustion process is considered. In addition, the salts can concentrate in runoff waters and seriously retard the growth potential of surrounding lands.

A2. Conventional Ammonia Technology

The objective of the current reserach program is to use the manure as the major carbon and energy sources for a conventional anhydrous ammonia process. In the conventional flow scheme, natural gas is reformed with steam and air to produce a synthesis gas which is a mixture of CO_2, CO, H_2, and N_2. This gas is then passed through a shift converter which uses steam to convert the CO to H_2 and CO_2. The CO_2 is then stripped from this gaseous mixture and the product stream which is nearly pure H_2 and N_2 in a three to one molar ratio is sent to the ammonia converter section. In that section a special catalyst converts the gaseous mixture into NH_3, anhydrous ammonia.

The function of the natural gas is two-fold, it provides the CO and H_2 for the synthesis gas and it is used to produce the steam needed in the reforming and shift reactions. The objective of the proposed process is to use manure to produce a synthesis gas mixture with the char being combusted to produce steam.

A3. Partial Oxidation Studies

Tests made in a small two-inch diameter reactor which was fed manure, air, and steam indicate that a gaseous mixture could be produced which, after reforming, and CO shifting, would lead to a gas suitable for ammonia synthesis. A typical gas composition leaving the reactor is given in Table VIII. The amount of gas generated per pound of manure was found to be a strong function of the mean reactor temperature (11, 33).

TABLE VIII

Reactor Effluent Gas Analysis*

Component	Volume Percent
N_2	34.5
CO_2	18.7
CO	11.5
H_2 (by difference)	24.2
CH_4	6.8
C_2H_4	3.7
O_2	0.6

*Dry-basis-water not included.

The fraction of the carbon in the manure that was converted to the gas phase ranged up to 50 percent of that fed. Approximately 15 percent of the carbon did not react and was removed from the reactor in the form of char. The remaining fraction of the carbon appeared in the form of tarry substances in the condensates.

The char was approximately 50 percent ash and 50 percent combustibles. It has the appearance of granulated charcoal with little or no odor. It has a heating value of approximately 4800 BTU/lb which indicates that it should be useful in generating the steam needed for reforming.

Due to the small scale of the reaction system. it was almost impossible to make accurate heat balances. However, assuming that on an as-received basis, manure contained 15 percent moisture and 25 percent ash, approximately 700 pounds of ammonia could be produced from the gases generated from one ton of manure.

A3. Economic Considerations

There are many technically feasible manure conversion schemes which are not economically appealing. In order to assess the economic feasibility of the ammonia conversion sequence, a preliminary process flow sheet was constructed. Due to the small scale of the initial experiments, there are large uncertainties associated with the projection of this data to a large scale. Nevertheless, such projections are essential to delineate the areas that are worthy of particular attention in later studies.

The selling price of ammonia has increased dramatically due to the energy crisis and the shortage of natural gas. During the course of this investigation, the wholesale price has more than tripled. Due to the uncertainties associated with this price, it was decided to estimate only the cost of the manure conversion sequence as shown in Figure 3. The down-stream equipment needed to remove the CO_2 and synthesize the ammonia was not included in the costs. The estimated installed cost of the major equipment items and the economic criteria used in making the economic evaluations are listed in Tables IX and X (33, 34).

As the data in Table IX indicate, the total investment decreased substantially as the projected reactor pressure increases. Although this is consistent with logic, the influences of reactor pressure will be investigated in future studies to confirm these calculations.

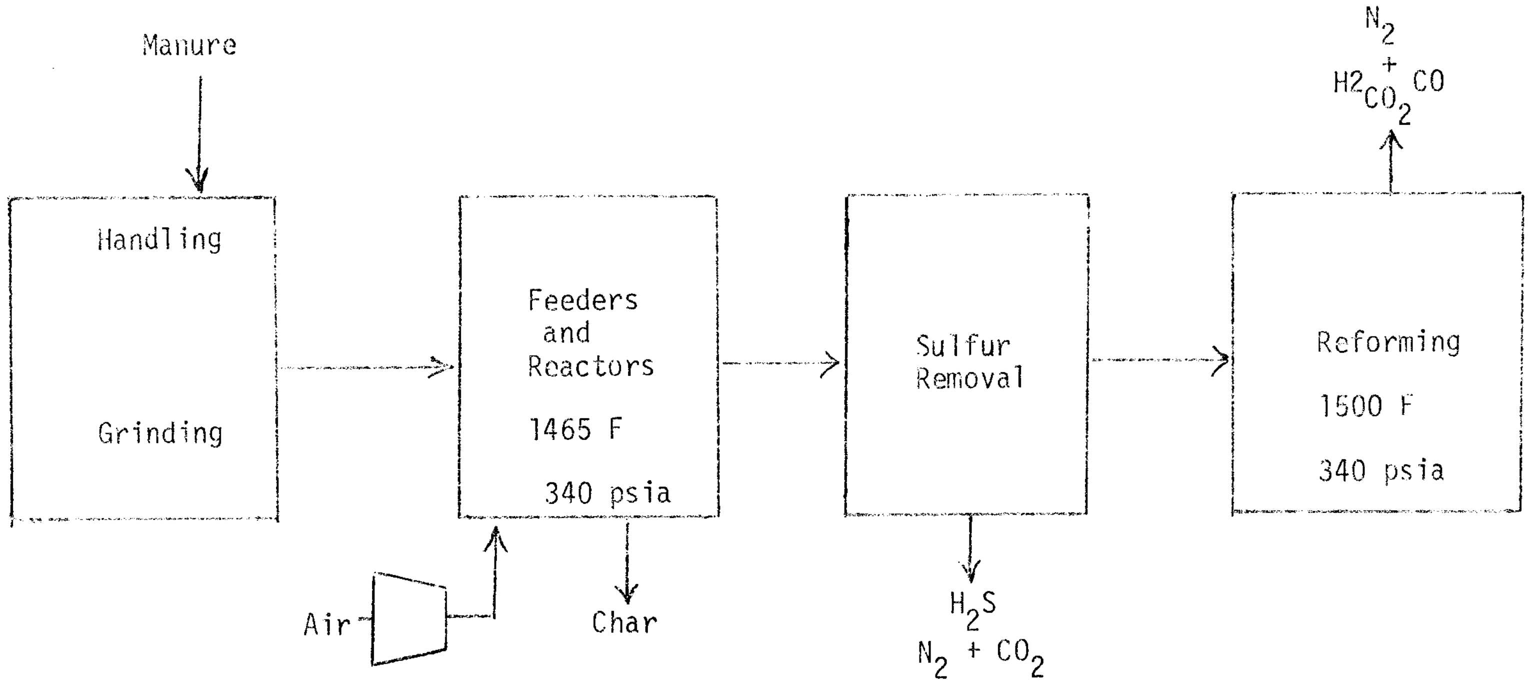


Figure 3 Process for
Synthetic Gas from Manure

TABLE IX

Installed Cost of Major Equipment

Operating Pressure (psia)	30	Percent of Total	100	Percent of Total	340	Percent of Total
Total Investment	$31,887,110		$22,523,940		$14,150,240	
Reactors and Feeder Section	4,942,500	15.5	5,405,740	24.0	6,013,850	42.5
Desulfurization and Reforming*	8.832,730	27.8	5,811,178	25.8	3,636,610	25.7
Compressors and Boilers	18,048,100	56.7	11,293,408	50.1	4,482,790	31.6
Operating Costs	4,446,120		3,286,190		2,592,580	

*Does not include catalysts.

TABLE X

Economic Criteria

Size (Tons/Day)	1000 (Tons Ammonia)
Project Life (Year)	20
Depreciation Schedule	11 Year Sum-of-Digits
Interest Rate (Year-End Discount)	10%, 14%
Income Tax	48%
Fixed Capital Investment	4.1 of Major Equipment Costs
Maintenance	4% of FCI/Year
Salvage	5% of FCI/
Supervision	20% of Labor
Labor	$5/Operating-Man Hour
Payroll	25% of Labor plus Supervision
Plant Overhead	50% of Labor
Working Capital	5% of FCI
Local Taxes	2% of FCI

The number of prime interest is the projected cost of synthesis gas production at a 340 psia operating pressure and a discounted cash flow rate of 14 percent on the capital investment. This value ranges from $11.80 per ton of ammonia produced if the manure is delivered to the plant size at zero cost. If it costs $3.00 per ton to have the manure delivered to the plant site, this value increases to $18.39 per ton of equivalent ammonia.

In conclusion, the technical and economic feasibility of manure to anhydrous ammonia conversion sequence are appealing on the basis obtained from small scale studies. The proposed process requires large numbers of cattle in a small area in order to justify a large plant while minimizing transportation costs (34).

Texas has a unique role to play in the development of animal waste resource recovery processes because it feeds approximately one-fourth of the nation's fed cattle and the state has a fully developed chemical processing industry. The consideration of processing options are unavailable to other parts of the country. The overall objective of the reserach program to convert these wastes to valuable resources is to improve the economic viability of these to important industries.

B. Pyrolysis of Municipal Solid Waste

There are several pyrolysis and partial oxidation processes for disposal of MSW (8, 35), but one of the most attractive for the State is the Garrett Reserach and Development Process (G R & D) for producing an oil product. (36). This process is attractive for Texas because, as noted previously, there are only a few coal-fired utility boilers in the state and a significant pipeline system exists within the State for transporting different liquid products. The process may be described as a true pyrolysis in that no oxygen is utilized in converting the MSW to oil or gas. Various feedstocks have been studied and an oil product can be produced from all; these feedstocks include MSW, tree bark, animal manure, agricultural wastes (rice hulls, grass, straw, etc.) and rubber tires. Thus, the process may be considered to be a general processing scheme for many solid wastes. G R & D has estimated that if an oil were produced from all of the above sources, 1.6 billion barrels of oil could be recovered which is approximately 27.6% of all the oil used for all purposes in the U.S. in 1971. A realistic recovery estimate in this case is approximately 20% or the equivalent of 320,000 million barrels of oil/year for the nation. Similar values should be expected Texas or even higher due to the concentration of agricultural industry. Most of G R & D's work has been directed towards MSW and this is discussed below.

A schematic diagram of this pyrolysis process is shown in Figure 4 (36); note that the entire process includes front-end processing with materials recovery. Also produced is the organic fraction of MSW which is dried (3% moisture) and ground to feed to the pyrolysis reactor (20 mesh, 5-10 lb/ft^3). From the reactor, gas, oil, and char products are obtained. All products could, of course, be sold, but it is expected that char and gas will be reused internally to supply heat for the endothermic pryolysis reaction. The char, if sold, could probably be used as an activated carbon for adsorption purposes. The key or new technology in the process is the reactor (26).

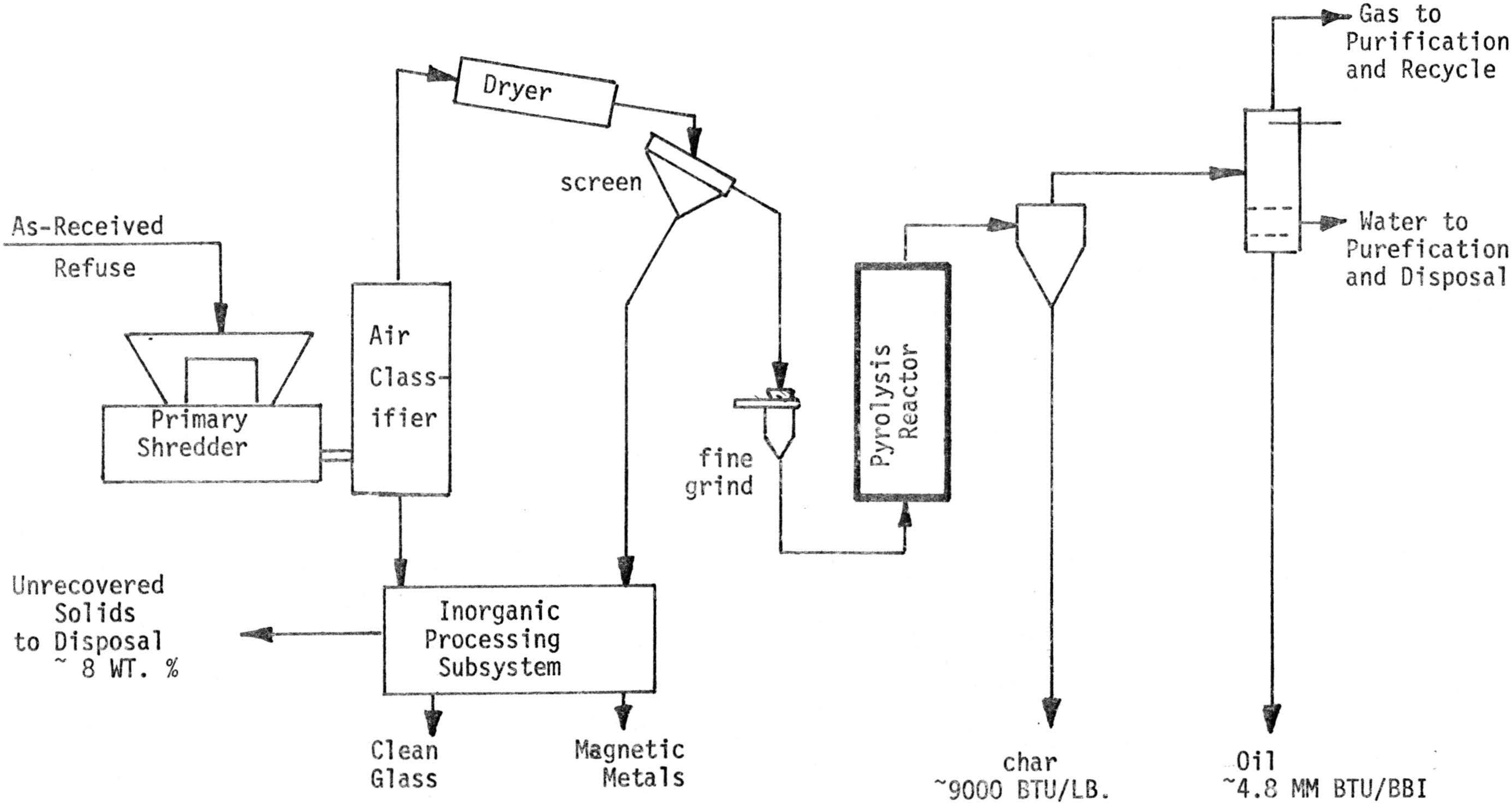


Figure 4 Process for Oil or Gas from Solid Waste (36)

In the reactor, small MSW particles are brought rapidly up to temperature by a proprietary heat exchange system. The particles then proceed through the reactor for reaction to the extent desired. Liquid products are obtained if reaction temperature is maintained at approximately 480°C (900°F) whereas gas-fuel is obtained by increasing reaction temperature to approximately 760°C (1400 °F). Little information is available on the reactor, but the design probably includes a residence time for the reaction between 3-10 seconds.

The basic development reactor module is a 30 foot high structure which will not be increased in size for large commercial units (26). Thus, assuming the reaction residence time and velocity must remain essentially constant to obtain a given product, it seems clear that multiple reactor units would be required for a 500-1000 ton per unit to prevent reactor diameter (pilot plant = 6 inches) from exceeding materials strength restrictions at the operating temperature (480-780°C).

Corrosion problems with MSW are thought to be minimal in this processing scheme because chlorides are converted to methyl chloride (B.P. = 40°C) which exits with the gaseous products. One potential process problem is in maintaining constant feed conditions (flow, pressure, solids content). Unless the reactor feed is maintained at precise conditions, heat transfer and, hence, reaction temperature and products, will be highly variable.

Data for accurate economic assessments and identification potential problems will become available after a 150 ton per day demonstration plant is built in San Diego, Calif. The cost of this plant is approximately 6.3 MM ($42,000/daily ton) which is high, but compares favorably to other full-scale processes; the economy of scale and firm design plans should reduce this cost to the expected range of $15,000-20,000/ daily ton for 500 ton per day plants or greater.

Tables XI and XII give typical properties for the pyrolytic gas and oil produced from this process (36). With a heat content of 770 Btu/ft^3, the gas may be considered a low Btu gas. The oil product, which has generated the most interest at this time, has been tested by an independent firm (Combustion Engineering) in pilot-scale laboratory experiments. The results indicated that the oil or blends with No. 6 fuel "can be successfully burned in a utility boiler". Ignition stability of the oil and its blends with No. 6 oil were equivalent to that for No. 6 oil alone. Stack emissions of unburned carbon were negigible when $\geq$ 2% excess oxygen was amintained.

This pyrolytic fuel oil does have two deficiencies with regard to materials handling and transportation. First of all, the oil is thermally unstable above 200°F and will polymerize if held at this temperature (high oxygen content suggests this behavior) for an extended time (1 day? 4 days?). The oil is also somewhat corrosive to mild steel at 200°F but no attack on 304 or 316 stainless steel has been noted. It should also be noted that the oil is not miscible with hydrocarbons (< 10% by weight) and 50% of the product cannot be distilled.

Of the product formed from various solid wastes, oil from grass straw and rice hulls was equivalent to that of the MSW; oil from tree bark also appears to be comparable; and oil from cow manure has approximately 10% lower oxygen content and 1000 Btu/lb higher calorific

TABLE XI

COMPOSITION OF GAS PRODUCED BY PYROLYSIS OF MSW (36)

Component	% by Volume
H_2	16.7
CH_4	15.4
CO	17.9
CO_2	23.1
C_2 hydrocarbons	22.2
C_3-C_7 hydrocarbons	4.7
Calorific value (calc.)	770 Btu/ft^3

Note: The MSW processed was dry and free of inorganics.

TABLE XII

TYPICAL PROPERTIES OF PYROLYTIC OIL (36)

	No. 6 Fuel Oil	Pyrolytic Oil
Carbon, wt.%	85.7	57.5
Hydrogen	10.5	7.6
Sulfur	0.5 - 3.5	0.1 - 0.3
Chlorine	-	0.3
Ash	< 0.5	0.2 - 0.4
Nitrogen Oxygen	) 2.0)	0.9 33.4
Btu/pound	18,200	10,500
Sp.Gr.	0.98	1.30
Lb/gallon	8.18	10.85
Btu/gallon	148,840	113,910
Pour point °F	65 - 85	65 - 90
Flash point °F	150	133
Viscosity SSU @ 190°F	90 - 250	1,000
Pumping temperature °F	115	160
Atomization temperature °F	220	240

value. Nitrogen content of the manure oil was 5-7% by weight, and NO_x emissions are expected to be high.

In summary, this pyrolytic process would appear to be adaptable to a wide range of solid wastes. When combined with the partial oxidation process discussed previously, this technology would appear to be an attractive alternative to combustion for the State.

Biochemical Processing

Biochemical processing or the utilization of microorganisms is another alternative for energy recovery from solid waste. Two basic schemes exist: one to produce an edible protein (39) and one to produce a methane gas (40,41). The latter process utilizes known technology of anerobic digestion and will not be discussed further, except for economics.

For methane generation, the direct cost of digestion has been estimated at $4.75 per MM Btu (40). At this cost, digestion does not appear to be competative with other processes. A major portion of this cost is gas purification. Elimination of this cost may make digestion economical. One way to eliminate the cost of purification is to utilize an existing purification plant such as a CO_2 manufacturer. Such an arrangement has been proposed in Chicago, Ill., to possibly yield a competitive gas at $1.50/MM Btu (41).

For production of proteins, the LSU process (9, 39) appears to have been developed to the highest degree; however, this process is still in the first pilot plant stage. One of the keys to this technology is pre-treatment of the cellulosic solid wastes with alkali. The alkali apparently exposes the cellulose substrate to attack by the microorganism. Projected cost of this product is $0.14-0.20 per pound protein which is similar to that for soybean protein (1970 costs; 39). These costs are the projected values for sugar cane bagasse, but not information is yet available on municipal solid wastes. The process for MSW would appear to be attractive enough to warrent the financial support a major engineering firm (42). A process utilizing mesquite wood for production of a cattle feed has been proposed for Texas (43).

In general, we conclude that biochemical processing for energy recovery has not been developed to the degree necessary for serious consideration at this time. The various schemes do, however, offer some attractive alternatives which may prove fruitful within the next ten-fifteen years.

ECONOMICS OF ENERGY RECOVERY FROM SOLID WASTE

Most of the cited economic evaluations cited in the preceding material agree generally with the cost analysis proposed by Abert, et al., (15). This article also proposes a simplified accounting method which should be useful in making a cost analysis of a specific process for a given locality. For these reasons this article is included in Appendix V.

In their article, Abert, et al., (15) estimate that materials recovery alone will require a dump fee of approximately \$8/ton for a relatively small 500 ton per day plant. This dump fee is the net charge to a community and is that cost required to provide a 15% operating profit to a private enterprise and retire capital investments debts (20 years buildings; 7 years equipment at 8% simple interest). This value should be compared to the maximum \$8.66/ton value cited in Table VII. For energy recovery alone, the estimated dump fee would be \$7.56/ton (Figure 5, Appendix V; Add \$562,000 + \$618,000 and divide by 156,000 ton). This value is between the \$4-5/ton for the St. Louis project and the \$11/ton estimated for the RESCO North Shore Facility cited previously. The differences reflect differences in volume, assumed selling prices, and location.

The investment cost cited by Abert, et al., of approximately \$2.5 MM for a 500 ton per day plant would appear to be low compared to current commercial estimates of \$15,000-\$20,000 per daily ton at the 1000-4000 ton per day level (8, 26, 7), i.e., \$15,000 per ton per day times 500 ton per day = \$7,500,000 capital investment. Another consideration is volume. The proposed St. Louis project by Union Electric has an estimated capital investment of \$70,000,000/8000 daily ton = \$8750/daily ton (10). This single project is equivalent to 20% of the total MSW realistically available within the entire State of Texas. These differences must be kept in mind while reviewing the article and the estimates given below.

Recognizing the danger in projecting costs, one may project that the net dump charge to a municipality for a combined energy and materials recovery plant will be \$4-6 per ton for 500 to 3000 ton per day plants due to the availability and cost of both energy and materials. Such a value is consistent with the St. Louis project (15) and the materials recovery plant currently proposed by Garrett Reserach and Development (26) and would probably be approached by the North Shore Facility (7) if materials recovery were included.

If so, this \$4-6 per ton is a small incremental cost for disposal of solid wastes. For example, the cost to a typical family of four in Texas would only be \$9-13 per year above their normal collection bill. This value was calculated assuming 60% of the MSW generated is residential, i.e., (0.6) (4.8) = 3.0 lb/person-day = 0.55 ton per person year; 4 x 0.55 x \$4 = \$8.80/per year; 4 x 0.55 x \$6 = \$13.20 per year; or \$0.75-\$1.10 per month. The cost to commercial establishments would be pro-rated depending upon volume. It should be noted that many cities do <u>not</u> pro-rate commercial users. Instead, collection-disposal costs are charged on a customer or per stop basis.

The investment is such facilities can be significant. Assuming the realistic energy potential for Texas to be as estimated, 1.4×10^{14} Btu/yr for 1985, the projected capital investment rates from \$575 MM to \$1,207 MM depending upon the rate of inflation and volume; these calculations are as follows:

$$\frac{1.4 \times 10^{14}\ \text{BTU}}{\text{YR}} \left| \frac{\text{year}}{365\ \text{day}} \right| \frac{\text{lb}}{5000\ \text{BTU}} \left| \frac{\text{ton}}{2000\ \text{lb}} \right.$$

= 38,356 ton per day

@ $15,000/daily ton, Investment = 38,356 x 15,000

= $575 MM

@ $20,000/daily ton, Investment = $767 MM

@ 7% inflation, $15,000/daily ton; $(1.07)^{11} = 2.104$

or 15,000 x 2,104 = $31,560/daily ton

Investment = $1,207 MM

More detailed estimates could, of course, be made but such cost projections do not seem warrented at this time. It is clear, however, that the Texas should be prepared to invest approximately 3/4 of a billion dollars, if energy from solid waste is considered to be a worthy goal. We conclude that such investment is justified to help make the State and Nation self-sufficient and solve our solid waste disposal problems. The incremental cost to a Texan family, as indicated above, is small enough to not penalize any social-economic group. Since solid waste generation rates can be correlated with income or level of economic development (6, 23), such incremental costs could also be pro-rated to residences to reduce the impact on the lower income groups.

LEGAL PROBLEMS AND LEGISLATIVE REQUIREMENTS

To assist in determining operational problems in the solid waste disposal area, comments have been solicited from leading resource recovery system designers and marketers such as Browning-Ferris Industries, Dow, Allis-Chalmers, Combustion Engineering Associates, and the Resource Recovery Division of the Environmental Protection Agency. The most frequent comment has been that before significant resource recovery ventures can be organized, the current laws will have to be enforced. The fact that more than 70 percent of the landfills have not been in compliance is evidenced by the Texas State Department of Health survey shown in Table XIII. Several sources suggested that as long as the state does not enforce the law in this area there will be little incentive to develop improved resource recovery procedures.

Resource recovery center operators would also have minor problems in complying with "Municipal Solid Wastes Rules, Standards, and Regulations" published by the Texas State Board of Health. In particular articles D-1.6 which indicates that MSW may not be stored more that 24 hours awaiting processing and D-21.b which requires that the plant stop receiving MSW if a mechanical breakdown occurs should be revised. We conclude that these articles may be unnecessarily restrictive, especially when current technology is considered. For example, the RESCO North Shore Facility being constructed at Saugus, Mass., has storage capacity of 2.3 days for steam generation in an incinerator. The process is consistent with proven European technology (13).

A final question in this area concerns the establishment of a resource structure within Texas. We conclude that such an organization is needed

TABLE XIII

Texas State Department of Health

Status - Solid Waste Disposal Sites in Texas

May 1, 1973

I. Status of Sites as to Category and Compliance with State Rules and Regulations:

Category	Compliance	Non-Compliance	Undetermined	Total
A. I	175	584	7	766
B. II	11	23		34
C. III	12	44		56
D. IV	69	87	1	157
TOTAL	267	738	8	1,013

II. Number of Identified Sites by Type of Operation

A. Type I	-	251
B. Type II	-	42
C. Type III	-	42
D. Type IV	-	271
E. Dump	-	398
F. Undetermined	-	9
TOTAL		1,013

III. Status of Solid Waste Disposal Site Inspections:

A. Sites inspected May 72 - Apirl 73 - 423

B. Sites inspected May 71 - April 72 - 433

C. Sites not inspected since 1969 - 251

for the guidelines stated in establishing a Resource Recovery Authority (RRA) in Connecticut (37). Specifically, a knowledgeable branch of the government is needed because resource recovery

a. relies on sales of product on the open market for revenue; thus, skills are needed to insure that these markets do indeed exist before a venture is contracted at the local level.

b. uses sophisticated technology that is rapidly evolving; thus, a central pool of technical expertise is required to assist a local government in selecting a process and/or operating an efficient process to reduce direct engineering costs.

c. is highly capital intensive; thus, significant state matching funds will be required and, to be spent wisely, these funds must be obtained at the lowest cost and managed by knowledgeable individuals.

d. requires rapid decisions and involves significant regulation to meet environmental standards; thus, skilled personnel must be available to local governments to assist in achieving needed economic solutions to solid waste disposal problems and insuring all environmental standards are met. Quick action may be needed when existing facilities are shut-down for non-compliance reasons and existing departments may not have the flexible capability needed (37).

In addition, it should be noted that some private companies will not submit a proposal unless the markets, financing, and necessary decision authority already exist. This attitude has been adopted because many localities were requesting proposals without any real knowledge of the business other than "it sure would be nice to sell our garbage".

The Connecticut RRA employs a staff of 30 for general administration and planning. It has authority to borrow by issuing bonds and notes (with approval of the State Treasurer), to charge fees for services, to receive revenue from any source, and to make loans to municipalities and is exempt from taxes. The RRA may also select locations, select types of projects, acquire land, design projects, own and operate projects (this is generally contracted to a private firm), and sell any or part of a project. The relationship with local municipalities is largely by contractural arrangements. Finally the Connecticut RRA also has authorization to issue contracts for designs, construction, and management of resource recovery projects (37).

Thus, the Connecticut RRA essentially has control over all resource recovery within the State. This is certainly feasible within a small state with similar geographic restrictions. Within Texas, it may, however, be desirable to establish a regional authorities to provide regional expertise for the diverse geographic and needs within the State. At the very least, we suspect that a division for rural and urban areas will be needed.

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APPENDIX I

1. Statement, by James E. Halligan, January 4, 1974

2. Approved Project

STATEMENT TO THE PROGRAM COMMITTEE ON NEW TECHNOLOGY

OF THE GOVERNOR'S ENERGY ADVISORY COUNCIL

A. E. Dukler, Chairman

Prepared by

James E. Halligan

Texas Tech University
Lubbock, Texas

January 4, 1974

Chairman Dukler and Members of the Committee: Thank you for providing me with the opportunity to appear before you to present my views concerning solid waste use for energy generation and conservation.

The recent drastic change in the price of energy from approximately \$0.15 to \$1.00 per million BTU's present both a challenge and an opportunity to our society. In the past, many processes to recycle a portion of, or to recover the energy from solid wastes have met with limited financial success due in part to the artificially low price for energy. Although it is generally recognized that it is highly desirable to increase the fraction of our nation's resources that are recycled, at the outset that we must recognize that this is a difficult problem which will require considerable time and patience to solve. However, in order to avert a future crisis concerning the availability of virgin resources or the disposal of mountains of garbage, we must begin now to efficiently utilize this presently wasted resource.

SOLID WASTE GENERATION RATES

I. AGRICULTURAL; U.S.A. - 2 BILLION TONS ANNUALLY
RELATIVELY DIFFUSE - HOMOGENEOUS

3 MILLION TONS OF CATTLE FEEDLOT MANURE PRODUCED ANNUALLY ON THE HIGH PLAINS OF TEXAS
CALORIC VALUE - 6,000 BTU/LB

II. MUNICIPAL-INDUSTRIAL - 0.36 BILLION TONS ANNUALLY
RELATIVELY LOCALIZED - HETEROGENEOUS

800,000 TONS PER YEAR COLLECTED IN DALLAS
4.8 LBS/PERSON-DAY; CALORIC VALUE - 4000 BTU/LB

SOLID WASTE PROBLEMS AND POTENTIALS

PARIS GENERATES 30% OF ITS ELECTRICAL POWER BY INCINERATING GARBAGE.

THE AI & SI ESTIMATES THAT $4.5 BILLION SPENT TO BURY $5 BILLION WORTH OF METALS.

METAL CANS MAKE UP APPROXIMATELY 5% OF THE SOLID WASTE. MAGNETIC SEPARATION WILL INCREASE LAND FILL LIFE BY 25%.

ONE IN FOUR DISPOSAL SITES IN THE STATE OF TEXAS ARE CURRENTLY IN COMPLIANCE WITH STATE REGULATIONS. ENERGY RECOVERY WOULD REDUCE THIS HAZARD AS WELL AS THE LAND FILL REQUIREMENTS.

The products which are classified as solid wastes cover a spectrum of materials but they originate as a result of two distinctly different types of activities, namely, those associated with agriculture and those associated with municipal-industrial activities. In terms of tons produced, the national yearly production rate of solid wastes in the cities is approximately 0.36 billion tons while that produced as a result of agricultural operations amounts to over 2 billion tons.

When viewed as a resource, each of these general types of waste feedstocks have some unique advantages. Our research group at Texas Tech has had an on-going research project to develop useful products from cattle feedlot manure for many years. Research supported by the Pioneer Natural Gas Company, The Texas Cattle Feeders Association, and the Environmental Protection Agency has demonstrated the small-scale feasibility of using feedlot manure as a carbon and energy source to produce anhydrous ammonia. These firms provided initial support, and have been sufficiently confident of the first phase results to invest additional funds to support a second phase study at a larger scale. Future plans call for a tons-per-day plant to be built within the next two years and we remain optimistic concerning the success of this project.

It is the opinion of our research group that our results are applicable to a variety of agricultural solid wastes and that many of these wastes can be used as carbon and energy sources to produce synthesis gas, a basic building material in the petrochemical industry. With this in mind, our group has initiated studies to determine the reaction products when sawdust is fed to our reactor system. The eventual research objective is to

RESOURCE RECOVERY PROCESSES

Petrochemical Feedstocks

1. Anhydrous ammonia from cattle feedlot manure
2. Fuel oil from municipal solid wastes

Power Generation

1. Steam from incineration
2. Power gas from pyrolysis

Material Recovery

1. Ferrous materials by magnetic separation
2. Fibrous materials by skimming

conduct similar investigations for many of the large-scale agricultural wastes found in Texas.

When considering agricultural wastes, there is one central problem that comes to mind: that the sources of possible waste feedstock are frequently small and dispersed. However, the scale and concentration of agricultural operations in Texas is constantly increasing, and this tends to ameloriate this problem. Our calculations indicate that in the Hereford-Dimmitt area of Texas the feedlots within a circle of radius fifteen miles could support a conventionally sized ammonia plant. If the manure-to-synthesis gas technology were well established, this would probably accentuate a further concentration of the cattle feedlot industry due to the availability of an economically appealing solid-waste disposal technique.

Unlike those within the agricultural sector, the solid wastes generated by the municipal-industrial sector of our society have one very undesirable trait, heterogeneity. However, thse materials should still be viewed as a wasted resource within our society. Some obvious side benefits to a resource recovery program are the recycle of valuable metals, reduced landfill requirements, and minimization of health problems. This latter point can be underscored by noting that in a recent survey only about one in every four disposal sites in Texas was in compliance with State regulations. With regard to the recycle of metals, making 1,000 tons of steel reinforcing bars from scrap instead of from virgin ore takes 74 percent less energy and 51 percent less water, creates 86 percent less air pollution emissions, and generates 97 percent less mining wastes.

ANHYDROUS AMMONIA PRODUCTION

1. SMALL SCALE REACTOR SYSTEM OPERATED AT TEXAS TECH
2. SIGNIFICANT EXTERNAL REVIEW AND SUPPORT
3. THERMALLY-BALANCED, CONVENTIONALLY-SIZED PLANT CAN BE OPERATED IN SEVERAL LOCATIONS IN TEXAS
4. LARGER SCALE REACTOR SYSTEM BEING CONSTRUCTED

OIL PRODUCTION FROM MSW

1. 200 TON PER DAY DEMONSTRATION PLANT SCHEDULED TO BE OPERATIONAL BY NOVEMBER, 1974

2. PROJECTED YIELDS PER TON OF REFUSE:
   1 BARREL OF FUEL OIL (2/3 H.V. OF #6 F.O.)
   140 LBS OF FERROUS METALS
   120 LBS OF GLASS

3. PROJECTED NET COSTS - $6 PER TON
   $4 MM INVESTMENT FOR A 200 T/D PLANT

In the final analysis however, the best way to insure that efficient solid waste resource recovery procedures are implemented is to make them economically attractive. Previous process development experience also suggests that any good process will exploit some local advantage. With this in mind, the process of the Garrett Research and Development Corporation being developed with the help of an Environmental Protection Agency grant at El Cajon, California, which converts municipal solid waste to oil, assumes particular importance. This process is designed to produce approximately 250 pounds of oil, 140 pounds of ferrous metal, and 120 pounds of glass from one ton of refuse. Present plans call for a tons-per-day demonstration plant to be built in the near future.

Due to the importance of the petrochemical industry to the local economy, I feel that the State of Texas should carefully monitor this project with the objective of transferring this technology to a suitable Texas location as soon as the feasibility is reasonably assured. It should be anticipated that some modifications may be needed to adapt this process to the local situation.

There is another encouraging process development with respect to the utilization of the energy contained in solid wastes, namely, the St. Louis incinerator project. As many of the committee may know, the Europeans have been producing power by incinerating municipal solid waste for some time. The city of Paris generates 30 percent of its electrical requirements by this method. A recent conversation with Mr. Robert Lowe of the EPA indicates that they are very optimistic concerning the future applicability of this

POWER GENERATION FROM MSW

1. St. Louis demonstration in second phase. 20% of boiler heat load being supplied by MSW (150 tons per day). Each ton of refuse generates about 1000 kilowatt hours of electricity.
2. Metals being recovered by magnetic separation.
3. Gross operating costs are $8 - $11 per ton of MSW.

POWER GAS FROM PYROLYSIS

1. BALTIMORE, MD. 1000 TON PER DAY PYROLYSIS OF MSW TO FUEL GAS DEMONSTRATION BEING CONSTRUCTED.

2. ROTARY KILN - OFF THE SHELF TECHNOLOGY. $6.15 PER TON NET COST (STEAM, GLASS, METAL CREDITED).
   $16 MM INVESTMENT FOR A 1000 T/D PLANT.

3. METALS RECOVERED BY MAGNETIC SEPARATION.

process to other locations. Engineering representatives from 30 cities have visited St. Louis to review the project to date. Current gross operating costs are quite high, \$8 - \$11 per ton of MSW processed, but these costs will be reduced by credits for the BTU's conserved and for the magnetic separations product reclaimed. This latter product is currently being sold for about \$20 per ton and comprises approximately 6 percent of the MSW fed. These data indicate that although the process presently has some economic drawbacks, it has sufficient potential that the State of Texas should carefully monitor the project and provide technical reports to interested parties within the state.

Finally, under EPA sponsorship, Monsanto's Envirochem Division is building a 1,000 ton per day pyrolysis unit in Baltimore, Maryland. This unit involves little new technology and is being constructed with equipment normally found in the petrochemical industry. The pyrolysis gas is fed to an afterburner with the hot gases exiting through a waste heat boiler to produce steam. Net costs are still quite high, \$6.15 per ton processed, but the process contains few technological uncertainties. No special nozzles or ash handling modifications are required in the boiler.

In summary, I would like to recommend to this committee that it support a serious review of current United States and European technology with respect to resource recovery from solid wastes. The objective of this review would be to provide a current, independent technological assessment as well as to recommend appropriate processes and locations

COMMENTS

1. TRULY SOPHISTICATED RESOURCE RECOVERY PROCESSES WILL ALWAYS BE DESIGNED TO EXPLOIT LOCATIONAL ADVANTAGES.

2. TEXAS HAS A LARGE PETROCHEMICAL INDUSTRY AND A MASSIVE NETWORK OF PIPELINES. THOSE PROCESSES WHICH WOULD PRODUCE PRODUCTS CONSISTENT WITH THIS INDUSTRY WOULD BENEFIT FROM A LOCATIONAL ADVANTAGE.

RECOMMENDATIONS

1. Support a serious review of current U.S. and European technology with respect to solid waste resource recovery.

2. Determine sites in Texas which would have unique locational advantages.

3. Special effort to transfer technology associated with conversion to petrochemical feedstocks.

within Texas for implementation and evaluation. In addition, the petrochemical industry is so central to the economic welfare of the State of Texas that I feel that an on-going review should be made of those processes which have the potential of converting agricultural and/or municipal-industrial solid wastes to petrochemical feedstocks. Most of these processes are still in the testing stages, but their importance is so great that they should be closely monitored and reported on to be certain that any local advantages, such as the existence of a large pipeline network, are fully exploited to the advantage of the people of Texas.

The statement I have prepared has been neither endorsed, denied, approved nor rejected by Texas Tech University. Indeed, while copies will be furnished to the Texas Tech University Administration, no member of the Administration has been asked for comments concerning the statement. This statement represents my views and, generally, the views of my colleagues who have been working with me on the problems associated with solid waste resource recovery at Texas Tech.

THE STATE OF TEXAS
GOVERNOR'S ENERGY ADVISORY COUNCIL

PROJECT N/T - 10

TITLE: POTENTIAL FOR SOLID WASTE USE AS AN ENERGY SOURCE IN TEXAS

BACKGROUND:

The municipal and agricultural wastes of Texas represent two significant resources which could help alleviate the energy shortage. These resources can be utilized for the production of process gases (methane, steam, etc.) or converted to petrochemical feedstocks (ammonia, ethylene, etc.). As an example of the availability of such wasted resources, three counties on the High Plains of Texas annually produce 1.2 million tons of cattle feedlot manure which contain the energy equivalent of the natural gas required to heat 120,000 homes annually. The solid refuse produced by a family of four Texans (4 tons per year) has the potential of supplying 33% of the household's annual heating requirements supplied by the natural gas system.

In light of the current and projected energy deficiency, a serious study should therefore be made to

1. assess the technology of solid waste conversion processes for energy generation or petrochemical feedstock production and

2. determine those locations in Texas where such conservation processes would be feasible in terms of local supply and energy needs.

Significant energy conservation could also result from magnetic separations of some of the metal contained in municipal solid waste, e.g., production of steel reinforcing bar from scrap instead of virgin ore requires 75 percent less energy. The American Iron and Steel Institute estimates that $4.5 billion a year is spent to dispose of garbage containing $5 billion worth of reusable metals. An additional benefit of a program to utilize the energy in solid wastes would be a significant reduction in both the pollution potential and volume of the waste. This would minimize sanitary landfill requirements and other disposal problems.

SCOPE OF WORK:

I. a. Summarize municipal and agricultural solid waste production rates and classify waste types for SMSA's in Texas. Choose key locations for further analysis. Published data are to be utilized.

b. Critique waste conversion processes on a national basis and assess technology for application to Texas municipalities. Evaluate various processes for combined agricultural and municipal wastes in areas with a low population density. Some possible waste combinations to be considered are:

1. Municipal waste-sewage sludge-waste polymer (Gulf Coast)
2. Municipal waste-cotton gin trash (South Texas)
3. Municipal waste-feedlot manure (West Texas)
4. Municipal waste-sewage sludge (Metropolitan Areas)

II. Estimate energy recovery and economics for representative locations and processes.

III. Recommend key locations and processes for more detailed economic analysis. Assess research and development needs for more efficient or novel processes which would apply specifically to problems within Texas

INVESTIGATOR:

Dr. James E. Halligan
Texas Tech University

Appendix II

Calculations of Energy Potential from Solid Waste for Texas

APPENDIX II

The calculations given below show how the potential of energy from solid waste in Texas was estimated.

A. Municipal Solid Waste Calculations

1. Data

   (a) State and national surveys indicate a typical Texan will generate 4.8 pound, solid waste per day.

   (b) Energy content of solid waste = 5000 BTU per pound, on the average, as received.

   (c) State population = 11, 196, 730 (1970 census)

   (d) One Barrel Oil = 5.6×10^6 BTU

   (e) Population growth in Texas = 3%

2. Maximum Estimate

   (a) Current estimate (1970 Census) - 80% Recovery Assumed

$$\frac{11{,}196{,}730 \text{ people}}{} \left| \frac{4.8 \text{ lb}}{\text{person day}} \right| \frac{5000 \text{ BTU}}{\text{lb}} \left| \frac{0.8 \text{ recovery}}{} \right.$$

= 2.15×10^{11} BTU/DAY

= 38,393 BBL OIL/DAY EQUIVALENT

= 7.85×10^{13} BTU/YR

= 14.1×10^6 BBL OIL/YR EQUIVALENT

   (b) Year 1985 estimate made by multiplying above values by $(1.03)^{15} = 1.56$

   (c) Year 2000 estimate made by multiplying above values by $(1.03)^{30} = 2.43$

3. Realistic Estimates

(a) Data

(1) Only metro-centers with populations greater than 150,000 can support economical resource recovery centers. Nine such centers exist in Texas with a current population of 4.25×10^6 people (38% of total).

(2) Earliest operational date for a center is estimated to be in mid-1978. Assume two such centers are available then and one per year afterwards. Total centers by 1985 = 9 or full capacity

(3) Year 2000 estimated capacity is increased to match population growth and assuming that 3 additional centers can be formed, e.g., Amarillo.

(b) $\dfrac{4.25 \times 10^6 \text{ people}}{} \left| \dfrac{4.8 \text{ lb/per}}{\text{person day}} \right| \dfrac{5000 \text{ BTU}}{\text{lb}} \left| \dfrac{0.8 \text{ recovery}}{} \right| \dfrac{1.56 \text{ growth by 1985}}{}$

$= 1.273 \times 10^{11}$ BTU/DAY

= 22,651 BBL/DAY

$= 4.646 \times 10^{13}$ BTU/YR

$= 8.267 \times 10^6$ BBL/YR

(c) Year 2000

$$\frac{4.646\times10^{13}\text{BTU}}{\text{YR}} \left| \frac{2.43}{1.56} \right. + \frac{3 \text{ centers}}{} \left| \frac{0.15\times10^6 \text{population}}{4.25\times10^6} \right| \frac{4.646\times10^{13}}{1.56}$$

$= 7.237 \times 10^{13} + 0.315 \times 10^{13}$ BTU/YR

B. Agricultrual Solid Waste

1. Data

(a) Actual cattle is estimated to 2.5×10^6; Generation rate = 8lb/cow day

(b) Manure = 6250 BTU/lb

(c) National estimates indicate ASW is 4 times MSW. Use a factor of 2 for the estimate of non-cattle waste in the absence of other data.

2. Maximum Estimate

(a) Current

$$\frac{2.5 \times 10^6 \text{ cows}}{} \left| \frac{8 \text{ lb.}}{\text{cow day}} \right| \frac{6250 \text{ BTU}}{} \left| \frac{0.8 \text{ recovery}}{} \right.$$

$$+ \frac{2, \text{ factor}}{} \left| \frac{2.15 \times 10^{11} \text{ BTU from population}}{\text{DAY}} \right.$$

$$= 1.010 \times 10^{11} \text{ BTU/DAY} + 4.3 \times 10^{11} \frac{\text{BTU}}{\text{DAY}}$$

$$= 5.3 \times 10^{11} \text{ BTU/DAY}$$

$$= 94{,}306 \text{ BBL/DAY}$$

$$= 193{,}450 \times 10^{13} \text{ BTU/YR}$$

$$= 34.42 \times 10^6 \text{ BBL/YR}$$

C. Industrial Waste

1. Data

(a) Assume 2 centers, e.g., Houston and Beaumont-Port Arthur area, with population equivalents of 150,000

(b) Assume normal growth per population

2. Maximum and Realistic Estimates

(a) Current

$$\frac{300{,}000}{11{,}196{,}730} \left| \frac{7.85 \times 10^{13}}{} \right. = 0.210 \times 10^{13} \text{ BTU/YR}$$

(b) 1985 and 2000 estimates were made using the population ratio.

D. Electrical Power Equipment

1. Data

(a) Approximate Electrical power consumption in January-February, 1974 = 8×10^9 kwhr/month

(b) 2.93×10^{-4} kwhr/BTU

$$\frac{8\times10^{9}\ \text{kwhr}}{\text{month}}\ \Big|\ \frac{\text{month}}{30\ \text{day}}\ \Big|\ \frac{\text{BTU}}{2.93\times10^{-4}\ \text{kwhr}}\ \Big|\ \frac{\text{BTU Input}}{0.4\text{BTU Output}}$$

= 2.275×10^{12} BTU consumed/day

2. Calculation of Maximum Potential

MSW + ASW in 1974 = $2.15 \times 10^{11} + 5.30 \times 10^{11} = 7.45 \times 10^{11}$ BTU/day maximum

MSW + ASW, % Electrical

$$= \frac{0.745\ \big|\ 100\%}{\big|\ 2.275}$$

= 32.75% maximum

3. Calculation of Manure plus 9-Metro Centers

MSW + ASW in 1974 = $1.273 \times 10^{11} + 1.248 \times 10^{11} = 2.521 \times 10^{11}$ BTU/DAY

$$= \frac{0.2521\ \big|\ 100\%}{\big|\ 2.275}$$

= 11.08% existing ASW-MSW

APPENDIX III

CORROSION POTENTIAL IN UTILITY BOILERS FIRING A MIXTURE OF FOSSIL FUEL AND MUNICIPAL SOLID WASTE AND RECOMMENDED INVESTIGATIONS

CORROSION POTENTIAL IN UTILITY BOILERS FIRING A MIXTURE OF FOSSIL FUEL AND MUNICIPAL SOLID WASTE AND RECOMMENDED INVESTIGATIONS

An Interim Report

by

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CORROSION POTENTIAL IN UTILITY BOILERS FIRING A MIXTURE OF FOSSIL FUEL AND MUNICIPAL SOLID WASTE AND RECOMMENDED INVESTIGATIONS

Preface

The discussion given below relates, briefly, the preliminary conclusions and recommendations that Drs. J. E. Halligan and W. J. Huffman have reached while assessing the technology of municipal solid waste (MSW) processes for the Governor's Energy Advisory Council of Texas. The views expressed are not necessarily those of the Council and have not been approved, denied, or reviewed by any other members of the Council.

The authors of this paper request that this discussion be held confidential until their final report to the Council has been approved, probably in October 1974. As such, this report should be considered an interim report on the corrosion potential for mixed, fossil fuel/MSW utility boilers. The report is not a research proposal, but does contain our current recommendations on studies that will probably be needed to establish a data base for formulating possible solutions or operating techniques.

Utilization of MSW In Utility Boilers

Resource recovery systems involving MSW have received much attention in the past few years due to limited space for sanitary landfills, air pollution restrictions on municipal incinerators, and the increasing volume of solid waste. The utilization of MSW as a supplemental fuel in utility boilers is one of the resource recovery processes which has become highly visible since the energy crisis of 1973 and the projected deficiency in the United States energy supply.

The supplemental fuel concept has been proven by the demonstration project supported by the Union Electric Company of St. Louis. MSW as a supplemental fuel is especially attractive because such a process appears to have the lowest capital investment and operating cost per ton of all resource recovery processes proposed for MSW. The process may even be less expensive than sanitary landfills for those locations which generate solid waste equivalent to a population of 400,000, based upon projections by the Midwest Research Institute. For these reasons and because fuel recovery was the best short-term process for disposal of MSW (1), a resource program utilizing MSW as a supplemental fuel has been initiated for the State of Connecticut (initial boiler is coal-fired); RFP's are being reviewed for an oil-fired boiler in Monroe County, New York (2). In addition, the Union Electric Company has decided to build a $70MM system (3). We conclude, therefore, that supplemental MSW fuel processes will become an integral part of utility operations over the next ten years.

Potential For Boiler Tube Corrosion

There appears to be a high potential for corrosion of boiler tubes when firing a mixed feed of MSW and coal in utility boilers because the relative concentration of compounds containing both sulfur and chlorine may be higher than that generated when either of the two fuels are fired alone. These effects are, however, largely unknown because of limited experience in the United States and conflicting reports on European practice (1, 4, 5, 6).

In the U.S., the most visible experience has been with the Combustion Engineering reheat boiler currently being used at the St. Louis project (3). To date, no corrosion problems have been encountered and the demonstration tends to minimize any concern about corrosion. The Union Electric Co. is conducting corrosion probe tests but the results have not been evaluated at the time of this writing (6).

On the basis of our site visit, there are, however, two important factors which must be considered in assessing the corrosion potential: the boiler itself and current combustion of MSW. The boiler is an older, oversized unit with significant over-design in tube-wall thickness. The current demonstration has not achieved full energy conversion of the MSW as evidenced by large volumes of unburned material at the ash disposal site (6). Thus, although the demonstration is clearly encouraging from the standpoint of processing MSW, it does not necessarily define the true corrosion potential because 1.) the boiler tubes may be sufficiently thick to permit extended operation before corrosion effects are noted and 2.) volatilization of chloride and sulfate salts may be incomplete due to the low temperature the MSW actually encounters or achieves. We tentatively conclude that modern, optimized boilers firing pulverized MSW may be more susceptible to corrosion than current results of the demonstration indicate.

There are conflicting reports on the seriousness of corrosion in European water-wall incinerators (4, 5), but it seems clear that severe metal wastage has been observed which is largely unpredictable and unexplained. The reports also suggest the caution that must be practiced when utilizing MSW in a boiler. The most detailed study by Miller, et. al. (5) recommends that MSW incinerators "not be used to generate high-temperature, super-heated steam" even though the practice is not uncommon in Europe. As indicated in the Miller report, the conflicting data may be due to the wide temperature range of operations in Europe (tube metal temperatures = 700-1100°F) as well as the "unbelieveably bad" (variable) combustion conditions that exist in the burning of raw, unshredded MSW per European practice. Thus, on the basis of incinerator experience, one may conclude that U.S. utilities should proceed with caution in the mixed firing of MSW for supplemental energy. Ony may also infer from the Miller report that MSW should only be used to generate 175 psig-375°F steam for use as a preheated feed to a fossil fuel boiler. Despite this evidence, a high temperature operation (flue gas = 1600-2000°F) is scheduled for one site in the United States; the unit will incorporate 100% excess air and corrosion problems are expected to be minimal on the basis of European experience with the design (7).

The mechanism of boiler tube corrosion is generally considered to involve the attack of sodium and potassium salts on boiler tubes whose action is accelerated by the presence of chlorine and sulfur (5, 8, 9). Some of the proposed reactions which illustrate the role of chlorine are:

$$2KCl + SO_2 + 1/2\ O_2 + H_2O \rightarrow K_2SO_4 + 2HCl$$

$$Fe + 2HCl \rightarrow FeCl_2 + H_2$$

$$2HCl + 1/2\ O_2 \rightarrow H_2O + Cl_2$$

$$Fe + Cl_2 \rightarrow FeCl_2$$

$$4FeCl_2 + 3O_2 \rightarrow 2Fe_2O_3 + 4Cl_2$$

$$K_2O + 2HCl \rightarrow 2KCl + H_2O$$

Regardless of the specific mechanism, the presence of sulfur and chlorine in the gas phase or flue gas have been shown to be key factors (8, 9). These effects have not yet been assessed in combined fossil-fuel/MSW boilers, but the effects must be considered because fossil fuels are generally high in sulfur but low in chlorine whereas MSW is high in chlorine and low in sulfur. Thus, the combined chlorine-sulfur concentration may be potentially higher than firing either fuel separately. Alternately, the rate limiting concentration may have a higher value when firing the mixed fuel.

Recommended Research

On the basis of the data discussed above, we have concluded that a serious study of the corrosion potential in fossil fuel boilers utilizing MSW should be undertaken. The study should include two major parts. One part should measure flue gas composition and metal wastage rates in a commercial boiler utilizing MSW to provide base-line data. A second part should involve small scale laboratory studies on the kinetics of formation of gaseous compounds containing chlorine and sulfur; a wide range of MSW-fossil fuel compositions and temperatures should be explored to obtain a data base established on the principles of reaction kinetics. This second part would provide the basic data for projecting the corrosion potential which might exist during boiler upsets, uneven firing of the MSW/fossil fuel mixture, and start-up/shut-down of the boiler as well as higher refuse loadings (BTU equivalents).

The base-line data on flue gas composition and metal wastage should be conducted on a joint basis with the Union Electric Company. Initial data from this full-scale test could be obtained within a relatively short time period if no changes were made in the current operation of the boiler and proven methods for isokinetic gas sampling were used. Preliminary metal wastage data could be obtained utilizing the techniques specified by Miller, et. al.(5). On the basis of these initial data, a more thorough investigation could then be developed. We anticipate that such an extended study would provide flue gas and metal wastage data as a function of the type of MSW fuel, e.g., two-three particle sizes and different compositions. Finally, in all cases, ash samples should be collected and burned completely to provide an indirect, but reliable, estimate of the MSW temperature actually achieved during firing.

The initial laboratory studies should not be done using a batch reactor as is normally done in such small scale studies. Instead, the study should combust the MSW/fossil fuel (initially coal + MSW) in a flow system which approximates a back-mixed vessel. Such a flow system would provide a reasonable approximation of a tangentially-fired boiler operating at a steady-state conditions. One such reactor of this type does exist in our laboratory and approximately two years of experience have been accumulated on the feeding of small volumes of various solids (∿ 1 lb/hr) into high temperature reactors.

We conclude that such studies, as outlined above, would provide a realistic data base for assessing the corrosion potential in utility boilers which fire a mixture of MSW/Coal. The results should aid designers in specifying materials of construction. In addition, the investigation would provide data within a short term (1-2 yrs) that could be used to determine the need for more fundamental data and/or MSW/oil data.

Added Comment

The studies outlined above should also consider the possibility of determining the presence or absence of known carcinogens such as bis(chloromethyl) ether (10). The presence of organic acids at concentrations ranging from 35-340 ppm has been detected from two incinerators (5) so the presence of reduced organics must be assumed until experimental data have established otherwise. Compounds such as the Bis(chloromethyl) ether may be harmful at concentrations in the ppb range. Hence, the projected need of a variance from air pollution restrictions for a MSW-boiler (6) may be difficult to obtain despite the apparent reduction in over-all pollution from MSW.

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APPENDIX IV

CENTRAL HEATING AND COOLING SERVICES PROJECT WITH SOLID WASTE FUELED PLANT

CENTRAL HEATING AND COOLING SERVICES PROJECT WITH SOLID WASTE FUELED PLANT

By Carl Avers

GENERAL MANAGER & CHIEF ENGINEER

NASHVILLE THERMAL TRANSFER CORPORATION

Nashville, TN.

IDHA Article

CENTRAL HEATING AND COOLING SERVICES PROJECT WITH SOLID WASTE FUELED PLANT

CARL E. AVERS, *General Manager*
Nashville Thermal Transfer Corp., Nashville, Tenn.

Introduction

The Nashville Thermal Transfer Corporation Central Heating and Cooling Service Project, which includes a solid waste fueled plant, can be characterized as a tale of two marriages: one the marriage of private enterprise and government, the other a marriage between two well-proven technologies. These marriages will become evident as the salient features of the project are presented. This presentation includes:

1. The project's objectives.
2. A general description of the concept and services.
3. A description of the plant and distribution system facilities.
4. A description of the organization and financing of the corporation.
5. The general application of solid waste as a source of energy for central energy plants.

16500000 / 720 = $22,916 /dt

Objectives of the Project

The primary objectives of the $16,500,000 Central Incineration, Heating and Cooling Service Project, which will serve the Center City area of Nashville, are:

= $0.15/MM BTU
Amor. at 30 yr
~should be less than $1.00/

1. Provide low cost district heating and cooling to Nashville's Center City area buildings.
2. Recover energy in all combustible solid waste not recycled for other purposes.
3. Virtually eliminate the need for sanitary landfill in Nashville.
4. Reduce substantially and almost eliminate the solid waste disposal cost for Nashville.
5. Improve water and air quality in urban Nashville by meeting solid waste disposal, water and air emission standards with a central plant which incorporates effective environmental control equipment. Debateable
6. Provide for major ferrous material recycling from incinerator residue. No. Not being done, yet.
7. Create and operate a solid waste fueled central heating and cooling plant project that has a favorable economic and environmental impact on the community.

$22916	1 ton	lb	1000000 BTU	
ton	2000 lb	5000 BTU	30 yr	MM BTU

= $76.39/MMBTU · 365 = $0.21/MMBTU

A $1.00/MMBTU, Depreciation $5-7 yr payout

Background and Description of the Concept and Services

To achieve these objectives, the Nashville Thermal Transfer Corporation was established in 1970. Under construction is the $16,500,000 facility which will carry out the above objectives. Construction began in June 1972, and it will go into preliminary operation in late 1973 or early 1974.

The project is called "Cash for Trash" in Nashville. In the trade magazines it is referred to as "one of the most exciting things in the business of running cities and living ecologically."

The project will heat and cool Nashville's downtown high-rise buildings with energy recovered by combusting the city's garbage and trash. The design engineers, I. C. Thomasson & Associates of Nashville predict that within a year, more than three-fourths of the air pollution which is currently emitted by the buildings to be served will be eliminated. At the same time, the building owners will enjoy saving between 15 and 50 per cent on their normal building heating and cooling costs.

The new convention hotel, expected to be completed soon after the project is ready for services, will save an estimated $400,000 in capital costs by not having to install its own in-building heating and cooling plant. The average price for chilled water will be $4.14 per ton-hr, and the price for steam about $1.50 per M lb. The Metropolitan Government of Nashville and Davidson County will save about $1.25 million yearly by avoiding operation of expensive, and hauling to, remotely located sanitary landfills.

~$1.50/MMBTU

Building owners will not have to worry about shortages of gas, oil, and coal, because the project's fuel will essentially be 100 per cent solid waste, which is in constant and increasing supply. By helping to save on the demand on the nation's fossil fuels, the Nashville project is energy conservation at its best. The thermal energy value in a pound of solid waste is roughly one-third to one-half the value of a pound of coal, and it is a very good fuel.

Today this fuel is being discarded by cities across the country, and it amounts to 543,000 tons per day. If the country's solid waste were all converted into cooling capacity, it would amount electrically to about 16 million kw, which is twice the peak electricity demand of New York City.

Throwing solid waste away eliminates the opportunity to utilize this free fuel, and it also costs a lot just to bury it properly. The normal landfill cost exceeds $5 per ton. Disposal costs in the nation for sanitary landfill operations are estimated at $500 million per year, and landfills consume about 60,000 acres of valuable land annually.

This concept sounds so reasonable and attractive that one wonders what the catch to a "cash for trash" system is. There doesn't seem to be any at all. However, some obvious questions are: Will this project create a nuisance in the downtown area by causing traffic problems, pollution and odors? Will it concentrate all the pollution into one smokestack? Does garbage actually burn well? Who pays for this process? Is the project subsidized? Are the economics proven? Is this an experimental plant? Why hasn't it happened before now? Why aren't all large cities installing a similar project now?

These questions will be answered specifically in this presentation when the operation and design of the plant are described in detail. However, the answers in general, to some of the more serious potential problems follow:

1. How will the odor problem be handled? The waste will be hauled in covered trucks to a pit that is within a heating building. Fresh air will be circulated from outdoors over the pit, picking up the odiferous air, and it will be incinerated in the process plant.

2. How about pollution? The 27 buildings that will initially be served by the system are currently emitting particulate matter. The thermal plant will reduce this by over 75 per cent. Also, because of the 27 individual heating and cooling plants utilizing sulfur-laden coal and oil for energy, the sulfur dioxide created to produce the energy in the individual plants is substantial. The Thermal plant will reduce current sulfur dioxide emissions from this source by 90 per cent. Nitrogen oxides will not be generated by the plant, because the furnace temperature will be less than 1800 F. Additionally, the individual buildings concentrate their pollution into the five winter heating months, while Thermal's plant will not.

3. Does garbage and trash burn? Yes, surprisingly well, without any additional fuel, so long as the solid waste is relatively dry. Ignition is not a very exotic process; it can be started simply by tossing in a match.

4. Is this a well-proven idea? This plant is similar to many existing plants. There are hundreds of central steam and cooling plants throughout the United States; and plants in Europe have been, for a number of years, combusting solid waste in heat recovery systems. Therefore, the Nashville project really isn't anything new. However, it will be the world's first large-scale plant to produce both steam and chilled water from solid waste. The project is a combination of proven ideas, a marriage of proven technologies.

This is in the era of increasing fuel costs and limited fuel, and the environment needs to be improved. Central heating and cooling plants have proven to be a way of conserving energy, reducing pollution, and reducing capital and operating costs for building heating and air conditioning plant facilities. At this point, this Nashville enterprise appears to prove the old adage that problems are merely unexploited opportunities. The Nashville-type system is beginning to be utilized as a model for other cities with high solid waste disposal costs, and a genuine interest in keeping their downtown areas vital by providing modern heating and cooling services.

Every community seems to be in the same boat on solid waste. It makes sense to make garbage pay its own way, rather than it being a burden on the community taxpayer.

Thermal Transfer — How Does It Work?

Thermal's dual-purpose central energy plant will produce steam and chilled water, with its primary fuel being energy recycled from solid waste loosely compacted and delivered by the Nashville solid waste collection process. Fig. 1 is a simplified flow diagram which describes the various systems in the process.

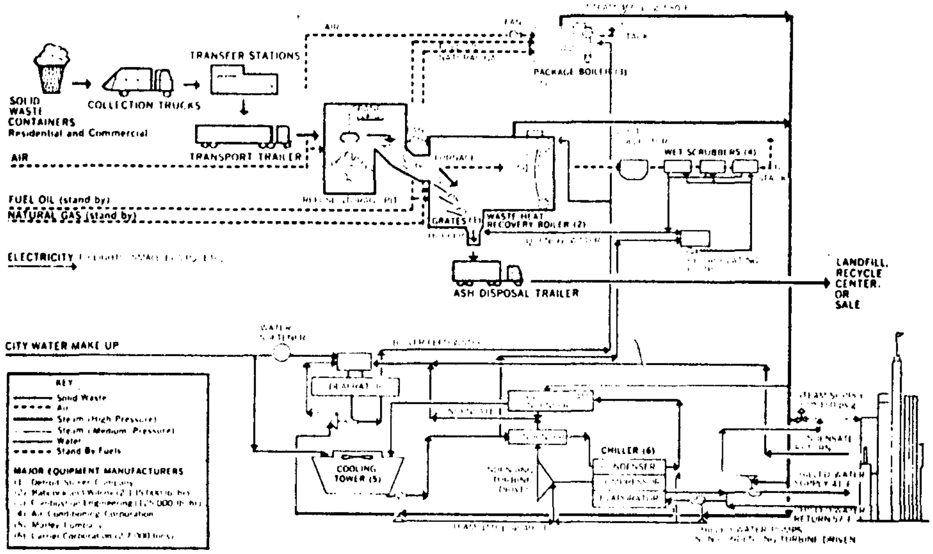

Fig. 1 — Simplified flow diagram of the solid waste fueled plant.

Local garbage and trash route trucks operating throughout the county deliver their solid waste to three strategically located transfer stations. At these stations, solid waste from many local, relatively small trucks is placed in large 65 and 75 cu yd trailer trucks. The solid waste is then delivered to the plant in these large, fully enclosed semi-trailer trucks, and dumped into a refuse pit large enough to permit weekday and weekend operation on weekday deliveries. One or two deliveries per hour will be made to the central plant. The transfer station process significantly reduces annual travel, and keeps local trucks off the main roads and permits them to return to their routes more quickly, thus saving fuel and labor costs.

A crane will pick up the solid waste in one-ton bites, and feed it into the multi-level steam generating incinerator-boilers. The plant will include two 360-ton per day steam generators manufactured by Babcock and Wilcox Co., and eventually will be expanded to include about three additional 360-ton units. These boilers can also operate on 100 per cent natural gas or oil fuel. The solid waste is continuously fed into the steam generator by agitating grates, manufactured by the Detroit Stoker Co.

Ash from the incinerator is dropped into an ash hopper and sprayed with water from the scrubber tank. Spraying cools the ash and eliminates dust problems during the removal and disposal process. This is also the method of disposing of the particulate matter that is scrubbed out of the stack gases. Trucks haul ash from the plant, and the sterile residue will provide a dense road bed fill or building block material, where desirable. If trucked to landfills, it will not require earth cover. It is planned to add a ferrous recovery system, which will allow recycling of all ferrous material in the incinerator residue, when a market can be established for the ferrous material.

Combustion air, drawn into the plant through the solid waste storage room, allows incineration of odors in the steam generator, thus eliminating any potential odor problem in the plant area. The furnace is sealed and operated under a slight negative pressure to prevent escape of dust and odors. The 1800 F heat in the furnace explodes most of the glass into tiny fragments much like sand. The odorous gases are removed when exposed to temperatures above about 1500 F.

For maximum heat recovery, the flue glass will exit from the boiler sections through an economizer bank, wherein the temperature of the gases is reduced to approximately 500 F. These gases then go through sophisticated particulate and gas collection devices, in order to meet emission criteria. The gases first are subjected to a dry "cyclone" for removal of large particulate matter, and then to "wet scrubbers" to remove the remaining particulates and water soluble gaseous constituents. The cleaned gases leave the scrubbers at about 140 F, and then discharge via stack heaters into the atmosphere through low profile stacks. These scrubbers include three sets of water sprays and two sets of wetter baffles, all in series.

Pollution control is a very important part of the project. Very low particulate matter and sulfur dioxide emission rates are accomplished with the combination of dust collectors and the series of wet scrubbers built by the Air Conditioning Corp. of Greensboro, N. C. The level of particulate and sulfur dioxide emissions is reduced by 75 and 90 per cent respectively, over the pre-existing in-building systems replaced by the Thermal plant, as previously presented.

For heating purposes, steam at 400 lb pressure and 600 F goes directly from the boilers into noncondensing steam turbines, and then into the distribution network. For cooling, steam generated in the boilers is piped to non-condensing turbines, whose exhaust steam drives two condensing steam turbine driven Carrier Corp. chillers rated at 14,000 tons of cooling capacity.

Two cooling towers reject heat from the refrigeration cycle. Each Marley Co. tower has a water capacity of 90,000 gal, and a recirculating water rate of 17,000 gal per minute. At full load, when both chillers and boilers are operating at capacity, the plant has a make-up water requirement of approximately 1,500,000 gal per day, which will be supplied by the Nashville city water system. This exceptionally high water requirement, however, is less than the demand by plants replaced by the Thermal operation. Less than two per cent of the total water used by the plant is fed back into the Nashville sewer system. Initially, no water will be used directly from the Cumberland River, and no water will be returned directly to the river.

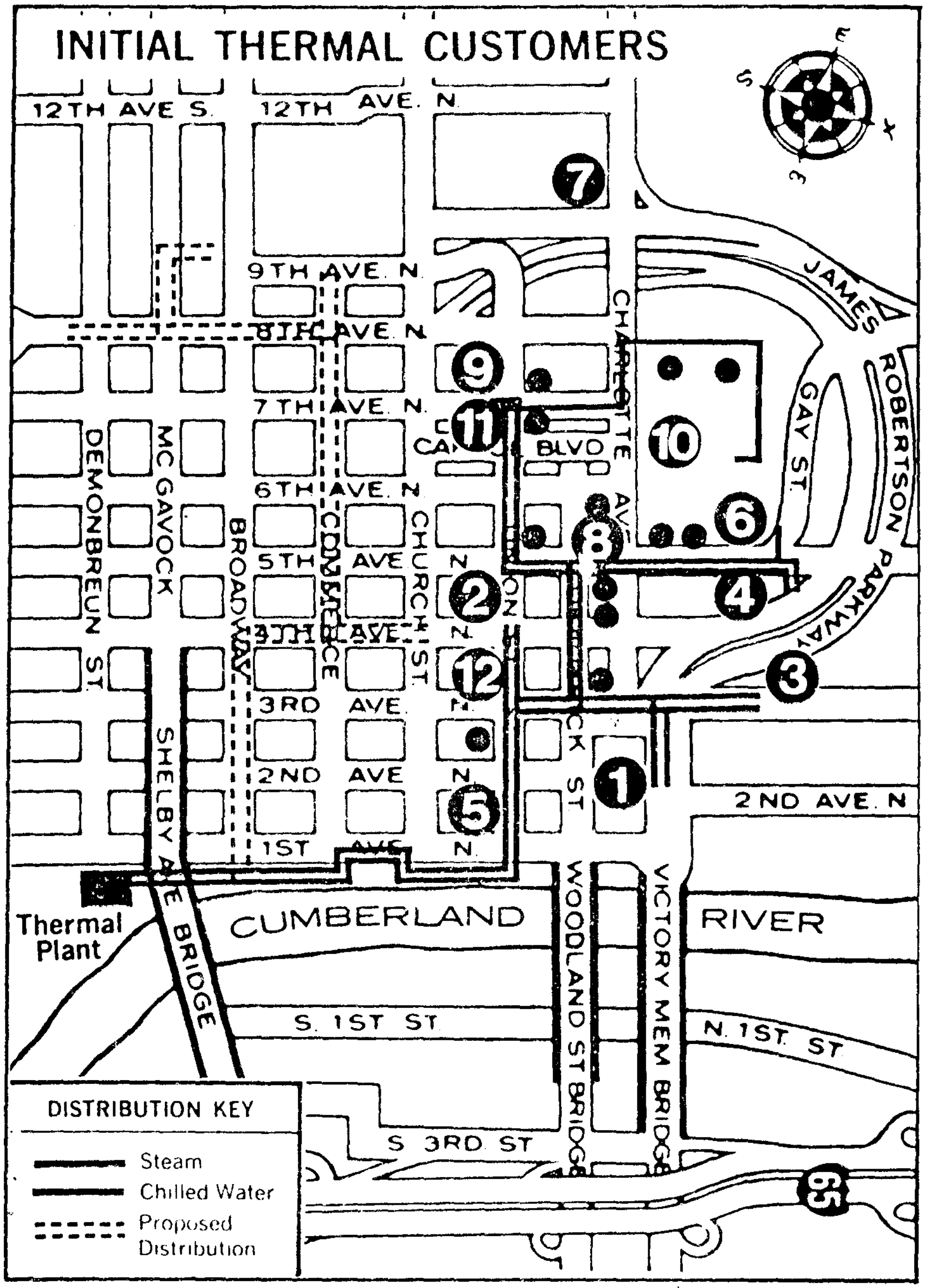

Fig. 2

Steam and 41 F chilled water is piped under city streets through a four-pipe distribution system 15,000 trench ft in length. Fig. 2 shows the layout of the distribution system superimposed on a Nashville street map. The condensed steam and 57 F chilled water is returned to the district plant in closed recirculatory systems. Each customer is billed according to the quantity of cooling and heating utilized.

This four-pipe distribution system consists of a chilled water supply line, a chilled water return line, a steam feed line, and a condensate return line. Fig. 3 shows a typical pipeline cross section. The normal operating pressure of the steam lines will be about 150 lb. Both chilled water and steam service supply lines will terminate at meters installed on the customer's premises.

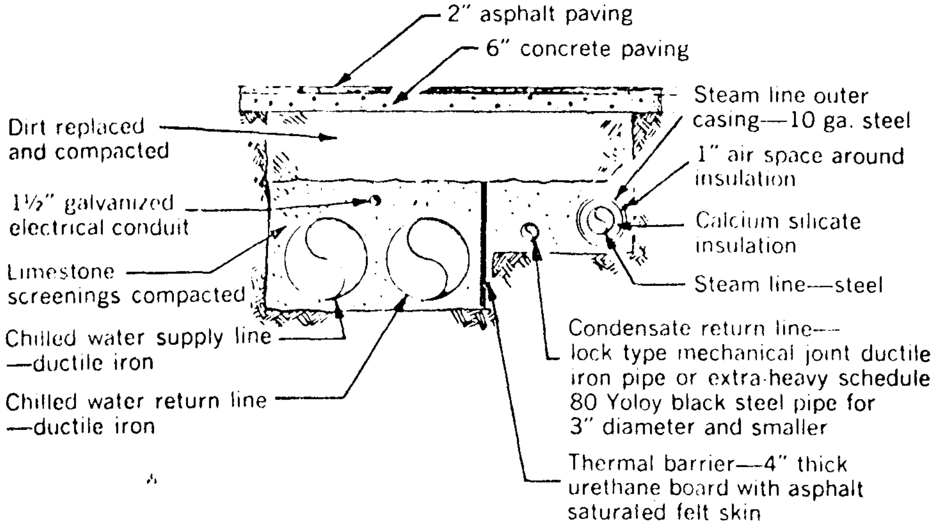

Fig. 3 — Typical pipeline cross section for the four-pipe distribution system.

Although solid waste is the principle fuel for steam production, each incinerator is equipped with gas and oil burners. The auxiliary fuels are deemed necessary by systems engineers for the maintenance of consistent steam pressure, in the event of an unusually high moisture content of the solid waste. In addition, a 125,000 lb per hr stand-by and supplemental package boiler, fired by gas or oil, is also available to increase the overall plant reliability and operational flexibility during maintenance periods. This unit will be supplied by Combustion Engineering. Natural gas and waste oil will be the principle stand-by fuels. The engineers estimate average auxiliary fuel usage at less than ten per cent of the energy required.

That generally is how Thermal Transfer will work — that is, work in an engineering sense. But Thermal, like any other organization must also work in a political and economic sense, and the corporation is also rather unique in these respects.

Nashville Thermal Transfer Corporation

Originally, Thermal was not conceived as a means of solving Nashville's solid waste disposal problem. The project began in mid-1969, when Nashville Mayor Beverly Briley commissioned a study of the feasibility of constructing a central energy service facility for heating and cooling municipal buildings. The study by I. C. Thomasson & Associates established conclusively that the project was economically and technically feasible and would benefit the community, particularly if broadened to provide service to the entire downtown area.

Original plant specifications called for the use of conventional fossil fuels (gas and oil) to produce the necessary steam and chilled water. It was determined by Charles Griffith, then Director of Law for the City, that the Nashville Electric Service and the Nashville Gas Co. lacked the requisite authority to undertake the project without a public referendum. Best estimates for coordinating plant construction and customer demand, indicated that all plans had to be completed and bids ready for letting no later than the summer of 1971. Thus, timing ruled out the lengthy referendum process.

With this timing factor, the most practical means of organizing and financing the project appeared to be through establishment of a separate corporation. On May 14, 1970, the Nashville Thermal Transfer Corporation was chartered under the laws of Tennessee to construct, own and operate the central plant facilities, and to provide low-cost district heating and cooling services. The Executive Director of the Metropolitan Planning Commission, Farris Deep, was named as President of the new, not-for-profit corporation.

Shortly after initial contracts were made with potential customers, it was suggested that solid waste be substituted for conventional fossil fuels to produce steam for heating, and to drive coolant compressors. After intensive study and modification of the original plans, the consulting and design engineers concluded that the idea was feasible, and Thermal entered into the incineration business, along with heating and cooling. Nashville agreed to provide to Thermal, at no cost for the next 30 years, its current solid waste, which is now about 1400 tons a day.

Engineering and design of the facility were started early in 1971 by I. C. Thomasson's firm. The eight-acre site for the plant was selected and approved early in 1972. The project was financially sound based on firm 30-yr heating and cooling contracts with the State of Tennessee and private users, and firm 30-yr heating, cooling, and solid waste contracts with the Metropolitan Government of Nashville. Nashville's prime contractor, Foster & Creighton Co. of Nashville, began construction of the central heating and cooling plant in June, 1972, based on its low base bid of $8,358,026. Hardaway Construction Co., Nashville, is proceeding with the distribution system construction on a low bid of $3,996,371.

Thermal is directed by a nine-member Board of Directors. The State Attorney General, State Commissioner of Finance, Nashville's Executive Director of Planning, Director of Law, Director of Finance and Director of Public Works are among the Board Directors.

The General Manager reports directly to the Policy-Setting Board. Thermal will have about 20 full-time employees by late 1973. Thermal contracts with Chicago-based Duff & Phelps for management services, and with I. C. Thomasson for engineering services. Legal services are provided by a Nashville public and environmental law firm, Griffith & Stokes. Public auditing is done by the nation's largest public utility accounting firm, Arthur Andersen & Co.

The Corporation is specifically exempted from public utility commission jurisdiction. Rates are set under terms of a comprehensive bond indenture.

Thermal is financed by revenue bonds. The users of the system, through their 30-yr term agreements, provide the necessary revenues for operating at fixed costs.

The situation leading up to the formation of Thermal was influenced by the circumstances and local government of Nashville; and this, of course, brings us to the question of general applicability of our corporation type and system to other communities.

Application to Other Communities

There are several reasons why this type of project should be considered as an alternative to existing processes for solid waste disposal and district heating and cooling in all large communities.

1. Once cheap fossil fuels cost more today than just a few years ago, and these costs are projected to increase over the next few years by up to 250 per cent.
2. Industrial, commercial, and perhaps residential areas must concern themselves with the availability of fossil fuels for heating and cooling. Articles in *Newsweek* and other publications state that communities will experience so-called fuel and power "brown outs," like the ones that have occurred on the East Coast, Denver, and other areas this past heating season. There isn't enough fuel to go around.
3. Most cities are running out of sanitary landfill sites, and the Environmental Protection Agency will no longer allow cities to continue operating open dumps. EPA insists on sanitary landfill operations. This, of course, causes problems and higher costs, because sanitary landfill operations are perhaps double or triple the cost of open dump operations; and in areas like Nashville, there is another problem due to the lack of top soil. It is almost impossible to operate a sanitary landfill to meet the state standards in Tennessee.

Thermal Transfer Serving Nashville

In 1974, the first full year of operation for Thermal, heating and cooling customers will include at least 12 state office buildings, four municipal buildings, and 11 private buildings. These original contracts have been executed for 30-year terms, commencing with the initial delivery of service. Contracts with additional customers are being negotiated. It appears that the central plant will be expanded in 1974, with the installation of a third solid waste fueled boiler and an additional 7000-ton chiller. Also, major distribution system extensions will be installed to service new customers. Now that the project is essentially a reality, more customers in the downtown area are signing up for heating and cooling services.

Summary

Today on the Cumberland River bank, a few hundred yards south of Nashville's frontier beginning as Fort Nashborough, modern pioneers in the spirit of Nashville's founder, Colonel John Donelson, are setting a precedent with international potential. The Nashville project will be utilizing a new, free and expanding energy source to meet one of the critical challenges of the developing urban area. Solid waste, garbage and trash, historically disposed of in dumps and landfills, will be utilized as primary fuel in an efficient, modern, and economical central energy plant to heat and cool downtown community buildings.

Pioneering in thermal transfer, the Nashville Thermal Transfer Corporation hopes to demonstrate and help set a positive trend, which can benefit all communities as they strive to meet the challenges of supplying energy to fill the unique needs of modern communities, while preserving and improving the urban environment, and therefore, the quality of urban life.

APPENDIX V

"THE ECONOMICS OF RESOURCE RECOVERY

FROM MUNICIPAL SOLID WASTE"

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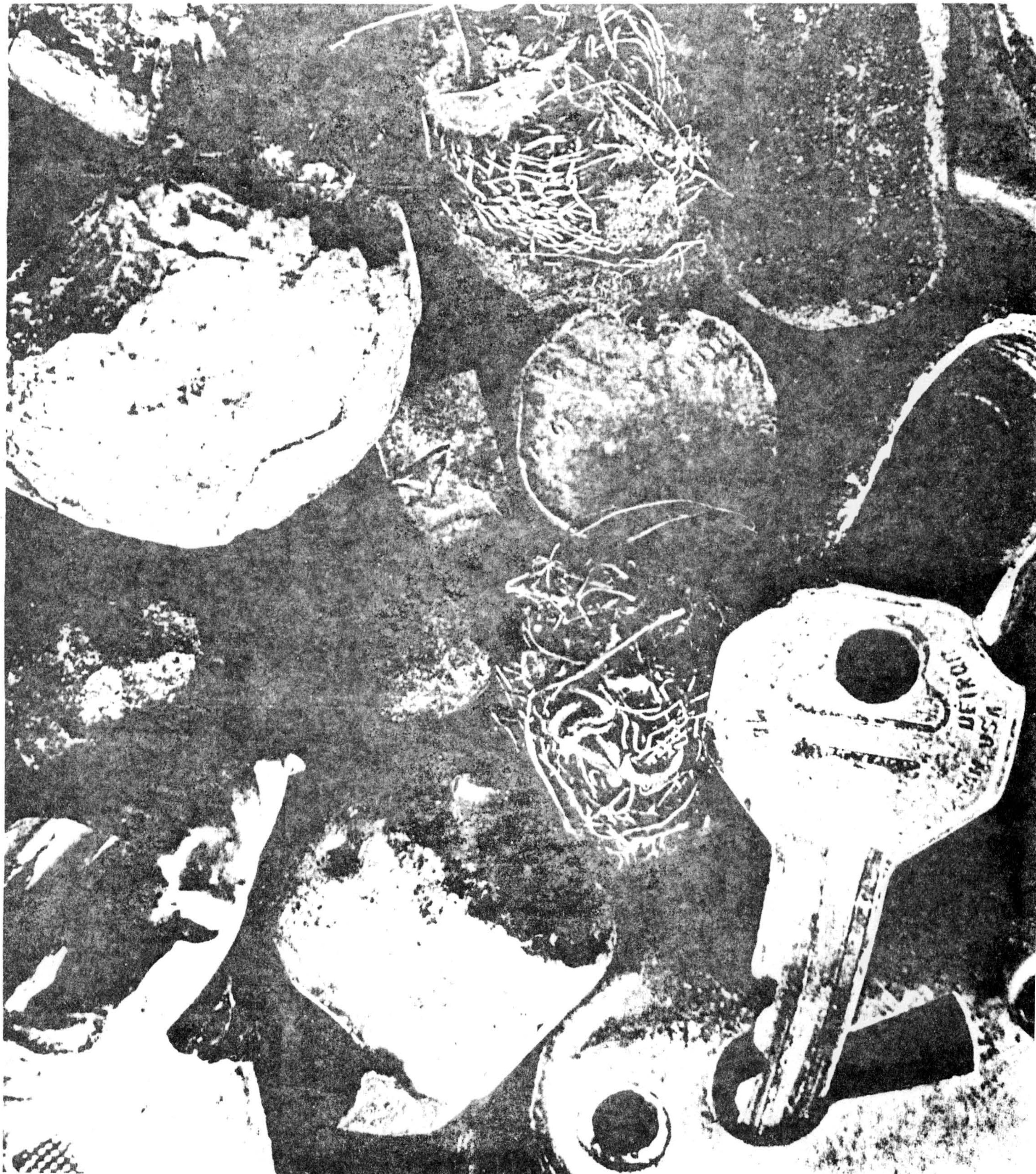
SCIENCE

The Economics of Resource Recovery from Municipal Solid Waste

James G. Abert, Harvey Alter, and J. Frank Bernheisel



COVER

Mixed, nonferrous metals recovered from municipal refuse. See page 1052. [H. Alter, National Center for Resource Recovery, Inc., Washington, D.C.]

The Economics of Resource Recovery from Municipal Solid Waste

James G. Abert, Harvey Alter, and J. Frank Bernheisel

Environmental concern has drawn attention to means for recovering material and energy resources from urban solid waste, particularly from the household portion (1). Recently, federal support has been given for this purpose (2). The public viewpoint is that the metal, glass, and other materials found in ordinary refuse are resources to be saved, preserved, and recovered rather than discarded. Recovery, outside of separation by the householder, depends on the availability of suitable separation technology operated at a reasonable cost to the community.

Unfortunately, progress in affecting the installation of recovery facilities to meet the needs of communities has been slow. Much of the work done has been beset with technical, and, more often, economic difficulties. However, the rising cost of traditional and environmentally acceptable means of disposal may allow new systems to become economically competitive. New systems hold promise. The Environmental Protection Agency in late 1972 announced four grants, under Section 208 of the Resource Recovery Act of 1970 (3, 4), for the construction of resource recovery plants of at least 200 tons per day capacity to demonstrate new technology. Many unit operations familiar in chemical, mechanical, and minerals processing engineering practice can be, and already have been, applied to refuse processing and resource recovery (5). Their final adoption will depend on their costs to the community being competitive with traditional methods of disposal, such as sanitary landfilling or incineration.

Raw Materials

Before considering the costs of resource recovery, one must examine what there is to recover—that is, what is likely to be in the solid waste stream. This article is focused on the household portion of the urban solid waste.

The results of several analyses (6) of the composition of household refuse by weight resulted in the values given in Table 1. Unfortunately, there is no such thing as an average refuse composition: The composition varies from city to city—probably geographically and no doubt seasonally and temporally, from year to year and on shorter time scales, all making definitive analysis difficult. There are, however, some general trends in composition that can serve as design input for technical and economic analysis. First, some nominal composition figures can be computed, using one's judgment, from the available data (7). Second, it is apparent that municipalities with a "high" refuse assay have an economic advantage in implementing recovery facilities. A high assay means that the content of the valuable, nonferrous metals must be about 1 percent.

Recovery potential falls into two basic groups of materials (see Table 1). The first group of items is labeled "mechanical recovery" and refers to that portion of the refuse stream which is available for essentially mechanical extraction and for reuse as a relatively pure raw material. The second group includes what are primarily organic materials, which, because of their physical characteristics, can only be recovered through conversion. Organic materials are generally suitable for some sort of derived product, such as com-

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post, or a manufactured product, such as fiberboard building material (*3*, *5*, *8*), or for chemical or biological conversion to a source of energy—either directly, by burning, or indirectly, by converting to a storable fuel (*9*).

Paper is included in both categories: Some is recoverable as a material, but most is not. This is due, in large part, to composite packaging (that is, paper laminated or otherwise attached to plastic or metal) and to the collection process. When mixed with other refuse, paper becomes contaminated with dirt, grease, and other materials that are not acceptable inputs to high-speed papermaking processes and that are difficult to remove, even with special processing (*10*). However, it is probable that some small fraction of paper, most likely bundled newsprint and corrugated board, can be efficiently separated from mixed refuse by hand in a form acceptable for some reuses.

Therefore, based on the composition of the refuse stream, recovery is essentially a two-phase process: First, materials recovery (glass, metals, and some paper); and second, recovery of the organic portion and reuse through conversion, probably as a source of energy.

One scheme for recovering materials and energy from solid waste is shown in Fig. 1. "Front end" refers to materials recovery with disposal of the organic portion by conventional means —for example, by landfill or incineration. This is a suboptimal system because it is incomplete. "Back end" refers to the recovery of the organic portion and its reuse as fuel or as raw material for a product (*11*).

A flow sheet for a front end recovery process proposed by the National Center for Resource Recovery (*12*) is shown in Fig. 2. The bases for choosing this type of materials recovery plant and details of the various unit operations have been described (*13*), as have other technically feasible processes (*5*). The system shown in Fig. 2 would recover five fractions: bundled paper, ferrous metals, glass, aluminum, and a mixture of other nonferrous metals (including nonmagnetic stainless steel). It would leave as residue the organic fraction (for disposal or recovery) and a small inert fraction consisting of bone, rubber, heavy plastics, grit, sludges, and dust from the processing (for disposal by landfill). An important aspect of "beginning" with the front end system is that the economic analysis does not have to include the normally high cost of marketing new products. This cost would be necessary for many back end systems, such as those which produce new kinds of building materials. Further, the economic viability of the front end system is not hampered by the high capital cost of constructing refuse-burning heat exchangers for energy recovery.

Cost Estimates

The first step in the economic analysis of resource recovery is to determine the capital costs and operating costs of the technology to be installed. A plant processing 500 tons of solid waste per day (like that in Fig. 2, which would serve most of the needs of a community

Table 1. Expected ranges in mixed municipal refuse composition. [Source: (*6*, p. 5)]

Component	Composition (% of dry weight)* Range	Nominal	
Metallics	7 to 10	9.0	Mechanical recovery
Ferrous	6 to 8	7.5	Mechanical recovery
Nonferrous	1 to 2	1.5	Mechanical recovery
Glass	6 to 12	9.0	Mechanical recovery
Paper	37 to 60	55.0	Mechanical recovery / Conversion recovery
Newsprint	7 to 15	12.0	Mechanical recovery / Conversion recovery
Cardboard	4 to 18	11.0	Mechanical recovery / Conversion recovery
Other	26 to 37	32.0	Mechanical recovery / Conversion recovery
Food	12 to 18	14.0	Conversion recovery
Yard	4 to 10	5.0	Conversion recovery
Wood	1 to 4	4.0	Conversion recovery
Plastic	1 to 3	1.0	Conversion recovery
Miscellaneous	< 5	3.0	Conversion recovery

* Moisture content: range, 20 to 40 percent; nominal, 30 percent.

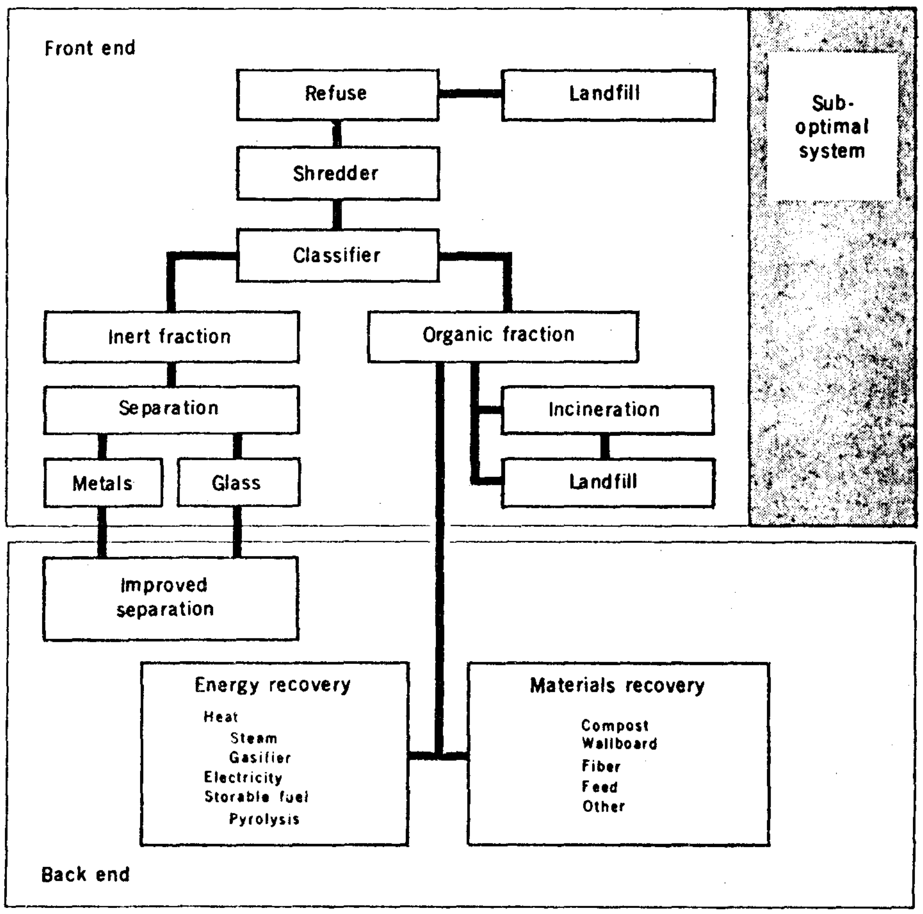

Fig. 1. A modular approach to resource recovery. Front end refers to materials recovery. Back end refers to direct utilization, or conversion, of the organic portion of the waste.

of about 200,000) has been estimated in some detail to have a capital cost of $2.4 million, exclusive of land (*13*). These costs are explained in Table 2. Operating costs have been estimated (*13*), and are summarized in Table 3, on the basis of a debt-to-equity ratio of 2 : 3. This would apply to the situation in which a private entrepreneur constructs and operates a plant of this kind as a business venture. Public ownership is also possible.

The costs of back end processing facilities are more difficult to obtain or analyze because the technology is generally new and often proprietary. However, it seems that the most efficient and inexpensive (in terms of capital) means of extracting energy from the organic fraction would be to use it as a supplementary fuel in existing coal-fired boilers for generating electricity, as is now being done in St. Louis (*14*). The cost of modifying the plant and any increase in the cost of operation of such a utility boiler may be paid for by the value of the organic fraction as a fuel.

General Economic Considerations

A great deal has been written about the economics of environmental quality, with discussions of internalization of costs, redistribution of income, costs and benefits to society, and so forth (*15*). It is not our intent to review or enter into these arguments here. Rather, we seek to determine the cost to a community of adding resource recovery to its solid waste management system. Put another way, we apply the "indifference principle"; the indifferent community is one for which the added resource recovery would cost the same as its present solid waste management practice. In this day of environmental concern, the indifferent community may also be one to which the extra cost of having resource recovery is acceptable as a means of participating in materials conservation programs.

A cost center concept is the basis for evaluating the recovery facility. Refuse is accepted for processing for a fee paid to the facility, and unrecovered byproducts and residues are disposed of for a fee paid by the facility. It is assumed that the facility is privately owned and is operated at a profit. If the facility is economically feasible under private ownership, it may be less expensive to implement under public ownership because a public body does not require a profit and can often borrow capital at lower interest rates.

For purposes of analysis, the characteristics of a prototype facility are assumed to be the same as those described in Tables 2, 3, and 4, with a profit before taxes or return on an equity of 15 percent, which is assumed to be the minimum that would attract private capital (considering present interest rates on certificates of deposit and other relatively safe, often tax-free, investments).

The fraction of incoming refuse recovered as salable material (Table 4) is determined by the expected efficiency of an operating plant and by the average expected composition of the incoming refuse (*13*).

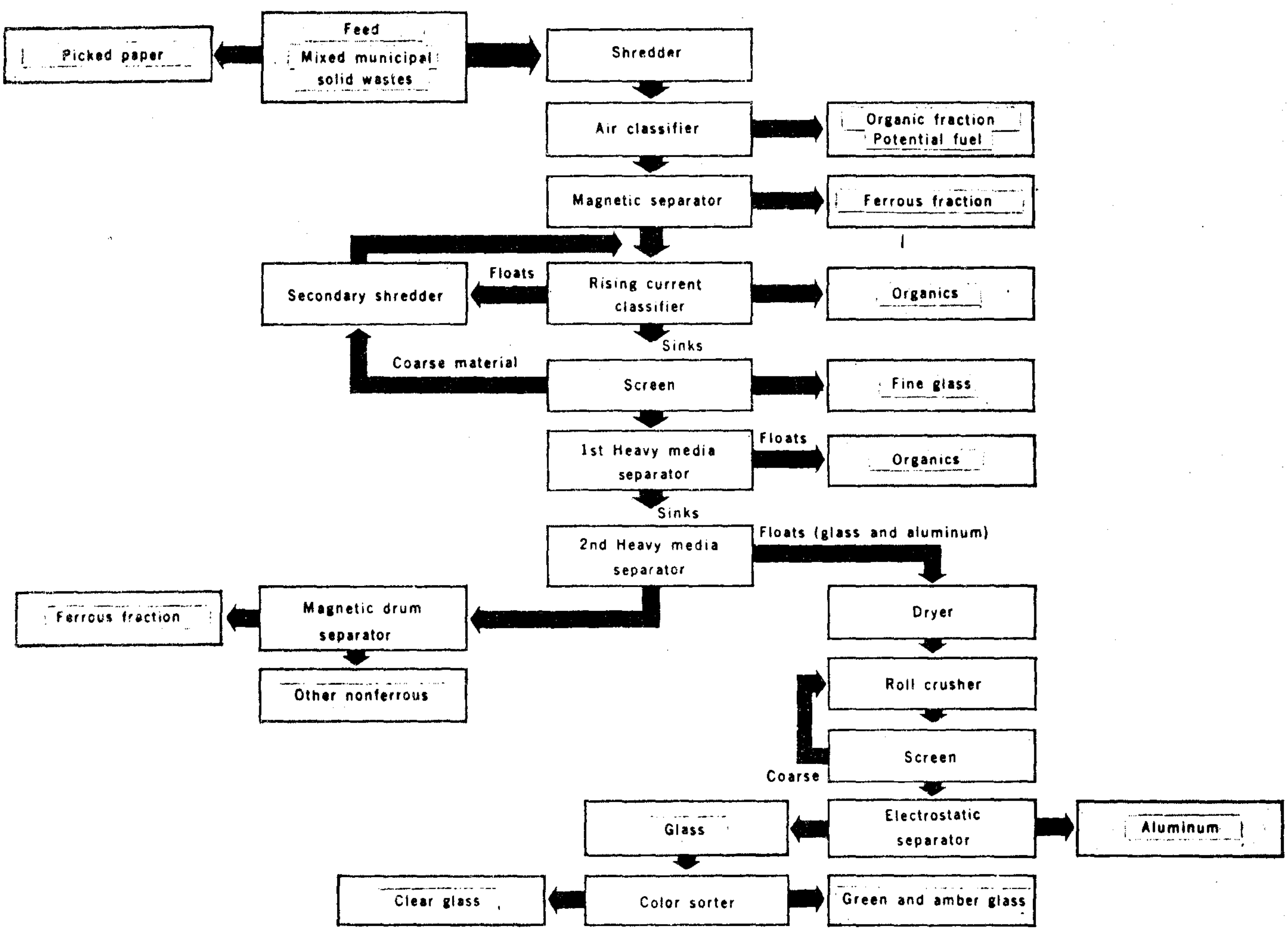

Fig. 2. Processing scheme for separating materials from mixed refuse.

The Operating Statement

Under the cost center concept, a prototypical operating statement can be used in economic analysis. Such a statement must include entries for all operating expenses and revenues for the stated equity, as well as target return on this equity. An example of an operating statement is shown in Fig. 3.

Net operating income provides the return on equity previously discussed. Total operating expenses are the sum of annual operating costs (derived as shown in Table 3) and waste product costs, which are costs resulting from the disposal of unrecovered material. By-product revenues are net proceeds from the sale of recovered fractions (*16*). The dumping revenue is a per-ton fee paid by the community or by private haulers to the facility for disposing of the refuse.

The by-product revenues are based on the expected annual recovery rate for each potentially recoverable resource and on the anticipated selling price for each material. The expected recovery of each material is listed in Table 4; the engineering estimates made to arrive at these figures have been described elsewhere (*13*). The expected selling price for each material is a judgment based on examination of analogous scrap prices quoted in trade publications (*17*), conversations with potential buyers, and freight charges over a likely distance.

The following net prices were arrived at: ferrous metals, at $15 per ton (based on a No. 2 scrap bundle price of about $35 per ton, delivered to the steel mill and allowing $20 per ton for transportation); glass, at $7 per ton (based on 12 percent of the glass output being sorted as flint at $12 per ton and the remainder being color-mixed at $8 per ton and allowing only for local transportation costs); paper, at $10 per ton (mostly No. 1 news, a standard paper stock—price estimates vary greatly with area of the country); aluminum, $200 per ton net (quote from an aluminum producer); and nonferrous metals, excluding aluminum, $120 per ton (based on prices paid per ton for metal contained in some nonferrous concentrates from automobile-shredding operations). The likely by-product revenues for the operating statement, calculated on these estimates, are listed in Fig. 3, with entries for all the costs and revenues established so far (*18*).

Table 2. Summary of capital costs. [Source: (*13*, pp. 9-1–9-53)]

Item	Cost ($)
Building	173,000
Electrical equipment	192,300
Water and sewage	124,000
Auxiliary equipment	119,830
Processing equipment	914,300
Subtotal	1,523,430
Architecture and engineering (10%)	152,343
General contracting and architect-engineer field supervision costs (23%)	350,389
Contingency (19%)	289,452
Working capital	100,000
Total	2,415,614

Figure 3 illustrates the oft-heard argument, and a correct one, that the by-product revenues from resource recovery cannot support the cost of separation. By-product revenues are listed as $562,000, falling short of expenses ($819,000) by $1.65 per ton of input. These arguments are incomplete, however, because they do not take into account other entries to the operating statement that must be added in order to determine the economics of such a facility.

First, the prototype plant discussed here processes 500 tons per day, 6 days a week. Of this input, 19 percent is recovered, and hence does not generate a disposal cost for the facility. In order to balance the operating statement and to determine the point of indifference mentioned earlier, the credit for the dump revenues and the debit for the waste product disposal costs must be such that the net operating income equals the target rate of return, $216,000 per year. This may be stated as:

$$156{,}000(DR) - 126{,}360(WPC) = \$473{,}000 \qquad (1)$$

The $473,000 are operating costs plus profit, minus by-product revenues. Dump revenues (DR) and waste product costs (WPC) are expressed in dollars per ton.

The equation can be solved for both DR and WPC if a relation can be established between the two unknowns. A plausible one is

$$0.75(DR) = (WPC) \qquad (2)$$

Table 3. Annual operating costs of a plant processing 500 tons per day, 6 days per week. Basis: 40 percent of capitalization debt; 60 percent equity. [Source: (*13*, pp. 9-1–9-53)]

Operating costs	Expenditure ($)
Variable	
Labor*	258,425
Maintenance materials	74,327
Utilities	64,800
Total variable	397,552
Fixed	
Depreciation†	306,530
Real estate taxes and insurance‡	39,429
Interest§	75,000
Total fixed	420,959
Total net	818,511

* Labor costs are based on paying time-and-a-half for the sixth day. †Depreciation is straight line based on 20 years for buildings and 7 years for equipment. ‡Land assumed to be provided rent-free by the municipality. § Based on borrowing 40 percent of capital cost at 8 percent simple interest, paid quarterly for 20 years on building and 10 years on equipment. Interest shown for the first year of operation.

Dumping revenue		$ ___	
By-product revenues (net)			
Ferrous metal	$ 159		
Glass	$ 76		
Aluminum	$ 218		
Paper	$ 62		
Other nonferrous metal	$ 47		
Total		$ 562	
Total operating revenues			$ ___
Waste product costs		$ ___	
Annual operating costs		$ 819	
Total operating expenses			$ ___
Net operating income			$ 216

Fig. 3. Protypical operating statement showing the format and fixed entries, of a resource recovery facility (annual rates in thousands of dollars; equity, $1.44 million; return on investment, 15 percent).

In other words, there is a 25 percent discount in the cost of disposing of the waste products after processing (shredding and removing of the inert material).

It is believed that this discount can be justified if the processed refuse is disposed of in a landfill, particularly in areas where land is expensive and dirt to cover the refuse is scarce. With the same mechanical effort, shredded refuse can be made more compact than unshredded refuse; it therefore requires less land for disposal. In addition, there is substantial evidence that shredded refuse does not need daily earth cover and thereby saves on clean fill, often a scarce and costly material (*19*). Shredded refuse without cover requires fewer earth-moving machines and compactors for landfilling than does unprocessed refuse. The lower requirement saves capital investment and daily operating costs. Finally, because shredded refuse as fill stabilizes more rapidly, compared to unshredded material, the filled land is available sooner for capital improvement. This is often an income-producing item for the municipality. The potential savings in each of these various categories have been estimated (*13*, *19*) and are summarized in Table 5. In the case of landfill without daily cover, Eq. 2 seems justified, if not conservative.

It is more difficult to make a similar case for Eq. 2 when the unrecovered fraction is disposed of by incineration. Although the burning of shredded wastes, such as bark and bagasse, has been practiced for years, it has only been in the last 2 years or so that municipal incinerators operating on shredded refuse have been put into operation. One such plant is in the city of Hamilton, Ontario. In the Hamilton plant, there are several design innovations aimed at reducing costs of incineration. Among these are conveyor belts, rather than overhead cranes, for handling refuse. Also, because of suspension burning, the combustion chamber is smaller than a conventional incinerator of the same capacity. Finally, there is no need for water quench of the ash; it is cooled in suspension by the air flow. Because the Hamilton plant is new, data on actual costs are not yet available. However, it is likely that the operating costs for the complete facility are slightly less than those for conventional incinerators using unshredded feedstock. In time, the coefficient in Eq. 2 will be determined for incineration of shredded refuse. Until then, 0.75 will serve as an estimate.

When Eqs. 1 and 2 are solved, the indifferent community is one where the cost of disposing of unprocessed raw refuse (*DR*) is $7.72 per ton and the cost of disposing of the shredded refuse (*WPC*) is $5.79 per ton. A completed operating statement is shown in Fig. 4.

It is important to point out the three sources of revenue for the front end recovery facility. First, it can sell the recovered materials; second, it does not have to dispose of the recovered materials; third, it can charge a fee for the service of preparing refuse for the landfill. (In the example here, the facility can charge 25 percent of the raw refuse disposal cost, or $1.93 per ton for this service.)

The Indifferent Community

A resource recovery facility of the sort described would be economically feasible when the cost of operating the landfill, or incinerating raw, unprocessed refuse, is the $7.72 per ton calculated above and when disposing of the shredded, unrecovered residue is, accordingly, $5.79 per ton. If these figures are exact, then the community is indifferent; resource recovery costs no more or less than present disposal practices. If the community is paying,

Dumping revenue			
(156,000 tons per year, at $ 7.72 per ton)		$ 1,204	
By-product revenues (net)			
Ferrous metal	$ 159		
Glass	$ 76		
Aluminum	$ 218		
Paper	$ 62		
Other nonferrous metal	$ 47		
Total		$ 562	
Total operating revenues			$ 1,766
Waste product costs			
(126,360 tons per year, at $5.79 per ton)		$ 733	
Annual operating expenses		$ 819	
Total operating expenses			$ 1,552
Net operating income			$ 216

Fig. 4. Protypical operating statement, for materials recovery alone, of a resource recovery facility (annual rates in thousands of dollars).

Dumping revenue			
(156,000 tons per year, at $3.96 per ton)		$ 618	
By-product revenues (net)			
Ferrous metal	$ 159		
Glass	$ 76		
Aluminum	$ 218		
Paper	$ 62		
Other nonferrous metal	$ 47		
Total		$ 562	
Total operating revenues			$ 1,180
Waste product costs			
(24,960 tons per year, at $5.79 per ton)		$ 145	
Annual operating costs		$ 819	
Total operating expenses			$ 964
Net operating income			$ 216

Fig. 5. Protypical operating statement, for materials and heat recovery, of a resource recovery facility (annual rates in thousands of dollars).

or expects to have to pay, more than this in the near future, obviously resource recovery would save it money. If current (or projected) costs are less, then a front end resource recovery system would be an add-on incremental cost.

This last circumstance warrants further discussion.

If the community is paying less than $7.72 per ton to dispose of its refuse, it is not indifferent, because recovery would cost more than the community would otherwise have to pay. The community would have to decide the worth of resource recovery in light of other demands such as those for schools, medical care, and housing. However, an example may place this new demand in perspective. A family of four generates aproximately 2 tons of refuse per year. An incremental cost of $2 per ton could be incurred as a result of a decision to construct and operate a front end resource recovery system. The $2 per ton figure is not exact, but is the likely size of the increment. The point is that, on a per family basis, this is not a very large incremental cost.

Utilization of the Organic Fraction

Figure 4 shows that 47 percent of the total operating expenses of the facility is the so-called waste product disposal cost; for the most part, this unrecovered residue is organic and, therefore, combustible. A more beneficial course would be to recover this residue for use as energy.

Consider the cost of burning the combustible portion of household refuse in an electric utility boiler, along with coal, to generate electricity. In order to prepare an operating statement for a facility in which the organic fraction is so utilized, certain assumptions must be made about the amount of combustible residue, the costs of utilizing this fuel, and the costs of disposing of the wastes.

Not all of the residue can be burned. In the example represented by Fig. 4, it is estimated that approximately 16 percent of the residue (24,960 tons per year) will not be combustible and, therefore, must be disposed of in a landfill. Assume also that the cost of disposing of the residue is the same as in the case of Fig. 4—that is, $5.79 per ton. Finally, assume that the value of the organic fraction as a fuel exactly offsets the cost to an electric utility for capital modifications necessary to accept and burn it (judged to be about $1 million) and any added operating costs, such as for ash handling, air pollution control, added maintenance, and so forth (*14, 20*). In other words, assume that the organic fuel fraction is delivered to the utility boiler at no net cost to the recovery facility. Under these assumptions, the prototypical operating statement of Fig. 4 is modified to Fig. 5, and the dump fee is reduced to $3.96 per ton. This illustrates the large economic advantage of such energy recovery. Disposal costs are obviously reduced. The indifferent community of the previous example, whose disposal costs for raw, unprocessed waste were $7.72 per ton, now saves $3.76 per ton on its disposal system.

The indifferent municipality is replaced by one whose alternative disposal costs are $3.45 per ton (*21*). This lower figure greatly expands the number of communities in which resource recovery is economically viable, provided that the community has an electric utility which can utilize the organic fraction and that all other assumptions hold.

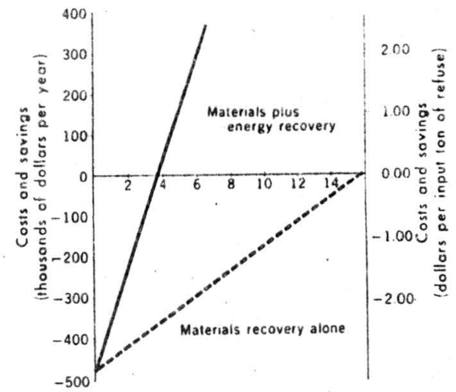

Fig. 6. Graph of incremental costs and savings for implementing resource recovery. No discount in the cost of waste disposal is assumed.

Table 4. Characteristics of prototype facility: size, 500 tons per day (156,000 tons per year input); capital cost, $2.4 million (exclusive of land); debt, $0.96 million; target return, 15 percent of equity ($216,000 per year).

Material	Weight recovered (%)
Ferrous metal	6.80
Glass	7.00
Aluminium	0.70
Paper	4.00
Other nonferrous metal	0.25
Total	18.75

Public Ownership

The same type of operating statement analysis can be used in cases where the facility would be publicly owned. The net operating income figure of $216,000 is not required, since most public bodies seek only to recover costs. In addition, the interest and depreciation entries must be modified for public financing. Also, the real estate tax entry is dropped. However, the community now loses this revenue, so, strictly speaking, in a total calculation of costs and benefits, real estate tax should be included as a cost (revenue decrease). Public financing may be through a revenue bond or general obligation bond (*22*). A 6-percent interest, 10-year bond with a level annual payment is assumed to supply the total capital requirement of $2,415,614 for the facility (Table 2). This results in a reduction of the community's disposal cost to $5.78 per ton for the materials recovery case and $2.09 per ton for materials plus energy recovery. Thus, resource recovery is possible for greater numbers of communities when some form of public financing is used.

Incremental Costs and Savings

The potential incremental costs or savings per ton for private resource recovery facilities are plotted in Fig. 6. The abscissa shows the disposal cost in dollars per ton. Both the materials recovery case and the materials plus energy recovery case are shown. In this case, no added value for the shredding process is assumed (in other words, $DR = WPC$). Hence, Fig. 6 represents a "worst possible case"—that is, the case in which the cost of disposing of shredded refuse is the same as the cost of disposing of raw, unprocessed refuse.

For the materials recovery case, the graph illustrates that, unless disposal costs are high (greater than $15.90 per ton), there is an incremental cost asso-

Table 5. Potential savings, by cost category, resulting from the use of milled refuse.

Cost category	Saving (%)
Land	62
Capital improvement	Varies
Equipment	42
Operating	42
Materials	11

ciated with resource recovery. For the community discussed previously, with a $7.72-per-ton disposal cost, the incremental cost is $240,000 per year, or $1.54 per ton. However, the line for materials plus energy recovery crosses the abscissa from cost to saving, indicating the indifferent community, at a disposal cost of $3.60 per ton. If current or near-term projected costs (say the average for the next 5 to 10 years) are above this value, there is a savings to be realized by installing materials and energy recovery. Figure 6 can be used to estimate the course a community might follow in planning a solid waste management system.

Summary

A prototypical operating statement similar to that used by business firms has been shown to be a useful decision-making tool for a community choosing a solid waste management system. When applied to resource recovery, it highlights the economics of recovery and the values of the input parameters necessary to achieve economic viability, whether in the case of public or private ownership (*23*).

In most communities, refuse processing to recover material resources must be based on more than one source of revenue. In addition to the revenues from the sale of by-products, there must be revenues from processing the incoming refuse and from a user, or dump, fee. In the first case discussed, that of materials recovery by a front end system, resource recovery is shown to be economically feasible for those communities in which the present cost of disposal is relatively high. The indifferent community was one having a current cost of $7.72 per ton; more accurately, this would be the cost for the near-term future. It is not necessary that current costs be used, since many communities are merely "dumping" their refuse. The indifference decision should be based on the cost of an environmentally sound alternative.

Energy recovery from municipal solid waste can increase the number of communities in which resource recovery will be an economic adjunct to a solid waste management system. The analysis presented here was based on the assumption that the value of the fuel recovered exactly offset the additional capital and operating costs of the utility which burns it. There could be costs above and beyond this; similarly, there could be a saving by taking into account the economic value of the organic fraction as fuel. However, it is believed that the assumption under which the materials-plus-energy case was analyzed seems to be realistic at this time.

References and Notes

1. Urban solid waste refers to all material collected in a community and consists of portions from households and commercial and industrial establishments, as well as construction and demolition rubble.
2. Resource Recovery Act of 1970, Public Law 91-512 (26 October 1970). Also S. 498, an extension of that act, passed 26 January 1973.
3. The awardees of Section 208 grants and the prime contractors or processes to be installed are State of Delaware—Hercules, Inc.; Baltimore, Landgard pyrolysis—Monsanto Enviro-Chem Systems, Inc.; Lowell, Mass.—Bureau of Mines Incinerator Residue; San Diego County, Calif.—Garrett Research and Development Company, Inc. For a description of the processes, see (*4*).
4. *Resource Recovery Catalogue of Processes*, prepared by Midwest Research Institute for Council on Environmental Quality (Council on Environmental Quality, Washington, D.C., February 1973).
5. J. G. Abert and M. J. Zusman, *Am. Inst. Chem. Eng. J.* 18, 1029 (1972).
6. N. L. Drobny, H. E. Hull, R. F. Testin, *Recovery and Utilization of Municipal Solid Waste* (Publ. No. Sw 10c, Environmental Protection Agency, Solid Waste Management Office, Washington, D.C., 1971). The authors cite several sources of data.
7. The judgment exercised in developing nominal figures for discussion is stressed. In contrast, if a specific resource recovery plant is to be built, exact numbers must be obtained for that community. One method of doing this is described by E. R. Kaiser, C. Zimmer, D. Kasner, in *Proceedings of the National Incinerator Conference* (American Society of Mechanical Engineers, New York, 1970), pp. 25–31.
8. *A Study to Identify Opportunities for Increased Solid Waste Utilization*, report to National Association of Secondary Materials Industries, Inc., (Battelle Columbus Laboratories, Columbus, Ohio, 1972).
9. Storable fuel may be created from waste by several methods. Pyrolysis and anaerobic digestion processes are described in (*4*).
10. See, for example, J. F. Laundrie and J. H. Klangress, *Pap. Trade J.* 157 (No. 16), 34 (1973).
11. Many wastes do not have a use or have a very low economic use and, therefore, are not suitable for recovery. Hence, there will always be a need for some kind of landfill as an ultimate disposal method.
12. R. L. Lesher, *Environ. Sci. Tech.* 6, 1078 (1972).
13. *Materials Recovery System, Engineering Feasibility Study* (National Center for Resource Recovery, Washington, D.C., 1972).
14. D. L. Klumb, *Solid Waste Disposal Seminar, Proceedings* (Union Electric Company, St. Louis, Mo., 1972).
15. For a recent discussion, see J. D. Headley, *J. Environ. Qual.* 1, 377 (1972).
16. We do not intend to discuss the availability of markets and similar topics. These are covered adequately elsewhere—for example, in testimony before the Joint Economic Committee, subcommittee on fiscal policy, *The Economics of Recycling Waste Materials* (92nd Congr., 1st sess., 1971). It is obvious that recovered materials will have to be sold according to specifications, like any other commodity. It is our experience that, under such conditions, buyers can be found when there is, or is to be, an assured source of reasonable tonnages of appropriately processed products.
17. See, for example, publications such as *Iron Age*, *Waste Product Journal*, and *Official Board Markets*.
18. Perhaps the only other material thought to be recoverable is plastics, for which no revenue is shown here. Although some plastics can be recycled if separated and cleaned, at present there are no efficient means of separating them from mixed municipal refuse in a sufficiently clean form for reuse in new products. It appears that the best use for plastic waste is as fuel. Some plastics have a high heat of combustion; that of polyethylene, for example, is 46×10^6 joules per kilogram. [J. Brandrup and E. H. Immergut, *Polymer Handbook* (Wiley-Interscience, New York, 1966), p. VI–44].
19. J. Reinhardt, "A report on the demonstration of the Gondard grinding mill for pulverizing refuse and landfilling milled refuse without daily cover," final report to the Department of Health, Education, and Welfare, grant 5 001 U1 00004, undated.
20. R. A. Lowe [*Energy Recovery from Waste* (Publ. No. SW-36d.ii, Environmental Protection Agency, Washington, D.C., 1973), p. 13] states that solid waste as a fuel contains 0.1 percent sulfur and has a fuel value of about 11×10^6 joules per kilogram. Our own experimental studies (unpublished) indicated that, when air classified, the waste has a fuel value of about 19×10^6 joules per kilogram, dry weight basis. Therefore, at about 25 percent moisture, as received, and sold for $0.40 per 10^9 joules, the processed waste would be worth in excess of $5 per metric ton as a fuel.
21. To identify the indifferent community, Eqs. 1 and 2 must be restated. In Eq. 1, the waste product tonnage for materials plus energy recovery, 24,960 tons, is substituted for 126,360 tons of the materials recovery alone. Equation 2 remains the same. The result is:

$$156{,}000(DR) - 24{,}960(WPC) = 473{,}000 \quad (1)$$

$$0.75(DR) = (WPC) \quad (2)$$

The solution is $DR = \$3.45$ per ton and $WPC = \$2.59$ per ton.
22. The Pollution Control Bond is a form of the tax-free Industrial Development Bond, first sanctioned by the Internal Revenue Service in 1957. These bonds are issued by local governments to buy or build equipment and plants that are then leased to private corporations. This kind of financing resulted in a significant loss in tax revenue; as a type of tax reform, Congress passed in 1968 the Industrial Revenue Bond Act, which stipulates that no individual offering could be larger than $5 million. However, an exception was made for industrial revenue issues that were intended to finance pollution control equipment. There is no limit on the size of these issues. Early beneficiaries of this exemption were corporations installing air and water pollution facilities. In April 1970, the Internal Revenue Service approved tax-exempt bonds for solid waste recycling facilities. To qualify, the processed material must be of no value to the producer; that is, it cannot be used or sold by the producer at the location of processing or at the time the bonds are issued. In addition, 65 percent of the input must fit this definition. A broad interpretation appears to have been given to the term "solid waste facility." According to the Internal Revenue Service, solid waste facility means any property used for the collection, storage, treatment, utilization, and processing of solid waste that results in the reconstitution or final disposal of such waste [sec. 103(C) 4 (E), U.S. Internal Revenue Code].
23. There have been, of course, recent dynamic changes in the nation's price structure. Building and equipment, as well as labor, costs have increased. However, secondary materials prices have risen as well. Therefore, an updating of the figures given here would be in order before any final decision to enter into resource recovery is made. Nevertheless, the method of analysis and, in general, the conclusions of this article are valid over a broad range of price structures.