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Energy Conservation Through Source Reduction

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ENERGY CONSERVATION THROUGH SOURCE REDUCTION

by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

As a result of energy shortages and rapidly rising prices for energy sources, there has developed a strong interest in ways to conserve energy. The investigation discussed in this report explored the potential for energy conservation through source reduction, in the use of input materials and the quantity of waste generated needing to be disposed of.

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ABSTRACT

This report deals with energy conservation through reduction in generation of post-consumer solid waste. The objective, scope, methodology and summary of the report are presented in Section 1. Section 2 contains the conclusions. Section 3 presents a review of output and input approaches to estimate the quantity and composition of post-consumer solid waste. Comparative notes on the two methods are included. Section 4 contains a compilation of estimates of energy consumed in the manufacture of discarded materials and in handling the solid waste. Section 5 studies potentials and possibilities of reducing refuse and estimates corresponding energy savings. Twenty examples of opportunities to reduce refuse at government, policy-maker, manufacturer, and consumer levels are proposed. The energy intensiveness of materials found in the waste stream, total energy residuals embedded in each material, and possible candidates for reduction with greatest energy savings are also presented.

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1 liter	= 0.264 gallon
1 liter	= 6.290×10^{-3} barrel
1 Kg	= 2.205 lb
1 metric ton	= 1.102 short ton
1 KWH	= 4,313 BTU

2. Customary units to metric units.

1 fluid ounce	= 0.0296 liter
1 gallon	= 3.785 liter
1 barrel	=158.983 liter
1 lb	= 0.454 Kg
1 short ton	= 0.907 metric ton
1 BTU	= 293×10^{-6} KWH

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SECTION I

INTRODUCTION

THE NEED TO CONSERVE ENERGY

Energy shortages and the need for energy conservation have been emphasized in recent years and are becoming universally recognized. The 1973 Arab oil embargo warned of future energy crises and political difficulties that the United States will face if heavy dependence on foreign oil persists. The impact of the severe natural gas shortage in the Northeastern States during the winter of 1976 is illustrative of the problem. The importance of conserving energy is reflected both in numerous Congressional hearings and recommendations and in various measures undertaken by Federal and State government. In the economic, scientific, and engineering communities, considerable research on energy sources and policy is being conducted in the public and private sectors at national, state, and local levels.

A review of energy consumption reveals that both total and per capita energy consumption steadily increased between 1950 and 1976. Total consumption more than doubled from 1950 to 1976 (or increased 3.1 percent annually), and per capita consumption rose 49.8 percent (or 1.6 percent annually) during the same period (Table 1).

Available energy resources are exhaustible. Indeed, today's only practical major energy sources are crude petroleum, natural gas, and coal. Less important sources are hydropower and nuclear power. Contributions from other energy sources (oil shale, tar sands, geothermal energy, and solar energy) are insignificant. These statements are based on the contribution of each energy source to total consumption from 1950 to 1976 (Table 2).

Recent data on all oil (the most important energy source) illustrate the critical aspect of energy supply and demand (Table 3). From 1950 to 1975, domestic demand grew 3.7 percent annually and decreased slightly from 1970 to 1975. Consequently oil imports increased at the rate of 8 percent annually during the same period. Futhermore, total oil reserves (that portion of identified resources that can be extracted with current technology) in the United States are estimated to be no more than 50 billion barrels, which, given the present levels of consumption, is at the most a 9 year supply.[2]

A review of other energy sources (coal, natural gas, hydropower, nuclear energy, oil shale, geothermal energy, and solar energy) would yield similarly discouraging results. Each energy source has its inconveniences and constraints, either quantitative (crude oil, natural gas, hydroelectric),

TABLE 1. ENERGY CONSUMPTION IN THE UNITED STATES, 1950 TO 1976*

Year	Resident population (millions)	Total consumption (trillions of KWH)	per capita consumption (thousands of KWH)
1950	151.9	9.955	65.311
1955	165.1	11.628	69.697
1956	168.1	12.303	72.926
1957	171.2	12.277	71.725
1958	174.1	12.284	70.554
1959	177.1	12.742	71.959
1960	180.0	13.053	72.340
1961	183.1	13.347	72.897
1962	185.8	13.947	75.035
1963	185.5	14.541	77.055
1964	191.1	15.087	78.813
1965	193.5	15.563	80.248
1966	195.6	16.732	85.402
1967	197.5	17.325	87.540
1968	199.4	18.294	91.553
1969	201.4	19.263	95.419
1970	203.8	19.596	95.770
1971	206.2	20.017	96.649
1972	208.2	20.972	107.749
1973	209.9	21.835	104.264
1974	211.4	21.283	100.749
1975	213.1	20.671	96.942
1976	214.7	21.672	100.749

* Source: Reference 1.

technological (geothermal, tar sand, solar), economical (oil shale, solar, nuclear), or environmental (coal, nuclear). It is logical to conclude, as did the Energy Policy Project of the Ford Foundation, (Final report, A Time To Choose, quoted by William, R. H.[19]), that the Nation's best approach to balancing its energy budget, safeguarding the environment, and protecting the independence of its foreign policy, is to limit energy consumption through policies that encourage more efficient use.

Objective and Scope

This study deals with the potential of energy conservation through reduction in the amount of refuse generated (source reduction). Refuse contains residuals of energy. Decreasing the amount of refuse reduces (a) the energy required in manufacture, (b) the energy imput necessary to collect, transport, process and/or recycle the refuse, (c) the land necessary for waste disposal, and (d) the environmental problems associated with management of large amounts of refuse. Reduction of refuse entails conservation of materials, since no matter how extensively recycling is carried out, significant amounts of materials are still lost in incinerators or in land disposal sites.

Source reduction is of particular interest in the United States where the waste generation rates are considerably higher than in other developed countries. The annual solid waste generation rate in the United States

TABLE 2. CONTRIBUTION OF MAJOR ENERGY SOURCES TO TOTAL ENERGY CONSUMPTION IN THE UNITED STATES, 1950 TO 1976*

	Percent			
Year	Coal	Petroleum	Natural Gas	Electricity (hydropower & nuclear power)
1950	37.2	37.2	20.3	NA
1960	22.8	41.8	31.7	3.7
1965	22.3	40.1	33.7	3.9
1966	22.2	37.9	34.4	3.7
1967	21.1	39.8	35.0	4.1
1968	20.5	39.8	35.7	4.0
1969	19.6	40.0	36.1	4.3
1970	19.0	40.4	36.3	4.3
1971	17.6	41.0	36.6	4.8
1972	17.3	42.3	35.5	4.9
1973	17.9	43.2	33.8	5.2
1974	17.8	42.5	33.4	6.3
1975	18.2	42.8	31.8	7.2
1976	18.6	43.9	30.6	6.9

* Source: Reference 1.

is approximately 680 Kg per capita (or a daily rate of 1.863 Kg per capita). By contrast, England generates 317; France, 272; the Netherlands, 206; Germany, 349; Switzerland, 249; and Italy, 211 Kg per capita each year[3]. These figures include household and commercial wastes.

Solid wastes fall into many categories (Figure 1), among which post-consumer solid wastes, or combinations of household and commercial solid wastes, are the most important. Results of the 1968 National Survey show that of the daily average of 2.410 Kg per capita, 2.039 Kg originate from households and commercial institutions[4]. This study deals with post-consumer solid wastes.

The materials commonly found in the waste stream are paper, ferrous metals, aluminum, other nonferrous metals, glass, plastics, rubber, textile, leather, wood, food wastes, yard wastes, and miscellaneous inorganic wastes. Only the first eight of these will be discussed, because they are highly energy - intensive materials, based on the energy per ton of material and on the total energy embedded in each material. The other components are not considered, principally because of the unavailability of data. In addition, the energy associated with yard wastes and miscellaneous inorganic wastes is

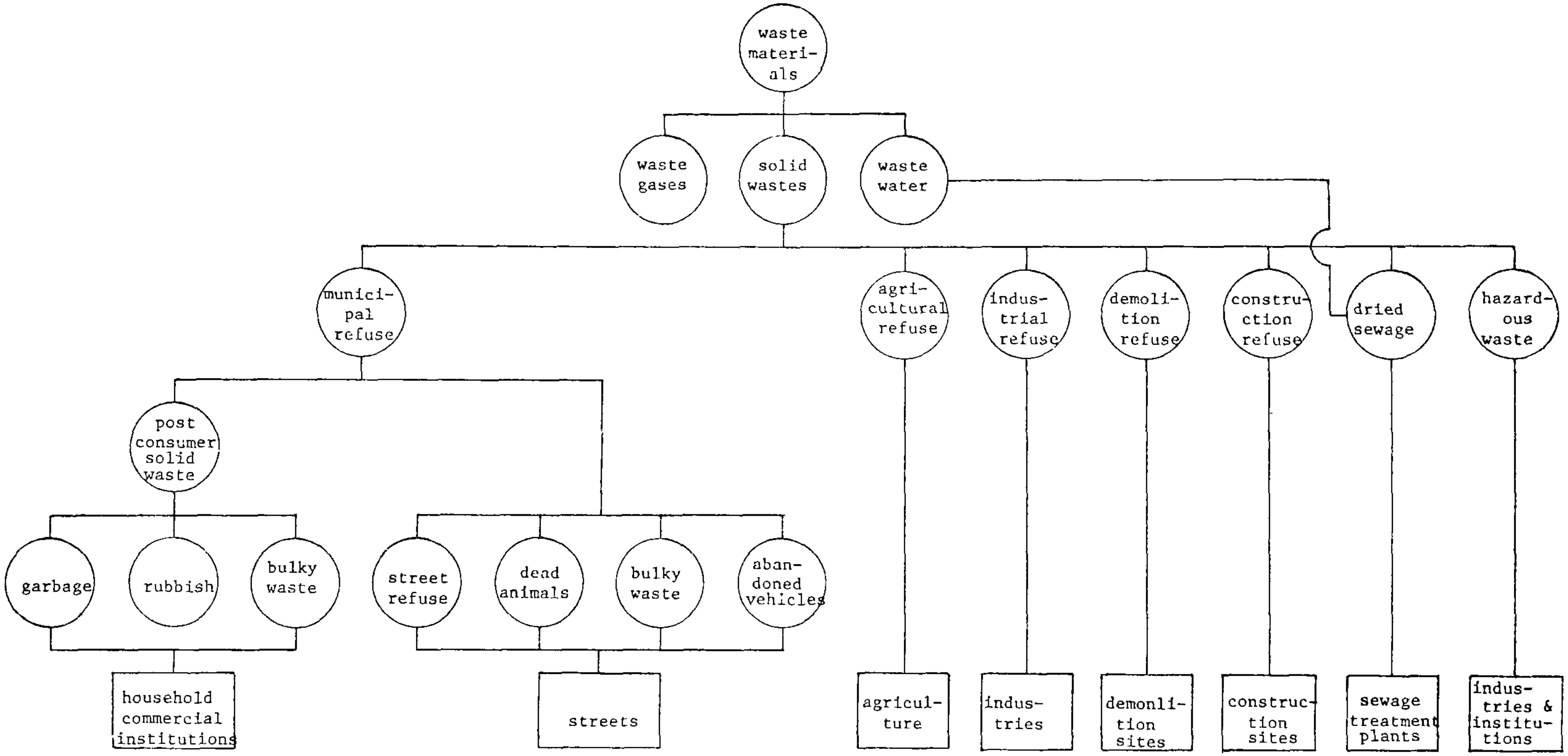

Figure 1. Sources and Classes of Solid Waste

assumed to be negligible. Reduction of food wastes is difficult and impractical, especially in an affluent society.

TABLE 3. SUPPLY AND DEMAND FOR ALL OILS, UNITED STATES.
(Millions of Barrels) * †

Year	Supply			Demand		
	Import	Domestic	Total	Export	Domestic	Total
1950	310.2	2,155.7	2,466.0	111.3	2,375.1	2,486.4
1955	455.7	2,766.3	3,211.9	134.2	3,087.8	3,222.0
1960	664.1	2,915.8	3,579.5	73.9	3,535.8	3,609.7
1965	900.7	3,290.1	4,190.9	68.3	4,125.5	4,193.7
1970	1,248.1	4,129.6	5,377.7	94.5	5,237.7	5,332.2
1971	1,432.9	4,077.8	5,510.7	81.8	5,417.6	5,499.4
1972	1,735.2	4,102.1	5,837.3	81.5	5,848.1	5,929.6
1973	2,263.6	3,998.5	6,262.0	84.2	6,297.3	6,381.7
1974	2,231.0	3,831.8	6,062.7	80.5	6,078.2	6,158.7
1975	2,198.9	3,661.7	5,860.6	76.4	5,946.2	6,022.6

* Source: Reference 9.

† Barrel is not a metric system unit but is internationally used in the oil industry.

This report estimates the amount of energy embedded in the waste stream, thus revealing the amount of energy that could be conserved if the quantity of refuse were reduced. This work requires prior review of the quantity and composition of solid waste and the energy associated with the manufacture and handling of discarded materials. Possible reductions will be identified and the associated energy savings will be estimated. Some incentives aimed at refuse reduction will also be proposed.

Summary and Methodology

Section 3 is a literature review of quantities and composition of solid waste generated across the country. Two methods are used for estimating quantities of refuse, the output and the input approach. The output approach directly measures the quantity of refuse. Refuse composition is also determined by sampling the refuse, classifying it and weighing each component. The quantity of each component in the waste stream can then be determined by multiplying its composition percentage with the refuse quantity. This approach is most appropriate to the study of a city waste stream but it can also be applied at the national level by devising an average composition for the national refuse. The imput approach estimates the quantity and composition of refuse by considering the flow of materials in the economy where consumer products (with the exception of food) are discarded after use. Various data relative to both output and input approach are compiled. Some comparative notes and statistical tests of hypotheses about quantity and composition of solid waste are incorporated in this section.

Section 4 is a compilation of data on energy associated with the manufacture and handling of solid discarded products. Data on energy required for the fabrication of products is not accounted for because they are not available.

Section 5 provides estimates of energy consumed in the manufacture and management of materials discarded in the national waste stream. The base year chosen was 1975. Data on quantity and composition of refuse developed by the Resource Recovery Division of the U. S. Environmental Protection Agency (EPA) were used in the analysis. Potential reductions in refuse are presented and estimates of associated energy savings are made. Also included are proposed incentives for reducing refuse generation. These require the cooperation of government, industry and the consumer.

In the appendix are presented computations details of statistical analyses made in Section 3.

Metric system units are used throughout the report, except when otherwise indicated. However, for practical purposes, instead of using a certain consistent unit system (e.g. CGS or MKS or MTS system), most familiar units for various quantities are used. Thus, for example, both metric ton and kilogram are used depending on the circumstances, also KWH is used as an energy unit although it does not belong to any specific unit system. Conversion factors given in the Metric Conversion Table are used except when otherwise noted. Only those units used in this report are compiled in the Metric Conversion Table.

SECTION 2

CONCLUSIONS

Based on a sample of 24 compositions of solid waste at various geographical locations throughout the country, it was found that the solid waste was statistically homogeneous. This means that the consuming and discarding habits of the consumers do not change significantly nationwide. Therefore, it would not be unreasonable to conceive common policies governing solid waste management for all states.

Though the energy consumed in handling the refuse is far from being insignificant (30,381 million KWH in 1975), it is very small compared with the energy consumed in the manufacturing of discarded materials (767, 708 million KWH in 1975) - about 4 percent of the latter. The efficient way to conserve energy in solid waste management is then through source reduction rather than through improvement of the collection, processing and disposal of the waste. Material recycling is most beneficial in resource recovery but represents an expensive route in energy conservation. Source reduction must be a joint effort among government policy makers, manufacturers, and consumers. Examples of incentives to reduce refuse at these three levels were incorporated in the report.

Total energy lost in the management of 123.5 million metric tons of solid waste generated in the base year 1975 was 798,089 million KWH, or 3.86 percent of the total national energy consumption (20.671 trillion KWH). This was a conservative estimate in two ways. First, the quantity of solid waste was an EPA material flow estimate (input approach), which yielded a·per capita generation rate significantly less than the population mean of generation rates determined by the output approach. Second, the figure represented only the energy consumed in handling the waste and in manufacturing the materials found in the waste stream, but did not include the energy consumed in producing products. With the hypothetical reductions shown in Table 33, it would have been possible to save at least 184 billion KWH-23.06 percent of the total energy spent on managing the refuse, or 0.89 percent of the national energy consumption. In terms of fuel conservation, the equivelent of 19.02 billion liters of gasoline or 17.22 billion liters of diesel fuel would have been saved.

These figures are significant in light of the current energy dilemma, but it is possible that even greater savings could be realized. The hypothetical source reductions proposed here are only the most feasible. A more detailed examination of the waste stream, the products currently available on the market, and their packaging could uncover other possibilities.

Any reduction of refuse at its source implies conservation of our irreplaceable natural resources. Manpower is also conserved and environmental impacts of the waste is reduced. Significant source reduction cannot be achieved, however, without accompanying changes in industry, commerce, and lifestyles. It is hoped that cooperation among government agencies, industry, and consumers will make any necessary inconveniences acceptable to the majority.

It was found herein that intensive materials are, in decreasing order, aluminum, rubber, copper, plastics, textiles, ferrous metals, paper, glass. Materials bearing greatest amounts of total residual energy are paper, ferrous metals, plastics, rubber, aluminum, glass, textiles, copper and other nonferrous metals. This means that as far as energy savings in reducing one unit weight of material is concerned, it is most advantageous to reduce aluminum, whereas paper is the material with greatest energy savings potential. In terms of consumer products, possible candidates for reduction with greatest energy savings are major appliances, rubber tires, corrugated paperboard, aluminum beverage cans, glass beverage containers, grocery paper sacks. Other research topics in energy conservation might involve comparisons between various activities, such as material recycling, energy recovery through pyrolysis, using shredded refuse as fuel (RDF) etc.

SECTION 3

QUANTITIES AND COMPOSITION OF SOLID WASTE

A knowledge of the quantities and composition of solid waste generated is essential to its management, and particularly to any consideration of energy conservation in the manufacturing and handling of solid waste. Estimating quantities and composition of solid waste is difficult because of the heterogeneous nature of the waste, which depends on the season, size, and lifestyle of the community.

Various research groups have come up with many different results on the quantities and composition of post consumer solid waste generated. Two basic methods have been used: the output and the input approach. The output approach involves direct evaluation of solid waste quantities by weighing or by other measures. The input approach, also called material flow approach, estimates quantities of materials involved in the manufacturing or marketing of products that will ultimately go into the waste stream.

One major item of interest is the quantity of recycled materials from the waste stream, especially since passage of the Resource Recovery Act by Congress in 1970.

QUANTITIES OF SOLID WASTE

Output Approach

The output approach is usually based on questionnaire survey data obtained from solid waste collection agencies (the sample size is generally too large to be measured by a single investigator).

1968 National Survey of Community Solid Waste Practices--

This survey was designed by the Solid Wastes Programs, U. S. Department of Health, Education and Welfare. Survey data available on July 1, 1968, were presented in their basic forms[5] and also in concise statistical format[6]. All land disposal sites and facilities at which public and/or private collectors deposited solid wastes were to be surveyed, regardless of the size of community served by the site. Unauthorized dumpings at roadsides or in other areas were not considered in this survey. In addition, private disposal sites or facilities owned and operated by industrial, commercial, or institutional establishments solely for reduction or disposal of their own solid waste were not surveyed. Onsite disposal facilities such as apartment house incinerators and household garbage grinders were also excluded.

A total of 6,259 communities were surveyed, representing an estimated 1967 population of 92.5 million persons, or approximately 46.3 percent of the total population of the United States. On total population basis, the sample is approximately 75 percent urban in nature.

Most of the data available were estimates; only a small portion was measured. From the survey data, it was estimated that 172 million metric tons of solid waste were generated annually, corresponding to 2.410 Kg per capita daily. These figures include reported demolition, construction, industrial, and other municipal solid waste, in addition to household, commercial and institutional refuse of all kinds. Of the daily 2.410 Kg per capita, 1.880 Kg was estimated as the household and commercial contribution to the nationwide average (Table 4).

A more rigorous evaluation of the complete returns from the 1968 survey was subsequently conducted[7]. Figures based on estimates from a selected sampling of the returns are shown in Table 5.

1971 Private Sector Collection Survey.

As part of a study of the private sector refuse collection industry[8], Applied Management Sciences, Inc. (AMS), developed national estimates of U.S. per capita waste generation for 1970 based on quantities collected. Using large samples from private waste haulers, scaled up to national totals on the basis of estimated share of total customers covered by the private sector survey, AMS was able to estimate residential, commercial, and industrial solid waste. Private collectors play an important role in the collection of household and commercial solid waste: 32 percent of household waste and 62 percent of commercial waste is collected by private collectors[4]. The AMS total national estimates and per capita generation rate are shown in Table 6.

Other Results.

The daily per capita generation rates for 12 cities in the United States were compiled by the APWA in 1968 for 1957-58[10]. These cities had populations ranging from 4,500 to 8 million. The generation rates of six of these 12 cities from 1955 to 1968 are reported by APWA in Table 7.

The Quad - Cities New Jersey Solid Waste Project reports a daily generation rate in these cities of 1.241 Kg per capita for municipal waste during 1966-68[11].

EPA has recently supported two independent residential collection studies. One set of data covering a number of residential collection routes in each of 11 city or county jurisdictions was developed by ATC Systems, Inc., for a 12 month period during 1972-73[7]. The other set of data was made available by Applied Management Sciences, Inc., and involved analysis of more than 20 communities during the 1971-72 period[7]. Results of these two surveys are shown in Table 8.

Input Approach

TABLE 4. AVERAGE SOLID WASTE COLLECTED (Kg/PERSON DAILY), 1967*

Type of Solid Waste	Urban	Source Rural	National
Household	0.571	0.326	0.516
Commercial	0.208	0.050	0.172
Combined	1.191	1.178	1.192
Industrial	0.294	0.168	0.267
Demolition, construction	0.104	0.009	0.082
Street and Alley	0.050	0.014	0.041
Miscellaneous	0.172	0.036	0.140
Total	2.590	1.781	2.410

* Source: Reference 4

TABLE 5. REVISED ESTIMATES OF NATIONWIDE SOLID WASTE COLLECTION FOR 1967, BASED ON THE 1968 NATIONAL SURVEY OF COMMUNITY SOLID WASTE PRACTICES*

Source	Total Solid Waste Collected (millions of metric tons)		Daily Average Per Person (Kg)	
Residential	79.8		1.101	
Commercial and institutional	51.7		0.716	
subtotal	131.5		1.817	
	Low Estimate	High Estimate	Low Estimate	High Estimate
Other municipal	5.4	20.0	0.077	0.276
Demolition and construction	4.5	17.2	0.059	0.240
Industrial	30.8	95.2	0.430	1.314

* Source: Reference 7. Based on Environmental Protection Agency analyses of final questionnaire returns received by the 1968 National Unpublished data, May 1970.

The input or material flow approach is based on industrial production and/or trade statistics of all major materials and final products that become solid waste after they are used.

EPA Material Flow Estimating Method--

Frank A. Smith and Fred L. Smith, Jr. of EPA developed the material flow estimating method[7,12,13]. This method is based principally on U. S. Government and industrial trade association statistics and nationwide industrial production, marketing, foreign trade and consumption of major raw materials and final products. Using the principles of mass balances and a knowledge of the economy's material flow structure, the researchers adjusted the original material product data where necessary for industrial scrap losses, product lifetime, and material recycling to yield the final estimates of net waste disposal for the manufactured goods component of solid waste.

TABLE 6. 1970 NATIONWIDE SOLID WASTE COLLECTION ESTIMATES BASED ON PRIVATE SECTOR SOLID WASTE MANAGEMENT SURVEY.*

Source	Total Yearly Collection (millions of metric tons)	Daily Average Per Person (Kg)
Residential	116.1	1.567
Commercial	52.6	0.711
Subtotal	168.7	2.278
Demolition and other	10.9	0.145
Industrial	59.9	0.784
Grand total	239.5	3.207

* Source: Reference 7

The solid waste is divided into two categories, the non-food product solid waste, and the food, yard and miscellaneous waste. Only the former type (non-food product waste) is estimated directly using the actual material flow approach. Food, yard and miscellaneous waste are estimated indirectly from data on non-food product waste and from data on municipal waste composition developed by Niessen and Chansky[14]. Estimates were adjusted to reflect the moisture transfer occurring during storage and collection of waste components, and the "as discarded" and "as disposed" moisture content of each category was used.

TABLE 7. REFUSE GENERATION RATES IN SIX CITIES, 1958-68 (Kg PER CAPITA DAILY)*

City	1958	1965	1968
Cincinnati, Ohio	1.369	1.533	1.694
Garden City, N. Y.	1.785	1.623	1.805
Los Angeles, C. A.	2.081	2.945	3.147
New York, N. Y.	1.644	1.841	-----
Seattle, W. A.	1.700	1.872	1.776
Washington, D. C.	2.033	1.917	2.158

* Source: Reference 6.

Estimates of net post-consumer solid waste for 1971 through 1975 are shown in Table 9. Tables 10 and 11 show solid waste generation and resource recovery for 1975.

Projections of post-consumer solid waste generation, resource recovery and net waste disposal for 1980, 1985 and 1990 were also estimated and shown in Table 12.

TABLE 8. PER CAPITA SOLID WASTE COLLECTION: COMPARISONS FROM TWO RECENT STUDIES*

Item	Solid waste collected daily (Kg per capita) ACT Systems, Inc. 1972-73	Applied Management Sciences, Inc. 1971-72
Unweighted arithmetic average of individual community data	1.078	1.065
Median	1.101	1.087
Range of values	0.779 - 1.554	0.498 - 1.540

* Source: Reference 7.

URS Research Company Prediction Model--

URS Research Company, under contract with EPA, developed a prediction model for residential and commercial solid waste.[16, 17] The theory behind the model is that waste generated by a community is derived primarily from the goods and materials consumed there and that therefore waste quantities and characteristics can be estimated from the data on the consumption habits of the community. Quantitative results at the national level were not presented in the URS's final report, but the computation methodology was explained thoroughly.[17]

International Research and Technology Corporation Forecasting Method--

Under contract with the EPA, the International Research and Technology Corporation (IR & T) has developed a method of forcasting the composition and weight of household solid wastes using input-output techniques.[18] The forecasting model uses data from the input-output table provided by the Department of Commerce. Projections of input-output tables and of micro variables in association with them are made by the Bureau of Labor Statistics.

The input-output table represents all accounting transactions in the economy. Any row of the input-output table can be represented by an equation of the following kind:

$$t_{i1} + t_{i2} + \text{---} + t_{in} + f_i = x_i$$

where t_{ij} is the sales of sector i to sector j, f_i is the sales by sector i that go to final uses, and x_i is the total sales of sector i.

The input-output model is obtained by making the following assumption:

$$t_{ij}/x_j = a_{ij}; \text{ or } t_{ij} = a_{ij}\, x_j$$

where a_{ij} is assumed to be constant.

TABLE 9. POST-CONSUMER NET SOLID WASTE DISPOSED OF BY MATERIAL AND PRODUCT CATEGORIES, 1971-75*
(As-generated wet weight, in millions of metric tons)

Materials and products	1971	1972	1973	1974	1975
Material composition:					
Paper	35.5	38.5	40.1	39.3	33.7
Glass	10.0	11.5	12.0	11.7	12.1
Metal	10.7	11.0	11.2	11.8	11.0
Ferrous	(9.6)	(9.8)	(10.0)	(10.4)	(9.8)
Aluminum	(0.7)	(.8)	(0.9)	(0.9)	(0.8)
Other	(0.4)	(.4)	(0.3)	(0.3)	(0.4)
Plastics	3.8	4.3	4.5	4.1	4.0
Rubber and leather	3.0	3.1	3.3	3.7	3.0
Textiles	1.6	1.6	1.7	1.9	2.0
Wood	4.2	4.3	4.5	4.3	4.5
Total nonfood product waste	69.7	74.3	77.3	76.8	70.3
Food waste	20.0	20.1	20.3	20.5	20.7
Total product waste	89.7	94.4	97.6	97.3	91.0
Yard waste	21.9	22.2	22.7	23.1	23.6
Miscellaneous inorganics	1.6	1.6	1.7	1.7	1.7
Total	113.2	118.2	122.0	122.1	116.3
Product composition:					
Newspapers, books, magazines	9.3	9.9	10.2	10.4	9.0
Containers and packaging	37.8	40.9	42.4	41.2	37.8
Major household appliances	1.9	1.9	1.9	1.9	2.1
Furniture and furnishings	2.9	3.0	3.1	3.0	3.1
Clothing and footwear	1.1	1.1	1.2	1.2	1.2
Other products	16.7	17.7	18.5	19.1	17.1
Total nonfood product waste	69.7	74.5	77.3	76.8	70.3
Food waste	20.0	20.1	20.3	20.5	20.7
Total product waste	89.7	94.6	97.6	97.3	91.0
Add: Yard and misc. organics	23.5	23.6	24.4	24.8	25.3
Total	113.2	118.2	122.0	122.1	116.3

* Office of Solid Waste, Resource Recovery Division, and Franklin Associates, Ltd. Revised February 1977. This table is reproduced from Reference 15.

Then:

$$
\begin{aligned}
&(1-a_{11})x_1 - a_{12}x_2 - \ldots - a_{1n}x_n = \delta_1 \\
&-a_{21}x_1 + (1-a_{12})x_2 - \ldots - a_{2n}x_n = \delta_2 \\
&\cdot \\
&\cdot \\
&\cdot \\
&-a_{n1}x_1 - a_{n2}x_2 - \ldots + (1-a_{nn})x_n = \delta_n
\end{aligned}
$$

This is the set of simultaneous equations of the input-output model, which in matrix form becomes:

$$(I - A)X = Y \quad \text{or} \quad X = (I-A)^{-1}Y = BY$$

where $B = (I-A)^{-1}$ is the inverse of the matrix (I-A).

Consider the following mass balance condition:

weight purchased - industrial waste=embodied waste

If the two following adjustments are made in the inverse matrix, the latter can provide information that can be used to infer the amount and composition of post-consumer solid waste:

1. The effect of prices must be eliminated so that purchases of inputs define the weight of inputs; and
2. The amount of industrial waste must be subtracted.

The purpose of this brief review of the input-output technique is only to show the methodology. It is beyond the scope of the report to go into the actual computation steps which are described in details by IR & T.[18] The computation steps require a number of assumptions and a series of adjustments in the entries of the input-output table.

This technique has been used by IR & T in Table 13 to compute the composition of household and commercial solid waste generated for the base year 1971. The table also contains corresponding results developed by the National Center for Resource Recovery (NCRR)[21] and by EPA (Fred L. Smith, Jr.).[12]

EPA Strategic Environmental Assessment System (SEAS)--

The Strategic Environmental Assessment System (SEAS) is an extensive model developed by EPA that utilizes demographic, economic, and technological projections to forecast environmental conditions to the year 1985. SEAS is closely related to IR & T's input-output technique in a number of ways, particularly in its methodology and its use of data from INFORUM (The Interindustry Forecasting Model of the University of Maryland).

Let $M_{ij}(t)$ be the amount of material i, by weight, flowing into product class j in year t. $M_{ij}(t)$ can be estimated through the input-output technique by a rather complex formula.[20] Each of the entries in the $M_{ij}(t)$ matrix represents commodities flowing into finished products. At some time in the future, these commodities become waste. The model next projects the quantity of material i embodied in product j, which is disposed of in year t. This is calulated by timelagging the M_{ij} matrix.

Some selected results of SEAS solid waste projections are presented in Table 14.

Quantities Of Recycled Materials

EPA figures for materials recycled from the solid waste stream from 1971 to 1975 are shown in Table 15. Notice that these estimates are generally smaller than both NCRR estimates[21] and Midwest Research Institute estimates[22], because EPA excludes converting wastes and a number of special

TABLE 10. MATERIAL FLOW ESTIMATES OF RESIDENTIAL AND COMMERCIAL POST-CONSUMER NET SOLID WASTE DISPOSED OF, BY MATERIAL AND PRODUCT CATEGORIES, 1975*

Material category	Product category (In millions of metric tons, as-generated wet weight)							Totals			
								As-generated wet weight		As-disposed wet weight	
	Newspapers, books, magazines	Containers, packaging	Major household appliances	Furniture, furnishings	Clothing, footwear	Food products	Other products	Million tons	Percent	Million Tons	Percent
Paper	8.9	17.3	Tr	Tr	-	-	7.6	33.7	29.0	40.7	34.9
Glass	-	11.1	0.1	Tr	-	-	0.9	12.1	10.4	12.2	10.5
Metals	-	5.4	1.9	0.1	-	-	3.6	11.0	9.6	11.4	9.8
Ferrous	-	(4.7)	(1.6)	(0.1)	-	-	(3.3)	(9.8)	(8.6)		
Aluminum	-	(0.6)	(0.1)	Tr	-	-	(0.1)	(0.8)	(0.7)		
Other nonferrous	-	-----	(0.2)	Tr	-	-	(0.2)	(0.4)	(0.3)		
Plastics	-	2.4	0.1	0.1	-	-	1.4	4.0	3.4	4.5	3.8
Rubber and Leather	-	Tr	Tr	Tr	0.6	-	2.3	3.0	2.6	3.1	2.6
Textiles	-	0.1	Tr	0.5	0.5	-	0.8	2.0	1.6	2.0	1.7
Wood	-	1.6	Tr	2.3	-	-	0.5	4.5	3.8	4.5	3.8
Total nonfood product waste	8.9	37.8	2.1	3.1	1.1	-	17.1	70.3	60.5	78.4	67.3
Food waste	-	-	-	-	-	20.1	-	20.7	17.8	17.3	14.9
Total product waste	8.9	37.8	2.1	3.1	1.1	20.1	17.1	91.0	78.3	95.7	82.2
Yard waste								23.6	20.2	19.0	16.3
Misc. inorganics								1.7	1.5	1.8	1.6
Grand total								116.3	100.0	116.5	100.0

* Office of Solid Waste, Recovery Division and Franklin Associates, Ltd., Revised January 1977. This Table is reproduced from Reference 15.

TABLE 11. POST-CONSUMER AND COMMERCIAL SOLID WASTE GENERATED AND AMOUNT RECYCLED, BY PRODUCT CATEGORY, 1975* ‡
(AS-GENERATED WET WEIGHT, IN THOUSANDS OF METRIC TONS)

Product category	Gross discards	Material recycled		Net waste disposed of		
		Quantity	Percent	Quantity	% of total waste	% of nonfood product waste
Durable goods:	13,369	354	3	13,015	11	19
Major appliances	2,204	136	6	2,068	2	3
Furniture, furnishings	3,057	0	0	3,057	3	4
Rubber tires	1,623	172	11	1,451	1	2
Miscellaneous durables	6,485	46	1	6,439	5	9
Nondurable goods, exc. food:	21,895	2,517	11	19,378	17	27
Newspapers	8,027	1,651	21	6,376	5	9
Books, Magazines	2,789	231	8	2,558	2	3
Office paper	4,725	635	13	4,090	4	6
Tissue paper, incl. towels	2,027	0	0	2,027	2	3
Paper plates, cups	440	0	0	440	-	-
Other nonpackaging paper	948	0	0	948	1	1
Clothing, footwear	1,134	0	0	1,134	1	2
Other misc. nondurables	1,805	0	0	1,805	2	3
Containers and packaging:	42,221	4,322	10	37,899	33	54
Glass containers:	11,356	336	3	11,020	10	16
Beer, soft-drink	5,755	227	4	5,528	5	8
Wine, Liquor	1,624	27	2	1,597	1	2
Food and other	3,977	82	2	3,895	3	6
Steel cans:	5,011	249	5	4,762	4	7
Beer, soft-drink	1,215	59	5	1,156	1	2
Food	2,898	145	5	2,753	2	4
Other nonfood cans	689	36	5	653	1	1
Barrels, drums, pails, misc.	209	9	5	200	-	-
Aluminum:	698	77	11	621	1	1
Beer, soft-drink †	462	73	16	389	-	1
Other cans	23	0	0	23	-	-
Aluminum foil	213	4	2	209	-	-
Paper, paperboard:	20,983	3,660	18	17,323	15	25
Corrugated	11,356	2,499	22	8,857	7	13
Other paperboard	4,961	653	13	4,308	4	6
Paper packaging	4,666	508	11	4,158	4	6
Plastics:	2,390	0	0	2,390	2	3
Plastic containers	381	0	0	381	-	-
Other packaging	2,009	0	0	2,009	2	3
Wood packaging:	1.633	0	0	1,633	1	2
Other misc. packaging	150	0	0	150	-	-
Total nonfood product waste	77,485	7,193	9	70,292	61	100
Add: Food waste	20,666	0	0	20,666	18	29
Yard waste	23,591	0	0	23,591	20	33
Misc. Inorganic wastes	1,723	0	0	1,723	1	2
Total	123,465	7,193	6	116,272	100	164

* Office of Solid Waste, Resource Recovery Division, and Franklin Associates, Ltd. Revised January 1977.
† Includes all-aluminum cans and aluminum ends from nonaluminum cans.
‡ This Table is reproduced from Reference 15.

TABLE 12. U. S. BASELINE POST-CONSUMER SOLID WASTE GENERATION PROJECTIONS*

	Estimated		Projected		
	1971	1973	1980	1985	1990
Total gross discards					
Millions of metric tons per year	121	131	159	182	204
Kg per person per day	1.595	1.699	1.939	2.116	2.265
Resource recovery					
Millions of metric tons per year	7	8	17	32	53
Kg per person per day	0.095	0.104	0.203	0.367	0.584
Net waste disposal					
Millions of metric tons per year	114	123	142	150	151
Kg per person per day	1.499	1.595	1.726	1.749	1.681

*Source: Resource Recovery Division, Office of Solid Waste Programs, U. S. EPA.
This Table is reproduced from Reference 23.

TABLE 13. COMPARISON OF THREE STUDIES OF THE QUANTITY AND COMPOSITION OF POST-CONSUMER SOLID WASTE GENERATED IN 1971 (IN MILLIONS OF METRIC TONS)*

			IR & T	
Materials	NCRR	Smith	Household	Commercial
Paper	34.6	35.5	26.8	14.2
Newsprint	6.9	----	9.6	----
Newspaper, books and magazines	----	9.3	11.7	----
Containers and packaging	----	18.5	14.8	----
Glass	9.8	11.0	9.4	3.1
Containers	8.8	10.1	8.2	----
Metals	8.1	10.8	11.28	----
Steel containers	4.9	4.9	4.9	----
Steel other	3.2	4.7	5.3	----
Aluminum containers	.23	.5	.19	----
Aluminum other	.34	.2	.39	----
Other metals	.41	.2	.5	----
Plastics	2.0	2.9	1.7	1.0
Containers	----	2.3	0.8	----
Containers and film	1.7	----	----	----
Durables	.09	----	.14	----
Textiles	2.6	1.6	3.8	----
Wood	----	4.2	7.7	2.2
Containers	----	1.6	----	----
Furniture	----	2.1	.9	----
Rubber	1.5	----	1.3	.5
Rubber and leather	----	2.9	----	----

* Source: Reference 18.

obsolete scrap sources. Two EPA estimates are, however, quite comparable (Table 14).

COMPOSITION OF SOLID WASTE

As in the study of quantities of solid waste, the composition of solid waste can be estimated by either the sampling or the material flow approach. The sampling approach (output approach) provides the composition of solid waste generated by a certain community. Statistical analysis of a large sample representing different areas of the country could yield the composition of an average national solid waste. Data obtained by the material flow approach (input approach) represent the composition of an average solid waste either at the national or community level, depending on the model used.

TABLE 14. COMPARISON OF SEAS WITH SMITH RESULTS FOR MUNICIPAL WASTE, 1973 (MILLIONS OF METRIC TONS)*

Solid Waste Component	Gross discards		Resource recovery		Net waste	
	SEAS	Smith	SEAS	Smith	SEAS	Smith
Paper	48.0	48.1	7.6	7.92	40.36	40.1
Glass	12.0	12.3	0.24	0.25	11.8	12.0
Plastics	5.0	4.5	----	----	5.0	4.6
Rubber	2.0	2.5	0.45	0.36	1.5	2.4
Aluminum	0.9	0.9	0.06	0.04	0.6	0.9
Other non-ferrous metals	0.4	0.4	0.09	----	0.3	0.4
Ferrous metals	13.2	10.2	0.73	0.36	12.5	10.0
Textiles	4.2	1.7	0.36	----	3.8	1.7
Wood	7.8	4.5	----	----	7.8	4.5
Leather	----	0.9	----	----	----	0.9
Total non-food products	93.5	86.0	9.53	8.93	83.7	77.5
Food, yard and miscellaneous	49.3	44.7	----	----	----	44.7
Total waste	142.8	130.7	9.53	8.93	130.6	122.2

Source: Reference 23

TABLE 15. TRENDS IN MATERIAL RECOVERY FROM POST-CONSUMER MUNICIPAL WASTE, 1971-75 BY TYPE OF MATERIAL*
(IN THOUSANDS OF METRIC TONS)

	1971	1972	1973	1974	1975
Paper and paperboard	6,798	7,324	7,918	7,646	6,176
% of gross paper and board discards	15.9	16.0	16.5	16.3	15.5
Aluminum	18	27	32	47	79
% of gross aluminum discards	2.4	3.2	3.4	5.0	8.7
Ferrous metals	127	181	272	363	433
% of gross ferrous discards	1.3	1.4	2.4	3.4	4.4
Glass	200	248	277	297	334
% of gross glass discards	1.8	2.1	2.3	2.5	2.7
Rubber (including tires and other)	233	222	198	176	171
% of gross rubber discards	8.9	7.9	6.8	6.1	6.9
Total materials	7,376	8,002	8,697	8,529	7,193
% of gross nonfood product waste	9.5	9.6	10.1	10.0	9.3
% of total post-consumer waste	6.1	6.2	6.7	6.5	5.9

* Source: Office of Solid Waste, Resource Recovery Division, and Franklin Associates, Ltd. This Table is reproduced from Reference 15.

Sampling Approach (Output Approach)

Most existing estimates of solid waste composition were obtained by the sampling approach which consists of sampling, manual sorting, separating, and weighing refuse at the disposal site. A variation of the manual sorting technique is the photographic sorting technique, which was developed in 1974. The sampling technique is the most simple and direct method for determining the composition of solid waste.

In the Quad-City solid waste project[11], trucks to be sampled were selected on a random basis. The composition analysis was performed by hand picking the various types of material and placing them into corresponding containers. Eight containers were used, each with a description of the type of material to be deposited in it. When the sorting was complete, each container (55-gallon drum) was weighed to the nearest pound, and the tare weight of each type of material, from which the composition of solid waste was computed.

Systems Technology Corporation (SYSTECH), Xenia, Ohio has conducted in recent years several sampling analyses of solid wasted for the cities of Cincinnati, Oakwood, and Franklin, Ohio, and Atlanta, Georgia, under various projects with EPA (Personal communication, Joseph T. Swartzbaugh, SYSTECH, Xenia, Ohio; and "Summary of Sort Procedures for Mixed Municipal Waste", 1975, SYSTECH, unpublished). Special consideration was given to obtaining representative samples by using a random number generator to select the truck to be monitored. The solid waste from the selected vehicles was then well mixed by using a front-end leader before sampling. Furthermore, verticle samples were taken to assure the homogeneity of the solid waste to be analyzed. Six 200-to-300-lb. samples were taken from each truck. Each sample was manually sorted into 11 categories and weighed. Results are divided by the total sample weight to yield the mass fraction of each material type. As an alternative to the direct sorting and weighing method, SYSTECH recommended the photographic inversion procedure. This sorting method uses an area/mass composition inversion technique developed by metallurgists. This technique was first applied to solid waste in mid-1974. This technique involves taking 35-mm color slides of solid waste, projecting the slides on a grid and reading the composition of waste under each node. The summed node counts define the area fraction of each waste component. If it is assumed that the area composition remains the same regardless of the slice taken through the refuse pile, the area distribution can be inverted into a mass distribution using appropriate bulk densities. SYSTECH reported that there were no significant differences in the results obtained by the classical manual sorting and weighing method and this newly developed photographic sorting method.

Table 16 shows 24 sets of data on the composition of solid waste at various locations across the United States, including Quad-City project and SYSTECH findings. The compositions of average urban refuse developed by Bell[25] and by Niessen[26] are shown in Table 17.

Material Flow Approach (Input Approach)

The composition of solid waste estimated by the material flow approach is derived from the studies of solid waste quantities under Input Approach.

TABLE 16. COMPOSITION OF SOLID WASTE, OUTPUT APPROACH (PERCENT)

Location	Paper	Glass	Plastics	Rubber and Leather	Metals	Textiles	Woods	Food Waste	Yard Waste	Misc.	Date	Reference
Johnson City, TN	45.5	10.9	1.7	1.0	10.8	1.3	0.3	25.9	1.6	1.0	1967	24
Johnson City, TN	34.9	9.0	3.4	2.4	10.4	2.0	0.8	34.6	2.3	0.2	1968	24
Memphis, TN	29.8	9.8	------3.0-------		6.6	4.8	1.7	19.7	12.1	12.5	1968	26
Cincinnati, OH	42.0	7.5	1.6	1.0	8.7	1.4	2.7	28.0	6.4	0.7	1966	a
Cincinnati, OH	41.83	7.81	------6.93------		8.34	6.46	1.79	8.09	15.66	3.09	1974	b
Oakwood, OH	50.0	10.1	------4.5-------		7.3	4.9	1.6	7.6	7.9	6.1	1974	b
Philadelphia, PA	54.4	9.1	0.2	1.5	8.4	2.6	2.4	5.0	16.0	0.0	----	c
Quad-Cities, NJ	43.87	6.44	------2.66------		9.44	4.52	2.96	8.3	13.3	8.96	1966	11
Hempstead, NY	42.6	9.6	------4.0-------		8.5	3.1	3.2	10.9	17.6	0.5	1966	d
Oceanside, NY	53.3	11.9	------3.5-------		10.6	2.2	1.5	16.7	0.3	0.0	1967	e
Genesee County, MI	34.0	14.3	------1.8-------		11.8	0.4	0.7	26.0	10.8	0.2	----	f
Alexandria, VA	55.3	7.5	------3.1-------		8.2	3.7	1.7	7.5	9.5	3.4	1968	26
San Diego, CA	46.16	8.31	0.27	4.73	7.64	3.46	7.48	0.81	21.14	0.0	1966	g
Santa Clara, CA	47.5	12.7	1.0	1.0	7.6	1.2	1.0	2.3	23.8	1.9	1967	h
Berkeley, CA	44.6	11.3	1.9	0.3	8.7	1.1	0.0	12.0	13.1	7.1	1967	10
Los Angeles, CA	28.17	6.14	2.68	1.39	4.96	2.96	3.61	4.68	17.02	28.39	1973	i
Los Angeles, CA	23.57	6.15	3.42	1.38	5.6	3.28	6.26	4.31	17.26	28.77	1974	i
Los Angeles, CA	16.20	7.79	4.34	1.53	8.17	4.7	6.01	5.17	18.79	27.30	1975	i
Los Angeles, CA	15.61	8.11	3.43	1.4	6.54	4.04	6.74	4.53	20.41	29.19	1976	i
Chandler, AR	42.7	7.5	0.4	1.0	9.8	1.9	2.3	21.8	1.3	11.3	----	i
Atlanta, GA	53.2	6.5	------2.6-------		8.8	2.0	3.2	17.5	2.8	3.4	1968	k
Atlanta, GA	49.1	14.0	------7.4-------		11.6	4.2	0.6	6.9	1.2	5.0	1974	i
Tampa, FL	24.1	6.0	2.4	0.6	5.9	2.8	1.5	9.1	41.5	6.1	----	21
New Orleans, LA	44.9	9.5	------3.5-------		8.1	3.2	3.1	11.0	9.6	6.9	1969	1

a. USPHS. Solid Wastes Program, Cincinnati, Ohio. Solid Wastes Study of a Residential Area. 1966 Quoted by Niessen[26].

b. Private communication, Dr. Swartzbaugh, J. T., Systems Technology Corporation (SYSTECH), Xenia, Ohio. 1975.

c. Proceedings - Institute for Solid Waste - 1966. Quoted by Niessen[26].

d. Kaiser, E., C. D. Zlit, and J. B. McCoffery. Municipal Incinerator Refuse and Residues. Presented at the 1968 National Incinerator Conference, 1968. Quoted by Niessen[26].

e. Kaiser, E. R. Composition and Combustion of Refuse. In Proceedings; MECAR Symposium, New York, 1967. Metropolitan Engineers Council on Air Resources, 1967. p. 1-9. Quoted by Darney[22].

f. USDHEW. The Solid Wastes Disposal Study, Genesee County, Michigan, 1968. Quoted by Niessen[26]

g. Hoffman, D. A., and R. A. Fitz. Batch Retort Research on Pyrolysis of Solid Municipal Refuse. Paper presented at Engineering Foundation Research Conference, University School, Milwaukee, Wisconsin, 1967. Environmental Science & Technology, Nov. 1968. Quoted by Drobny[27]

h. FMC Corporation. Systems Analysis for Solid Waste Disposal by Incineration, 1968. Quoted by Niessen[26]

i. Private communication, Mr. Jack M. Betz, Bureau of Sanitation, City of Los Angeles, 1976.

j. American Public Works Association. Municipal Refuse Disposal, Second Edition. Chicago, Public Administration Service, 1966. Quoted by Darnay[22].

k. Bureau of Solid Waste Management, unpublished. Quoted by Darney[22].

l. Bureau of Solid Waste Management, unpublished. Quoted by Darney[22].

TABLE 17. COMPOSITION OF AVERAGE URBAN SOLID WASTE OUTPUT APPROACH (PERCENT)*

Researcher	Note	Paper	Glass	Plastics	Rubber and leather	Metals	Textiles	Wood	Food Waste	Yard Waste	Misc.	Date
Niessen, W. R.[26]	Un-seasonal state	32.6	7.6	1.0	1.3	7.5	1.8	2.3	18.2	26.1	1.6	1968
Niessen, W. R.[26]	Semi-seasonal state	35.1	8.1	1.1	1.4	8.1	1.9	2.4	19.5	20.7	1.7	1968
Niessen, W. R.[26]	Seasonal state	38.2	8.8	1.1	1.5	8.7	2.0	2.7	21.1	14.1	1.8	1968
Bell, J. M.[25]	Composite	42.0	6.0	0.7	0.9	8.0	0.6	2.4	12.0	12.0	15.5	1959-62

*As - discarded basis

TABLE 18. COMPOSITION OF AVERAGE SOLID WASTE, INPUT APPROACH (PERCENT)*

Researcher	Paper	Glass	Plastics	Rubber and leather	Metals	Textiles	Wood	Food Waste	Yard Waste	Misc.	Date
Office of Solid Waste, U. S. EPA	37.8	10.0	3.8	2.7	10.1	1.6	3.7	14.2	14.6	1.5	1971
Office of Solid Waste, U. S. EPA	34.9	10.5	3.8	2.6	9.8	1.7	3.8	14.9	16.3	1.6	1975

* As - disposed basis

These compositions are shown in Table 18.

COMPARATIVE NOTES

One question now arises concerning which of the output and input approaches is the best method to estimate the quantity and composition of solid waste generated in the United States. There is no direct and clear-cut answer to this question.

Conceptually, the output approach should provide more accurate data for a town or a city but it requires careful measuring and recording practices and therefore is less convenient. At national level this approach has an additional disadvantage that it must rely on results of survey questionnaires and thus the investigator cannot control nor check the validity of the data reported. It is also impossible to account for unrecorded and unreported solid waste disposed of in rural areas or at unauthorized dumping sites.

The input approach is perhaps more convenient, but its major drawback is that its validity cannot be guaranteed in principle, because the method is based on assumptions that cannot be proved nor justified (one example is the assumed lifetime of products). The URS Company method is more applicable at community level than at national level while the EPA material flow method and SEAS model can only be used at national level.

In the following paragraphs we will consider some applications of statistical techniques to test hypotheses about quantities and composition of solid waste. This analysis would serve as a link between the input and output approaches. The daily generation rate in Kg per capita per day is thought of as an univariate random variable and the composition is thought of as a p-dimension multivariate random vector; each of the p-elements of the vector represents the percentage of one component of the solid waste (paper, glass etc.). Notice that we will not include the percentage of miscellaneous materials as a component of the vector composition because they are of no importance with regard to energy.

Quantity

1. The daily generation rates Kg per capita per day of six cities in the United States (Table 7) are reproduced below:

	Group 1 1958	Group 2 1965	Group 3 1968	
	1.369	1.533	1.694	
	1.785	1.623	1.805	
	2.081	2.945	3.147	
	1.644	1.841	-----	
	1.700	1.872	1.776	
	2.033	1.917	2.158	
Total	10.612	11.731	10.580	32.923

An analysis of variance is carried out to test the hypothesis of equal means between three groups.

	SS	df	MS	F
Between groups	0.332	2	0.166	0.751
Within groups	3.098	14	0.221	$F_{.95}$ (2, 14)=3.74
Total	3.425	16		

Since $F < F_{.95}$ (2, 14), we conclude that at the level of significance $\alpha = 0.05$ we cannot reject the null hypothesis $H_0: \mu_1 = \mu_2 = \mu_3$. This means that there is not enough evidence to reject the hypothesis that the generation rates in 1958, 1965 and 1968 came from the same population with mean μ unknown at the 0.05 significance level. Details of the computation are presented in the Appendix.

2. The quantity of solid waste generated in 1971 computed by the EPA material flow approach is 113.398 million metric tons[7]. It was estimated that the increase in solid waste from 1967 to 1971 was 11 percent[7], the quantity of solid waste generated in 1967 is then 102.16 million metric tons, or 1.417 Kg per capita per day. From data in Table 7 reproduced above, we can compute:

sample mean $\bar{x} = 1.935$
sample standard deviation $s = 0.463$

We now want to test the null hypothesis that the sample comes from a population with mean $\mu \leq \mu_o = 1.417$, against the alternative hypothesis that $\mu > \mu_o$:

H_o: $\mu \leq \mu_o$
H_a: $\mu > \mu_o$

$$t = \frac{\bar{x}-\mu_o}{S/\sqrt{n}} = \frac{1.935-1.417}{0.463/\sqrt{17}} = 4.613$$

Since $t > t_{.95}(16) = 1.746$, the null hypothesis is rejected.

Composition

Consider the composition of solid waste as an 8-dimension multinormal random vector (P=8):

$$X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \end{bmatrix}$$

where: x_1 is the percent of paper
x_2 is the percent of glass
x_3 is the percent of plastics, rubber and leather
x_4 is the percent of metal
x_5 is the percent of textile
x_6 is the percent of wood
x_7 is the percent of food waste

x_8 is the percent of yard waste

Also, consider a sample including the 24 values of X shown in Table 16. Some inferences about the composition of solid waste can be made as follows.

1. To test for the homogeneity of solid waste, we divide arbitrarily the data set into 2 groups. Group 1 is composed of data relative to the following states: Tennessee, Ohio, Pennsylvania, New Jersey, New York, Virginia, and Michigan. Group 2 is composed of data relative to other states

We carry out a one-way multivariate analysis of variance to test the hypothesis that the mean μ_1 is equal to the mean μ_2 of group 2.

$$H_o: \mu_1 = \mu_2$$
$$H_A: \mu_1 \neq \mu_2$$

where:

$$\mu_1 = \begin{bmatrix} \mu_{11} \\ \mu_{12} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \mu_{18} \end{bmatrix} ; \quad \mu_2 = \begin{bmatrix} \mu_{21} \\ \mu_{22} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \mu_{28} \end{bmatrix}$$

The computer program BMD 12 V is used in this one-way MANOVA (Appendix). Since F (calculated) = 2.5802 is smaller than $F_{0.95}$ (8, 15) = 2.64, we cannot reject the null hypothesis at an $\alpha = 0.05$ significance level.

2. We now test the hypothesis that the pooled sample (group 1 and group 2 pooled together) came from a population with mean μ equal to the composition vector μ_o determined by the material flow approach. The Hotelling T^2 statistic is used in this test:

$$T^2 = N\,(x - \mu_o)^T\, S^{-1}\,(x - \mu_o)$$

where: $\underline{N}$ is the sample size
$\bar{X}$ is the vector sample mean
μ_o is the vector population mean under null hypothesis (Table 18, year 1971)
S^{-1} is the inverse of the sample covariance matrix S.

when the null hypothesis is true, the quantity

$$F = \frac{N - p}{p\,(N - 1)}\; T^2$$

has the F distribution with degrees of freedom p and N - p. (In this case the degrees of freedom are 8 and 16).

The computer program to compute S, T^2 and F is presented in the Appendix.

Since the observed F = 27.3957 is in excess of $F_{.95}$ (8, 16) = 2.59, the null bypothesis is rejected. However, a follow-up analysis (Appendix) revealed that only the component plastics, rubber, and leather, and the component wood (components χ_3 and χ_6 of the vector composition) contributed to the rejection of the null hypothesis, the other six components do not.

We wish to note that the data used in the above statistical analyses were unsophisticated in several ways. Many composition data belonged to the years 1966-68; only a few data relative to recent years (1973-76) could be obtained, and all data on generation rate belonged to the period 1958-68. The number of data on generation rate was also very limited (the generation rate was obtainable at only site cities). We did not consider the results of the 1968 national survey in these analyses because most of them were estimated figures and thus their accuracy was questionable. If more data were available, the reliability of the inferences would increase and some other statistical inferences would also become feasible. With this in mind, some concluding comparative statements between input and output approach results can be made as follows.

1/- The per capita generation rate does not change significantly during the period from 1958 to 1968.

2/- At a significance level of $\alpha = 0.05$, we can agree with the statement that the daily generation rate is greater than 1.417 Kg per capita, which is determined by the input approach. Therefore, as we will use input approach estimates in subsequent sections, we will remain on the conservative side.

3/- As we cannot reject the null hypothesis that the means of the composition of solid waste of the two groups are equal, at a .05 significance level, we cannot reject the null hypothesis that the solid waste (of the two groups) is homogeneous.

4/- Although the null hypothesis that the mean of the compositions determined by the output approach is equal to the composition determined by the input approach is rejected, only the component "plastic, rubber, and leather", and the component "wood" contribute to the rejection. (the percentage of plastics, rubber, and leather of the input approach is significantly greater than that of the output approach).

SECTION 4

SOLID WASTE AND ENERGY CONSUMPTION

Energy consumption is associated with post-consumer solid waste in two ways: the manufacture of products and the handling of solid waste. Unless otherwise noted, energy consumption refers to gross energy. When many data are available for the same energy consumption, those values that are out of line with most other data will be disregarded. Usually, the higher values or their averages are selected.

ENERGY ASSOCIATED WITH THE MANUFACTURE OF PRODUCTS

Energy is consumed in the manufacture of products that enter the waste stream after they are used. Table 19 shows that in 1971, the manufacturing sector consumed 4.7 trillion KWH (net energy) or 27.9 percent of total U. S. energy requirements. Conceptually, the direct and indirect energy use for a given product could be derived by means of imput - output analysis, but an input - output table with the necessary detail on energy use does not exist[28]. The energy consumption reported in this paper represents only the energy required to manufacture each material. Energy needed to produce end products is not included, except when otherwise indicated.

As reported in Section 3, the principal components of solid waste are paper, glass, metals (ferrous, aluminum, and other nonferrous), plastics, rubber and leather, textiles, wood, food waste, yard waste, and miscellaneous inorganics. A review of energy consumed in the manufacture of each of these materials is given in subsequent sections.

Paper

The Conference Board[28] provides various estimates of total energy consumed by the paper industry in 1971: American Paper Institute, 703.2 billion KWH, Bureau of the Census, 556.7 billion KWH, and Conference Board, 615.3 billion KWH. Interagency Task Force on Energy Conservation[29] presents energy data for 1972. In 1972, 694.4 billion KWH were utilized by some 750 pulp and paper mills and some 5,000 converting plants; the product was 54.0 million metric tons of paper and allied products in 1972 coresponding to 12.9 thousand KWH per metric ton of product. The paper industry is also the largest consumer of oils in the manufacturing sector. In 1971, it used between 175,000 and 192,000 barrels of fuel oil per day[29], more than 25 percent of the total manufacturing consumption. In 1972, paper industry oil usage rose to about 206,000 barrels per day.

TABLE 19. DISTRIBUTION OF ENERGY CONSUMPTION BY SECTOR, 1971 (TRILLIONS OF KWH)*

	Purchased Fuels		Purchased fuels plus electricity†	
Sector	KWH	%	KWH	%
Household/commercial	4.184	20.7	5.110	30.6
Transportation	4.973	24.6	4.978	29.8
Industrial	5.945	29.4	6.629	39.6
Manufacturing	(4.198)	20.8	4.713	(27.9)
Non-manufacturings	(1.748)	8.6	1.916	(11.7)
Electrical generation	5.111	25.3	-----	------
Total	20.213	100.0	16.717	100.0

* Source: Reference 29.
† Purchased electricity at its thermal equivalence of 3,412 BTU/KWH.

Gordian Associates[30] provides energy consumption per metric ton for four major paper products (Table 20).

Glass

Glass accounted for 9.7 percent (13.3 million metric tons) of all post-consumer solid waste in 1971. Of this amount, 12.2 million metric tons were container and packaging glass[12]. The glass container industry consumed about 1 percent of the total energy used by the manufacturing sector in 1971. In absolute terms, it consumed roughly 38.1 billion KWH of fuel and 3.2 billion KWH of electricity[29].

The energy consumption per metric ton of glass container was estimated separately by the Interagency Task Force on Energy Conservation[29], Gordian Associates, and Makino and Berry[31] and is shown in Table 21.

Steel

The steel industry consumed 19 percent of the total energy consumed by the manufacturing sector in 1971[29]. The energy consumed in the manufacture of raw steel and finished steel is estimated variously as shown in Table 22. Note that 1.516 tons of raw steel is necessary to produce 1 ton of finished steel[32].

Aluminum

Total energy used by the aluminum industry in 1971 was 285.8 billion KWH. This consumption approximated between 5.5 and 6 percent of total energy use by manufacurings. Of the total energy estimated to have been used in the primary metals industries, aluminum accounted for approximately 28 percent.[28]

Enery consumption per ton of aluminum was estimated as follows (KWH per ton):

U. S. Environmental Protection Agency[33]	86,985
Interagency Task Force on Energy Conservation[29]	63,027
Gordian Associates[30]	55,956
Midwest Research Institute (quoted by Williams)[32]	85,597
Hannon (quoted by Williams[32])	93,733
Atkins (quoted by Williams[32])	73,263
Bravard (quoted by Williams[32])	71,810

TABLE 20. ENERGY CONSUMPTION IN MANUFACTURING FOUR PAPER PRODUCTS (KWH PER METRIC TON)

Item	Newsprint	Writing Paper	Corrugated Container	Folding Boxboard
Total net purchased energy	3,766	6,277	6,709	6,256
purchased fuels	(2,334)	(5,579)	(6,574)	(5,906)
purchased electricity	(1,432)	(698)	(135)	(350)
Total gross purchased energy†	7,087	7,901	7,020	7,071

* Source: Derived from Reference 30.
† Conversion of net electric energy into primary energy (gross energy) is detailed in Reference 30.

TABLE 21. ENERGY CONSUMPTION IN PRODUCING 1 METRIC TON OF GLASS CONTAINER (KWH)

	Makino and Berry*	Interagency Task Force on Energy Conservation (1971)†	Gordian Associates (1971)‡
Total net purchased energy	5,715	4,043	5,644
Purchased fuels		(3,734)	(5,389)
Purchased electricity		(309)	(255)
Total gross purchased energy		4,665#	5,864

* Source: Reference 31.
† Source: Reference 29.
‡ Source: Reference 30.
\# 3.0138 KWH of primary energy is needed to generate 1 KWH of net electric energy[30].

Other Nonferrous Metals

Copper is taken as representative of other nonferrous metals, all of which account for only 0.3 percent of post-consumer solid waste. Energy consumption for the production of copper is 32,816 KWH per ton.

TABLE 22. ENERGY CONSUMPTION IN THE MANUFACTURE OF RAW AND FINISHED STEEL (KWH/METRIC TON).

Source	Raw Steel	Finished Steel
Gordian Associates[30]	5,631	
Conference Board[28]	7,325	
Interagency Task Force on Energy Conservation[29]		9,288
Williams[32]*		14,357

*Williams's estimate is the average of three other independent estimates.

Plastics

Energy consumption for production of the four following thermoplastics are available: low-density polyethylene (LDPE), high-density polyethylene (HDPE), polystyrene, and polyvinyl chloride (PVC). These thermoplastic resins represent approximately 83 percent of the production of thermoplastics and 64 percent of the total production of plastic materials over the period 1970-1972[30]. Total gross energy consumed in producing LDPE, HDPE, polysteryne, and PVC resins is, respectively, 27,393, 25,972, 34,404, and 24,296 KWH per metric ton.[30] The average figure is 28,016 KWH per metric ton of thermoplastics.

Textiles

Major cellulosic fibers are rayon and acetate. Major non cellulosic, organic fibers are polyester, nylon, acrylicmodacylic, and olefin fibers. These fibers are used to manufacture apparel, carpets, blankets etc. that are found in the waste stream after being used and discarded. Table 23 shows the energy consumed in producing 1 metric ton of these synthetic fibers in 1973.

Containers

Table 24 shows the energy consumed in producing containers. These figures include the energy consumed in manufacturing the materials (steel, glass etc.) and in producing end packaging products (steel cans, glass bottles etc.)

TABLE 23. ENERGY CONSUMED IN THE MANUFACTURE OF 1 METRIC TONE OF SYNTHETIC FIBERS, 1973*

Fiber	Energy Consumed (KWH per metric ton)
Rayon	32,547
Acetate	40,687
Polyester	11,172
Nylon	13,303
Acrylic modacrylic	28,027
Olefin	12,270
Average	23,001

* Source: Foster D. Snell, Inc. Industrial Energy Study of the Plastics and Rubber Industries. Prepared for the Department of Commerce and the Federal Energy Office, 1974. Quoted by Energy Task Force on Energy Conservation[29].

ENERGY ASSOCIATED WITH THE HANDLING OF SOLID WASTE

The municipal solid waste management system consists of five groups of unit processes (Figures 2 and 3):

Group 1. Storage and collection.
Group 2. Optional preparatory processes (transfer station, size reduction, baling).
Group 3. Transportation
Group 4. Alternative unit processes (composting, incineration, resource recovery, energy recovery).
Group 5. Disposal methods (sanitary landfilling, millfilling, other disposal methods).

The energy associated with the handling of solid waste includes the energy consumed in these five groups of unit processes. Current major energy consuming functions are collection, transportation and disposal of solid waste. Only limited and scattered information is available on the energy consumption of solid waste processing systems (group 2 and 4), but they are assumed to account for only a small percentage of total energy consumed. However, as the potential for resource recovery increases because of the economics of both material and energy resources, the energy used for recycling is likely to increase considerably.

Shuster[34] has estimated that the total annual fuel consumption involved in the collection and land disposal of solid waste in the United States is 2.3 billion liters (Table 25). In terms of KWH's the collection function accounts for roughly 17.0 billion KWH, and the disposal function consumes

TABLE 24. ENERGY REQUIRED TO PRODUCE TYPICAL CONTAINERS.*

Type of container	KWH required/container
Internal packaging.	
16 oz. (0.473 liter) coca cola reternable bottle (0.5 Kg)	2.85
16 oz. (0.473 liter) coca cola nonreturnable bottle (0.3 Kg)	1.71
Half gallon (1.893 liter) returnable milk bottle (1.8 Kg)	5.18
16 oz. (0.473 liter) vegetable jar (0.2 Kg)	1.19
12 oz. (0.355 liter) steel beverage can (0.051 Kg)	1.16
12 oz. (0.355 liter) aluminum beverage can (0.020 Kg)	1.91
Aluminum container (TV dinner)	1.74
16 oz. (0.473 liter) glass bottle (0.209 Kg)	1.16
1 qt. (0.946 liter) glass jar (0.318 Kg)	1.78
Folding box (medium, 0.057 Kg)	0.75
Folding box (large, 0.145 Kg)	1.92
Dept. store box (medium, 0.148 Kg)	2.18
Setup box, small	0.84
Half gallon (1.893 liter) sanitary container (0.064 Kg)	0.88
Molded pulp tray (size 6, 0.020 Kg)	0.45
Styrofoam tray (size 6, 0.068 Kg)	0.25
1 qt. (0.946 liter) polypropylene bottle	3.20
1 qt. (0.946 liter) PVC bottle	3.80
1 qt. (0.946 liter) PE bottle	2.90
Wooden berry basket	0.08
Hampers	1.63
Stove basket	1.59
12" x 12" x 8" appliance corrugated box (0.241 Kg)	3.12
Shipping containers.	
12" x 16" x 20" corrugated box (0.863 Kg)	9.80
Wireband box (1.044 Kg)	2.30
Wooden crate (nailed)	10.00

* Source: Reference 31.

roughly 6.6 billion KWH. Shuster does not indicate the year for which these estimates were provided, but because many of the data sources were dated in 1972 and 1973, it is assumed that these estimates can be applied to the year 1971. Energy consumption is then 150 KWH per metric ton for collection and 58 KWH per metric ton for land disposal, assuming that solid waste collected and disposed of in 1971 is 113.2 million tons (Table 9).

The energy consumption for Los Angeles solid waste is 7.926 liters of diesel fuel per metric ton of refuse (or 85 KWH/metric ton) for collection and 0.303 liters of diesel fuel per metric ton of refuse (or 4 KWH/metric ton) for disposal. (private communication. Jack M. Betz, Director, Bureau of Sanitation, City of Los Angeles. 1976).

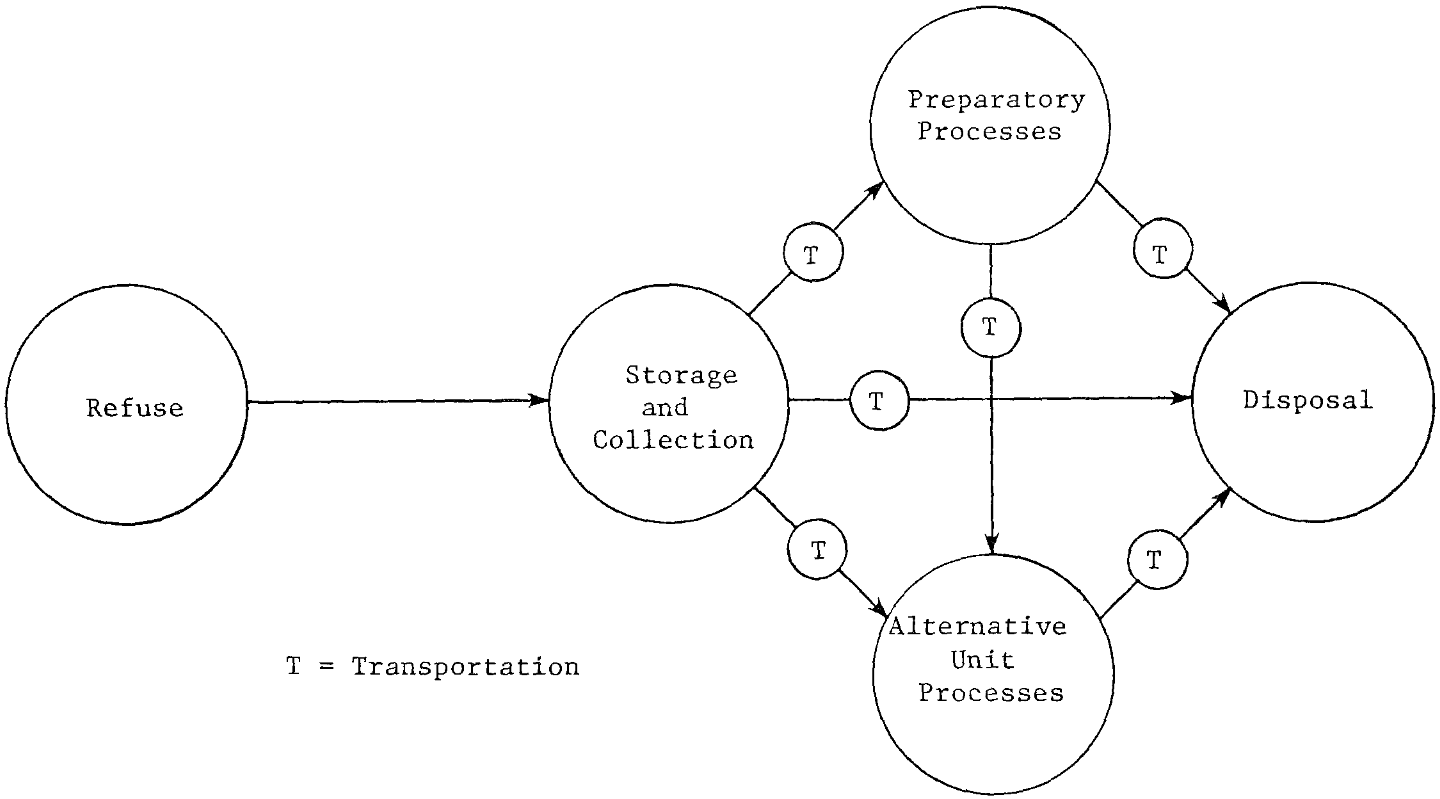

Figure 2. Simplified Municipal Solid Waste System

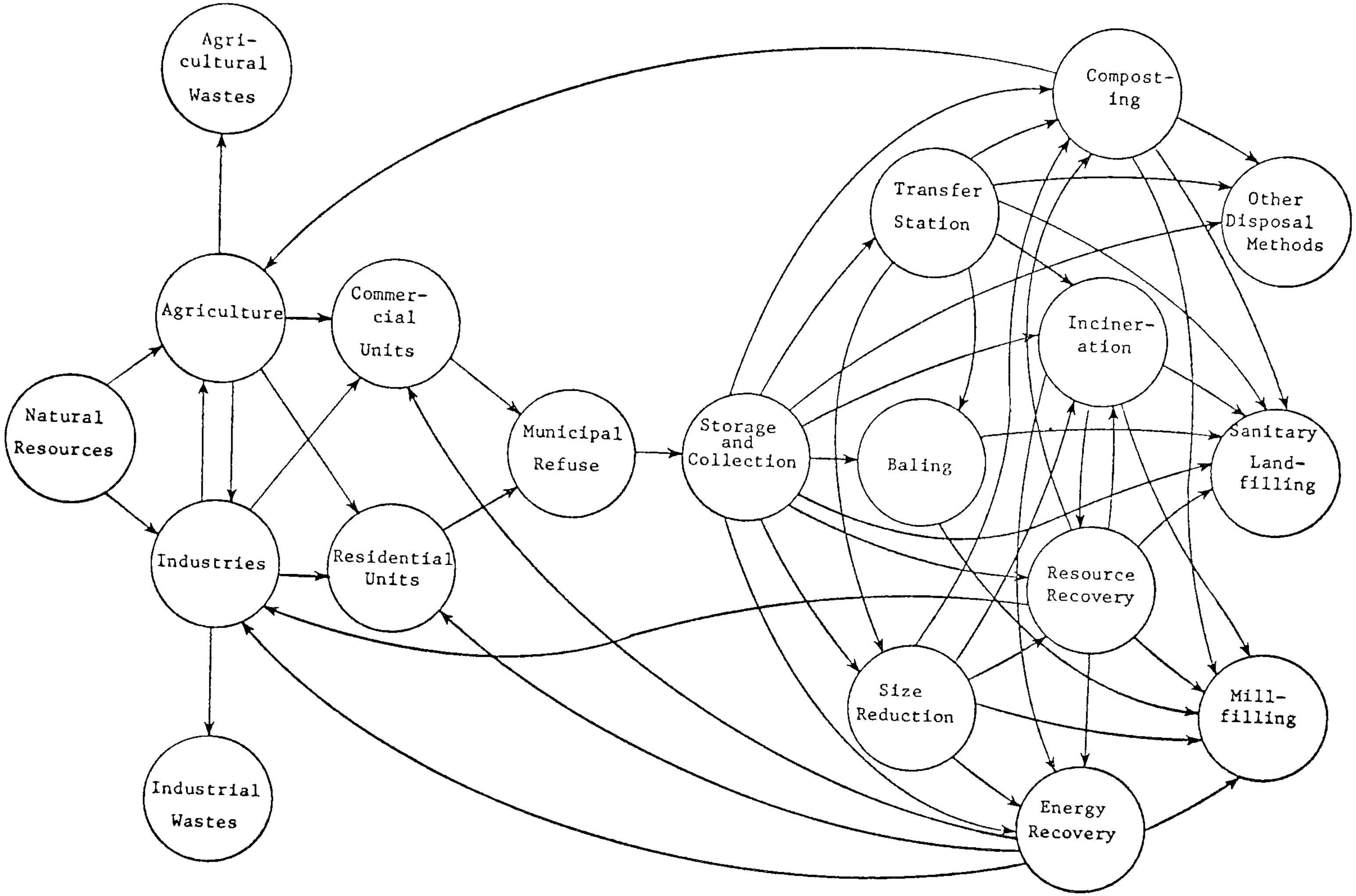

Figure 3. Complete Solid Waste Management System

Makino and Berry[31] made the following estimates of solid waste energy requirements (for Chicago, Illionois):

Collection.	82.7 KWH/metric ton
Incineration.	26.1 KWH/metric ton
Transport and disposal at landfill.	80.8 KWH/metric ton

Reinhardt and Ham[35] estimated the energy consumption in sanitary landfilling of milled refuse as follows

Processor and end-loader.	25.5 KWH/metric ton
Transport to landfill	77.1 KWH/metric ton
Maintain landfill	22.6 KWH/metric ton
Total	125.2 KWH/metric ton

TABLE 25. FUEL CONSUMED ANNUALLY IN THE COLLECTION AND LAND DISPOSAL OF SOLID WASTE (LITERS/YEAR)*

Type of fuel	Amount of fuel consumed: Residential sector	Commercial sector	Subtotal
Collection			
Diesel	219,983,254	390,850,493	610,833,747
Gasoline	244,155,210	840,841,005	1,084,996,215
Land disposal			
Diesel	----	-----	615,790,734

* Source: Reference 34.

Hannon[36] estimated that the energy requirement to transport solid waste to a sanitary landfill and to maintain the landfill is 145.5 KWH per metric ton. The energy consumption of open dumping was estimated at 97 KWH per metric ton.

The average energy consumption for three compost systems (Metro compost system, International Disposal Corporation compost system and Fairfield-Hardy compost system)[2] is as follows:

400 ton/day plant: 33,768 KWH/day or 93 KWH/metric ton
200 ton/day plant: 24,384 KWH/day or 134 KWH/metric ton

It seems reasonable, then, to estimate the average energy consumption of all compost systems to be 114 KWH per ton.

Williams[32] provided information on energy consumed in recycling metals from solid waste. The energy required to recycle steel, aluminum, and copper is, respectively, 1,978, 2,784, and 1,963 KWH per metric ton.

Makino and Berry[31] provided data on energy consumed in recycling packaging materials. Paper that has been recycled consists of mixed waste paper (largely clean commercial waste, 27 percent; used corrugated boxes, 26 percent; and newspaper, including overruns, 20 percent). The estimated energy consumption for the entire process is as follows:

Truck collection and hauling	176 KWH
Baling and handling	264 KWH
Freight to mills	165 KWH
Pulping	463 KWH
Total per metric ton of recycled pulp	1,068 KWH

A similiar paperboard from virgin material would require 2,119 KWH to produce[31].

Plastics are very difficult to recycle because of the task of separating paper from plastics and different kinds of resins. However if the technology is ever developed to separate plastic resins in fairly homogeneous states, recycling would be expected to cost 586 KWH per ton of plastic processed, compared with the 14,588 KWH per ton needed to produce plastic from virgin materials[31].

The recycling of glass to use as cullet offers no energy savings over using glass sand because glass making is primarily the melting of raw materials. Hannon[36] concluded that, given present technology, recycling glass from solid waste for bottle making would cost at least three times the energy required to start from virgin resources. However, if glass containers are voluntarily collected, the only costs are those for transportation (about 231 KWH per metric ton), melting, and forming the glass (4,996 KWH per metric ton). There would be a savings of up to 485 KWH per ton in the material acquisition. This would lower the overall cost of the finished bottle less than 1 percent[31].

The average energy consumed to collect, transport, and dispose of 1 ton of solid waste can be estimated as follows.

The energy required for collection can be estimated by taking the average of data for Los Angeles (85 KWH per metric ton) and Chicago (82.7 KWH per metric ton), which is 83.9 KWH per metric ton.

The energy consumed at the incinerator (26.1 KWH per metric ton) and later to transport the residue to the landfill and to maintain the landfill (80.8 KWH per metric ton) is 106.9 KWH per metric ton. About 8 percent of the total solid waste is incinerated yearly[37].

The energy consumed for composting is 114 KWH per metric ton. Composting and hog feeding accounted for 2 percent of total solid waste[37]. Another data source showed that 18 composting plants in the United States processed 745,205 metric tons of solid waste in 1969[27]. We can assume that composting processes about 1 percent of the total solid waste yearly.

The energy consumed at a sanitary landfill is estimated to be an average of 99.7 KWH per metric ton[35] (excluding energy for reduction of refuse, 23.1 KWH per metric ton, which is strictly for mill filling), and 130.9 KWH per metric ton 36, or 115.3 KWH per metric ton. About 5 percent of the total solid waste is disposed of in sanitary landfills[37].

The energy for recycling is summarized as follows for 1971:

			Millions of KWH/Year
Paper----------------	6,798,000 ton/year	x 1,068 KWH/ton=	7,260.3
Aluminum-------------	20,000 ton/year	x 2,645 KWH/ton=	47.6
Steel----------------	127,000 ton/year	x 1,978 KWH/ton=	251.2
Glass----------------	275,000 ton/year	x 5,227 KWH/ton=	1,045.4
Total			8,604.5

Total recycled material in 1971 is 7.376 million metric tons, or about 6 percent of total solid waste. The energy consumed to recycle is then 1,167 KWH per metric ton of recycled material.

Open dumping accounts for the remaining 80 percent of the total solid waste collected. Energy consumed is 97 KWH per metric ton.

The national energy consumed to collect, process, transport and dispose of 1 metric ton of solid waste is then:

		KWH/ton
Collection and incineration.	(82.7 + 106.9) 8% =	15.168
Collection and composting.	(82.7 + 114.0) 1% =	1.967
Collection and recycling	(82.7 + 1,167.0)6%=	74.982
Collection and sanitary land filling .	(82.7 + 115.3) 5% =	9.900
Collection and open dumping.	(82.7 + 97.0) 80%=	143.760
Total average.		245.777

In subsequent sections, the rounded figure of 246 KWH per metric ton will be used.

SECTION 5

REDUCING REFUSE TO CONSERVE ENERGY

PATHS OF ENERGY CONSERVATION IN SOLID WASTE MANAGEMENT

Any reduction in refuse generation implies savings of energy that would otherwise be consumed in handling the waste, no matter how good the management. Many recommendations have been made for improving solid waste management practices to optimize the energy consumed. For example, Shuster[38] proposed 11 short-term steps and three long-term steps to conserve fuel in solid waste management.

Part, but by no means all, of the residual energy in solid waste could be recovered by material recycling. The Midwest Research Institute[32] estimated that 85 percent of steel, 65 percent of aluminum, and 75 percent of copper is potentially recycleable. Plastics are very difficult to recycle[31] and recycling of glass offers no energy savings [31,36]. On the other hand, a significant amount of energy is required to recycle and to process and dispose of unrecovered materials; also, the energy consumed to produce consumer's end products connot be recovered.

Energy recovery processes can likewise conserve only a portion of the total energy associated with the waste.

The optional alternative, then, is to look for incentives aimed at source reduction, which has a number of advantages for the national economy and environment. In addition to energy conservation, source reduction helps to conserve material, manpower, and land necessary for disposal and to alleviate the environmental impacts of handling a large amount of refuse.

ENERGY CONSERVATION POTENTIALS

According to EPA (Table 11), the 1975 gross solid waste generated in the United States was 123.5 million metric tons. Of this figure, 116.3 million metric tons were disposed of and 7.2 million tons of material were recycled. The energy associated with this quantity of refuse is the sum of two categories: the energy consumed in the manufacture of 116.3 million metric tons of disposed of materials, and the energy consumed in the handling of 123.5 million metric tons of generated refuse.

The energy consumed in manufacturing disposed of materials in 1975 is estimated in Table 26. The energy required to produce consumer's end products is not included (except for glass containers) because of the unavailability of data. The energy embodied in each metric ton of disposed of ref-

TABLE 26. ENERGY CONSUMED IN MANUFACTURING DISPOSED OF REFUSE, 1975.

Material	Quantity (millions of metric tons)*	Energy consumed	
		KWH/metric ton	Millions of KWH
Paper	33.7	7,270[a]	244,999
Glass	12.1	5,864[30]	70,954
Ferrous metal	9.8	14,357[32]	140,699
Aluminum	0.8	82,278[b]	65,622
Other nonferrous metals	0.4	32,810[30]	13,124
Plastics	4.0	28,016[c]	112,064
Rubber	2.0	38,272[30]	76,544
Textiles	1.9	23,001[d]	43,702
Wood	4.4	unknown	-------
Food waste	20.7	unknown	-------
Yard waste	23.6	negligible	-------
Leather	1.0	negligible	-------
Misc. Inorganic	1.7	negligible	-------
Total	116.3		767,708

* See Table 9. Assume the quantity of rubber is double that of leather.
a-Average of four types of paper products in Table 20.
b-Average of five estimates made by U.S. EPA, Midwest Research Institute, Hannon, Atkins and Bravard (References 32, 33).
c-Average of 4 types of thermoplastics[30].
d-Average of 6 types of synthetic fibers (Table 23)

TABLE 27. ENERGY CONSUMED IN MANUFACTURING DISPOSED OF REFUSE, 1971-75.*†

Material	Energy consumed (millions of KWH)				
	1971	1972	1973	1974	1975
Paper	258,085	279,895	291,527	285,711	244,999
Glass	63,918	67,436	70,368	68,609	70,954
Ferrous metals	137,827	140,699	143,570	149,313	140,699
Aluminum	57,595	65,822	74,050	74,050	65,622
Other nonferrous metals	13,124	13,124	9,843	9,843	13,124
Plastics	106,461	120,469	126,072	114,866	112,064
Rubber	76,544	79,223	84,198	94,532	76,544
Textiles	36,802	36,802	39,102	43,702	43,702
Total	750,356	803,470	838,730	840,626	767,708
KWH/metric ton of refuse	6,629	6,798	6,875	6,885	6,601

Average energy consumed (1971-75) = 6,758 KWH/metric ton of refuse.

* For data on quantity of material, see Table 9.
† For data on energy consumed in manufacturing 1 metric ton of each material, see Table 25.

use in 1975 is: 767,708 x 10^6/116.3 x 10^6=6,601 KWH/metric ton.

TABLE 28 - TOTAL ENERGY CONSUMED IN THE SOLID WASTE MANAGEMENT, 1971-75.

Year	Solid waste (millions of metric ton)		Energy consumed yearly (millions of KWH/year)			Energy consumed per metric ton of generated refuse (KWH/metric ton)
	Gross generated*	Net disposed of†	Handling gross generated solid waste‡	Manufacturing net disposed of materials#	Total	
1971	120.6	113.2	29,668	750,356	780,024	6,468
1972	126.2	118.2	31,045	803,470	834,515	6,613
1973	130.7	122.0	32,152	838,730	870,882	6,663
1974	130.6	122.1	32,128	840,626	872,754	6,683
1975	123.5	116.3	30,381	767,708	798,089	6,462

* Sum of net disposed of refuse (Table 9) and recycled material (Table 15).
† Table 9.
‡ 246 KWH per metric ton (see Section 4)
\# Table 26.

TABLE 29. U.S. SOLID WASTE GENERATION RATES, 1971-75.*†

Year	Kg/capita per year	Kg/capita per day
1971	585	1.603
1972	606	1.660
1973	623	1.707
1974	618	1.693
1975	580	1.589

* The quantity of gross discards in the sum of net solid waste disposed of (Table 9) and materials recycled (Table 15).

† The population is based on Table 1.

TABLE 30. POTENTIALS OF ENERGY SAVINGS THROUGH SOURCE REDUCTION, 1975.

% Reduction	Refuse reduction (millions of metric ton)*	Energy savings (millions of KWH) †
10	12.4	79,809
20	24.7	159,618
30	37.0	239,427
39.8 ‡	49.2	317,639

* Gross discards in 1975 is 213.5 million metric tons (Tables 9 and 15)

† Total energy consumed in solid waste management in 1975 is 798,089 million KWH (Table 28).

‡ A refuse reduction of 39.8 percent would decrease the refuse generation rate in the U.S. to that of West Germany (highest generation rate in Western Europe).

By a similar computation method, the energy consumed in manufacturing disposed of refuse from 1971 to 1974 was computed and shown in Table 27 along with the results for 1975. The average energy residual (energy consumed in manufacturing the components of solid waste) embodied in 1 metric ton of refuse, 1971-75, was computed to be 6,758 KWH/metric ton.

Average energy consumption required to collect, process, transport, and dispose of 1 metric ton of gross discards was estimated earlier at 246 KWH. The energy needed to handle the solid waste generated in 1971-1975 was estimated and shown on Table 28, along with the total energy required for the solid waste management, which is the sum of the energy required for manufacturing and handling the waste.

Note that the total energy consumed in the management of solid waste in 1975 is 798,089 million KWH (Table 28), which is equivalent to 82.5 billion liters of gasoline, or 74.7 billion liters of diesel fuel, or 3.86 percent of total U.S. energy consumption in that year (20.671 trillion KWH[1]).

The United States generates more refuse than any other country in the world. Following are the generation rates of Western countries[3]:

	Kg/capita per year
Netherlands.	206
Italy.	211
Switzerland.	249
France	272

England. 317
West Germany 349

The U.S. generation rates for 1971-74 are shown in Table 29. These figures are based on EPA material flow estimates, which are conservative estimates, as we have indicated in Section 3. Suppose that American consumers would reduce their refuse generation, the energy savings would be quite significant. Table 30 shows the potentials of energy savings through reduction in refuse. These figures represent hypothetical savings corresponding to various levels of reduction. Note that a reduction of 39.8 percent would bring the generation rate in the United States to that of West Germany, the highest generation rate of Western Europe.

SETTING PRIORITIES FOR REDUCING REFUSE

The highest priority for refuse reduction should be attached to the most energy intensive material. Table 31 thus establishes the list of high priority materials to be reduced in the waste stream.

On the other hand, if we consider the total disposed of refuse generated in 1975, the total amount of energy embodied in aluminum (65.6 billion KWH) is less than the total amount of energy embodied in ferrous metal (140.7 billion KWH) even though aluminum is more energy intensive than ferrous metal. Thus, based on this total energy (instead of energy per metric ton of material) we should consider the priority list found in Table 32.

REDUCTION IN REFUSE: A JOINT INITIATIVE

The consumers do not bear alone the responsibility for the high rate of refuse generation in the United States. Indeed, from birth citizens have learned from society luxurious habits of consuming and discarding goods. Everyone believes that used products, especially packaging products, are manufactured to be thrown away. Tossing things into trash cans is not only a matter of course, but an inevitable decision, since that appears to be the only way to get rid of most items.

On the other hand, manufacturers alone cannot be blamed for producing material and energy-consuming products that are discarded after use, because, in the business world, the production option that most benefits the company will be chosen.

The effort to reduce refuse generation must be a joint one involving government policy makers, manufacturers, and the consumers. Responsible policy makers can initiate wise practices governing the consumption of energy and the production of consumer goods, including packaging products. Industry can choose manufacturing and marketing alternatives that will best conserve materials and energy. And finally, consumers can contribute through voluntary undertakings, such as source separation, reuse of products (paper and plastic shopping bags etc.) and use of returnable beverage containers. Consumers should particularly avoid generating unnecessary refuse for the sake of convenience.

TABLE 31. PRIORITIES FOR ENERGY - INTENSIVE MATERIALS IN THE WASTE STREAM.

Priority	Material	Energy intensiveness (KWH/metric ton)*
1	Aluminum	82,278
2	Rubber	38,272
3	Copper	32,810
4	Plastics	28,016
5	Textiles	23,001
6	Ferrous metal	14,357
7	Paper	7,250
8	Glass	5,864

* Sources: See Table 25.

TABLE 32. PRIORITIES FOR MATERIALS IN THE WASTE STREAM BASED ON TOTAL ENERGY

Priority	Material	Total energy in the waste stream* (million of KWH)
1	Paper	244,999
2	Ferrous metal	140,699
3	Plastics	112,064
4	Rubber	76,544
5	Aluminum	73,124
6	Glass	70,954
7	Textiles	43,702
8	Copper and other non ferrous metals	13,124

* 1975 (Table 26).

Examples of incentives to reduce refuse at the national policy level are as follows:

1. Institute a tax on disposable products to discourage their use.
2. Institute a tax on new packaging products to promote their reuse.
3. Institute a tax to discourage high energy consuming products and favor low energy consuming competitors.
4. Require a mandatory deposit and free repair policy during the lifetime of a durable product (household appliances, lawn mowers etc.). Such requirement would be imposed on manufacturers or their local agents, and the lifetime of a product would be determined by the manufacturer. When the lifetime of a product is finished, it would be returned to the manufacturer for complete overhauling or recycling, and the deposit would be returned to the consumer.
5. Require a mandatory deposit for reusable products such as beverage containers.
6. Require mandatory source separation to facilitate reuse of products and material recycling. For example, each household might have several trash cans painted with different standard colors to differentiate refuse components.
7. Establish product reuse centers and material recycling centers.
8. Increment pricing of solid waste collection and disposal.

Examples of incentives to reduce refuse at the manufacturing level are:

9. Redesign products to reduce the amount of material per product (durable goods, containers, and shipping packaging).
10. Increase lifetime of products.
11. Promote and facilitate reuse by fabricating both standard durable goods and standard packaging products.
12. Reuse packaging products. Damaged packaging products, especially those for shipping, can be repaired and reused.
13. Standarize products to promote reuse of undamaged components.
14. Reduce newspapers, magazine, and book overruns by careful surveys and analyses of demand.
15. Reduce catalogs, directories, and commercial printing.

Examples of incentives to reduce refuse at the consumer level are:

16. Practice source separation to facilitate recycling and reuse.
17. Return discarded consumer and packaging products to local agents of manufacturers or central collection warehouses to facilitate reuse and/or recycling.
18. Cooperate with other government and/or manufacturer incentives to reduce refuse.
19. Refrain from discarding products when they are still usable.
20. Carry out voluntary steps to reduce refuse generation; think of the implications of refuse generation when purchasing products.

POSSIBLE REDUCTIONS AND ASSOCIATED ENERGY SAVINGS

The following suggestions are based on the post consumer solid waste of 1975 by detailed product category as shown in Table 11.

Durable Goods

Major Appliances and Miscellaneous Durable Goods--

Major appliances and miscellaneous durables account for 8,689,000 metric tons of refuse (Table 11). Of this figure, 5,222,000 metric tons are ferrous metals, 81,000 metric tons are aluminum, and 300,000 metric tons are other nonferrous metals. Ferrous metal is the difference between total ferrous metal (which is the sum of disposed of ferrous metal (Table 10) and recycled ferrous metal (Table 15), and steel cans (Table 11).

Exact realizable refuse reduction and energy savings are unknown, but energy savings associated with various assumed levels of reduction can be estimated as follows.

10 - percent reduction (868,900 metric tons of refuse)	Millions of KWH
Ferrous metal. . . .522,200 metric tons x 14,357 KWH/metric ton=	7,497.2
Aluminum . . . . . . 8,100 metric tons x 82,278 KWH/metric ton=	666.5
Other nonferrous . . 30,000 metric tons x 32,810 KWH/metric ton=	984.3
TOTAL energy savings.	9,148.0

% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
10	868,900	9,148
20	1,737,800	18,296
30	2,606,700	27,444
50	4,344,500	45,740

Rubber Tires--

Some 1.6 million metric tons (Table 11) of rubber tires were discarded in 1975. There are three types of car tires: bias, belted bias and radial ply. The most inexpensive type should provide satisfactory performance for 15,000 to 20,000 miles, and the most expensive type (radial) should last for more than 40,000 miles. Estimates show[39] that if all tires in original equipment were radial an annual 38 percent reduction in tire waste (616,740 metric tons) would result. If replacement tires were all radial, the total waste reduction could be as high as 50 percent.[39]

Energy savings corresponding to various levels of reduction are as follow (38,272 KWH/metric ton of rubber[30]).

% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
10	162,300	6,212
20	324,600	12,424
30	486,900	18,636
40	649,200	24,848
50	811,500	31,060

Nondurable Goods, Except Food

Newspapers--

Newspaper waste accounts for 8.0 million metric tons in 1975. The energy consumed in producing 1 metric ton of newsprint is 7,087 KWH/ metric ton (Table 20)[30]. If reduction could be made (one possibility is by reducing overruns), energy savings would be achieved.

% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
5	401,350	2,844
10	802,700	5,689
15	1,204,050	8,533

Books, Magazines and Office Paper--

Some 2.8 million metric tons of books and magazines and 4.7 million metric tons of office paper are generated annually. The energy consumed in manufacutring writing paper is 7,901 KWH per metric ton. One possibility to reduce this type of solid waste is by reducing overruns. Energy savings would be as follows.

% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
5	139,450	1,102
10	278,900	2,204
15	418,350	3,306

Catalogs and directories are classified under this category of waste paper. They include such items as telephone books, mail-order catalogs, and business and professional directories. In 1973, catalogs and directories was estimated at 861,650 metric tons[40]. If we assume an annual increase of 1 percent, the 1975 figure would be 878,882 metric tons. Such publications are of transitory value and are usually replaced annually. Energy savings could be realized if these periodical publications were completely replaced biennially, or even every 3 years and updated by supplements every other year when necessary. The resulting reduction could amount to 40 percent. Energy savings associated with various levels of reduction are as follows.

% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
10	87,888	694
20	175,776	1,389
30	263,664	2,083
40	351,552	2,778

Also classified under this category is the so-called commercial printing, which includes direct-mail advertising, booklets, brochures, leaflets, reports, promotional materials, forms, etc. In 1966, commercial printing accounted for some 1.8 million metric tons of refuse--more than one third of printing paper consumption for that year.[40] Commercial printing was estimated at 2.6 million metric tons for 1973.[40] With a 5 percent annual increase, the 1975 figure would be 2.9 million metric tons. Energy savings corresponding to various levels of reduction in commercial printing are as follows.

% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
30	870,000	6,874
50	1,450,000	11,456
70	2,030,000	16,039
90	2,610,000	20,622

Paper Plates, Cups--

EPA[41] provides comparative energy requirements for paper and reusable plates. Paper plates (manufactured, used once, and discarded) require 1,641 KWH per 10,000 plates (or 16,273 KWH/metric ton). Reusable plates (manufactured, used once, and washed once--each plate can be used and washed 6,000 times before being discarded) require 379 KWH per 10,000 plates. The energy ratio (paper/reusable) is 4.340/1 and the weight ratio is 132/1. This ratio is based on one use and is computed as follows. One paper plate weighs 0.010 Kg and can be used one time; one reusable plate weight 0.454 Kg and can be used 6,000 times. Therefore, the weight ratio (paper/reusable) corresponding to one use is:

$$\frac{0.010}{0.454/6,000} = 132$$

In 1975, paper plates and cups accounted for 440,000 metric tons of solid waste. If these had been replaced by reusable ones, the energy savings and reductions in refuse would have been as shown (16,273 KWH/metric ton of paper plates).

% Replacement	Refuse reduction (metric tons)	Energy savings (millions of KWH)
50	218,000	825
80	349,000	1,320
100	437,000	1,650

Tissue Paper--

In 1975, tissue paper amounted to some 2.0 metric tons (Table 11). Four major categories of tissue paper are: toweling, table napkins, facial tissue, and toilet tissue. The former three accounted for 55 percent and the latter accounted for 42 percent of total tissue paper in 1966.[40] Assume these percentages held true in 1975, and assume the energy consumed to manufacture tissue paper is equal to that for newsprint. If reduction of toweling, table napkins, and facial tissue could be achieved, resulting energy savings would be as shown.

%Reduction of three categories of tissue paper	% Reduction of total tissue paper	Refuse reduction (metric tons)	Energy savings (millions of KWH)
20	11	222,970	1,580
40	22	445,940	3,160

Clothing--

Reduction in discarded clothing would result in energy savings as estimated in the following (Energy consumed to produce textile is 23,001 KWH per metric ton).

% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
10	113,400	2,608
20	226,800	5,216
30	340,200	7,824

Containers and Packaging

Glass Beverage Containers--

Based on 1972 data, refillable containers accounted for about 20 percent of all glass beverage containers.[41] If it is assumed that this proportion held true in 1975, total refillable containers for that year would have accounted for 1.2 million metric tons and the throw-away glass containers would have accounted for 4.6 million metric tons. (Table 11 shows total beverage glass container discards in 1975 to be some 5.8 million metric tons).

Hannon[36] computed the energy ratio of the throw-away system to the refillable system (15 refills) to be 4.6. A shift to 100 percent refillable bottles would result in an energy savings of

$$4.604 \times 10^6 \times 5,864 \times \frac{3.6}{4.6} = 21,129 \text{ million KWH}$$

The average unit weight is 0.454 Kg (1.0 lb.) for the 0.473 liter (16 oz) returnable bottle, and 0.298 Kg for the 0.473 liter throw-away bottle.[36] One returnable bottle can be used 15 times before being discarded. The refuse reduction is then

$$4,604,000 - \frac{4,604,000}{(15 \times .298)/.454} = 4,136,000 \text{ metric tons}$$

The energy savings and refuse reduction corresponding to a usage level of 50 percent for refillable bottles are estimated in the following:

Energy savings: 21,129 x 50% = 10,565 million KWH
Refuse reduction: 4,126,000 x 50% = 2,158,000 metric tons

Steel Beverage Cans--

The energy requirement per lb. of steel beverage cans is 37,640 BTU, or 25,318 KWH per metric ton. The energy associated with 1.2 million metric tons of steel cans generated in 1975 is then

$$1.215 \times 10^6 \times 25,318 = 30,761 \text{ million KWH}$$

The energy ratio of throw-away cans versus 15-trip refillable bottles both 12 oz. (0.355 liter) was determined to be 2.91[36]. A shift from steel cans to refillable bottles (both 12 oz.) would result in the following savings.

100-percent replacement

Energy savings:

$$30,761 - 30,761 \times \frac{1}{2.91} = 20,190 \text{ million KWH}$$

Refuse reduction:
(weight of 1 steel can is 0.05119 Kg; weight of 1 refillable bottle is 0.45359 Kg)

$$1,215,000 - \frac{1,215,000}{15 \times 0.05119/0.45359} = 497,266 \text{ metric tons}$$

% Replacement	Refuse reduction (metric tons)	Energy savings (million KWH)
100	497,266	20,190
70	348,086	14,133
50	248,633	10,095

Aluminum Beverage Cans--

The all-aluminum cans are 33 percent more energy consuming than the steel cans,[36] therefore, the energy ratio of throw-away aluminum can versus 15-trip refillable glass bottles (both 12 oz or 0.355 liter) is 3.88. A 100-percent shift from aluminum cans to refillable glass bottles in 1975 would have resulted in savings of

$$462{,}000 \text{ metric tons} \times 82{,}278 \text{ KWH/metric ton} \times \frac{2.88}{3.88} = 28{,}215 \text{ million KWH}$$

% Replacement	Energy savings (millions of KWH)
100	28,215
80	22,572
50	14,108

Because one aluminum can weighs approximately 0.198 Kg, only a shift to returnable glass bottles (1 lb or 0.454 Kg) with at least a 25-trip life would result in a reduction in refuse tonnage. But in any case, the reduction in refuse volume would be considerable.

Packaging Paper--

Packaging paper constitutes 53 percent of all containers and packaging materials found in the waste stream. In 1975 discarded packaging paper accounted for some 21.0 million metric tons of paper, which can be classified as corrugated paperboard or containerboard (11.3 million metric tons), other paperboard (5.0 million metric tons), and flexible packaging paper (4.7 million metric tons).

Corrugated paperboard--Corrugated paperboard constitutes the most important fraction of all packaging paper. Almost all corrugated paperboard is used for boxes or interior packings, and most of it is very suitable for reuse, since usually it is not damaged during use. The energy savings corresponding to different levels of waste reduction are as follow.

% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
20	2,271,000	15,944
30	3,407,000	23,916
60	6,813,000	47,832

Paper milk containers--In 1975, some 1.4 million metric tons of paper sanitary containers were discarded; of this figure milk cartons accounted for 41 percent [31,42] or 584,000 metric tons. Hannon[36] computed the energy ratio for the throw-away paper versus the 33-trip glass returnable milk delivery system to be 1.43. One half-gallon (1.892 liter) plastic coated paper container weighs 0.127 Kg and one half-gallon glass returnable container weighs 0.908 Kg. A 100-percent shift from throw-away paper milk containers to returnable glass containers would result in an energy savings of (energy consumed to produce paper containers is 13,183 KWH per metric ton)[31]

$$584{,}000 \times 13{,}183 \times \frac{1}{1.43} = 5{,}384 \text{ million KWH}$$

The reduction in refuse tonnage is

$$584{,}000 - 584{,}000 \times \frac{0.908}{0.127 \times 33} = 457{,}000 \text{ metric tons}$$

% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
20	91,000	1,077
40	183,000	2,154
60	274,000	3,230

Grocery paper sacks--Paper sacks are made from unbleached kraft paper and used as grocery bags. These sacks come in a variety of sizes, all of which are used once and discarded although they are usually undamaged and look like new. If these paper sacks were reused once or twice, considerable amounts of energy and material could be saved. In 1966, bag paper accounted for 1.5 million metric tons of refuse (of a total of 4.3 million metric tons of flexible packaging paper). If a 4.1 percent annual increase is assumed[42], the 1975 figure is 2.2 million metric tons. Savings corresponding to different levels of reduction are as follow

% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
30	660,000	4,633
50	1,100,000	7,722
60	1,320,000	9,264

Shipping paper sacks--Shipping sacks are used to carry powder and granular products such as fertilizers, cement, carbon black, feeds, etc. Energy savings effected by reduction in discards can be estimated in a manner similar to that for grocery sacks.

Quantity of shipping sacks in 1966: 900,000 metric tons
Quantity of shipping sacks in 1975 (2% increase): 1,075,000 metric tons

% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
20	215,000	1,509
30	323,000	2,267
50	538,000	3,777

These possibilities for reducing refuse and saving energy are shown in Table 33.

TABLE 33. POSSIBILITIES FOR REFUSE REDUCTION AND ENERGY SAVINGS, 1975.

Waste Source	% Reduction	Refuse reduction (metric tons)	Energy savings (millions of KWH)
Major appliances and misc. durable goods	30	2,606,700	27,444
Rubber tires	40	649,200	24,848
Newspaper	10	802,700	5,689
Books and magazines	10	278,900	2,204
Catalogs and directories	40	351,552	2,778
Commercial printing	70	2,610,000	20,622
Paper plates, cups	50	218,000	825
Tissue paper	22	445,940	3,160
Clothing	30	340,200	7,824
Glass beverage containers	50	2,158,000	10,565
Steel beverage cans	70	348,086	14,133
Aluminum beverage cans	80	negligible	22,572
Corrugated paperboard	30	3,407,000	23,916
Paper milk containers	40	183,000	2,154
Grocery paper sacks	60	1,320,000	9,264
Shipping paper sacks	30	323,000	2,263
Total		16,042,278	180,261
Plus energy saved in refuse handling		-------	3,719
Grand total (rounded)		16,000,000	184,000

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APPENDIX

COMPUTATION DETAILS AND STATISTICAL INFERENCES ON THE QUANTITY AND THE COMPOSITION OF SOLID WASTE (SEE SECTION 3)

TEST OF HYPOTHESIS OF EQUAL MEANS BETWEEN 3 GROUPS OF GENERATION RATES

This is an one-way univariate analysis of variance (see Reference 43).

H_O: $\mu_1 = \mu_2 = \mu_3$
H_A: at least one inequality.

Group 1 1958	Group 2 1965	Group 3 1968	
1.369	1.533	1.694	
1.785	1.623	1.805	
2.081	2.945	3.147	
1.644	1.841	-----	
1.700	1.872	1.776	
2.033	1.917	2.158	
T_{1+}=10.612	T_{2+} =11.731	T_{3+} =10.580	T_{++}=32.923

$$\sum_i \sum_j x_{ij} = 32.923 \quad ; \quad \sum_i \sum_j x_{ij}^2 = 67.185$$

<u>Between groups.</u>

$$\text{SS=Sum of squares} = \sum_i \frac{T_{i+}^2}{n_i} - \frac{T_{++}^2}{N}$$

$$=18.769 + 22.936 + 22.387 -63.760$$
$$=0.332$$

d_f = degrees of freedom = K-1 =3-1 =2

$$\text{MS = Mean square} = \frac{SS}{d_f} = \frac{0.332}{2} = 0.166$$

<u>Within groups.</u>

$$SS= \sum_i \sum_j x_{ij}^2 - \sum_i \frac{T_{i+}^2}{n_i}$$

$$=67.185 - 18769 - 22.936 - 22.387 =3.093$$

$$d_f = \sum_i n_i - K = 17-3= 14$$

$$MS= \frac{SS}{d_f} = \frac{3.093}{14} = 0.221$$

<u>F ratio</u>

$$F= \frac{\text{Mean square (between)}}{\text{Mean square (within)}} = \frac{0.166}{0.221} = 0.751$$

$F_{.95}$ (2,14) = 3.74

Since $F < F_{.95}$ (2, 14), we cannot reject the null hypothesis at an α = .05 significance level.

TEST FOR THE HOMOGENEITY OF SOLID WASTE

Following is the precoded computer program BMD12V[44], which was used to carry out the one-way multivariate analysis of variance (MANOVA) to test the hypothesis of equal means between 2 groups of composition of solid waste.

$H_o: \mu_1 = \mu_2$
$H_A: \mu_1 \neq \mu_2$

```
// EXEC BMD,PROG=BMD12V
//SYSIN DD *
PROBLMSLDWST 8 2 8 1  1
INDEX   2 12
DESIGNIR          $I,R(I).
(8(F5.2,1X))
    .
    .
    .
  24 data cards
    .
    .
    .
SUBPRO11111111
FINISH
```

The output of the program gave the approximate F statistic equal to 2.5802 with degrees of freedom 8 and 15. Since $F < F_{.95}$ (8,15) = 2.64, we cannot reject the null hypothesis at an α = .05 significance level.

TEST OF THE HYPOTHESIS THAT THE POPULATION MEAN OF COMPOSITIONS OF SOLID WASTE DETERMINED BY OUTPUT APPROACH IS EQUAL TO THE COMPOSITION DETERMINED BY EPA MATERIAL FLOW METHOD (INPUT APPROACH). (See Reference 45)

The quadratic form

$$T^2 = N(\bar{\chi} - \mu_o)^T S^{-1}(\bar{\chi} - \mu_o)$$

is called the single-sample Hotelling T^2 statistic,

where μ_o is the vector population mean under the null hypothesis

$\bar{\chi}$ is the vector sample mean

S^{-1} is the inverse of the sample covariance matrix S, which can be computed by

$$S = \frac{A}{N-1} = \frac{1}{N-1} \sum_{h=1}^{N} (x_h - \bar{x})(x_h - \bar{x})^T$$

where N is the number of observations and x_h denotes the vector composition h.

The quantity

$$F = \frac{N - p}{p(N - 1)} \times T^2$$

has the F distribution with degrees of freedom p and N - p.

The following computer program computes F using SAS manual[46].

```
PROC MATRIX;
X= 45.5 10.9 2.7 10.8 1.3 0.3 25.9 1.6/
34.9 9.0 5.8 10.4 2.0 0.8 34.6 2.3/
          .
          .
          .
      data cards
          .
          .
          .
24.1 6.0 3.0 5.9 2.8 1.5 9.1 41.1;
PRINT X;
MU=37.8 10.0 6.5 10.1 1.6 3.7 14.2 14.6;
PRINT MU;
NOBS=NROW(X);
NVAR=NCOL(X);
SUM=J(1,NOBS)*X;
XBAR=SUM#/NOBS;PRINT XBAR;
Y=X(*,1)-XBAR(1,1);
I=2;
LOOP1:IF I>NVAR THEN GO TO NEXT1;
YI=X(*,I)-XBAR(1,I);
Y=Y||YI;
I=I+1;GO TO LOOP1;
NEXT1:PRINT Y;
I=1;A=J(NVAR,NVAR,0);
LOOP2:IF I>NOBS THEN GO TO NEXT2;
AI=Y(I,*)'*Y(I,*);
A=A+AI;I=I+1;GO TO LOOP2;
NEXT2:PRINT A;
S=A#/(NOBS-1);PRINT S;
B=XBAR-MU;
HOTELGT2=B*INV(S)*B'#NOBS;PRINT HOTELGT2;
F=HOTELGT2#(NOBS-NVAR)#/(NVAR*(NOBS-1));
PRINT F;
```

Note that the vector MU is the composition of solid waste in 1971 determined by EPA material flow method as shown in Table 18.

The output gave a Hotelling T^2 statistic equal to 315.05 and a value of F equal to 27.3957. Since F is in excess of $F_{.95}$ (8, 16) =2.59, the null hypothesis is rejected. However, a follow-up analysis was done as follows and revealed that only the component plastics, rubber, and leather, and the component wood (components x_3 and x_6 of the vector composition) contribute to the rejection of the null hypothesis, the other six components do not.

Follow-up analysis (See Reference 45).

The values of the vectors $\bar{x}$ and μ and of the covariance matrix S were printed in the output of the above computer program as follows (μ_0 is the composition of solid waste shown in Table 18).

$$\bar{x} = \begin{bmatrix} 40.1379 \\ 9.08125 \\ 3.70667 \\ 8.43708 \\ 3.00917 \\ 2.63125 \\ 12.4329 \\ 12.5742 \end{bmatrix} ; \quad \mu = \begin{bmatrix} 37.8 \\ 10.0 \\ 6.5 \\ 10.1 \\ 1.6 \\ 3.7 \\ 14.2 \\ 14.6 \end{bmatrix}$$

Covariant Matrix S

Column 1	Column 2	Column 3	Column 4
137.859	9.06957	-5.22064	9.80475
9.06957	5.8872	-0.115474	2.68753
-5.22064	-0.115474	2.70635	-0.140132
9.80475	2.68753	-0.140132	3.26069
-3.25675	-1.15739	1.58952	-0.928972
-11.3855	-2.68809	0.997213	-1.91351
7.11356	4.09027	-3.94292	9.3332
-54.4326	-7.26733	-0.0490899	-11.3633

Covariant Maxtrix S (continued)

Column 5	Column 6	Column 7	Column 8
-3.25675	-11.3855	7.11356	-54.4326
-1.15739	-2.68809	4.09027	-7.26733
1.58952	0.997213	-3.94292	-0.040899
-0.928972	-1.91351	9.3332	-11.3633
2.19492	1.03911	-6.83241	2.47126
1.03911	4.32044	-9.33224	6.63387
-6.83241	-9.33224	84.6885	-49.7312
2.47126	6.63387	-49.7312	88.6249

the 95 percent simultaneous confidence intervals of Roy and Bose are used in this follow-up analysis (α =0.05).

$$a'\bar{x} - \sqrt{\frac{1}{N} a^T S a}\ T\alpha;p,\ N-p \leq a'\mu \leq a'\bar{x} + \sqrt{\frac{1}{N} a^T S a}\ T\alpha;\ p,\ N-p$$

Paper. $a^T = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$; μ(Paper) = 37.8

$$a^T\bar{x} = 40.1379 \ ; \ \frac{1}{N} a^T S a = \frac{1}{24} \times 137.869 = 2.397$$

$$T\alpha\ ;\ p,\ N-p = \sqrt{\frac{(N-1)p}{N-p}\ F\alpha\ ;\ p,\ N-p} = \sqrt{\frac{23 \times 8}{16} \times 2.59} = 5.458$$

$$40.1379 - 2.397 \times 5.458 \leq \mu \text{ (paper)} \leq 40.1379 + 2.397 \times 5.458$$

$$27.051 \leq \mu \text{ (paper)} \leq 53.2207$$

Since this interval does not contain the value 37.8, paper does not contribute to the rejection of the null hypothesis.

$\underline{\text{Glass}}$. $a^T = [0\ 1\ 0\ 0\ 0\ 0\ 0\ 0]$; μ (Glass) = 10.0

$$a^T\bar{x} = 9.08125 \ ; \sqrt{\frac{1}{N} a^T S a} = \sqrt{\frac{1}{24} \times 5.8872} = 0.49527$$

$$9.08125 - 0.49527 \times 5.458 \leq \mu \text{ (Glass)} \leq 9.08125 + 0.49527 \times 5.458$$
$$6.378 \leq \mu \text{ (Glass)} \leq 11.7844$$

Glass does not contribute to the rejection of the null hypothesis.

Plastics, rubber, and leather. μ (Plastics, rubber and leather)=6.5

$$a^T\bar{x} = 3.70667 \ ; \sqrt{\frac{1}{N} a^T S a} = \sqrt{\frac{1}{24} \times 2.70635} = 0.3358$$

$$3.70667 - 0.3358 \times 5.458 \leq \mu \text{ (Plastics, rubber and leather)} \leq 3.70667 + 0.3358 \times 5.458$$

$$1.8738 \leq \mu \text{ (Plastics, rubber, and leather)} \leq 5.58$$

Plastics, rubber, and leather <u>does contribute</u> to the rejection of the null hypothesis

Metals. μ (Metals) = 10.1

$$a^T\bar{x} = 8.43708 \ ; \sqrt{\frac{1}{N} a^T S a} = \sqrt{\frac{1}{24} \times 3.26069} = 0.36959$$

$$8.43708 - 0.36959 \times 5.458 \leq \mu \text{ (Metals)} \leq 3.43708 + 0.36959 \times 5.458$$
$$6.4198 \leq \mu\text{(Metals)} \leq 10.4543$$

Metals do not contribute to the rejection of the null hypothesis.

Textiles. μ (Textiles) = 1.6

$$a^T\bar{x} = 3.00917 \ ; \sqrt{\frac{1}{N} a^T S a} = \sqrt{\frac{1}{24} \times 2.19492} = 0.302415$$

$$3.00917 - 0.302415 \times 5.458 \leq \mu\text{(Textiles)} \leq 3.00917 + 0.302415 \times 5.458$$
$$1.35858 \leq \mu\text{(Textiles)} \leq 4.36775$$

Textiles do not contribute to the rejection of the null hypothesis.

Wood. μ (Wood) = 3.7

$$a^T\bar{x} = 2.63125 \ ; \sqrt{\frac{1}{N} a^T S a} = \sqrt{\frac{1}{24} \times 4.32044} = 0.424285$$

$$2.63125 - 0.424285 \times 5.458 \leq \mu\text{(Wood)} \leq 2.63125 + 0.424285 \times 5.458$$
$$0.3155 \leq \mu\text{(Wood)} \leq 2.94675$$

Wood <u>does contribute</u> to the rejection of the null hypothesis.

Food waste. μ (Food) = 14.2

$$a^T\bar{x} = 12.5829 \ ; \sqrt{\frac{1}{N} a^T S a} = \sqrt{\frac{1}{24} \times 84.6885} = 1.87848$$

$$12.5829 - 1.87848 \times 5.458 \leq \mu(\text{Food}) \leq 12.5829 + 1.87848 \times 5.458$$
$$2.330102 \leq \mu(\text{Food}) \leq 22.835698$$

Food waste does not contribute to the rejection of the null hypothesis.

Yard waste. μ (Yard waste) = 14.6

$$a^T\bar{x} = 12.5742 \; ; \sqrt{\frac{1}{N} a^T S a} = \sqrt{\frac{1}{24} \times 88.6249} = 1.92164$$

$$12.5742 - 1.92164 \times 5.458 \leq \mu(\text{Yard waste}) \leq 12.5742 + 1.92164 \times 5.458$$
$$2.0858 \leq \mu(\text{Yard waste}) \leq 23.0625$$

Yard waste does not contribute to the rejection of the null hypothesis.

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16. ABSTRACT

This report deals with energy conservation through reduction in generation of post-consumer solid waste. The objective, scope, methodology and summary of the report are presented in Section 1. Section 2 contains the conclusions. Section 3 presents a review of output and input approaches to estimate the quantity and composition of post-consumer solid waste. Comparative notes on the two methods are included. Section 4 contains a compilation of estimates of energy consumed in the manufacture of discarded materials and in handling the solid waste. Section 5 studies potentials and possibilities of reducing refuse and estimates corresponding energy savings. Twenty examples of opportunities to reduce refuse at government, policy-maker, manufacturer, and consumer levels are proposed. The energy intensiveness of materials found in the waste stream, total energy residuals embedded in each material, and possible candidates for reduction with greatest energy savings are also presented.

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17. KEY WORDS AND DOCUMENT ANALYSIS

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