1979

Resource recovery from solid waste: sub-system operating economic analysis of the Ames, Iowa, system

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8000135

GHERESUS, PETROS
RESOURCE RECOVERY FROM SOLID WASTE:
SUB-SYSTEM OPERATING ECONOMIC ANALYSIS OF THE
AMES, IOWA, SYSTEM.

IOWA STATE UNIVERSITY, PH.D., 1979

Resource recovery from solid waste: Sub-system operating economic analysis of the Ames, Iowa, system

by

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A Dissertation Submitted to the

Graduate Faculty in Partial Fulfillment of the

Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Department: Industrial Engineering
Major: Engineering Valuation

Approved:

Signature was redacted for privacy.

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1979

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CHAPTER I. INTRODUCTION

One of the most critical problems facing the United States today is the increasing volume of solid waste (refuse) generated by the population. Solid waste and refuse are the terms used to distinguish nonliquid waste from the sewage that flows from toilets and sinks. In this report the terms solid waste and refuse will be used interchangeably.

Disposal of the ever-increasing quantity of refuse without deterious effects on air and water quality or high capital expenditure continues to be a challenging task. Previous solid waste disposal practices appeared to operate free of problems. This may have been the result of a lack of information concerning the long-range environmental problems associated with such disposal practices as landfilling, open dumping, and incineration. However, numerous problems are currently being discovered which are associated with the persistent use of open dumps and ill-prepared landfills as solid waste disposal sites. The lack of environmental information combined with budgetary constraints causes open dumps and landfills to continue to be the least expensive and most popular solid waste disposal methods. However, these disposal methods offer short-range remedies while ignoring long-range environmental problems associated with the use of these practices.

Recognition of the environmental problems associated with the open dumps and landfill disposal practices prompted the formation of several organizations in the early 1970's. These organizations have sought legislative action to protect the environment from pollution. During this period environmentalists encouraged recycling of many items. Even though the true long-range cost of dumping and burying solid waste is difficult to measure, the emphasis today is to consider health/environmental consequences as determinants to the environmental solutions. Recycling projects continue to gain popularity as a partial solution to the environmental problems.

Solid Waste Generation, Disposing Techniques and Costs

The difficulties encountered by solid waste management cannot be fully appreciated until the quantity of solid waste materials generated daily in the United States is examined carefully.

Solid waste from residential, commercial, and institutional sources amounted to 140 million tons in 1976, enough to fill the New Orleans Superdome twice each day for 365 days per year. This quantity averaged a generation rate of 1,300 pounds per person per year, or over three and a half pounds per person per day. The volume is projected to reach 180 million tons by 1985 (United States Environmental Protection Agency, 1978a, p. 1).

Municipal solid waste is deposited at 18,500 sites with a total area of 500,000 acres (U.S.E.P.A., 1978a, p. 1). Eighty percent of the solid waste in the United States is deposited in open dumps and landfills; 10% is incinerated, and the remaining 10% is being dumped into the sea or discarded by other means (Barbour, 1974, p. 1).

Extensive use of landfills as solid waste disposal sites increases the competition for land that can be used for other purposes. The need for more landfill space is acute, especially in heavily populated areas. The problem for landfill space is so severe that the New Jersey Supreme Court ruled that importation of solid waste from another state was illegal. Prior to this ruling the City of Philadelphia had deposited solid waste in New Jersey's landfill. However, the new rule prohibits Philadelphia from transporting solid waste in the New Jersey landfill. The City of Philadelphia challenged the ruling as discriminatory and unconstitutional (Solid Waste Report, July 3, 1978a, p. 105). The matter was brought before the U.S. Supreme Court for a decision on the New Jersey Supreme Court ruling. The U.S. Supreme Court reversed the ruling as being unconstitutional. The court declared that discrimination by geographical location is unconstitutional. It also found that banning importation of solid waste from another state violates the free trade between the states, which is unconstitutional (Solid Waste Report, March 27, 1978b, p. 51). This incident between New Jersey and the City of Philadelphia demonstrates the mounting competition for land and landfill use.

In addition to the competition for space, landfill operating costs have increased threefold to fourfold in the course of 10 years. Currently, disposal charges of $10 to $15 per ton are common in the United States. In New York City, a fee in excess of $20 per ton is considered a low price (Cambourelis, 1978, p. 151). Municipal solid waste collection and disposal costs averaged $30 per ton or a total of $4 billion in 1974. Three-fourths of the total expenditure was attributed to collection and transportation (U.S.E.P.A., 1978b, p. 4).

The cost of transporting solid waste is aggravated by the increasing cost of fuel. Thus, the location of the landfill has had a major impact on the disposal costs. Once an existing landfill is exhausted, a new site is located far from residential or business areas where most of the waste is generated. Locating the landfill near either place is considered offensive. The location of landfill sites far away from the generation point, however, creates high transportation costs.

Solid waste transportation can be reduced by implementing a collection center or transfer stations near the refuse generating areas. Subsequently, the refuse can be transferred into the landfill in large loads. The city of St. Louis and Union Electric Co., operators of a solid waste recovery demonstration plant, proposed a central solid waste transfer station in order to cut transportation expense. However, the residents objected to the transfer station located in their neighborhood. As a result of the local opposition, the refuse transfer station project was abandoned (Gallese, 1977, p. 1). If landfills continue to be located far from the refuse generating population, it will become difficult to defend landfill as an economical refuse disposal method.

Problems with Existing Solid Waste Disposal Practices

Landfilling and incinerating are now being questioned on an environmental basis. Incineration is a mass burning of untreated refuse, which causes air pollution. Both methods contaminate either ground water or the air. Landfills and open dumps are also known to encourage rat breeding, to cause gas explosions through methane gas generation, and to scatter dirt and litter to the surrounding area.

Indiscriminate disposal on land of any type of waste is known to cause drinking water comtamination. In Rockford, Illinois, nine wells were abandoned from 1966 to 1972 due to a leachate problem caused by a landfill. The Rockford People Avenue Landfill, an unlined sand and gravel pit located near an industrial area, was used from 1947 to 1972. The site served about 125,000 people and accepted industrial, commercial, and residential waste. During this period nine drinking water wells were contaminated. In 1966 four Quaker Oats Company wells, in 1970 four residential wells, and in 1972 one public water supply had to be abandoned. Damage costs to the wells were estimated at $205,000, which covered the cost of drilling new wells only (Shuster, 1976, p. 3). This cost did not include some of the long-range environmental costs that are difficult to identify and quantify. In spite of the environmental problems associated with landfills, over 94% of the landfills in the U.S. are deemed unacceptable by environmental standards and their continued use is considered a threat to the public health (Mantell, 1975, p. 13). The potential contamination of drinking water as the result of the use of landfills should encourage the search for long-range disposal methods that are environmentally sound as well as economically feasible.

Government's Role in Solid Waste Disposal Practices

In an attempt to provide answers to the environmental problems created by solid waste, the United States Congress passed the Solid Waste Act in 1965. The Act encouraged research in developing new techniques of handling and disposing of solid waste that are environmentally acceptable by providing monetary grants of up to 50% of the total cost of developing such programs (National Center for Resource Recovery, 1974, p. 19).

On October 21, 1976, the Solid Waste Act was amended and came to be known as the Resource Conservation and Recovery Act. The Act, administered by the United States Environmental Protection Agency (U.S.E.P.A.), deals with both hazardous and nonhazardous solid wastes and stresses the following points:

1. Use of federal funds to enhance recycling activities.
2. Evaluation of advantages and disadvantages of various recycling methods.
3. Development of better disposal techniques that will eventually displace open dumping.
4. Support of solid waste disposal research demonstrations and programs.
5. Continuation in the study of new methods of solid waste disposal practices and evaluation of the environmental impact of the disposal methods, which will eventually lead to a national policy (U.S.E.P.A., 1978b, p. 9).

The Resource Conservation and Recovery Act is a definite commitment by the U.S. government in an effort to solve the increasing solid waste disposal difficulties by providing technical and financial aid.

Energy/Materials Recovery and Saving Potentials from Solid Waste

The value of solid waste is a very important factor, perhaps second to the service of removing the waste. Some of the materials previously discarded as worthless are becoming valuable sources of energy and recyclable materials.

Much effort is therefore being expended to recover many valuable resources from solid waste. If the entire municipal solid waste could be recovered, it is estimated that the energy equivalent of 400,000 barrels of oil per day would be made available for consumption. This energy production from solid waste is enough to fulfill the commercial and residential lighting needs of the United States, or one-third the flow of the Alaskan Oil Pipeline (U.S.E.P.A., 1978a, p. 10). Untreated solid waste is estimated to contain a heating value of 4,500 BTUs/lb., making it a valuable source of energy (U.S.E.P.A., 1978c, p. A2).

In addition to being a potential energy source, solid waste also contains many recyclable materials. Substantial energy can be saved in producing certain material through recycling efforts rather than producing the same material from virgin sources. For example, eight kilowatt-hours of electrical energy are required to produce one pound of aluminum from aluminum ore; but producing the one pound of aluminum from recycled aluminum scrap requires only 5% of the ore energy consumption. The 95% energy saving is translated to 80,000 BTU's saving for each pound of aluminum produced through recycling rather than through aluminum ore processing. Similarly, 50% or 4,500 BTU's of energy saving can be realized in producing one pound or iron from scrap metal rather than from iron ore (Hickman, 1977, p. iii).

In spite of the large energy and materials recovery potentials from solid waste, only 7% of the total solid waste in the United States is recovered and of that, only 1% is processed to deliver electrical, steam, or gas energy (U.S.E.P.A., 1978a, p. 10). The U.S. lags in the waste-to-energy effort as evidenced by the fact that many European countries convert solid waste into energy. The proportion of solid waste to energy conversion by country is given in Table 1.1 (U.S.E.P.A., 1978a, p. 10).

Table 1.1. Proportion of solid waste to energy conversion by country

Country	Proportion of solid waste converted into energy (%)
Denmark	60
Switzerland	40
Netherlands	30
Sweden	30
Germany	20
England	10
United States	1

Research Objectives

The City of Ames owns and operates the first full-scale commercial solid waste resource recovery plant in the U.S. which processes municipal solid waste for use as a supplementary fuel in an electric utility boiler. The decision to implement a solid waste resource recovery system requires a thorough economic and environmental evaluation. Various questions have been raised concerning the Ames Solid Waste Recovery System operations which need to be addressed. Some of the questions include:

1. What are the environmental consequences resulting from the burning of refuse derived fuel?
2. What is the impact on the health and safety of employees subjected to equipment noise, fire, explosions, refuse odor and dust, bacteria and viruses?
3. What quantity of valuable materials such as refuse derived fuel, ferrous and nonferrous metals can be reclaimed from solid waste?
4. What are the critical input parameters that affect the facility's operating cost effectiveness after such a system is implemented?

Although the above questions may not be inclusive of all questions asked regarding the Ames system operations, these questions appear to be of interest at this stage. While the questions listed above are all important, this research is conducted to address the last two.

Currently, various estimates are given as to the amount of valuable resources that can be recovered from solid waste. In addition, operation and maintenance costs of a solid waste resource recovery system of the type operated by the City of Ames have not been established; current operation and maintenance costs are based on design studies. Therefore, the thrust of this research is to investigate: 1) the magnitude and economic value realized from the Ames Solid Waste resources and, 2) the facility's operating characteristics.

Methodology

The refuse processing operation is divided into sub-systems. An operating cost model is developed using the input parameters (labor, energy and material costs) for each sub-system. The facility's sub-system categories by function include:

Refuse receiving system;

Shredding system;

Air density separation system;

Refuse derived fuel transport system;

Nonferrous metals separation system;

Ferrous metals separation system;

Rejected materials disposal system; and

Overall plant support.

The investigations of this report are confined to the Ames Solid Waste Resource Recovery System due to the lack of detailed cost information from other operating systems. The Ames system was modeled after the City of St. Louis' Solid Waste Resource Recovery Demonstration Plant. The Ames and St. Louis systems are not identical, but some comparisons can be made.

This report examines the Ames Solid Waste Resource Recovery System operations from July, 1977, through June, 1978, coinciding with the

City's fiscal year. The main concern of this research is confined to the facility's one year experience. Where information for more than one year is available concerning energy consumption, labor input, and quantity of resources recovered, this additional information will be used for comparison purposes. Changes were implemented in the facility in November of 1978, but the effects of these changes on the facility's operation are not discussed in this report because the information available to date is not sufficient to draw conclusions. However, qualitative information concerning the changes made is presented.

Most of the data and information analysis is based on actual measured data, while some of the information is measured indirectly.

The actual measured information includes the following items:

1. Wages and salaries: The wages and salaries used include regular and overtime payments and all benefits, if applicable.
2. Labor hours worked: The labor hours used include regular and overtime hours worked. No adjustment was made for the overtime hours worked when calculating the total number of hours worked; an hour worked on overtime was treated as if it were worked during a regular 8 hour day. However, the employee's wages did reflect compensation for the overtime hours worked.
3. Electrical energy consumption: The energy consumed by the 1000 H.P. electric motors of the primary and secondary shredders, the 200 H.P. electric motor in the ADS system, and the 200 H.P. electrical motor in the refuse derived transport system were measured individually using kilowatt hour meters. Many pieces

of the plant's electrical equipment were monitored by a single kilowatt hour meter. Thus the amount of energy consumed by the individual pieces of equipment must be estimated. Therefore, to obtain an estimate of the individual equipment's energy usage, the amount of energy consumed by these systems was assumed to be proportional to the equipment's electrical power rating.

4. Expenses: All of the expenses used in this research were the actual expenses incurred by the City of Ames while operating the facility.

5. Quantity of refuse derived fuel recovered: The amount of refuse derived fuel produced was measured indirectly. That is, the refuse derived fuel was the difference between the amount of refuse processed and the quantity of resources and rejected materials extracted. This method of indirect measurement was assumed to be reasonable.

Hopefully this sub-system operations analysis approach will provide vital information for persons concerned with the design and operation of present and future solid waste recovery systems.

CHAPTER II. LITERATURE REVIEW

The idea of energy and materials recovery from solid waste is gaining public support in the United States. Recognition of the vast energy and material recovery potential from solid waste has been a main catalyst in the resource recovery and conservation movement. Solid waste as an energy and materials source has been overlooked in the past. The earliest solid waste-to-energy conversion was accomplished through incineration. Early incinerating processes contributed to air pollution problems; thus they are deemed unacceptable to the environment. Currently, the emphasis has shifted to the development of solid waste processing systems that are capable of sorting energy and recyclable materials from the mixed solid waste.

From Solid Waste to Energy/Material Converting Systems

There are four general types of systems for recovery of energy and resources from solid waste: 1) incineration, 2) pyrolysis, 3) biomass conversion, and 4) solid fuel and materials production (Stuckenbruck and King, 1977, p. 32).

Incineration

Incineration is the combustion of unprepared waste, with energy as the principal recovered resource. This process has been in use for many years, particularly in the European countries. Combustion of unprepared waste is the most direct process of recovering energy from refuse. The refuse is burned in heat recovery incinerators to generate steam or electrical energy.

Energy recovery from solid waste using incineration is recent in the U.S. as compared to the European countries. The Nashville thermal transfer corporation project was the first incineration system implemented in the United States that generated steam and chilled water for heating and cooling 30 buildings (U.S.E.P.A., 1978c, p. 45). Currently, there are several incinerators in operation in the United States. Incineration releases a large volume of particulate emissions into the atmosphere which must be collected. Similarly, it produces large amounts of ash which must be disposed of.

Pyrolysis

Pyrolysis is the thermal decomposition of materials in the absence of oxygen. The temperature and the lack of oxygen cause a breakdown of the materials in the process (Fuels from Waste, 1977, p. 75). Products of this system are liquid and gaseous fuels. The operation of a pyrolysis system requires material handling equipment, fuel generating equipment, power generating equipment, and air pollution control equipment. Current pyrolysis operating information is based on pilot plant study results. Presently, two full scale pyrolysis systems, the 250 tons per day Landgard Plant in Baltimore and the 1000 tons per day Garret Plant in San Diego are in operation (Pavoni et al., 1975, p. 427). The operating experience of these two plants will provide valuable information concerning the pyrolysis operating characteristics; unfortunately these plants are not fully operational at the present time due to technical difficulties.

Biomass conversion

Biomass conversion is the anaerobic bacterial conversion of organic material to methane and carbon dioxide. This process involves the collection of the methane gas from landfills, or from a controlled anaerobic process. A biomass conversion process study was conducted at the University of Illinois in 1973 under a grant by the United States Environmental Protection Agency (Pavoni et al., 1975, p. 435). The study revealed that the proportion of methane and carbon dioxide gases produced is dependent upon the processing temperature and the process duration time.

The methane recovery by this process is slow and its heating value is low due to the presence of carbon dioxide. Many materials in the solid waste stream are inorganic; therefore, they do not produce any gas. In addition, the methane gas is contaminated. Therefore, it may require purification, depending upon its final use.

Solid fuel and materials production

The solid fuel and materials production process involves shredding or grinding the solid waste and then separating the combustible (light) portion by means of air classification. The heavy materials are then separated into metals which are recovered; the remaining materials are rejected. The prepared solid fuel can be burned as supplementary fuel in coal burning boilers.

The solid fuel producing system was implemented in St. Louis in 1970. This type of system was the first of its kind in operation in the United States. The St. Louis system was experimental; however, recently several communities, including Ames, Iowa; Milwaukee, Wisconsin; and Chicago, Illinois, have implemented full-scale operating systems (Stuckenbruck and King, 1977, p. 33). The Ames system was the first full-scale facility to operate in the U.S. after the St. Louis demonstration plant.

The St. Louis Solid Waste Recovery Demonstration Plant

In 1973, the city of St. Louis, Missouri, constructed a mechanical solid waste processing demonstration pilot plant. The facility was primarily designed to produce refuse derived fuel (RDF); it also has ferrous metals sorting capabilities. The RDF is burned with coal in power plant boilers to generate electrical energy. The RDF and coal mixture combustion experiment was the first of its kind in the United States (Skinner, 1975, p. 56).

Refuse processing technique

The St. Louis facility with its single stage shredder, air classifier, and magnetic separator processes residential refuse only. The refuse processing methodology is shown by Figure 2.1. The ferrous metals are magnetically extracted while light aerodynamic materials are separated from denser materials by an air density separating system. The lights are classified as RDF and the heavies as rejects. The RDF is stored and subsequently transported 18 miles by truck to the Union Electric Power Plant to be burned with coal to generate electrical energy. The ferrous metals are sold commercially to a scrap processor and the rejected materials, including nonferrous metals, are hauled to a landfill.

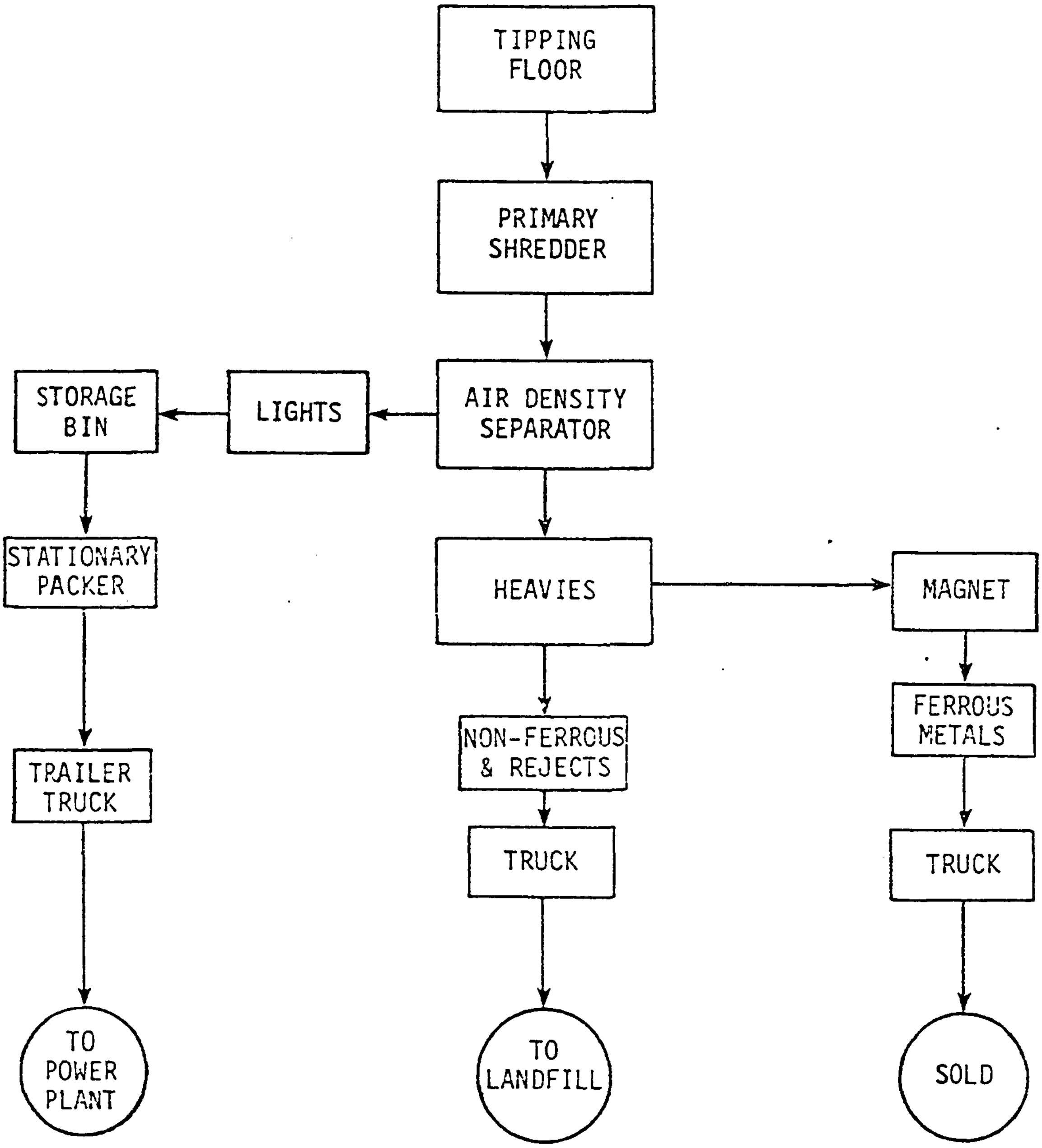

Figure 2.1. St. Louis refuse process flow diagram

Operating economics and resources recovered

The St. Louis refuse processing facility had an initial cost of $2.3 million. Refuse processing cost varied from $4.04 per ton in one month to $52.60 per ton in another month with an average of $7.49 per ton during one year's study. The lowest refuse processing cost of $4.04 per ton reflects the plant's operation to near capacity and without downtime or shutdown for scheduled maintenance (Midwest Research Institute, 1977, p. 2).

The St. Louis facility's major products are RDF and ferrous metals. Results from the facility reveal that 80.60% of the total processed refuse was classified as RDF, 4.25% ferrous metals, 7.31% rejected materials, and 7.57% as material loss (Midwest Research Institute, 1977, p. 67).

Current RDF producing facilities

The knowledge of potential energy recovery from solid wate prompted many communities to consider solid waste as a valuable source of materials. Several communities have implemented, or are in the process of implementing solid waste recovery plants similar to that of the St. Louis facility. The communities include the following: Ames, Iowa; Baltimore County, Maryland; Bridgeport, Connecticut; Chicago, Illinois; Lane County, Oregon; Milwaukee, Wisconsin; and Monroe County, New York (U.S.E.P.A., 1978a, p. 11).

The prime function of these facilities is to extract RDF from solid waste and subsequently use it as supplementary fuel with coal in power plants. In addition to RDF production, some of these plants have the capacity to extract ferrous and nonferrous metals such as sand and glass from solid waste.

CHAPTER III. THE AMES SOLID WASTE RESOURCE RECOVERY SYSTEM

In 1972 the City of Ames, Iowa, hired a consulting firm to make a feasibility study of burning RDF with coal in its existing municipal power plant boilers in which coal and natural gas have traditionally been primary fuels. The construction of the solid waste resource recovery facility was approved in 1972 and completed three years later. The $6.3 million dollar plant began processing refuse in November of 1975. The facility, designed to process refuse at a nominal rate of 50 tons per hour, is located one block from the city's power plant and three blocks from the city's central business district.

The Ames system occupies one city block and serves about 65,000 Story County residents, 45,000 of whom live in Ames. The processing plant is completely enclosed in order to control noise, odor, flying litter, and to protect personnel and equipment from severe weather. The refuse processing facility and the adjacent power plant are owned and operated by the City of Ames. The Ames system was the first full-scale facility of its kind in operation in the United States. The Ames system design is based on the St. Louis-Union Electric Company Solid Waste Resource Recovery Demonstration Plant.

Capital Investment

The cost of construction of the Ames Solid Waste Resource Recovery facility, RDF transporting and storage systems, and power plant's boiler modifications, originally estimated at $5.6 million, soared to $6.3

million. The entire system was financed through a general obligation bond at a 5.33% interest rate to be paid semi-annually with principal and interest over a 20 year period. The facility's total estimated and actual costs and the cost overun of each category are listed in Table 3.1. The total actual cost exceeded the estimated cost by 13 percent (Even et al., 1977, pp. 196-198).

Table 3.1. Predicted and actual capital investment comparison

Investment item	Predicted cost (%)	Actual cost (%)	Actual cost as percent of predicted cost (%)
Processing plant	3,898,000	4,116,526	106
Pneumatic conveyors	150,000	164,388	110
Storage bin & foundation	687,000	551,292	80
Supporting electrical work	114,000	314,020	275
Boiler modifications	179,000	178,988	100
Minor equipment & start-up	100,000	108,068	108
Land	156,000	376,896	242
Engineering	275,000	486,405	178
TOTAL	5,569,000	6,296,583	113

Refuse Processing
Methodology

Unsorted refuse is delivered and unloaded at the facility's tipping floor. The refuse is fed by an end-loader into a conveyor that feeds the primary shredder where it is reduced to a maximum size of 6 inches. The shredded refuse from the primary shredder is fed into the second shredder where it is reduced to its final size of an inch and a half (see Figures 3.1 and 3.2 for refuse processing and equipment flow diagrams, respectively). Then, it is conveyed into an air classifier system that sorts the shredded refuse into light refuse derived fuel (RDF) and heavy fraction noncombustibles by an updraft air flow. The RDF portion is carried into a cyclone bin by the air stream and subsequently transported penumatically 600 feet under ground through a 14 inch pipeline into a 500 ton storage bin. The city's power plant, located 300 feet from the RDF storage bin, conveys the RDF pneumatically through four underground pipelines where it is mixed with coal and burned to generate electrical energy (see Figure 3.3 for facility's layout (Funk, 1974, p. 212)). The heavy materials fall to the bottom of the air classifier and the ferrous metals not sorted by the first stage magnet are extracted magnetically in two stages. The remaining heavy materials, classified as rejects, are conveyed into storage bins and subsequently disposed of in the city's landfill, located 2 miles from the refuse processing facility.

The ferrous metals are sorted by magnets at three locations in the shredded refuse flow stream and sold commercially. The nonferrous metals

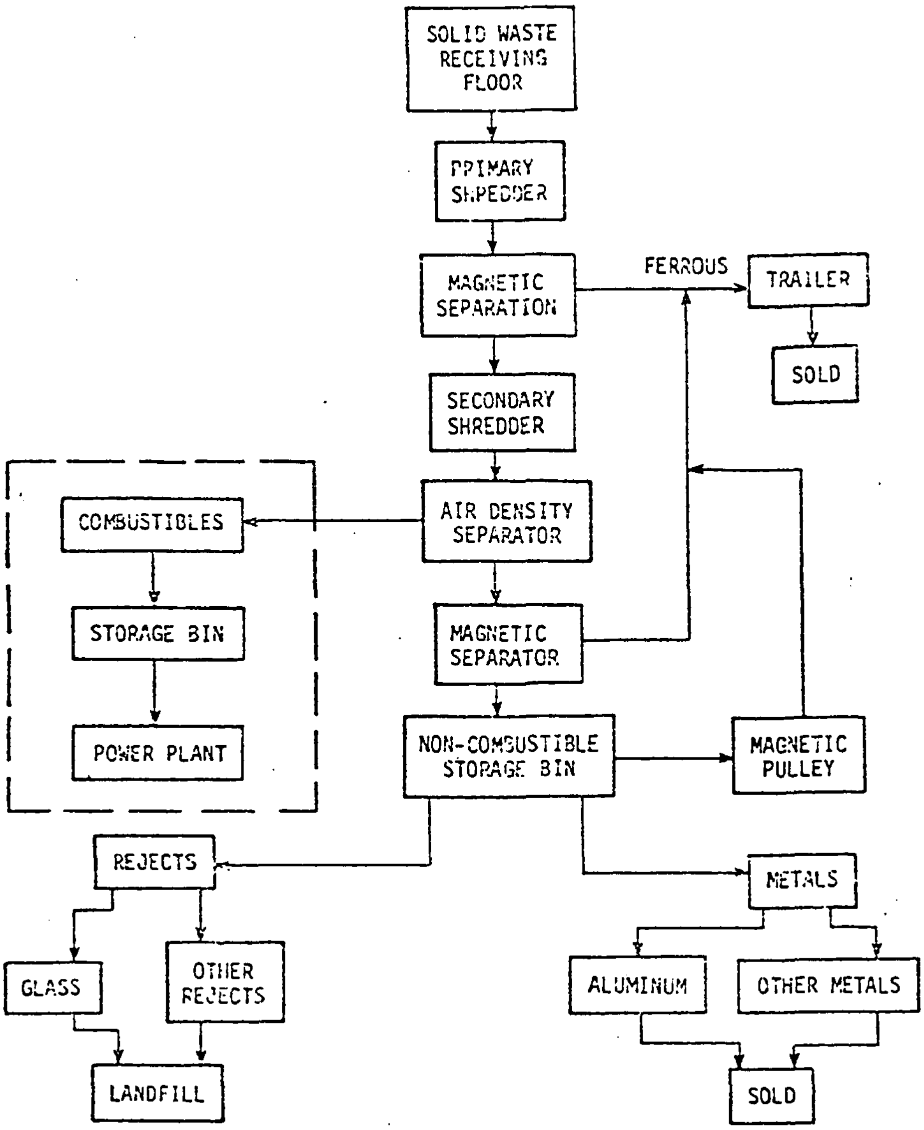

Figure 3.1. Refuse processing flow diagram

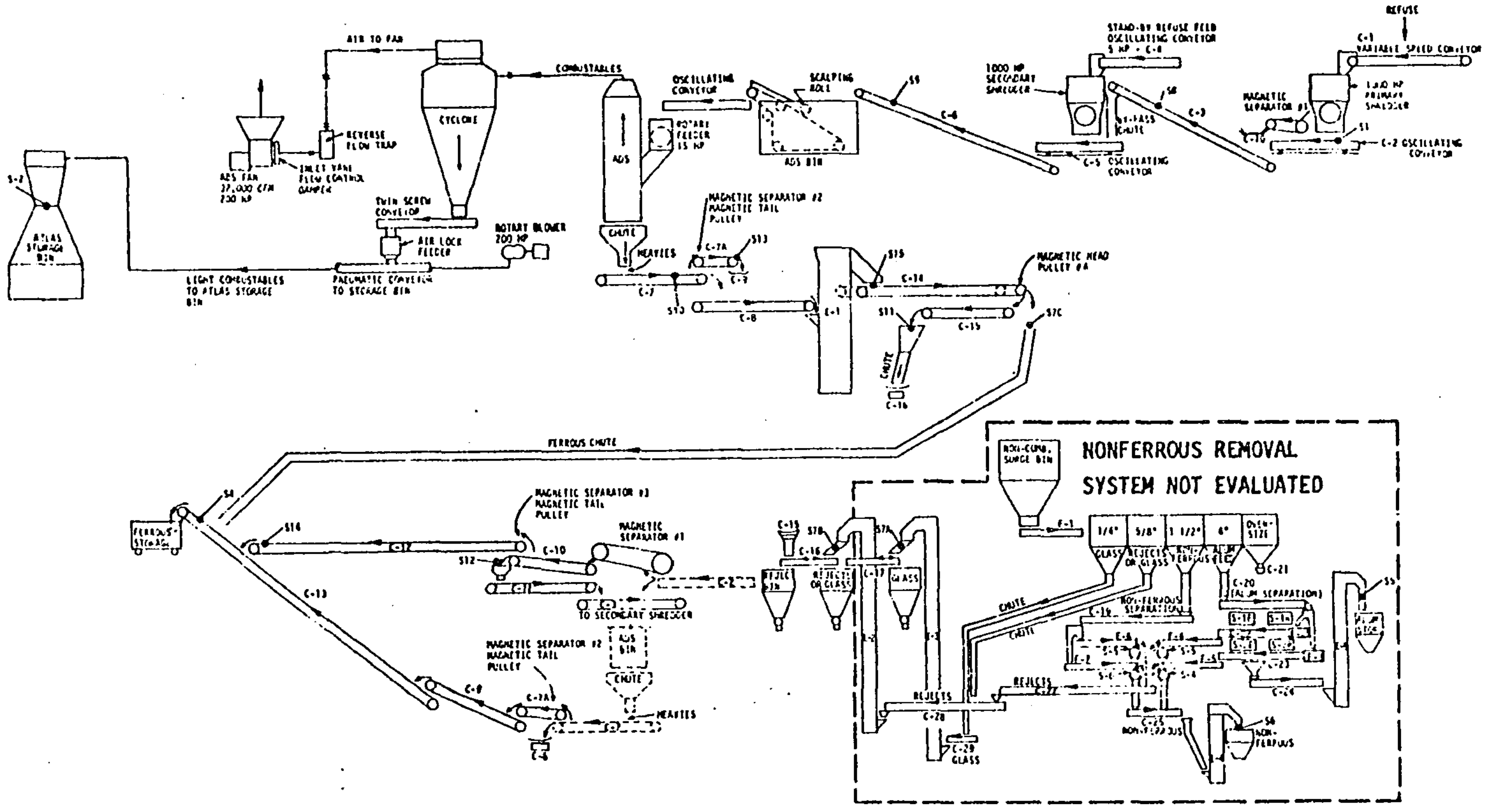

Figure 3.2. Process plant equipment flow diagram

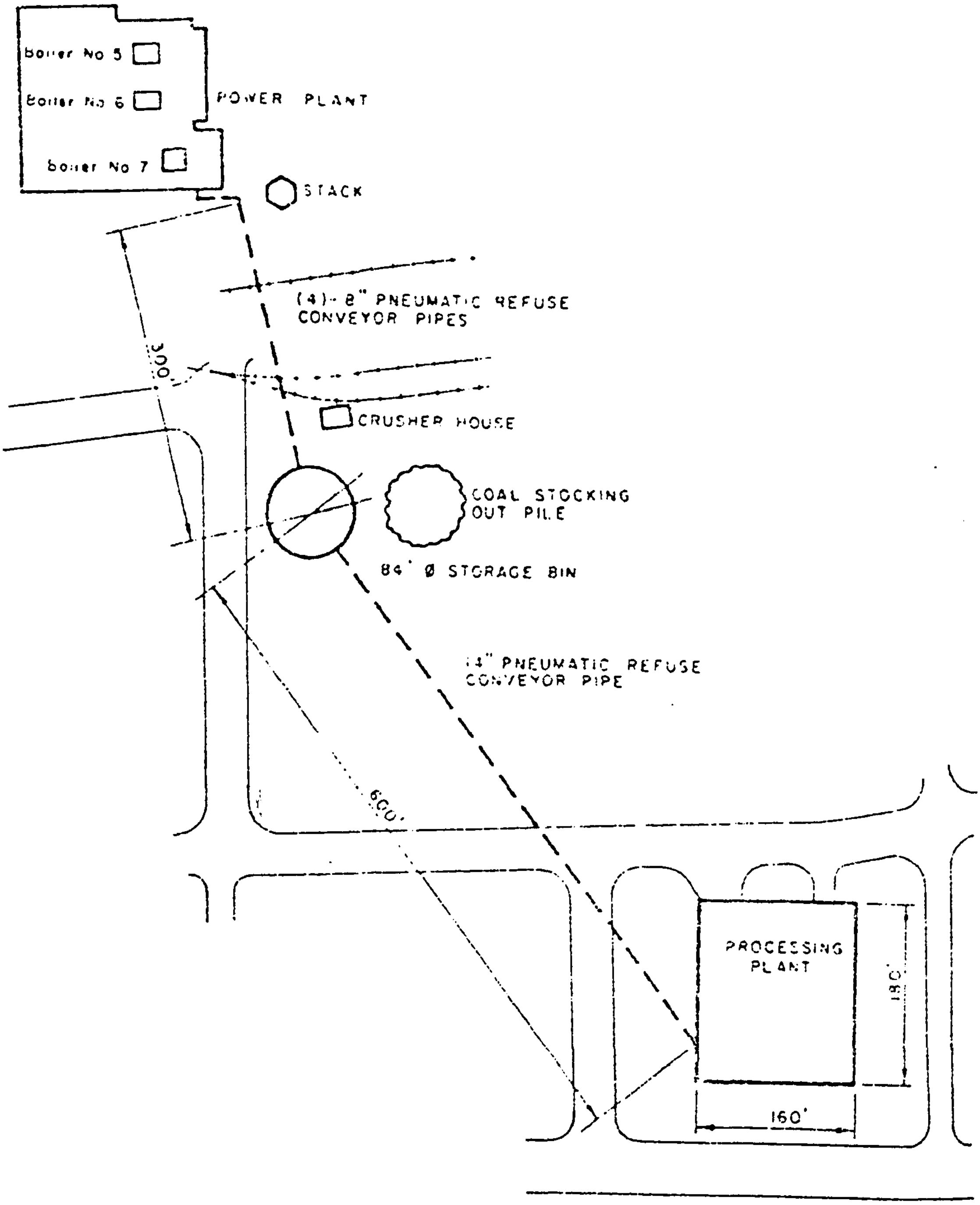

Figure 3.3. Process plant layout diagram

are extracted by a nonferrous classifying system and sold commercially. Nearly all of the refuse processing operation is monitored and controlled from a central location by a single operator.

Total Manpower Requirements and Responsibilities

The plant attempts to maintain 8 full and 8 parttime employees. The employees titles and responsibilities are summarized in Table 3.2. The facility has difficulty maintaining stable parttime employees. The parttime employee turnover has been high, as it is depicted by Figure 3.4. The following reasons can be cited for the instability of these employees:

a) All of the parttime workers, except for the clerk, are engaged in cleaning refuse spilled during plant operation. Thus, the working conditions are the least desirable in the plant due to the odor and dust problems they encounter.

b) The parttime employees are paid minimum wages and accrue no fringe benefits.

c) They are subjected to extreme working conditions. While those working in the office area are provided with a controlled environment, the parttime employees are subjected to extreme summer and winter weather variations.

d) University students who leave upon graduation or when class schedules change comprise the majority of the parttime workers.

The above reasons are some of the contributors to the high parttime labor turnover.

Table 3.2. Employees titles and responsibilities

Employee's title	Number of employees	Employee's duties	Employment term: Full-time	Employment term: Part-time
Plant manager[a]	1	In charge of all plant operations and public relations	X	
Operations supervisor[a] process controller	1	Monitors processing equipment control panel and assigns tasks to employees	X	
End-loader operator[a]	1	Piles refuse on receiving floor, feeds refuse into shredder, feeds log chipper and loads metals and rejects into bins	X	
Maintenance II	1	Electrical maintenance	X	
Maintenance II	1	Mechanical maintenance	X	
Maintenance I	1	Operates log chipper, paper baler, assists customers on tipping floor and sorts metals, rejects, and hazardous metals from tipping floor	X	
Maintenance I	1	Assists other maintenance personnel	X	
Truck driver	1	Hauls rejects to landfill and helps change ferrous metal trailer	X	
Clerk	1	Conducts plant tours and performs secretarial duties		X
Laborer	2	Assists in plant maintenance		X
Cleaners	4	Cleans and dusts processing equipment and floor		X
Custodian	1	Cleans office and conference areas		X

[a]Indicates salaried employees. In addition, 15% of the Public Works Director's time is charged against the refuse processing facility.

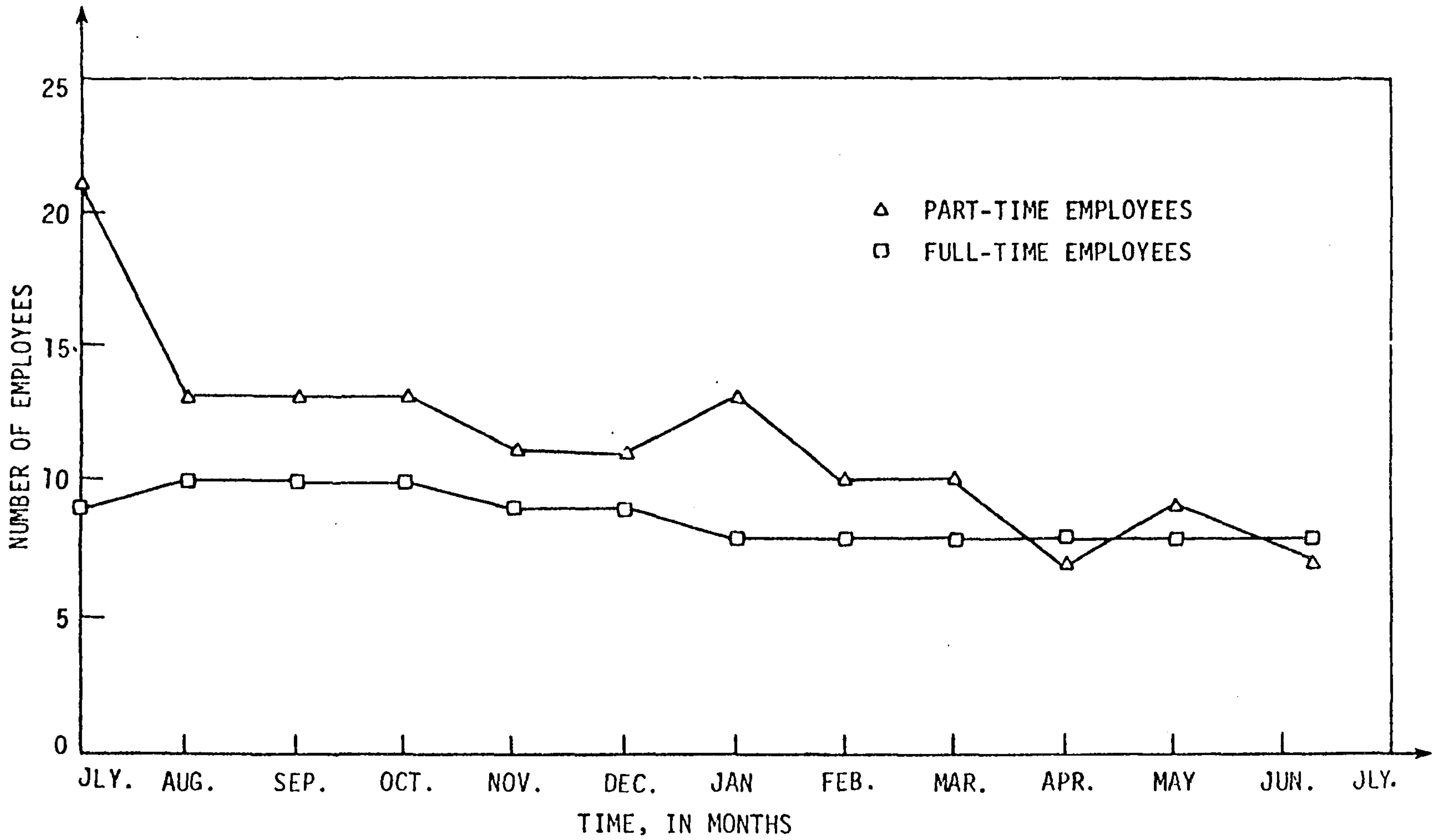

Figure 3.4. Full and parttime labor (1977-1978)

Sources and Amount of Refuse Processed

The Ames facility accepts refuse from commercial, industrial, and residential customers. Customers delivering refuse include commercial haulers, private customers, Iowa State University (I.S.U.), the Iowa Department of Transportation (I.D.O.T.), and the National Animal Disease Laboratory (N.A.D.L.). The monthly refuse contribution by these customers during the 1977-1978 study period, is summarized in Table 3.3. The individual customer's refuse contribution varied from 863.81 pounds per customer in July to 169.35 pounds in May. The private customer's refuse delivered quantity is estimated by the plant manager daily. In the summer of 1976 actual measured individual customer contributions indicated about 203 pounds per customer (Even et al., 1977, p. 72). The proportion of the total amount of refuse contributed by the various customers is shown in Figure 3.5. Commercial haulers are the major contributors, followed by I.S.U., private customers, the I.D.O.T., and the N.A.D.L.

The amount of refuse delivered by the private customers is a significant portion when compared to the contribution made by I.S.U. with its 23,000 student body. The private customer (car-line) service was established to accommodate customers with no commercial hauling services. However, even some customers with commercial refuse collecting services haul their own refuse into the facility. During the one year period 23,596 private customers driving their own private vehicles hauled refuse into the plant. This is an average of 1,966 vehicle trips per month, with each vehicle carrying an average of 535 pounds. The number of individual trips made increased from 11,427 trips in the last six

Table 3.3. Solid waste contribution by source

Month	Commercial (ton)	Private (ton)	I.S.U. (ton)	I.D.O.T. (ton)	N.A.D.L. (ton)	TOTAL (ton)
1977						
July	2,601.05	794.93	521.80	35.28	12.94	3,966.00
August	3,605.81	914.37	599.55	74.43	23.89	5,218.05
September	3,386.62	805.15	749.09	28.40	16.63	4,985.89
October	3,361.18	766.20	758.46	25.95	12.97	4,924.76
November	2,981.98	596.80	598.75	26.77	13.06	4,217.36
December	2,693.45	573.90	344.84	20.77	5.38	3,637.64
1978						
January	2,696.34	221.77	554.02	31.35	15.41	3,518.89
February	2,049.15	201.62	541.27	47.24	19.58	2,858.86
March	2,779.52	331.56	615.10	67.32	17.45	3,810.95
April	2,758.04	509.91	573.16	57.07	17.90	3,916.08
May	2,297.36	186.96	466.98	21.39	8.54	2,981.23
June	3,053.43	406.64	628.74	42.46	47.46	4,178.73
TOTAL	34,263.93	6,309.81	6,951.76	477.73	211.21	48,214.44
PERCENT OF TOTAL	71.07	13.09	14.42	0.99	0.43	100.00

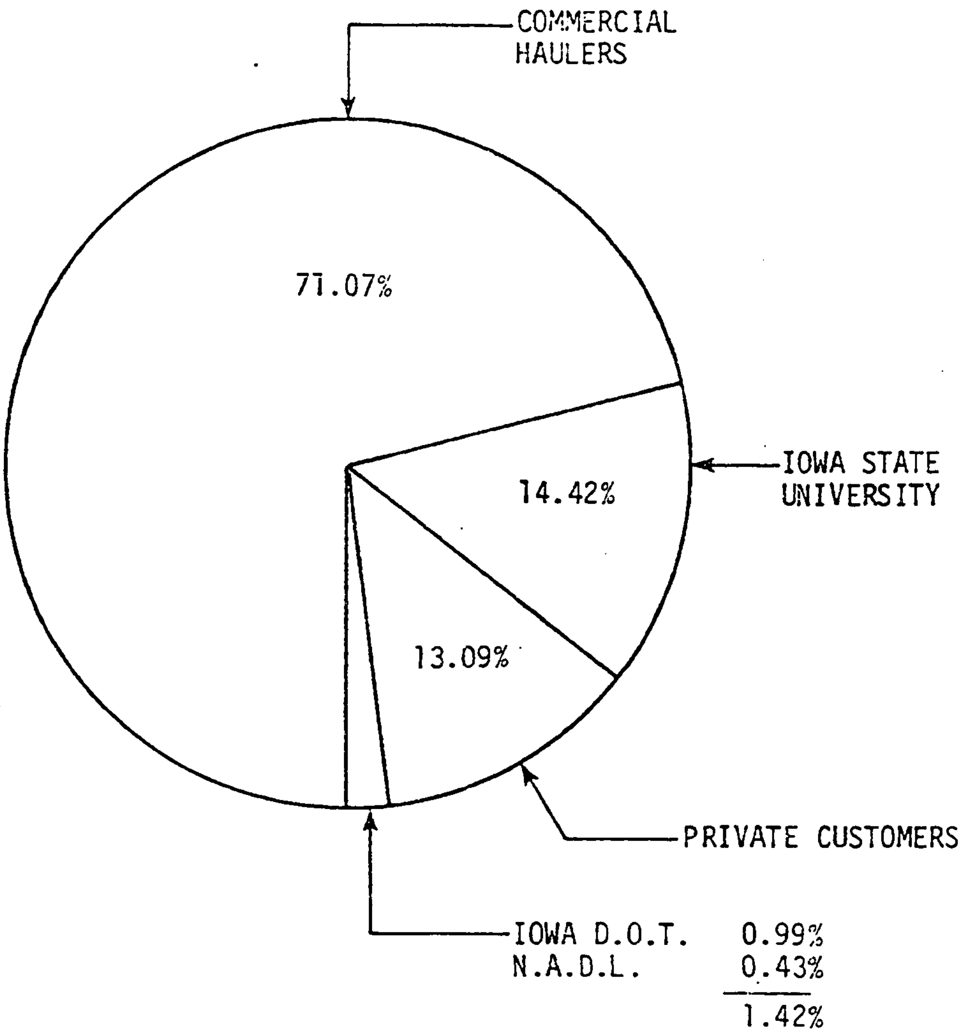

Figure 3.5. Refuse contribution by source, by weight

Table 3.4. Private customers refuse contribution

Month	Number of customers trips (#)	Total refuse delivered by private customers (tons)	Average weight (lbs/trip)
1977			
July	2,203	794.93	721.68
August	2,228	914.37	820.80
September	2,079	805.15	774.56
October	1,774	766.20	863.81
November	1,716	596.80	695.57
December	1,427	573.90	804.34
(SUBTOTAL)	(11,427)	(4,451.35)	(779.09)[a]
1978			
January	1,233	221.77	359.72
February	1,198	201.62	336.59
March	2,189	331.56	302.93
April	2,720	509.91	374.93
May	2,208	186.96	169.35
June	2,621	406.64	310.29
(SUBTOTAL)	(12,169)	(1,858.46)	(305.44)[a]
TOTAL	23,596	6,309.81	534.82[a]
AVERAGE PER MONTH	1,966	523	

[a]Average refuse weight per trip.

months of 1977 to 12,169 trips in the first six months of 1978, with an overall increase of 6.5%. More private customer trips were made in the spring and summer than in the fall and winter months. The private customers' monthly refuse contribution is summarized in Table 3.4.

Discussion

The facility, costing $6.3 million, processed refuse at an average rate of 4,018 tons per month during the 1977-1978 fiscal year operation. In view of the plant's large fixed cost payments, the quantity of refuse processed becomes an important factor in determining economic viability. Thus the fixed cost per ton of refuse processed is decreased only as the amount of refuse processed is increased.

Private customers contributed 13.09% of the total refuse delivered at the facility during the one year period. An average of 1,966 private customers per month delivered refuse at the plant, with most customers visiting the plant in the spring and summer months. The private customer's refuse disposing facility can accommodate only two vehicles (in series) at one time. Therefore, the facility user faces a long queue at times, which aggravates some of the customers and operating personnel. The waiting time causes customers to complain to management, creating undesirable public relations. The problem is difficult to alleviate with the existing facility set up. However, future planners need to evaluate this problem whenever private customer-refuse disposing services are being considered.

The plant also has had difficulty maintaining reliable parttime employees. Some of the reasons causing the high parttime employee turnover have been cited. However, management needs to evaluate this problem and attempt to rectify the difficulty, as the parttime employee services are essential to the facility's maintenance operations.

CHAPTER IV. QUANTITY OF VARIOUS RESOURCES RECOVERED FROM THE AMES SOLID WASTE

The primary product of the Ames Solid Waste Resource Recovery System is RDF. After RDF, ferrous metal is the second most important output and source of revenue. The remaining resources - wood chips, baled paper, and nonferrous metals, account for less than one-half of one percent by weight of all the recovered materials. The monthly quantity of the resources reclaimed from the Ames Solid Waste is listed in Table 4.1. The wood chipping and paper baling are separate operations, and the quantity produced is not a function of the amount of refuse processed. Wood chips, sold locally, are produced whenever a demand arises. Paper bales are also produced whenever management decides that it can realize a profit by selling baled paper rather than shredding and selling it to the power plant as RDF. The nonferrous metal separating system was not operational during the time of the study; the small amount of nonferrous metals sold were manually sorted. The wood chipping, nonferrous separation and baling operations will be discussed separately. The proportions of resources reclaimed and rejected materials extracted for the one year period are shown in Figure 4.1. The results of Figure 4.1 coincide very closely with an earlier study's results based on 24 months' worth of data compiled during the 1976 and 1977 operations (Adams et al., 1978, p. 85) (see Figure 4.2).

One of the important questions asked is - How much RDF, ferrous, and other resources can be realized from every ton of refuse processed? In

Table 4.1. Resources recovered from the Ames solid waste

Month		Refuse derived fuel[a] (tons)	Ferrous metals (tons)	Rejects (tons)	Nonferrous metals[b] (tons)	Wood chips (tons)	Baled paper (tons)	TOTAL (tons)
1977	July	3,310.81	240.00	409.00	-	6.00	-	3,965.81
	August	4,154.48	346.00	685.00	6.83	12.00	14.00	5,218.31
	September	3,992.15	348.00	640.00	-	-	6.00	4,986.15
	October	4,230.74	291.00	388.00	-	-	15.00	4,924.74
	November	3,747.10	269.00	201.00	-	-	-	4,217.10
	December	3,262.59	123.00	244.00	-	-	8.00	3,637.59
SUBTOTAL		(22,697.87)	(1,617.00)	(2,567.00)	(6.83)	(18.00)	(43.00)	(26,949.70)
PERCENT OF SUBTOTAL		(84.22)	(6.00)	(9.53)	(0.03)	(0.06)	(0.16)	(100.00)
1978	January	3,046.98	222.32	249.59	-	-	-	3,158.89
	February	2,482.47	199.09	173.48	-	-	3.82	2,858.86
	March	3,174.25	317.75	315.55	-	3.40	-	3,810.95
	April	3,177.99	284.01	444.99	-	9.09	-	3,916.08
	May	2,445.65	235.12	300.46	-	-	-	2,981.23
	June	3,439.52	295.25	443.96	-	-	-	4,178.73
SUBTOTAL		(17,766.86)	(1,553.54)	(1,928.03)	-	(12.49)	(3.82)	(21,264.74)
PERCENT OF SUBTOTAL		(83.55)	(7.31)	(9.07)	-	(0.06)	(0.02)	(100.00)
TOTAL		40,464.73	3,170.54	4,495.03	6.83	30.49	46.82	48,214.44
		83.93	6.58	9.32	0.01	0.06	0.10	100.00

[a] Weight by difference.

[b] Manually sorted.

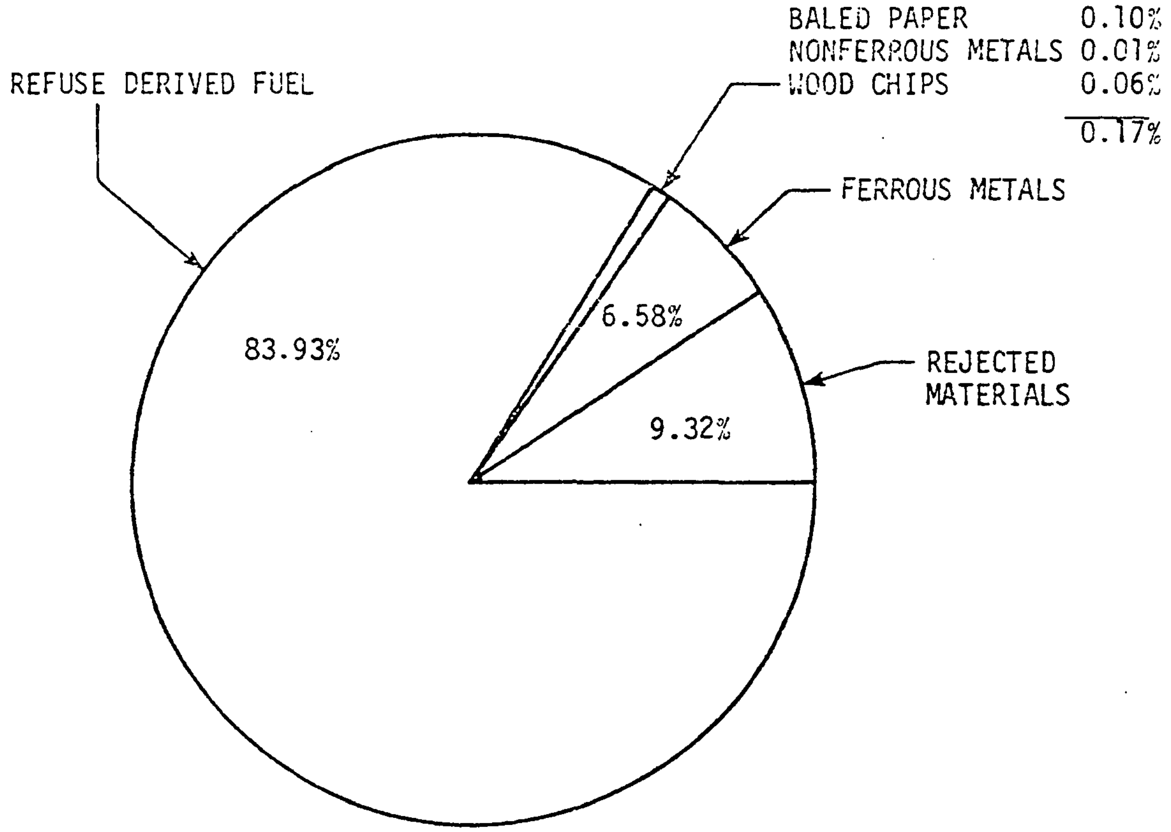

Figure 4.1. Resources recovered from the Ames refuse (June 1977-July 1978)

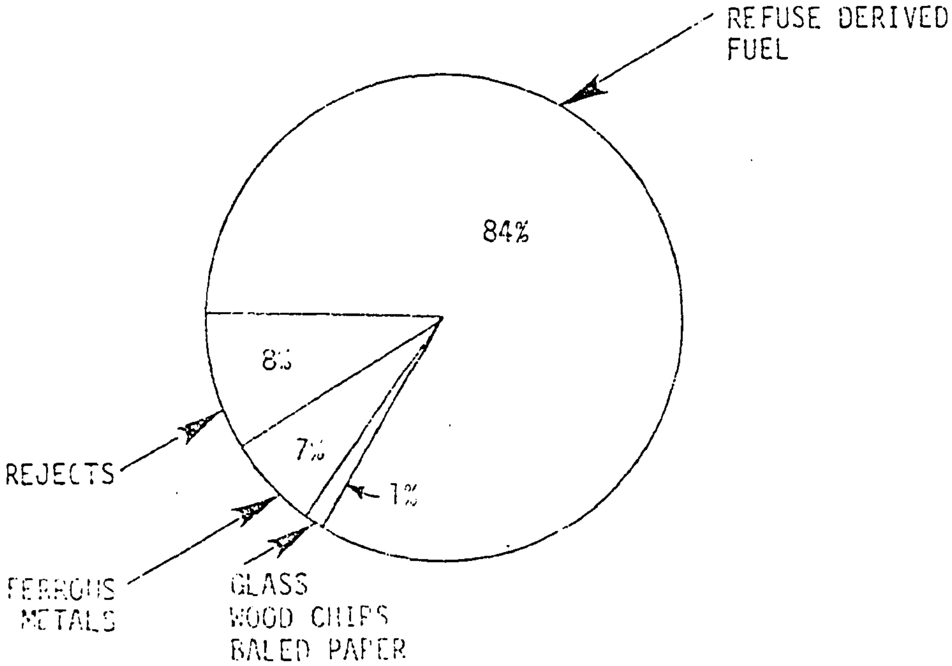

Figure 4.2. Resources recovered from the Ames Solid Waste (January 1976-December 1977)

an attempt to resolve this question, the relationship between the monthly quantity of refuse processed and the amount of RDF, ferrous metals and rejected materials are plotted in Figures 4.3, 4.4 and 4.5, respectively. This information includes data gathered from January, 1976, to December, 1978 (excluding November, 1978), a total of 35 months (see Table 4.2). The scatter plot of these relationships indicates a fairly linear relationship between the quantity of refuse processed and the amounts of RDF, re-metals, and rejected materials produced. Simple linear regression model estimators of these relationships yield the following equations:

1. RDF (tons) = 137 + (0.8061) (refuse processed, in tons)

   $R^2 = 0.98$ $n = 35$

   Standard error of
   - a. Intercept 75
   - b. Slope 0.0202

2. Ferrous metals (tons) = -21 + (0.0707) (refuse processed, in tons)

   $R^2 = 0.62$ $n = 35$

   Standard error of
   - a. Intercept 36
   - b. Slope 0.0096

3. Rejected materials (tons) = -134 + (0.1225) (refuse processed, in tons)

   $R^2 = 0.57$ $n = 35$

   Standard error of
   - a. Intercept 69
   - b. Slope 0.0187

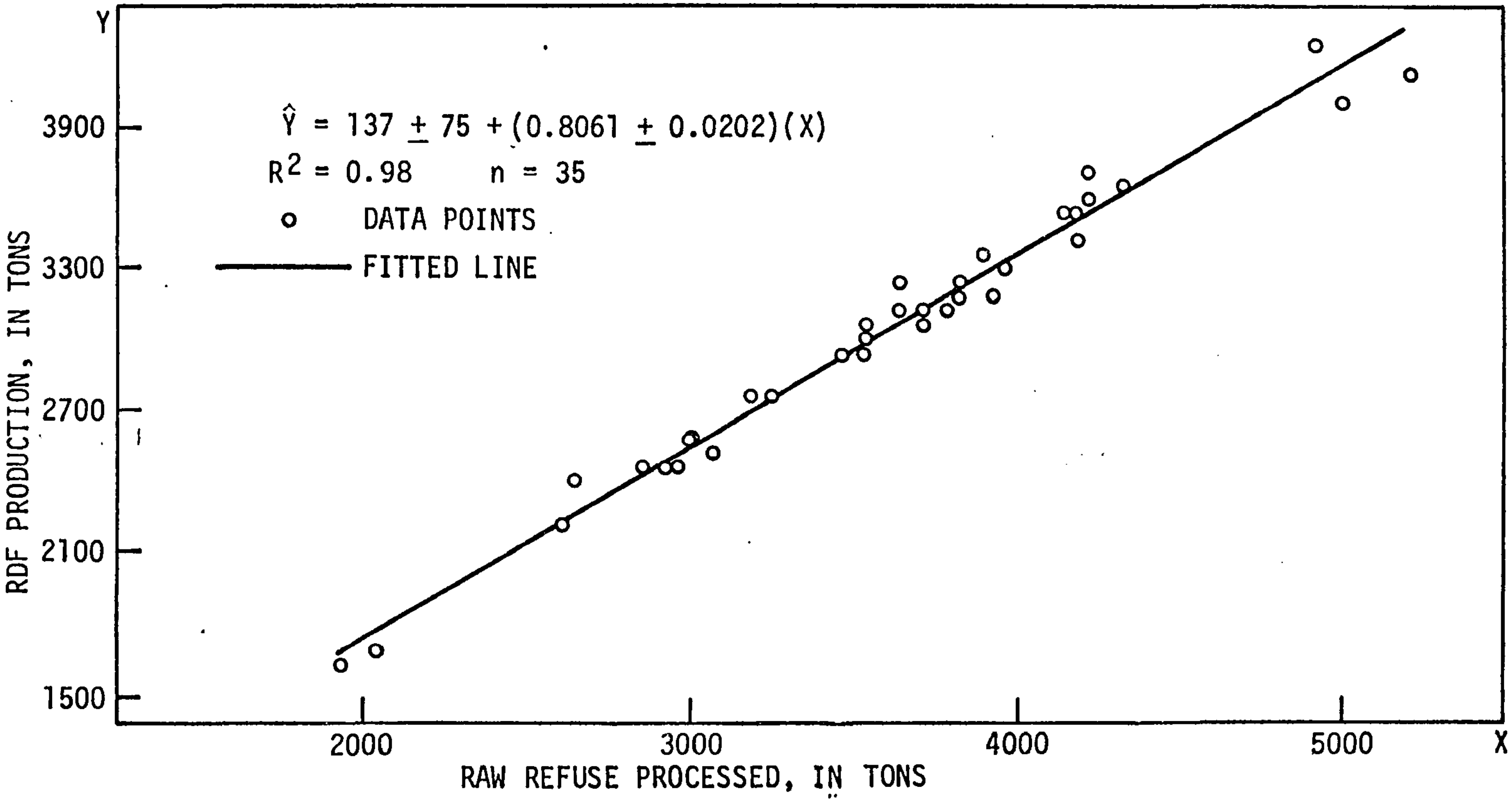

Figure 4.3. Raw refuse processed and RDF produced (Jan. 1976-Dec. 1978)

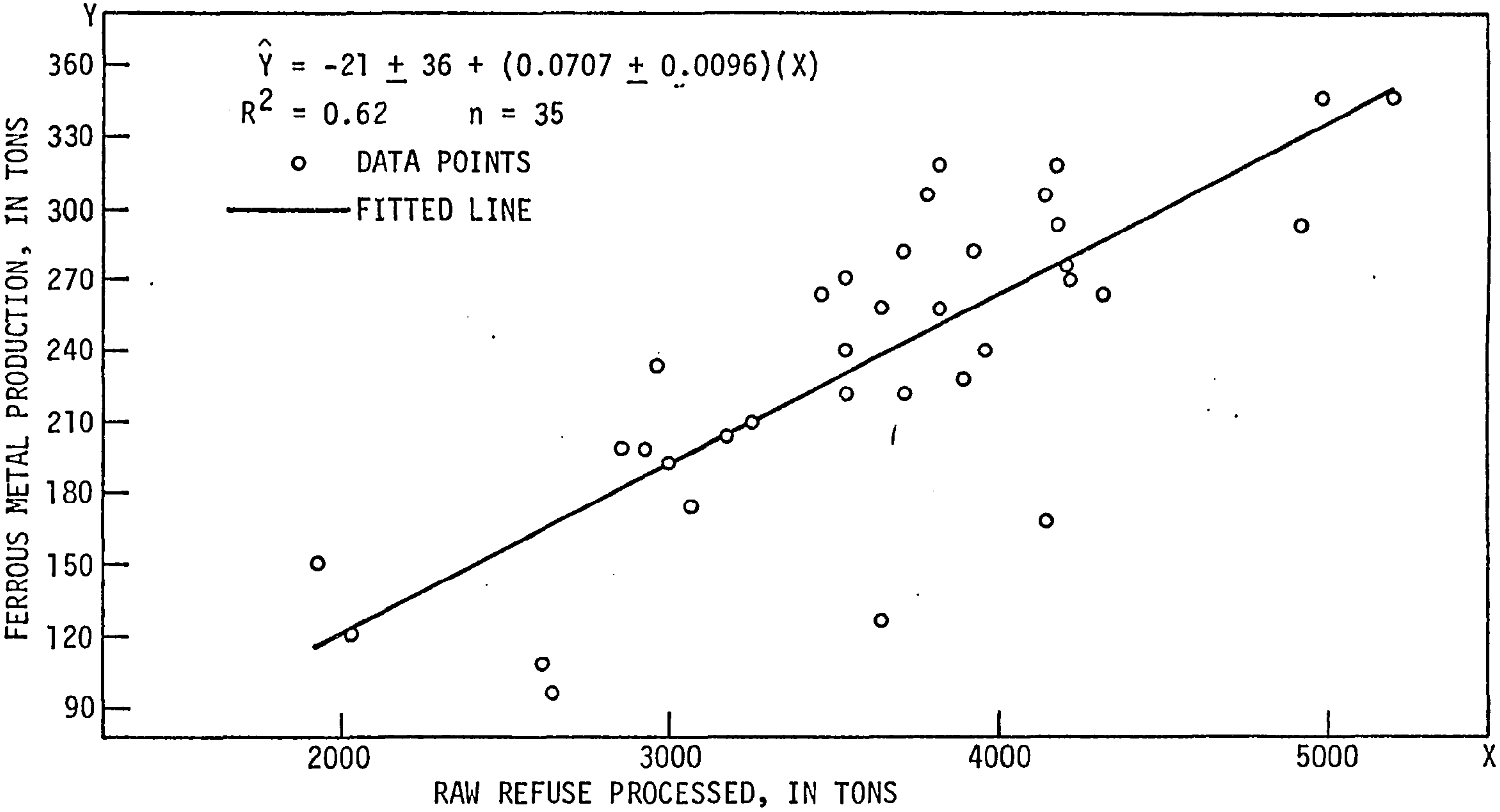

Figure 4.4. Raw refuse processed and ferrous metal reclaimed (Jan. 1976-Dec. 1978)

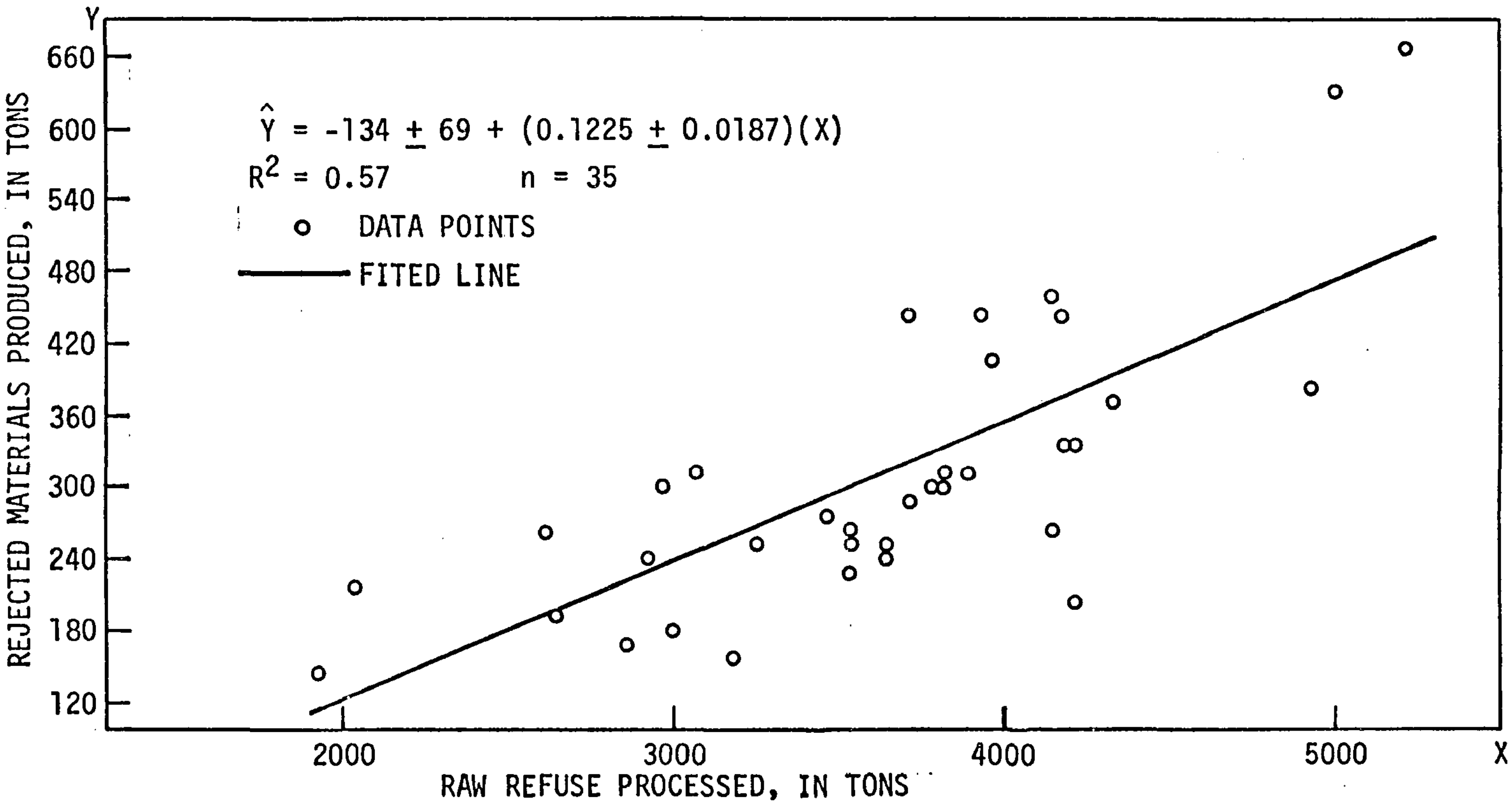

Figure 4.5. Raw refuse processed and rejected materials produced (Jan. 1976-Dec. 1978)

A 35 month period instead of the one year data is selected in order to establish a relationship between the amount of refuse processed and quantity of RDF, ferrous metals and rejected materials produced. The variability of the amount of rejected materials and ferrous metals produced is higher than that of the RDF. The ferrous metals quantity includes nonprocessed (nonshredded) large metal objects such as stoves, engine blocks and water heaters that are collected at the tipping floor and then sold as scrap metal commercially. The nonprocessed metal quantity delivered at the plant is not dependent upon the amount of refuse processed, which accounts for some of the variability indicated by the model.

The amount of rejected materials processed is dependent upon the quality and quantity of the refuse produced. When a large quantity of paper is processed, a small amount of rejected materials can be expected. Conversely, when a large proportion of construction materials is processed, a large quantity of rejects is produced. The RDF produced has the least variability of the resources recovered.

Comparison of Resources Recovered by the Ames and St. Louis Solid Waste Resource Recovery Systems

The proportion of various resources reclaimed from the St. Louis and Ames solid wastes are summarized in Table 4.3. The proportion of RDF and ferrous metals recovered from the Ames refuse is higher than that from St. Louis, while the quantity of rejected materials produced is also higher. The fraction of resources reclaimed from the Ames and

Table 4.2. RDF ferrous metal and rejected materials production from the Ames solid waste (1976-1978)

Month and year	Total refuse Processed (tons)	Materials Recovered[a] Ferrous metal (tons)	Rejected materials (tons)	Refuse derived fuel (tons)
1976				
January	3,190	202	150	2,732
February	2,997	194	183	2,569
March	3,070	174	306	2,539
April	4,299	277	332	3,596
May	3,832	260	302	3,228
June	3,697	279	288	3,094
July	3,520	269	232	2,929
August	3,653	260	250	3,126
September	3,525	238	262	3,006
October	3,769	306	305	3,110
November	1,917	147	148	1,622
December	3,462	261	276	2,913
1977				
January	2,594	105	268	2,218
February	3,259	207	249	2,781
March	4,179	315	337	3,510
April	4,147	303	264	3,519
May	4,323	265	366	3,689
June	2,929	196	240	2,475
July	3,966	240	409	3,311
August	5,218	346	685	4,154
September	4,986	348	640	3,992
October	4,925	291	388	4,231
November	4,217	269	201	3,747
December	3,637	123	244	3,263
1978				
January	3,519	222	250	3,047
February	2,859	199	173	2,482
March	3,811	318	316	3,174
April	3,916	284	445	3,178
May	2,981	235	300	2,446
June	4,179	295	444	3,440
July	3,710	220	438	3,052
August	4,159	170	455	3,535

[a]Does not include sand and glass, nonferrous metals, baled paper, and wood chips.

Table 4.2 (Continued)

Month and year	Total refuse processed (tons)	Materials Recovered[a] Ferrous metal (tons)	Rejected materials (tons)	Refuse derived fuel (tons)
1978 (Continued)				
September	3,889	226	317	3,347
October	2,043	118	216	1,709
November[b]	0	0	0	0
December	2,071	94	186	2,374
TOTAL	126,448	8,256	10,865	107,138
PERCENT OF TOTAL REFUSE PROCESSED	100.00	6.53	8.59	84.73

[b]Refuse not processed due to plant modifications.

St. Louis refuse differ from each other by less than five percent. The difference is to be expected because it is unlikely that the refuse composition of any two communities would be identical. In addition, the St. Louis demonstration plant accepted and processed residential refuse only, while the Ames facility processes residential, commercial, and industrial refuse. Nevertheless, results from both facilities demonstrate the presence of resources in solid waste. The magnitude of RDF and ferrous metals recovered from the Ames and St. Louis refuse indicates the significance of refuse as a potential source of energy and reusable materials.

Table 4.3. Proportion of resources reclaimed from St. Louis and Ames (by weight)

Location	Materials Reclaimed						
	RDF (%)	Ferrous metals (%)	Nonferrous metals (%)	Wood chips (%)	Baled paper (%)	Rejected materials (%)	Materials loss (%)
St. Louis[a]	80.60	4.52	-	-	-	7.31	7.57
Ames[b]	83.93	6.52	0.01	0.06	0.10	9.32	-

[a]Based on one year's data September, 1974, to September 1975.

[b]Based on one year's data July, 1977, to June, 1978.

RDF Composition and Energy Value

A study of the economics of energy recovery perhaps should start with the question - How good a fuel is solid waste? Consideration of the use of refuse as fuel requires that its composition and quality be examined as thoroughly as the available data permits. The composition, and physical and chemical characteristics of as-received refuse are expected to vary.

The composition of the Ames RDF based on a six months' sample is shown in Figure 4.6 (Adams et al., 1978, p. 85). In spite of large concentration of combustibles (over 95% by weight) in the RDF stream, there are some noncombustibles included with the RDF. These include sand, glass, ferrous and nonferrous metals. These materials increase the ash residue after combustion in the power plant's boiler, thus creating an extra ash handling task for the power plant operating personnel. In addition, the sand and glass, which act as an abrasive material, caused extensive wear to the underground RDF transporting metal pipeline, which required replacement. The sand, glass, ferrous and nonferrous metals are also known to cause slagging and deposits on the boilers' heat exchange surface.

The RDF heating value can be expected to vary according to the material composition and moisture content. No attempt has been made to examine the heating value of the different components included in the RDF stream; however, the RDF heating value and moisture content relationship has been explored. Forty-five weekly composite samples which were

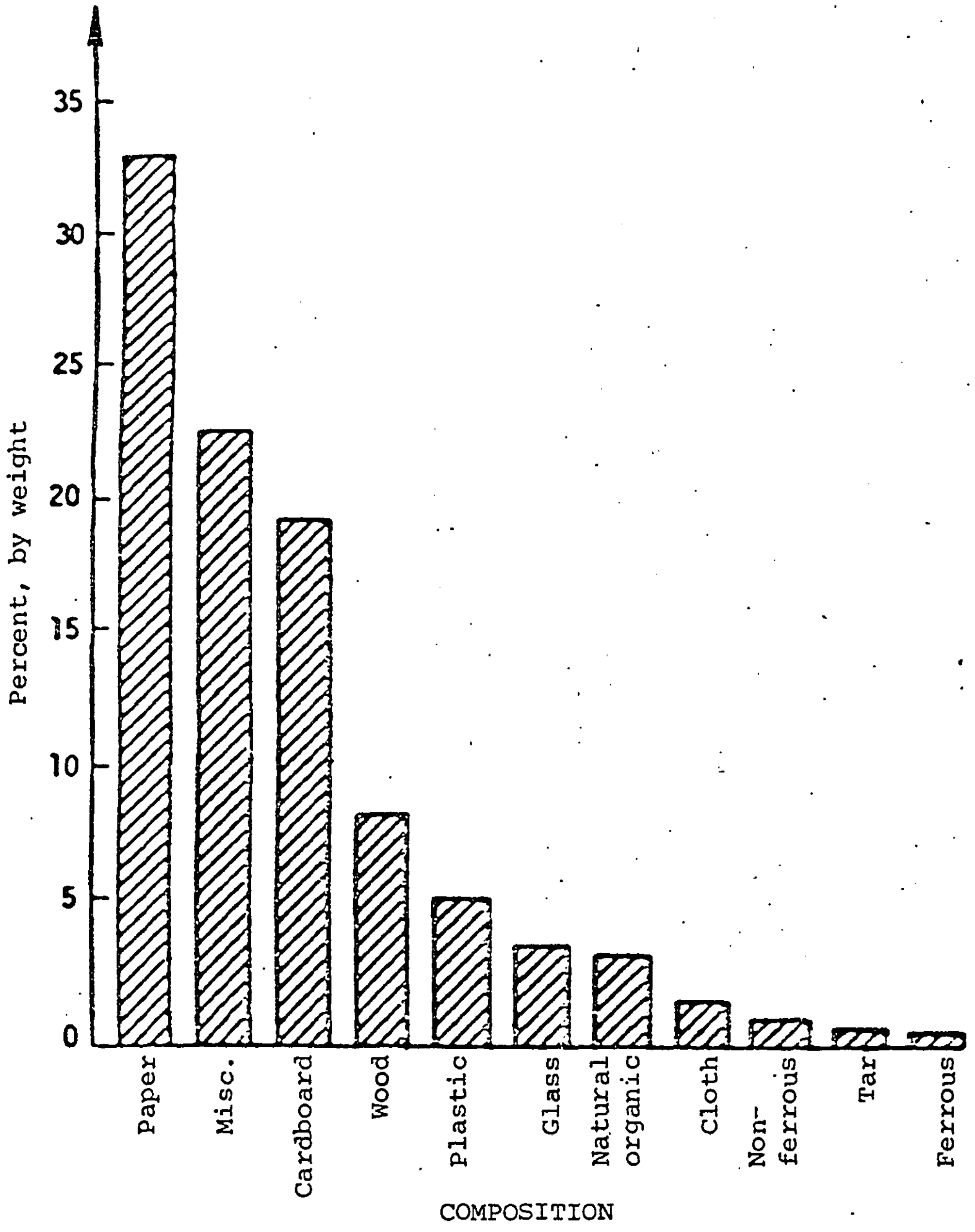

Figure 4.6.. Composition of RDF

taken were examined, and the results are presented in Tables 4.4 and 4.5. The RDF heating value with its moisture content varied from 6,725 to 4,545 BTUs per pound with an overall average value of 5,196 BTUs per pound. The moisture content by weight varied from 35-1.3% with an overall average of 22.21%. The RDF moisture free heating value ranged from 7,551-5,930 BTUs per pound with an overall average of 6,686 BTUs per pound (Table 4.5). The Ames Power Plant currently burns Colorado and Iowa coal with an average heating value of 11,200 and 9,500 BTUs per pound respectively (Hove, M., 1979, Personal communication, Power Plant, City of Ames, Iowa). The Ames RDF on the average, contains a heating value half that of coal.

An analysis of the RDF heating value and moisture content exhibits an inverse relationship as shown in Figure 4.7. A simple linear regression model estimator of this relationship yields the following equation:

Heating value (BTU/lb) = 6,484 - 58 (moisture content, in % by wt.)

$R^2 = 0.639$ $n = 46$

Standard error of
a. Intercept 152
b. Slope 7

The above equation reveals significant information and can be used to make a decision about whether the RDF is acceptable or not for a fuel source, based on its moisture content. For example, there may be an occasion when the RDF moisture content is so large that it may be unacceptable for burning in the power plant's boilers. In this case a decision must be made on whether to pre-dry the RDF prior to delivering it to the power

Table 4.4. Ames RDF moisture contents and heating values

Sampling				Sample Average Values[a]		
Year and month	Dates	Week #	Sample size	Moisture content (%)	Heating value with moisture (BTU/lb.)	Moisture free heating value (BTU/lb.)
1977						
July[b]	5-8	1	0	-	-	-
July	11-13	2	16	20.110	5800.770	7260.937
July	18-21	3	16	1.300	6622.988	6710.223
July	22-28	4	11	30.000	5161.723	7373.891
July-Aug.	29-4	5	22	25.700	5149.633	6930.863
Aug.	5-11	6	19	34.100	4733.758	7183.238
Aug.	12-17	7	18	35.000	4544.957	6992.238
Aug.	18-25	8	23	25.700	5210.316	7012.531
Aug.-Sept.	26-1	9	20	25.500	4913.082	6594.742
Sept.	2-8	10	12	32.600	4678.766	6941.781
Sept.	9-15	11	14	27.100	5193.223	7123.758
Sept.	16-22	12	24	23.600	5056.086	6617.910
Sept.	23-29	13	11	18.500	5440.555	6675.527
Sept.-Oct.	30-6	14	20	29.300	5235.680	7405.484
Oct.	7-13	15	11	28.300	5413.914	7550.781
Oct.	14-20	16	20	22.400	5065.477	6527.672
Oct.	21-27	17	12	30.000	4651.184	6644.543
Oct.-Nov.	28-3	18	14	28.700	4548.016	6378.703
Nov.	4-10	19	8	27.600	4626.398	6390.051
Nov.	11-17	20	12	23.500	5558.777	7266.371
Nov.	18-24	21	1	18.200	5341.816	6530.340
Nov.-Dec.	25-1	22	7	25.600	4945.117	6646.660

[a]Analyses by Raltech Scientific Services, St. Louis, Mo.

[b]Samples not taken.

Table 4.4 (Continued)

Sampling				Sample Average Values[a]		
Year and month	Dates	Week #	Sample size	Moisture content (%)	Heating value with moisture (BTU/lb.)	Moisture free heating value (BTU/lb.)
1977 (Continued)						
Dec.	2-8	23	3	22.400	5732.867	7387.715
Dec.[a]	9-15	24	0	-	-	-
Dec.[a]	16-22	25	0	-	-	-
Dec.	23-29	26	6	18.100	5564.582	6794.363
Dec.-Jan.	30-5	27	13	20.500	5174.156	6508.375
Jan.	6-12	28	5	19.100	5440.582	6725.066
Jan.	13-19	29	5	Missing	Missing	Missing
Jan.[a]	20-26	30	0	-	-	-
Jan.-Feb.[a]	27-2	31	0	-	-	-
Feb.	3-9	32	4	20.000	5043.777	6304.715
Feb.[a]	10-16	33	0	-	-	-
Feb.	17-23	34	3	17.800	5290.555	6436.195
Feb.-Mar.	24-2	35	5	17.700	5152.664	6260.828
1978						
Mar.	3-9	36	3	20.400	5070.879	6370.445
Mar.	10-16	37	6	29.000	4689.262	6604.598
Mar.	17-23	38	9	24.000	4687.566	6167.852
Mar.	24-30	39	4	24.400	4641.777	6139.910
Mar.-Apr.	31-6	40	3	19.300	5045.691	6252.402
Apr.	7-3	41	10	27.000	4670.633	6398.121
Apr.	14-20	42	4	14.700	5312.934	6228.523
Apr.	21-27	43	13	15.100	5551.750	6539.164

Table 4.4 (Continued)

Sampling				Sample Average Values[a]		
Year and month	Dates	Week	Sample size	Moisture content (%)	Heating value with moisture (BTU/lb.)	Moisture free heating value (BTU/lb.)
1978 (Continued)						
Apr.-May	28-4	44	9	13.000	6124.910	7040.121
May	5-11	45	7	18.300	5250.242	6426.242
May	12-18	46	7	25.000	4853.027	6470.699
May	19-25	47	18	18.000	4862.344	5929.684
May-June	26-1	48	4	21.000	4953.402	6270.125
June	2-8	49	24	21.500	5514.113	7024.344
June	9-15	50	18	3.190	6724.586	6946.160
June	16-22	51	22	14.700	5827.754	6832.062
June	23-29	52	19	23.500	4758.906	6220.789
June-July	30-6	53	14	20.900	5202.828	6577.527
July	7-13	54	19	15.100	5831.746	6868.957

Table 4.5. Ames' RDF heating values with and without moisture (1977-1978)

Variable	Sample size	Mean	Std. dev.	Minimum	Maximum
Heating value with moisture (BTU/lb.)	46	5196	489	4545	6725
Moisture content by weight (%)	46	22.21	6.75	1.3	35.00
Heating value moisture free	46	6686	392	5930	7551

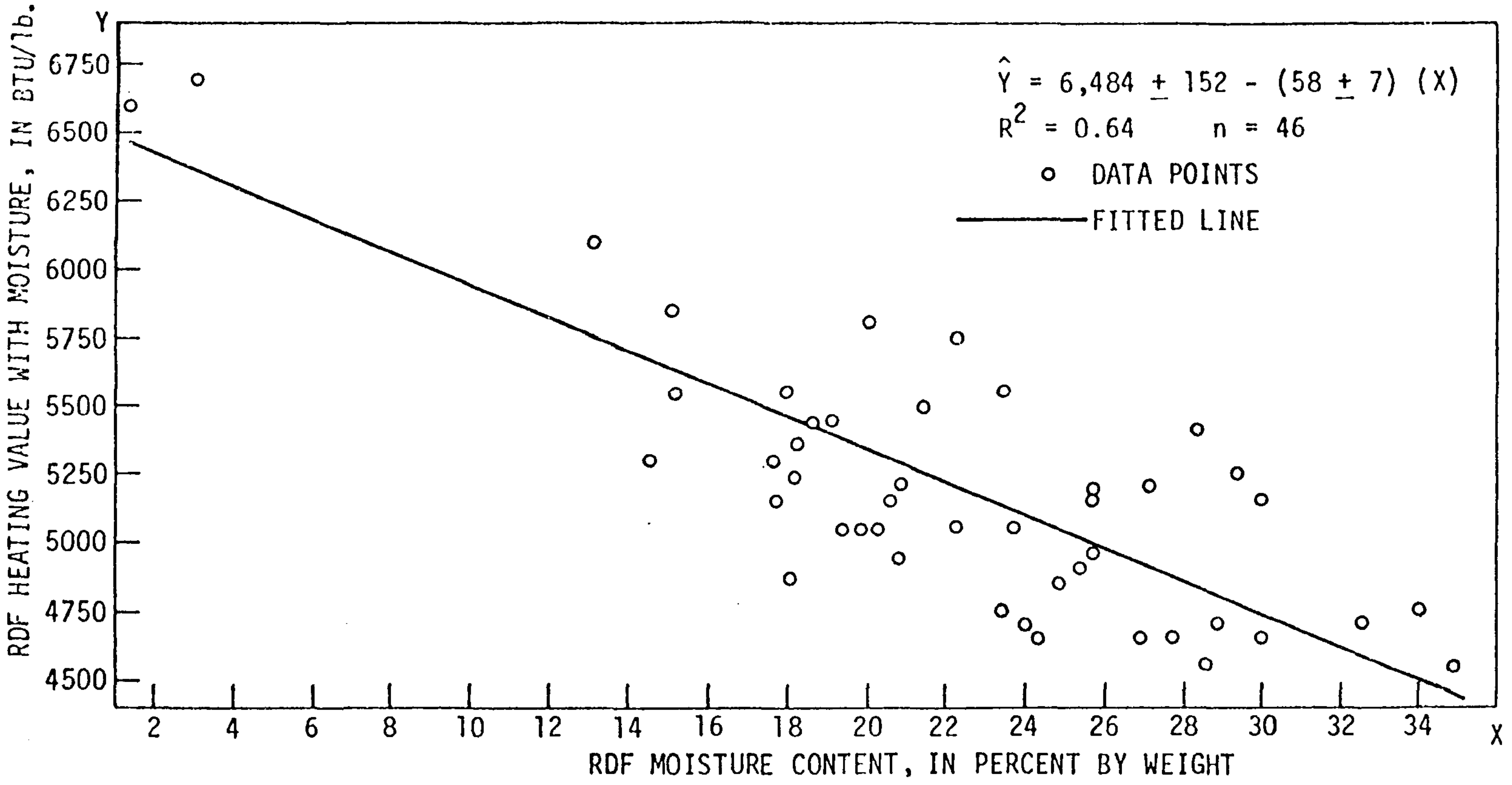

Figure 4.7. Moisture content vs. RDF heating value (July 1977-July 1978)

plant or simply to discard it as an unacceptable source of fuel. The RDF heating value and moisture content relationship information can provide management with vital information in making RDF production decisions.

Ferrous Metals Composition

The ferrous metals fraction is the second major salable product and source of revenue after RDF. The processed ferrous metals extracted at the three stages of the processing operation contain some contaminants. These include paper, cardboard, wood, plastic, organic materials, cloth, and nonferrous metal. The inclusion of these materials reduces the ferrous metal selling price. However, these contaminants account for less than 3% of the total ferrous metals reclaimed (Adams et al., 1978, p. 86) (see Figure 4.8).

The composition, size, and bulk density distribution of the shredded refuse at various processing stages of the Ames' facility have been documented. This information is based on six months' sampling data (Adams, et al., 1979a, pp. 13-42).

Rejected Materials Composition

The rejected materials are classified into cardboard, paper, plastic, wood, glass, ferrous, and nonferrous metals, cloth, tar, and miscellaneous. The rejected materials constituents are given in Figure 4.9 (Adams et al., 1978, p. 86). The rejected materials stream contains some usable items. The cardboard, paper, plastic, wood, organic materials, tar, and cloth are combustibles, while the ferrous and nonferrous metals

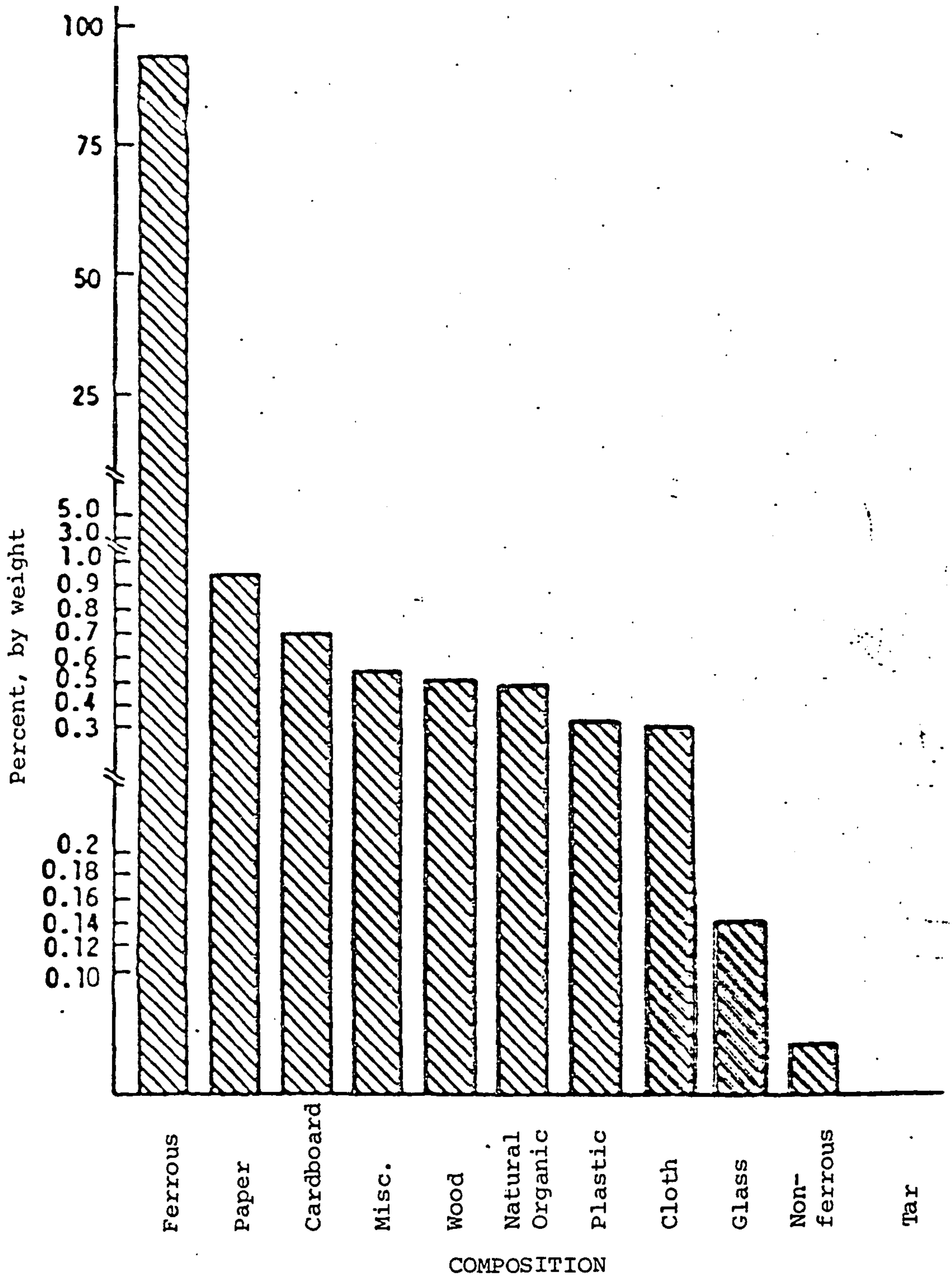

Figure 4.8. Composition of processed ferrous metal

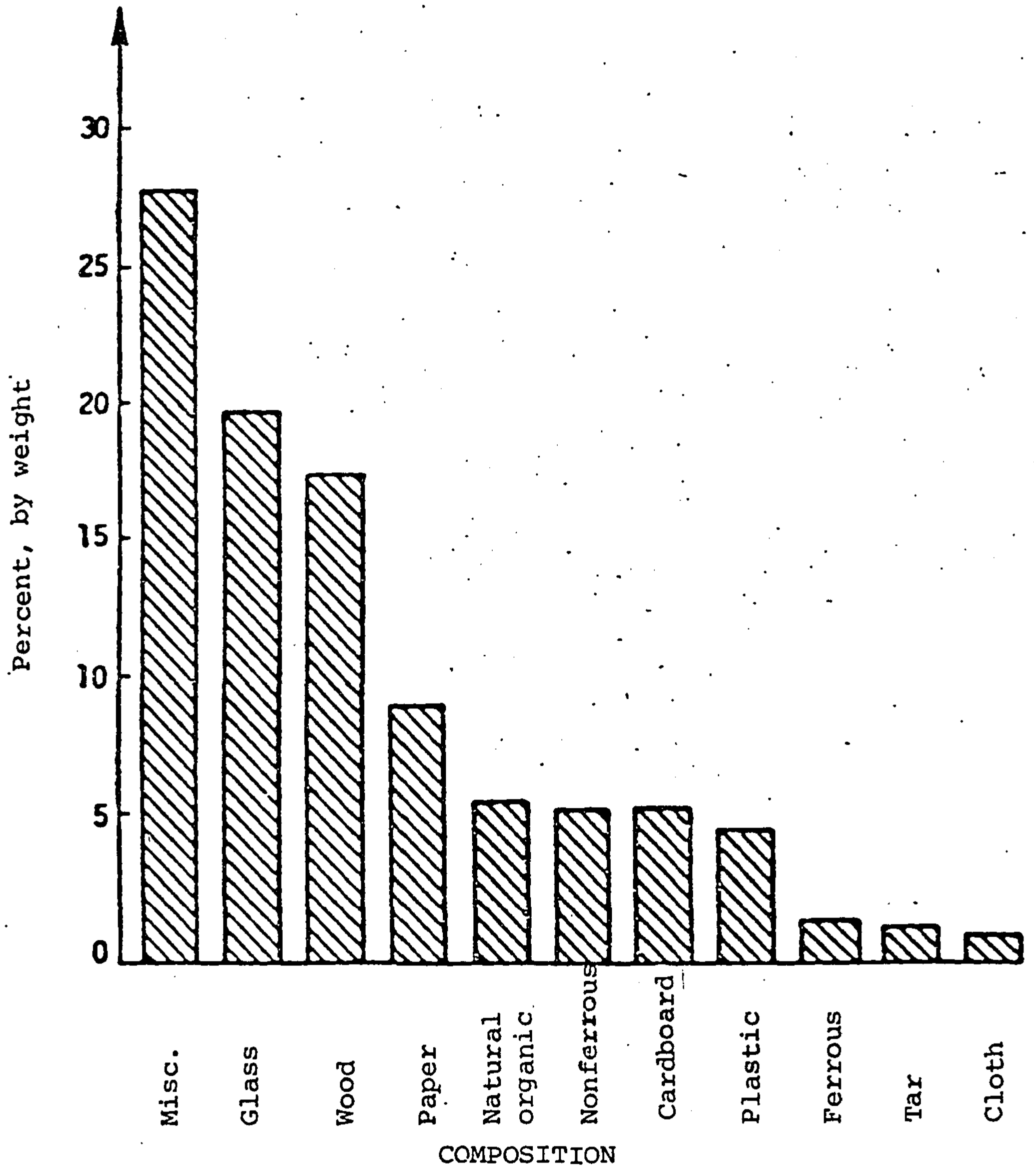

Figure 4.9. Composition of rejected materials

can be sold commercially. The wood, glass, and miscellaneous portion composes 18%, 20%, and 28% of the total rejected materials stream respectively. Further separation of the rejected materials would result in recovering some of the usable resources that are currently being buried at the landfill.

Discussion

The recognition of solid waste as a source of valuable recoverable materials was a primary consideration in constructing the Ames Solid Waste Recovery System. The quantity of RDF recovered by the St. Louis-Union Electric Demonstration Plant encouraged the implementation of the Ames system.

The Ames results indicate that on the average, 84% of the Ames refuse is combustible, while 8% is classified as ferrous metals and sold commercially. The RDF, which is burned with coal to generate electrical energy, has an average heating value of 5,145 BTU/lb., and is a viable source of energy.

However encouraging the Ames results, much technological improvement must be made in the resource recovery area. As shown earlier, the RDF portion contains noncombustible materials classified as combustibles by the air density separating system. The noncombustibles cause wear in the transport pipeline, slagging in the boilers, and an increased quantity of ASM that has to be removed from the boilers. Conversely, many combustibles are classified as rejected materials and hauled into the landfill. The ferrous metals are also contaminated by nonferrous materials, which could reduce their selling price. Adams et al. (1979a, pp. 1-79) gives a six month flow stream characterization analysis of the processed refuse in the Ames system. Pure materials separation can perhaps be attained by manual sorting, but this would be prohibitive in terms of labor input requirements. Thus, research is needed to improve the current resource reclaiming equipment.

The implementation of the solid waste recovery system has by no means eliminated the need for a landfill. The landfill is still used to dispose of demolition products, rejected materials from the refuse processing facility, and ash from the power plant. The reduction of refuse disposal into the landfill from 100% to less than 10% will prolong the landfill life by a factor of 10 times. The shredding rejected materials are compacted, thus adding to landfill life. In addition, RDF, ferrous, and nonferrous metals are recovered that would otherwise be buried in the landfill with no hope of future recovery.

The above discussion gives the advantages and disadvantages encountered in the Ames facility. Before implementing any type of solid waste recovery system, each community must carefully evaluate its refuse profile and construct a resource recovery system that matches its needs.

CHAPTER V. REFUSE RECEIVING SYSTEM

The Ames Solid Waste Recovery facility's 100 ft. by 160 ft. refuse receiving floor (tipping floor) is fully enclosed and can accommodate 600 tons, or three days' refuse delivery. The floor with its two separate entrances and exits, one for trucks and another for cars, receives refuse six days a week from 8 A.M. to 4 P.M.

Customers that dispose of their solid waste regularly are issued credit cards. These customers include commercial and noncommercial haulers. Regular customers enter the plant through the truck entrance (truck-line) where a scale is located. The customer inserts the credit card into a weight recording machine while the vehicle is stopped on the scale and the weight is automatically printed in the process control room. The customer drives ahead where the refuse is then unloaded on the floor and the customer leaves the facility through the truck exit door. Regular customers are assessed a tipping fee of $1.00 per trip and are billed monthly through the credit card logging system.

A separate entry (car-line) was established to serve customers that dispose of refuse on an irregular basis. These customers, who are referred to as private customers, enter the plant through the car-line entrance where they insert $0.50 into a coin operated gate that allows them access to an unloading lane. The customer then tosses the refuse over a 3-foot wall into the floor. There is no refuse weighing scale on the car-line; consequently, the amount of refuse hauled by the private customers is estimated by the plant's superintendent daily, based on the number of refuse delivering customers and the average load per customer.

Other customers who haul demolition (nonrecyclable) materials are escorted to the city's landfill to dispose of their refuse and are assessed a fee of $18.00 per ton (Hinderaker, P., 1979, City Records and personal communication, City of Ames, Iowa).

Some of the recovery process is accomplished at the tipping floor (see Figure 5.1). Items presorted by customers include metals, paper, and wood logs. These are unloaded at a designated location on the floor. Customers are advised through pamphlets not to dispose of fire hazard materials on the tipping floor, such as small gasoline and propane tanks, and wet paint cans. In addition, the floor attendant and the end-loader operator constantly search for fire hazardous materials and safely dispose of these items before they are fed to the shredding process, where most explosions occur. The sorted metals and paper are sold commercially; the wood logs are chipped and sold locally for animal and flower bedding, while the rejected fraction is hauled to the landfill.

Tipping Floor Activities

Various tasks are performed on the tipping floor. In this paper the tipping floor sub-system is divided into the following activities:

1. Feeding refuse to the primary infeed conveyor (C-1).
2. Piling refuse from truck and car lines.
3. Maintaining the car-line.
4. Cleaning the tipping floor with a powered sweeper.
5. Helping regular customers with the scale when it malfunctions.

The ferrous metals and reject sorting, log chipping, and paper baling operations are part of the tipping floor activities; however, these

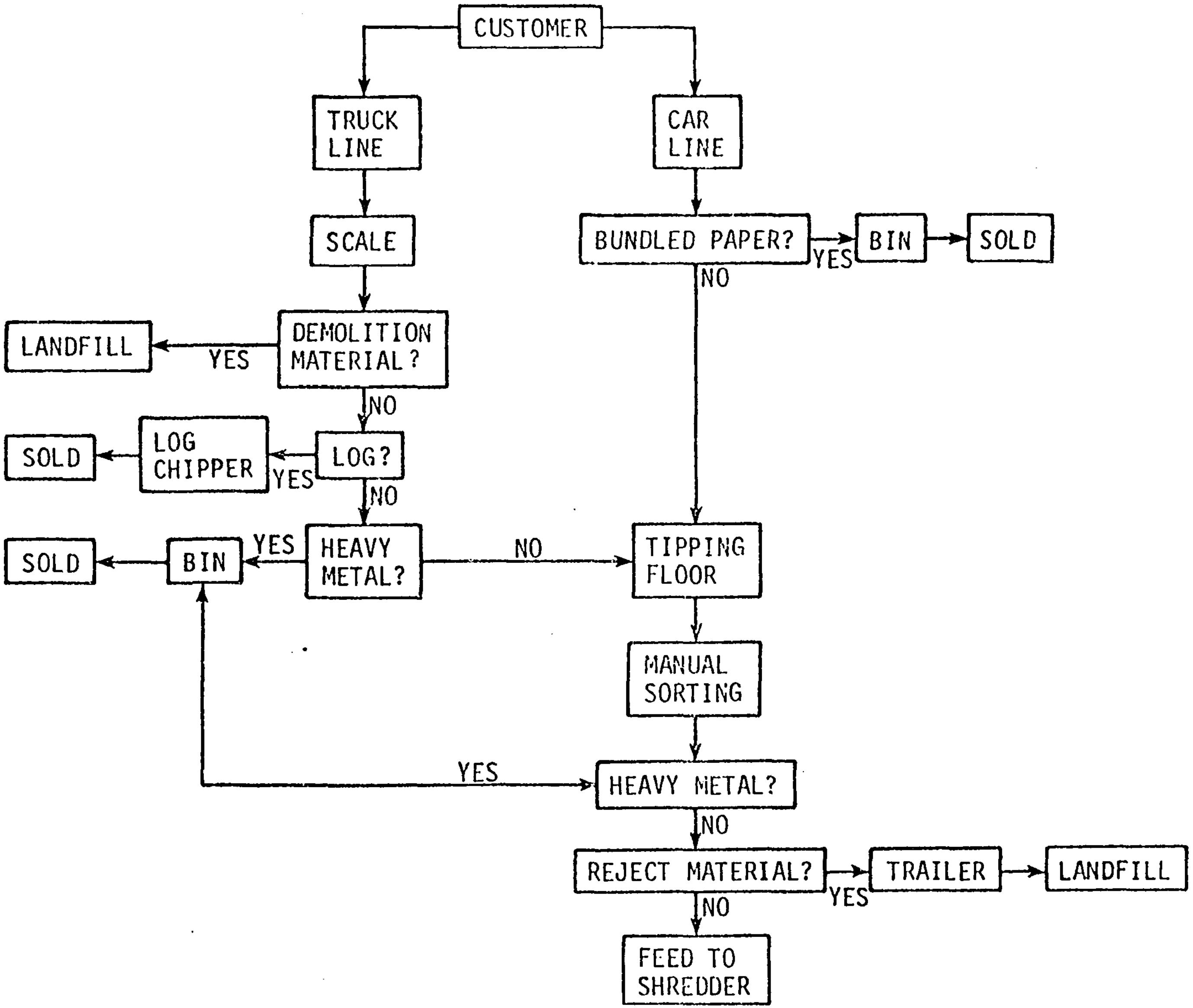

Figure 5.1. Tipping floor activity flow diagram

activities will be integrated with similar activities and treated separately in later chapters.

Task Description and Labor Hour Input Distribution

The floor is maintained by two people, a tipping floor attendant and a front end-loader operator. The floor attendant's duties include: 1) collecting tipping fees from car-line customers, 2) helping regular customers whenever the scale malfunctions, and 3) sweeping the floor and driveway areas. The end-loader operator tasks are: 1) feeding refuse into the infeed conveyor and 2) stock piling refuse received from car and truck-line customers.

The total monthly labor hours expended maintaining the tipping floor activities are summarized in Table 5.1. The floor attendant and the end-loader operator accounted for 42% and 58% of the total hours worked respectively. The proportion of time devoted by the end-loader operator and floor attendant to the various tasks is summarized in Figures 5.2 and 5.3, respectively. The floor attendant spent 76% of the time collecting tipping fees from the car-line customers. This task was designed to be accomplished by the coin operated automatic gate. This gate allows customers access to the floor upon depositing a $0.50 tipping fee. However, the gate did not operate, thus compelling the floor attendant to collect the tipping fee. Another 10% of the floor attendant's effort was used helping customers whenever the scale or the weight printer malfunctioned. When the weight printer malfunctions, the process control

Table 5.1. Monthly labor hours input distribution for the tipping floor

Month	Refuse processed (tons)	End-loader Operator Labor Input Distribution: Feed C-1 (hrs)	Pile Refuse: Reg. customer (hrs)	Pile Refuse: Car-line (hrs)	Tipping Floor Labor Input Distribution: Collect fee car-line (hrs)	Scale (hrs)	Sweeper (hrs)	TOTAL (hrs)
1977								
July	3,966	190.00	54.25	3.00	93.00	16.00	14.00	370.25
August	5,218	193.00	55.00	3.00	132.00	22.00	20.00	425.00
September	4,986	168.00	48.00	2.00	136.00	23.00	20.00	397.00
October	4,925	196.00	56.00	3.00	156.00	26.00	23.00	460.00
November	4,217	178.00	51.00	3.00	135.75	23.00	20.00	410.75
December	3,637	175.00	50.00	3.00	120.00	20.00	18.00	386.00
1978								
January	3,519	189.50	54.00	3.00	173.00	29.00	26.00	474.50
February	2,859	164.50	47.00	2.00	127.50	21.25	19.00	381.25
March	3,811	210.00	60.00	3.00	138.00	23.00	21.00	455.00
April	3,916	189.00	54.00	3.00	143.00	24.00	21.00	434.00
May	2,981	149.00	43.00	2.00	97.00	16.00	15.00	322.00
June	4,179	189.00	54.00	3.00	101.00	17.00	15.00	379.00
TOTAL	48,214	2,191.00	626.25	33.00	1,552.25	260.25	232.00	4,894.75
PERCENT OF TOTAL HOURS		44.76	12.79	0.67	31.71	5.33	4.74	100.00

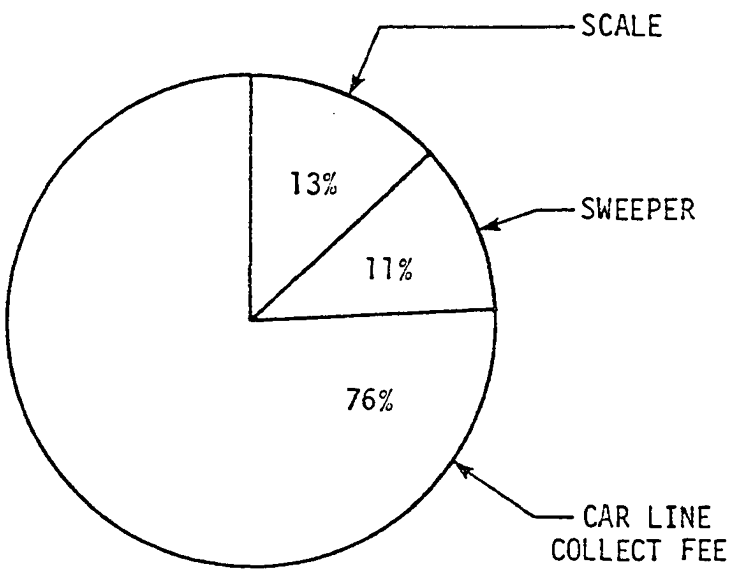

Figure 5.2. Tipping floor attendant's labor hours input distribution

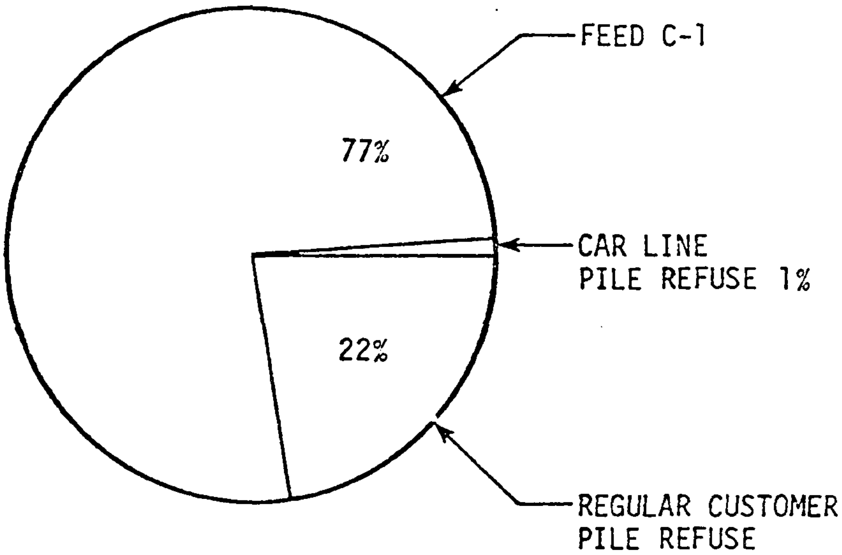

Figure 5.3. End-loader operator's labor hours input distribution

operator logs the customer's credit card number and weight manually. Thus, 89% (76% + 13%) of the floor attendant's time was committed in assisting customers in the car-line operation or with the refuse weighing scale. The frequent malfunctioning of the refuse weighing scale and the coin activated gate have consumed much labor effort that otherwise could have been used to maintain the tipping floor activities. The remaining 11% of the time was spent cleaning the tipping floor and driveways so that customers can dispose of their refuse without damaging their tires, etc. due to spilled and scattered refuse.

The end-loader operator spent 77% of his time feeding the primary shredder's infeed conveyor (C-1). The remaining 23% of his time was devoted to piling refuse received from the car-line and truck-line in order to accommodate customers who need unloading space. The end-loader operator's time was reasonably allocated to the various tipping floor activities.

Relationship between Labor Hours Required and Quantity of Refuse Processed

The monthly average labor hours required to process refuse varied from a low of 0.08 hr./ton in August and September to a high of 0.13 hr./ton in January and February. The overall average labor input was 0.10 hr./ton with a standard deviation of 0.02 hr./ton (see Figure 5.4). The high average labor requirement occurred when the facility was processing refuse at its lowest rate of 29.77 tons/hr. in January and 28.17 tons/hr. in February. The low average labor hour input occurred during the facility's highest refuse processing rate of 35.23 tons/hr.

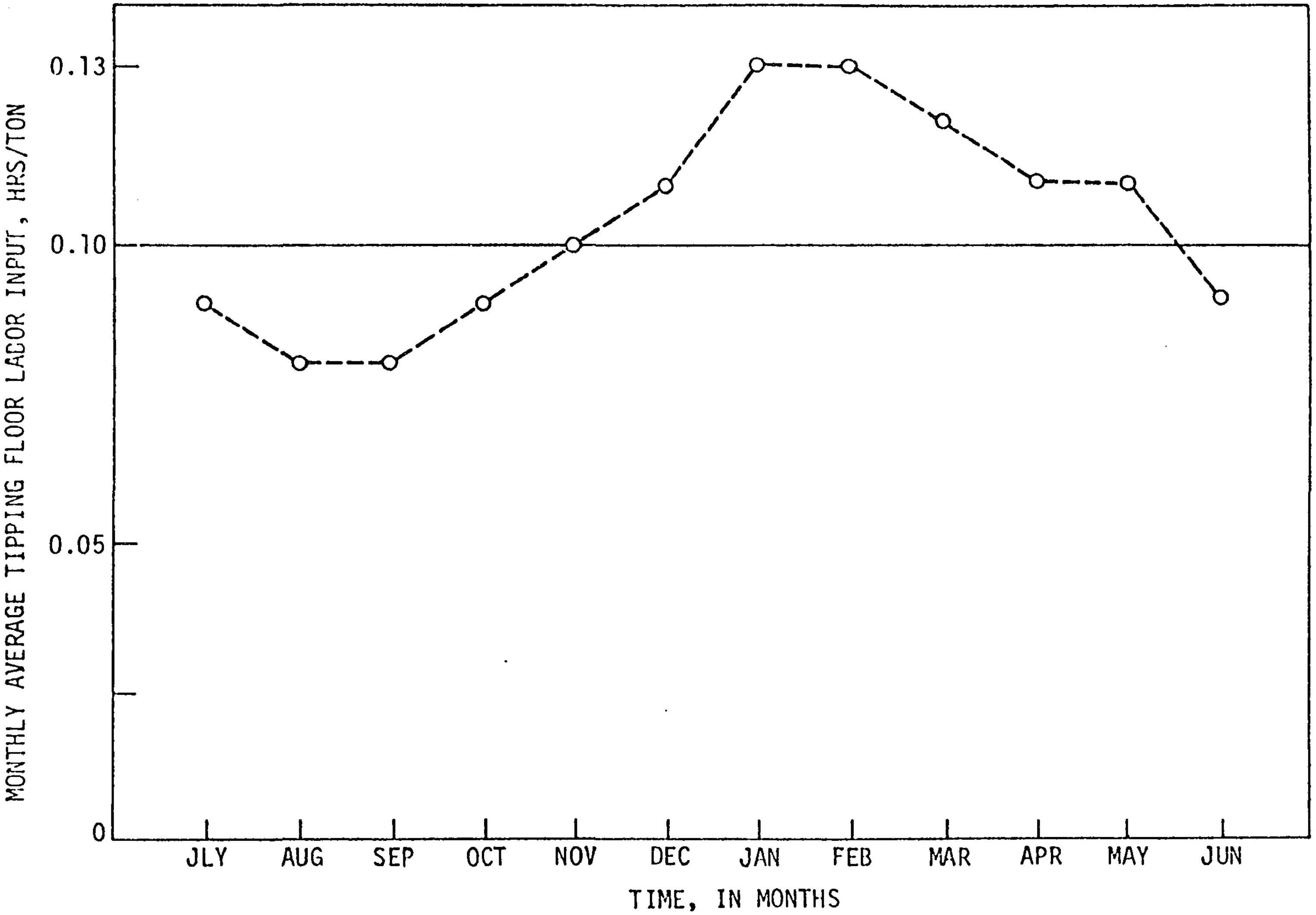

Figure 5.4. Tipping floor's average labor hours input per ton of raw refuse processed (1977-1978)

and 39.60 tons/hr. in August and September, respectively, which would be expected.

The monthly labor hours worked varied from 455 to 322 hours with an overall monthly average of 408 hours and a standard deviation of 43.99 hours per month. This result indicates that the monthly labor input is essentially constant and independent of the mass of refuse processed. This can be explained by the fact that the tipping floor attendant and the end-loader operator work eight hours per day, even if the facility processes refuse for less than eight hours per day. The variability of the average monthly labor input is dependent on the frequency of idle time and downtime encountered. Figure 5.4 indicates that the amount of labor hours worked was higher in the winter months than during summer months. However, this is not so, because the high labor input requirement during these months is primarily due to plant idle or downtime, which necessitates working overtime to process the accumulated refuse.

A visual inspection of the scatter plot of the total labor hours worked and the quantity of refuse processed reveals no definite relationship between these two variables (see Figure 5.5). However, a definite relationship exists between the average labor hours worked and the amount of refuse processed (see Figure 5.6). This relationship can be expressed by the following linear regression model:

Average labor input (hrs./ton) = 0.1836 - (0.00002) (refuse processed, in tons)

$R^2 = 0.65$ n = 12

Standard error of	a. Intercept	0.0185
	b. Slope	0.000005

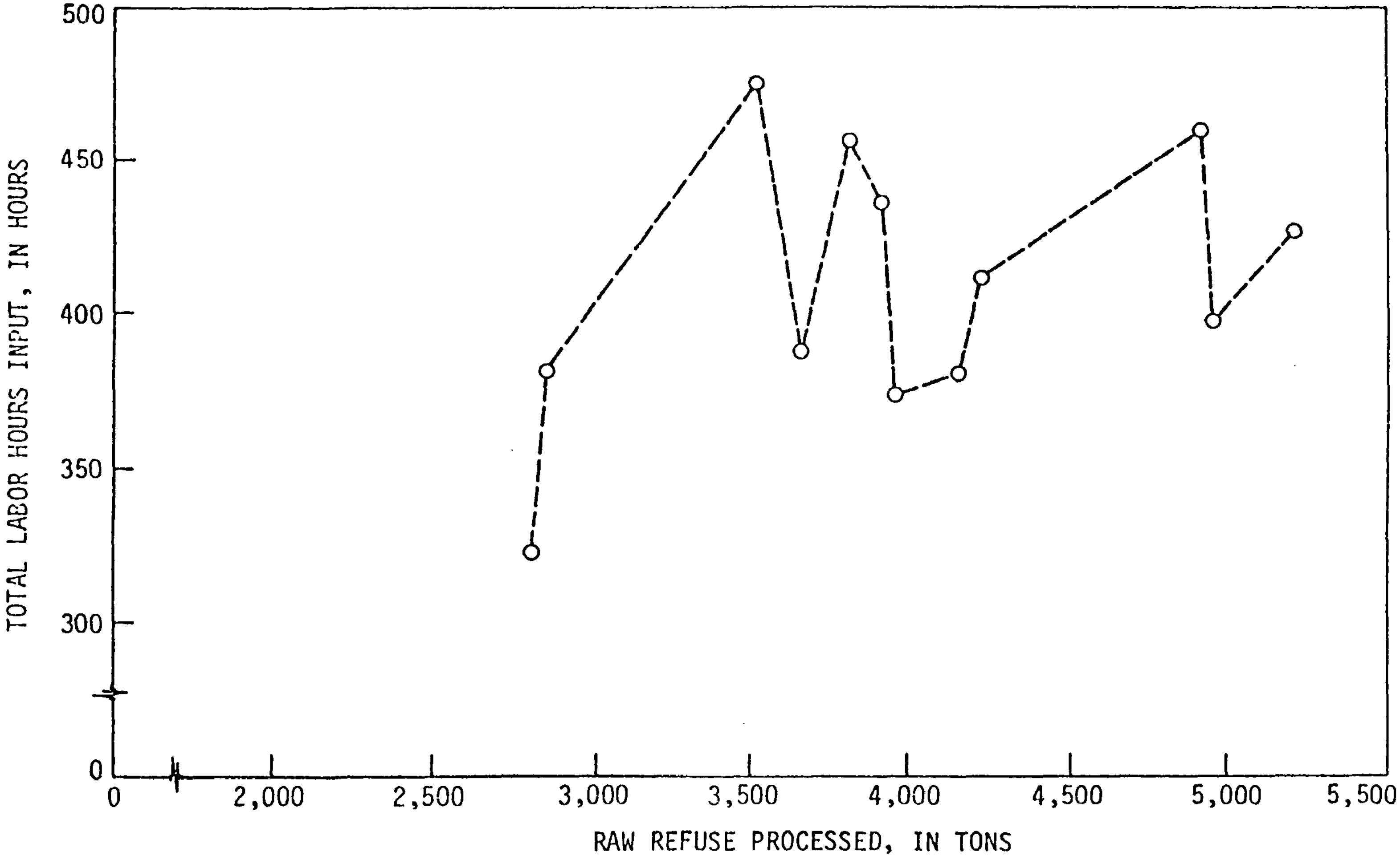

Figure 5.5. Raw refuse processed and total tipping floor labor hours required

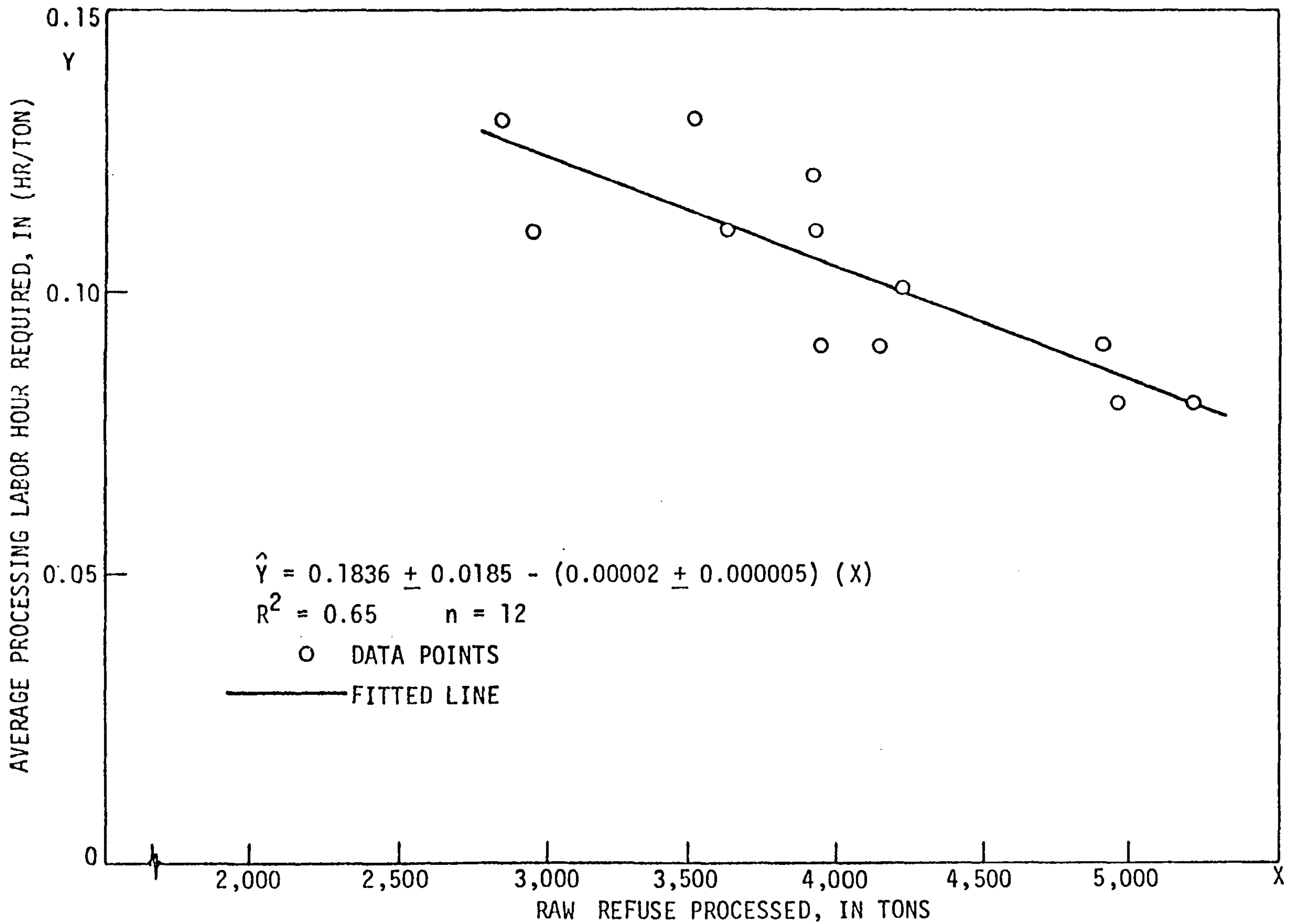

Figure 5.6. Raw refuse processed and tipping floor's average labor hours required

The model shows that as the quantity of refuse processed increases, the average labor hour input required decreases. The model reveals a significant relationship between the average labor hour input and the amount of refuse processed. The model result is a typical characteristic of a constant labor input processing operation. Under this assumption the labor input remains fixed regardless of the volume of refuse processed; however, the average labor input is expected to decrease as the quantity of refuse processed increases. On the tipping floor the labor input is fixed for eight hours whether the plant processes refuse at or below capacity, thus accounting for the decreasing average labor input as the refuse processed increased.

Electrical Energy Requirement and Cost

The tipping floor area is unheated because a large amount of ventilation is required to remove the exhaust gases generated by the end-loader and the incoming vehicles. The truck and car entrances, and exit doors remain open during plant operations, except during severe weather, to allow air to sweep through the flocr. During extremely cold weather space heaters are used to keep the floor attendant warm.

The tipping floor is equipped with forty-300 watt mercury vapor light bulbs, the sole electrical energy users. The lights operate 6 days a week, 12 hours a day Monday through Friday and 10 hours on Saturday, or an average of 14 hours a day five days per week. The daily electrical energy requirement is estimated to be 168 KW-HRS./DAY. The energy consumption estimate is calculated as follows:

$$\text{Daily energy consumption} = 40 \times 300 \text{ WATTS} \times \frac{1 \text{ K-WATT}}{1{,}000 \text{ WATTS}} \times \frac{14 \text{ HRS}}{\text{DAY}} = 168 \text{ KW-HRS/DAY.}$$

The total monthly energy consumption and cost is summarized in Table 5.2. The daily average energy consumption is assumed to be constant; however, the monthly energy expense will vary according to the monthly fuel costs (fuel adjusted factor) incurred by the power plant in providing electrical energy to its customers. The tipping floor used an average 0.89 KW-HRS. of energy per ton of refuse processed.

The tipping floor's energy consumption can be estimated by the following linear regression equation:

Energy requirement, in KW-HRS./MO. = 3077 + (0.1227)(Refuse processed, in TONS/MO.)

$R^2 = 0.20$ $n = 12$

Standard error of
a. Intercept 315
b. Slope 0.0773

Since the monthly energy consumption is fixed, the above equation is not a good estimator of tipping floor's energy consumption per ton of refuse processed.

Equipment and Supply Requirements

A floor sweeper and an end-loader used on the tipping floor are rented on a monthly basis. The sweeper is used to clean the tipping floor, truck and car-line entrances and exit driveways. The end-loader is used to feed refuse into the infeed conveyor (C-1), load ferrous metals

Table 5.2. Monthly energy consumption and cost for the tipping floor

Year and month	1 Estimated daily energy consumption (KW-HRS/DAY)	2 Plant open to process (DAYS)	3 (1x2) Monthly energy consumption (KW-HRS)	4 Average energy cost[a] ($/KW-HRS)	5 (3x4) Total monthly energy cost ($)
1977					
July	168	20	3,360	0.0409	137.42
August	168	23	3,864	0.0396	153.01
September	168	22	3,696	0.0435	160.78
October	168	22	3,696	0.0396	146.36
November	168	20	3,360	0.0415	139.44
December	168	20	3,360	0.0414	139.10
1978					
January	168	21	3,528	0.0435	153.47
February	168	20	3,360	0.0412	138.43
March	168	23	3,864	0.0427	164.99
April	168	20	3,360	0.0474	159.26
May	168	22	3,696	0.0510	188.50
June	168	22	3,696	0.0434	160.41
TOTAL		255	42,840	0.0430[b]	1,841.17

[a]Actual energy consumption charge.

[b]Average energy cost for 12 months.

and rejected materials from the tipping floor into their respective storage bins, load the log-chipper with logs, and to pile refuse. The equipment rental expense excludes maintenance and fuel costs. These costs are borne by the facility. When the rented end-loader breaks down, another loader is rented at $10/HR, while the rent on the broken end-loader continues to accrue. As a result, the monthly equipment rental varies considerably. The monthly end-loader and floor sweeper rental and maintenance expenses for fiscal 1977-1978 are summarized in Table 5.3.

Supply expenses are divided into: general, scale, and car-line expense categories. General expenses include all supplies used to maintain the tipping floor, such as overhead door repairs, odor control, and miscellaneous supplies. The scale supply includes all supplies used to maintain the scale on the floor as well as the weight recorder located in the process control room. Car-line supplies are used to repair the coin operated gate and the oil drain pit. The total monthly supply expenses are listed in Table 5.3.

Total Refuse Receiving System's Expense Distribution

The monthly total tipping floor operating cost for the one year period is summarized in Table 5.3. The average refuse processing cost varied from $2.19/TON in April of 1978 to $1.06 in November of 1977, with an overall average of $1.55/TON for the 12-month period (see Figure 5.7). The operating expense variability is affected by the plant's idle time and downtime. In addition, if the plant is down, then

Table 5.3. Total monthly operating cost for the tipping floor

Year and month	Refuse processed (TONS)	Supply			Energy ($)	Salaries		Equipment Rent		TOTAL COST ($)
		General ($)	Scale ($)	Car-line ($)		End-loader operator ($)	Floor Attendant ($)	End-Loader ($)	Sweeper ($)	
1977										
July	3,966	-	-	-	137.42	2,395.15	1,477.85	2,173.53	183.45	6,367.40
August	5,218	61.53	-	-	153.01	1,815.69	1,120.32	4,519.56	183.45	7,853.56
September	4,986	256.18	50.00	47.78	160.78	1,745.94	1,077.29	4,839.24	183.45	8,360.66
October	4,925	30.70	-	47.07	146.36	1,611.76	994.50	2,822.65	183.45	5,836.49
November	4,217	339.05	-	4.00	139.44	1,595.79	984.63	1,239.45	183.45	4,485.81
December	3,637	149.42	305.49	97.47	139.10	1,670.92	1,030.98	1,617.10	183.45	5,193.93
1978										
January	3,519	210.76	330.66	120.86	153.47	1,952.34	1,204.63	1,890.89	183.45	6,047.06
February	2,859	277.18	493.15	97.47	138.43	1,913.21	1,180.50	1,239.45	183.45	5,522.84
March	3,811	285.50	417.33	97.47	164.99	1,601.68	988.26	1,269.49	183.45	5,008.17
April	3,916	233.19	376.17	97.47	159.26	1,540.04	950.25	4,838.29	209.32	8,403.99
May	2,981	347.69	322.80	97.47	188.50	1,926.39	1,188.63	1,167.54	209.32	5,448.34
June	4,179	666.78	374.85	73.48	160.41	2,122.17	1,309.42	1,212.15	209.32	6,128.58
TOTAL	48,214	2,857.98	2,670.45	780.54	1,841.17	21,891.08	13,507.26	28,829.34	2,279.01	74,656.83
PERCENT OF TOTAL COST		3.83	3.58	1.05	2.47	29.32	18.08	38.62	3.05	

working overtime becomes necessary to process the already received refuse. Increasing overtime working conditions increases the refuse processing cost.

Even though the unit processing cost seems to vary, the cost per unit has a tendency to decrease as the quantity of refuse processed increases. This relationship is shown in Figure 5.7. It can be represented by the following linear regression model:

Average processing cost (\$/MO.) = 2.33 - (0.00019)(Refuse processing, in TONS/MO.)

$R^2 = 0.20$ $n = 12$

Standard error of	a. Intercept	0.0007
	b. Slope	0.1410

The model is not significant at the 5% level. However, the trend of decreasing the average processing cost as the quantity of refuse processed is increased is a significant result. The model indicates that the majority of the tipping floor operating expense is fixed.

A comparison of the monthly operating expense with the amount of refuse processed yields the following relationships:

Total operating cost (\$/MO.) = 2,664 + 0.8853 (Refuse processed, in TON/MO.)

$R^2 = 0.26$ $n = 12$

Standard error of	a. Intercept	1951.99
	b. Slope	0.4783

The model shows that \$2,664 per month is a fixed cost that is independent of the quantity of refuse processed. This value is reasonable when one considers that the end-loader's and floor sweeper's average monthly fixed charges are $1,250.00 and $189.92 respectively. The monthly energy cost and portion of the labor cost are also fixed. The fixed costs per ton of refuse processed can only be reduced if the plant processes more refuse without any diversion to the landfill.

The facility processed an average of 4,018 tons per month. Substituting this value into the above model yields average operating expenses of $6,099 per month, of which 44% ($2,6640.) is fixed.

The tipping floor's monthly operating expenses divided into supply, energy, salaries, and equipment rental are summarized in Table 5.3. Salaries and equipment rental accounted for 47% and 42% of the total tipping floor operating expenses. Energy and supply expenses accounted for 11% of the total cost (see Figure 5.8).

Discussion

Labor expenses accounted for 47% of the total tipping floor operating cost. In addition, 89% of the tipping floor attendant's effort was devoted to collecting tipping fees and aiding customers with the refuse weighing scale. Had the coin operated gate been operating and the scale functioning adequately, the amount of time spent in these areas could have been reduced substantially. The amount of time saved could have been spent in the plant's preventive maintenance program. This continuing labor misallocation is one of the causes of unfavorable plant operating economics.

Equipment rental expense accounted for 47% of the total expense.

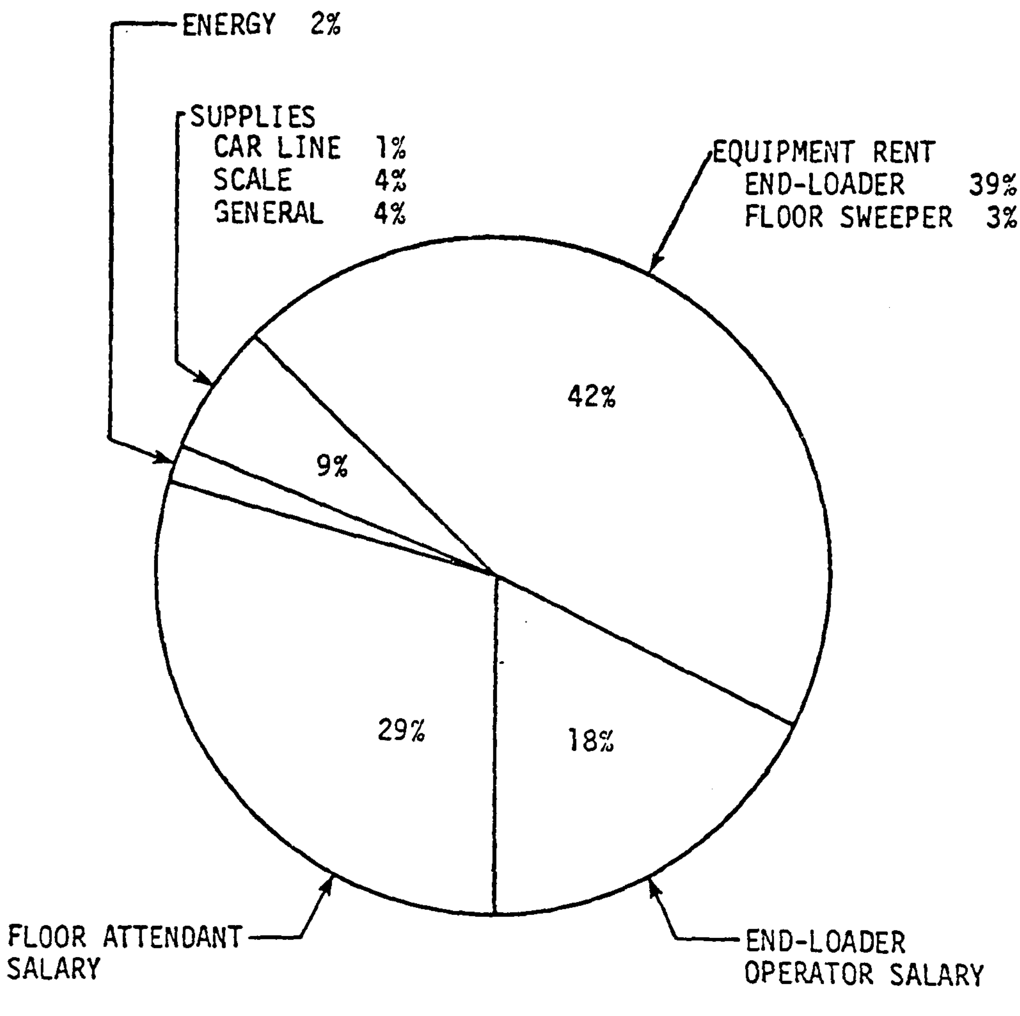

Figure 5.8. Tipping floor operating expense distribution

The end-loader and floor sweeper are rented at $1,250 and $189.92 per month respectively, excluding maintenance. In view of the magnitude of the end-loader and floor sweeper's yearly rental expenses, other alternatives to renting, such as a buying or lease-buying options, if available, should be explored. This arrangement may help recover the tipping floor's operating costs in the long run.

The tipping floor is neither heated nor air conditioned because of the large quantity of ventilation required to remove the exhaust gases produced by vehicles unloading refuse. As a result, the customer's entrance and exit doors remain open except during severe weather conditions. When the doors are closed, ventilation is provided by roof-mounted fan units. Due to the lack of heating and air conditioning, tipping floor employees are subjected to extreme temperature variation. In addition, they are exposed to vehicle noise from the end-loader, dust, and odor. Therefore an environmental evaluation of the tipping floor should be considered in order to protect employee's health and safety.

CHAPTER VI. SHREDDING SYSTEM

The shredding system consists of seven conveyors labeled C-1, C-2, C-3, C-4, C-5, C-6, C-11, and two shredders arranged in series (see Figure 6.1). The raw refuse can be fed from the tipping floor into either the primary or secondary shredder. Direct feeding to the secondary shredder would be done in the event of a failure in the primary shredder. To date no refuse has been fed into the secondary shredder directly from the tipping floor because it bypasses the first shredder, and single shredding would not produce the size reduction required for efficient combustion in the power plant's boilers. Therefore, refuse would be fed into the secondary shredder directly from the tipping only on an emergency basis.

The raw refuse from the tipping floor is fed into the infeed conveyor (C-1), by means of an end-loader. The amount of refuse carried by the infeed conveyor (C-1) into the first shredder is visually monitored by closed circuit television. The infeed conveyor's speed is adjusted manually by the process control operator as he observes the conveyor's operation through a television screen. Refuse is shredded to a nominal six inches and to one and one-half inches by the primary and secondary shredders, respectively. Each shredder contains 48 hammers and is driven by a 1,000 H.P. 720 R.P.M. electric motor. Both are horizontal hammer mills. The primary and secondary shredder hammers, weighing 150 and 50 lbs. respectively, are replaced in sets after processing approximately 24,000 and 12,000 tons of refuse. The

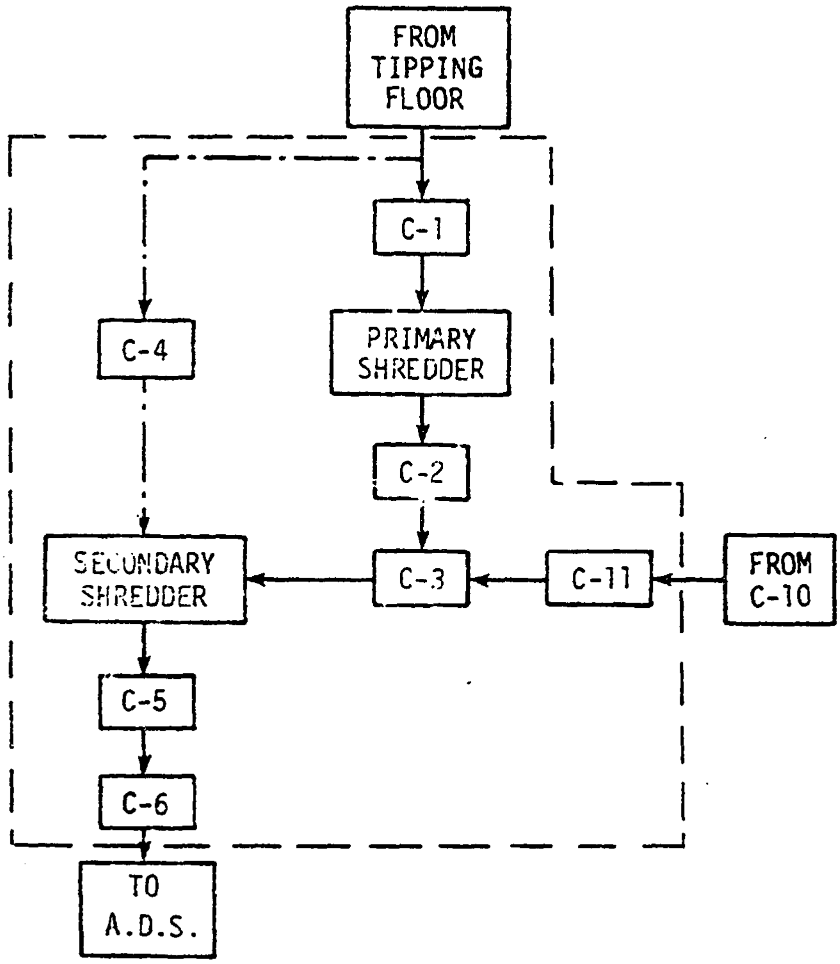

Figure 6.1. Shredding system process flow diagram

primary shredder hammers are turned to the other face after processing 12,000 tons of refuse and replaced after 24,000 tons. The secondary shredder hammers are not turned but discarded after processing 12,000 tons of refuse. The shredders' electrical current and bearing temperature are monitored in the process control room. The process control operator also monitors the shredding system conveyors by means of closed circuit television and mirrors. The shredded refuse leaves the shredding system and is transported to the air classifying system through conveyor C-6.

Labor Requirements and Expense Distribution

The labor hours expended maintaining the shredding system are divided between the two shredders and seven conveyors. The number of labor hours worked on each item of equipment during the 1977-1978 fiscal year is listed in Table 6.1. The shredder labor hours include the amount of time required to change and maintain the shredder hammers, accounting for 26% of the total primary and secondary shredders' labor input.

The remainder of the total labor input is used to maintain the seven conveyors associated with the shredding operation. This task primarily consists of unplugging conveyors congested with refuse. The proportion of time expended on these conveyors is shown in Table 6.1.

The conveyors consumed 66% of the total shredding system labor hours worked, with the remainder spent maintaining the two shredders.

Table 6.1. Monthly labor hours requirement distribution for the shredding system

Year and month	Shredders		Conveyors							TOTAL (HRS.)
	Primary (HRS.)	Secondary (HRS.)	C-1 (HRS.)	C-2 (HRS.)	C-3 (HRS.)	C-4 (HRS.)	C-5 (HRS.)	C-6 (HRS.)	C-11 (HRS.)	
1977										
July	23.50	25.00	61.50	37.25	23.50	-	9.00	8.50	-	188.25
August	22.75	32.00	70.00	0.50	9.50	-	-	-	-	134.75
September	34.50	13.50	88.00	-	-	-	9.00	7.00	-	152.00
October	126.00	6.50	109.00	1.00	1.50	-	1.00	5.00	-	250.00
November	30.00	27.50	167.50	17.00	6.00	-	4.00	7.50	1.50	261.00
December	14.00	25.00	59.50	28.00	1.00	0.75	1.50	1.50	0.50	131.75
1978										
January	47.75	4.75	44.50	7.00	4.50	-	2.50	0.50	1.00	112.50
February	43.00	23.50	93.50	20.75	0.50	1.00	23.50	-	-	205.75
March	17.50	17.00	65.50	7.00	23.50	-	9.50	22.00	-	162.00
April	11.25	11.25	93.00	2.00	41.25	6.00	2.50	-	0.50	167.75
May	76.50	32.50	80.50	4.50	11.50	1.50	3.50	0.50	-	211.00
June	16.75	24.25	48.75	16.00	4.00	-	-	-	0.50	110.25
TOTAL	463.50	242.75	981.25	141.00	126.75	9.25	66.00	52.50	4.00	2,087.00
PERCENTAGE OF TOTAL	22.21	11.63	47.02	6.76	6.07	0.44	3.16	2.52	0.19	100.00

Forty-seven percent of the total labor input in the conveying system was attributable to the infeed conveyor (C-1), which feeds refuse to the primary shredder. This particular conveyor was congested with refuse jammed in the pan sections frequently, thus requiring manual assistance to start it after each interruption. The remaining conveyors consumed 19% of the total hours worked, while the primary and secondary shredders used 22% and 12% of the total labor hours, respectively. The primary shredder required more labor hours than the secondary because replacing a set of hammers in the primary shredder requires 8 hours, while it takes only 4 hours to replace the secondary shredder hammers, mainly due to the larger mass of the primary hammers.

The labor cost of maintaining the shredding system operation during the 1977-1978 fiscal year is summarized in Table 6.2. The primary and secondary shredders accounted for 56% and 23% of the total shredding system operating cost, respectively.

The remaining 21% was used to maintain the seven conveyors. The primary and secondary shredders accounted for 79% of the total labor cost. The shredding operation required an average of 0.04 labor hours per ton of refuse processed, with an average labor cost of $0.14 per ton of refuse processed.

The labor requirement for the shredding system operation can be estimated by the following equation:

Labor requirement (HRS./MO.) = 186 - (0.0030)(Refuse processed, in TONS/MO.)

$R^2 = 0.002 \qquad n = 12$

Table 6.2. Monthly labor cost distribution for shredding system

Year and month	Labor Cost Distribution			
	Primary shredder ($)	Secondary shredder ($)	Conveyors (C1-6+11) ($)	TOTAL ($)
<u>1977</u>				
July	394.71	113.69	107.02	615.42
August	495.61	95.21	126.43	717.25
September	414.21	68.69	151.49	634.39
October	795.00	26.27	120.88	942.15
November	201.25	-	117.55	318.80
December	201.32	175.43	52.68	429.43
<u>1978</u>				
January	51.94	120.01	56.23	228.18
February	259.18	321.88	92.16	673.22
March	28.95	225.00	125.98	379.93
April	53.10	18.18	162.36	233.64
May	395.52	70.74	137.29	603.55
June	497.17	346.56	130.86	974.59
TOTAL	3,787.96	1,581.66	1,380.93	6,750.55
PERCENT OF TOTAL	56.11	23.43	20.46	100.00

Standard error of	a. Intercept	87
	b. Slope	0.0213

The labor hour input in this shredding system is fixed. The shredding system is maintained daily whether the system operates for short or long duration. Therefore, as more refuse is processed the average labor hour input is expected to decrease as shown by the model. During the 1977-1978 fiscal year operation the shredding system consumed an average of 0.04 labor hours for every ton of refuse processed.

Electrical Energy Consumption

The primary and secondary shredders, each with a 1,000 H.P. motor, consumed 36% and 54% of the total shredding system's electrical energy. The seven conveyors associated with the shredding system, with a total of 40 H.P., are estimated to account for 10% of the total shredding system's electrical energy consumption.

Primary and secondary shredder energy consumption are monitored separately. The plant's combined conveying, heating and air conditioning, and maintenance equipment systems' energy consumption is monitored by a single kilowatt hour meter. To obtain an estimate of the individual equipment energy usage, the amount of energy consumed by these systems is assumed to be proportional to the equipment's electrical horse power rating. In addition, the operating efficiency of all this equipment is assumed to be the same. Using these assumptions, the total energy usage monitored by a single meter is distributed proportional to the horse power ratings. Even (1977, p. 167) gives a complete list of the facility's equipment electrical horse power rating.

The proportion of energy consumed by the shredding system and the total energy cost are summarized in Table 6.3. The primary and

Table 6.3. Monthly energy consumption and cost distribution for the shredding system

Year and month	Shredders Primary (KW-HRS.)	Shredders Secondary (KW-HRS.)	Conveyors C-1 - C-11 (KW-HRS.)	Total energy usage (KW-HRS.)	TOTAL[a] cost ($)
1977					
July	16,700	33,200	5,794	55,694	2,277.88
August	24,700	46,100	8,550	79,350	3,142.26
September	31,200	38,800	7,704	77,704	3,380.12
October	27,500	36,100	7,380	70,980	2,810.81
November	20,500	29,900	6,400	56,800	2,357.20
December	19,200	30,100	5,454	54,754	2,266.82
1978					
January	28,700	26,600	6,085	61,385	2,670.25
February	18,200	26,400	5,371	49,971	2,058.81
March	19,100	35,100	6,434	60,634	2,589.07
April	22,800	38,700	5,970	67,470	3,198.08
May	18,597	29,372	4,795	52,764	2,690.96
June	23,004	36,924	6,300	66,228	2,874.30
TOTAL	270,201	407,296	76,237	753,734	32,316.56
PERCENT OF TOTAL ENERGY USAGE	35.85	54.04	10.11	100.00	

[a]Actual energy cost.

secondary shredders consumed an average of 54% and 36% of the total shredding system's energy, while the conveyors consumed 10% of the total shredding system's energy needs. The secondary shredder thus required 50% more energy than the primary shredder, even though the material to be shredded in the secondary is smaller than that of the primary. Mallan and Titlow (1975, p. 234) indicated that as the particle size reduction requirement increases, so does the total energy consumption. This relationship, however, is not linear over a wide range of size reduction, as shown in Figure 6.2. Diaz (1975, p. 113) points out that the average energy consumption in primary and secondary shredding is also affected by the refuse's moisture content and the shredding feed rate.

The relationship between energy consumption and quantity of refuse processed was explored using linear regression models. Based on the 1977-1978 fiscal year information, the model yields the following relationships:

1. Primary shredder energy consumption

   Energy input (KW-HRS./MO.) = 7157 + (3.8227) (Refuse processed, in TONS/MO.)

   $R^2 = 0.38$ $n = 12$

   Standard error of
   a. Intercept 6350
   b. Slope 1.5560

2. Secondary shredder energy consumption

   Energy input (KW-HRS./MO.) = 8,495 + (6.3331) (Refuse processed, in TONS/MO.)

   $R^2 = 0.66$ $n = 12$

   Standard error of
   a. Intercept 5856
   b. Slope 1.4348

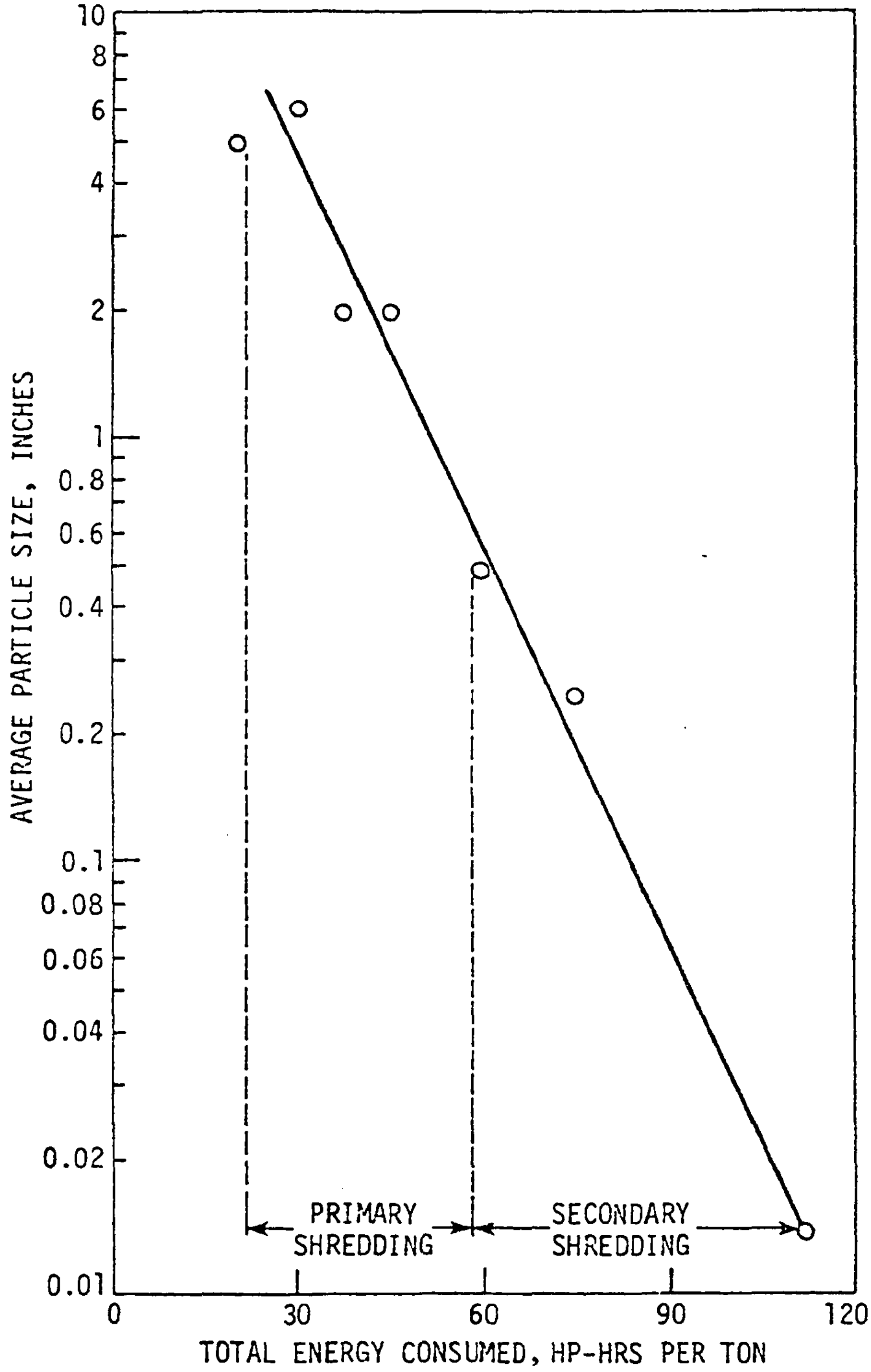

Figure 6.2. Shredding power consumption vs. solid waste particle size

3. Conveyors' energy consumption

Energy input (KW-HRS./MO.) = 1,009 + (1.3300)(Refuse processed, in TONS/MO.)

$R^2 = 0.87$ $n = 12$

Standard error of
a. Intercept 659
b. Slope 0.1615

4. Total shredding systems' energy consumption

Energy input (KW-HRS./MO.) = 16,662 + (11.4859)(Refuse processed, in TONS/MO.)

$R^2 = 0.79$ $n = 12$

Standard error of
a. Intercept 7,562
b. Slope 1.8531

The equations indicate a fairly linear relationship between the amount of refuse processed and energy consumed. The models also indicate that the secondary shredder consumes 1.66 (6.3331/3.8227) times as much energy as the primary shredder per ton of refuse processed. The relationship between the amount of energy consumed and mass of refuse processed for the primary and secondary shredders, conveyors, and the entire shredding system is shown graphically in Figures 6.3, 6.4, 6.5, and 6.6., respectively. The shredding system consumed an average of 15.63 KW-HR. per ton of refuse processed.

Another energy consumption analysis for the primary and secondary shredders based on 23 months' information yields similar results. The data included the shredders' energy consumption from June, 1976, to April, 1978. The linear regression equation results are as follows:

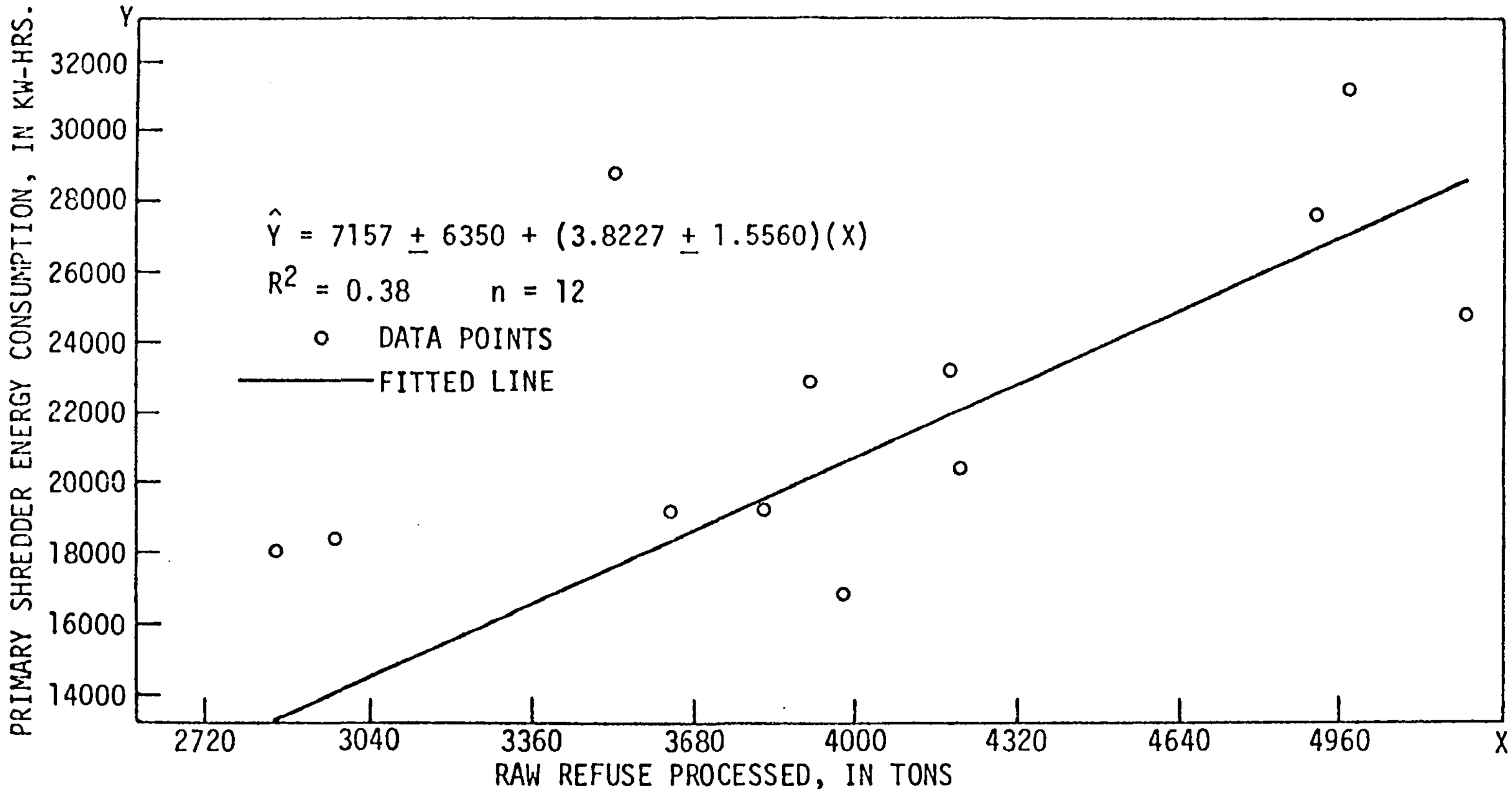

Figure 6.3. Primary shredder energy consumption vs. raw refuse processed

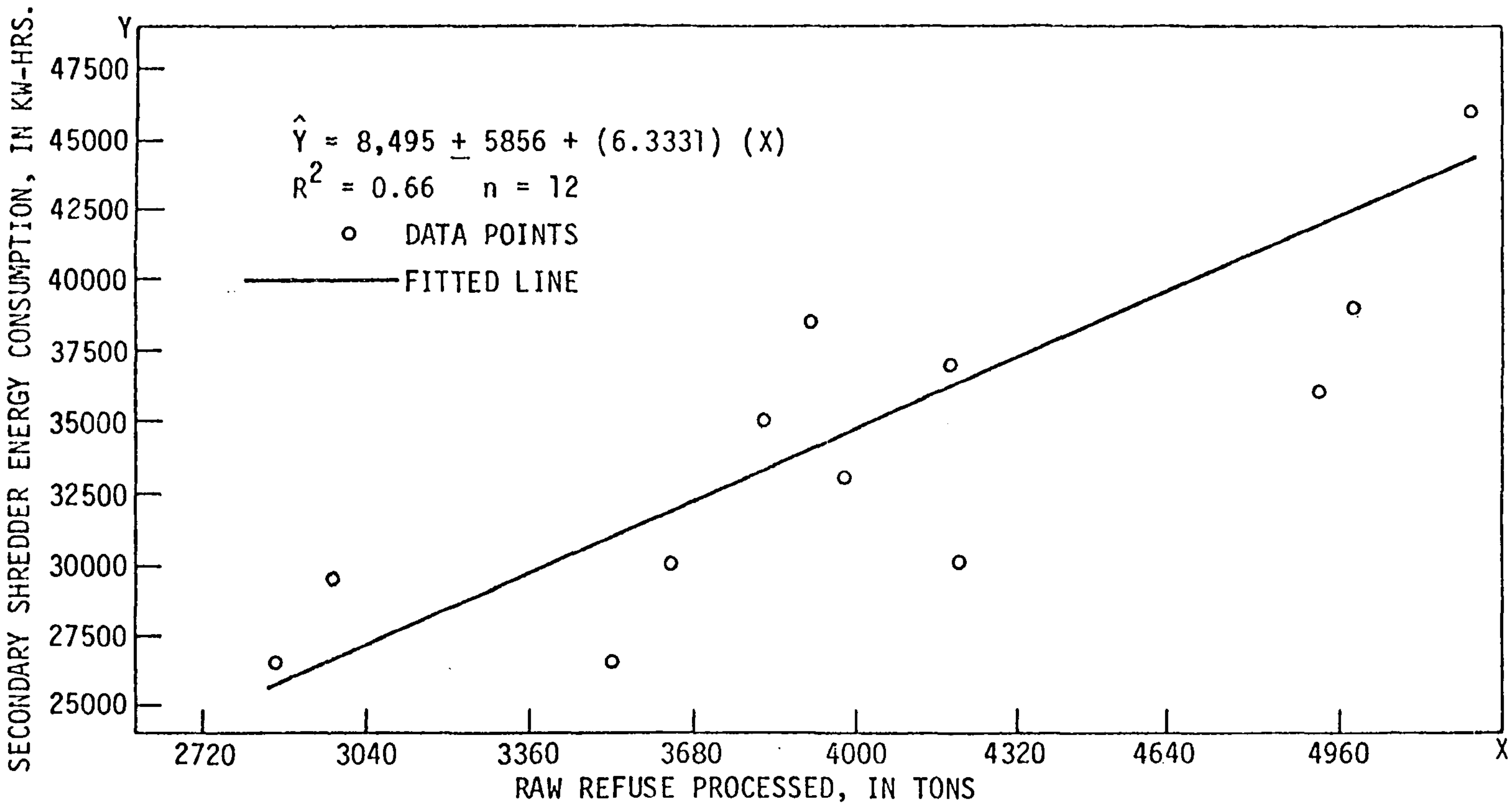

Figure 6.4. Secondary shredder energy consumption vs. raw refuse processed

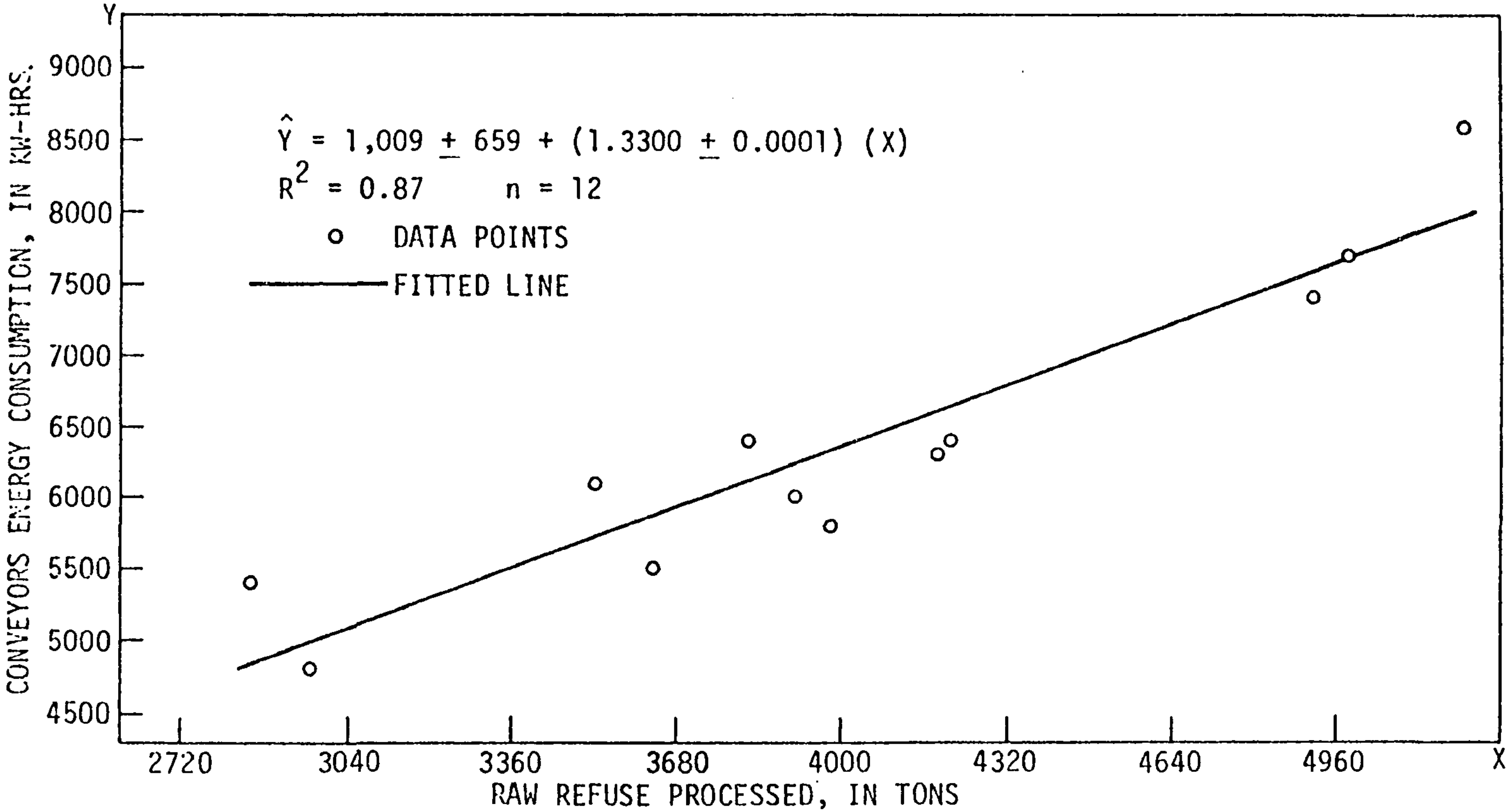

Figure 6.5. Shredding system conveyor's energy consumption vs. raw refuse processed

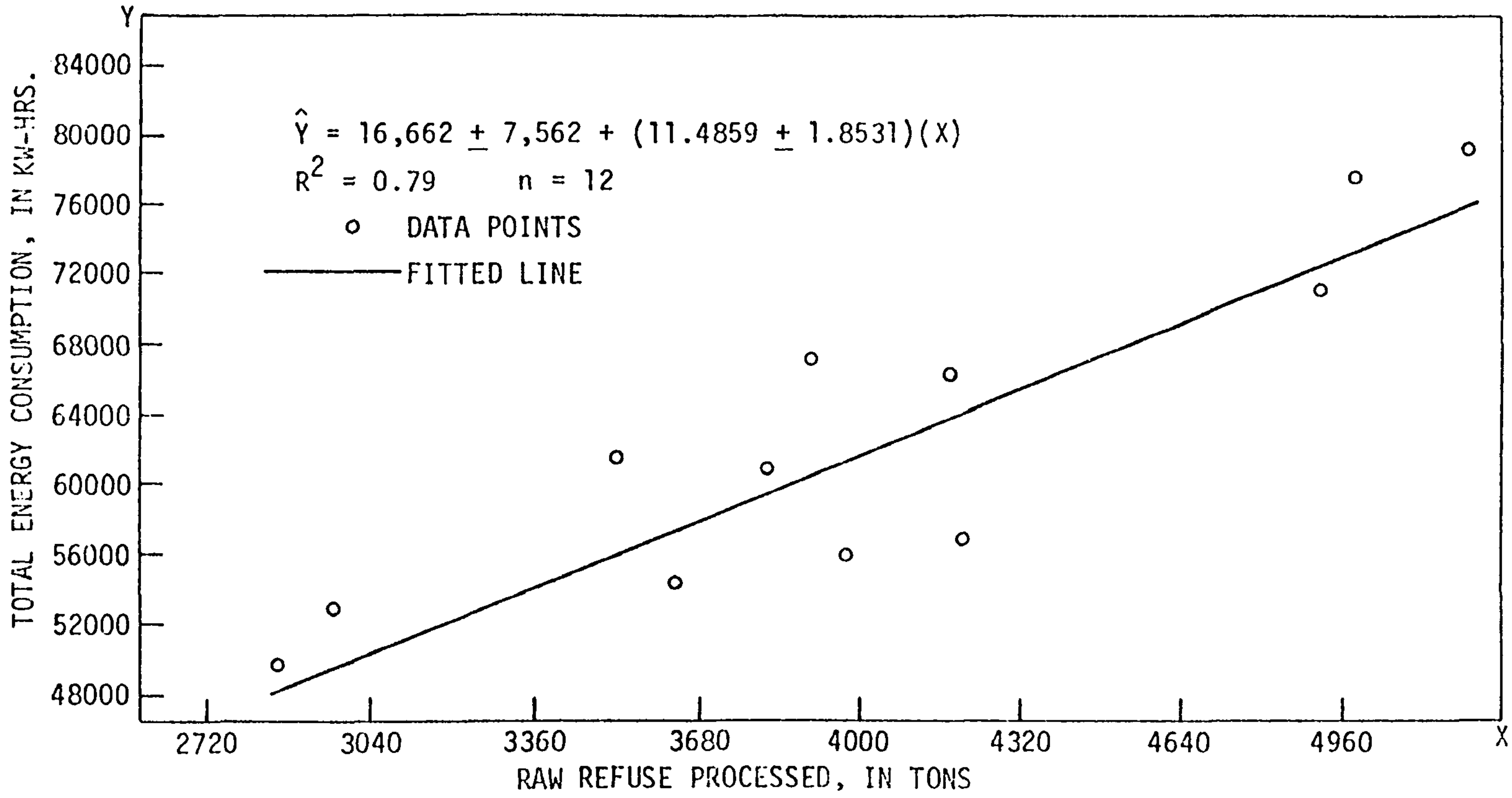

Figure 6.6. Shredding system total energy consumption vs. raw refuse processed

1. Primary shredder energy consumption

Energy input (KW-HRS./MO.) = 7,630 + (3.6788)(Refuse processed, in TONS/MO.)

$R^2 = 0.43$ $n = 23$

Standard error of
a. Intercept 3545
b. Slope 0.9296

2. Secondary shredder energy consumption

Energy input (KW-HRS./MO.) = 10,581 + (6.3035)(Refuse processed, in TONS/MO.)

$R^2 = 0.43$ $n = 23$

Standard error of
a. Intercept 6050
b. Slope 1.5864

Supply Requirement

Supply requirements include all items purchased and used in the shredding system operation. The major cost items include conveyor belts and fasteners, shredder hammers, electric motor repairs and lubricating supplies. The primary shredder hammers cost $125 each, or a total of $6,000 for a set of 48 hammers. The secondary shredder hammers cost $52 each with a total of $2,500. The shredders accounted for 78% and the conveyors 22% of the total supply expenses incurred in maintaining the shredding system. The shredding system's monthly supply cost is listed in Table 6.4. Supply expenses accounted for 36% of the total shredding system's operating cost. Energy, the largest single operating cost, accounted for 45% of the total shredding operation expense, while wages consumed 9% of the total cost (see

Table 6.4. Shredding system, materials, wages and energy cost distribution

Month	Material Usage					
	Shredders		Conveyors			
	Primary ($)	Secondary ($)	C-1 ($)	C-2 ($)	C-3 ($)	C-4 ($)
1977						
July	987.10	822.55	-	-	148.23	-
August	1,346.77	1,082.21	5.60	5.60	161.32	5.60
September	1,328.53	1,034.10	39.40	5.60	161.33	5.60
October	1,313.34	1,021.45	118.12	139.80	216.93	9.15
November	1,137.13	910.41	151.06	142.22	219.35	11.57
December	1,105.52	790.32	297.21	148.60	233.52	17.95
1978						
January	1,244.70	765.64	293.60	145.01	83.63	14.36
February	1,064.59	628.76	305.84	207.97	119.37	11.72
March	1,333.23	902.87	272.07	207.98	155.26	11.73
April	1,388.52	924.65	196.89	208.43	111.94	11.72
May	1,155.81	694.93	194.00	205.56	109.07	8.85
June	1,690.16	1,042.12	245.67	213.90	143.32	17.18
TOTAL	15,095.40	10,620.01	2,119.46	1,630.67	1,863.27	125.43
PERCENT OF TOTAL COST	20.97	14.75	2.94	2.27	2.59	0.18

Material Usage					
Conveyors			Wages ($)	Energy ($)	TOTAL COST ($)
C-5 ($)	C-6 ($)	C-11 ($)			
4.77	4.77	4.77	615.42	2,277.88	4,865.49
17.86	17.86	17.86	717.25	3,142.26	6,520.19
17.86	17.87	17.87	634.39	3,380.12	6,642.68
19.47	19.47	19.47	942.15	2,810.81	6,630.16
21.89	49.13	21.89	318.80	2,357.20	5,340.65
36.05	63.29	36.05	429.43	2,266.82	5,424.76
29.63	56.87	29.63	228.18	2,670.25	5,561.50
19.48	46.72	19.48	673.22	2,058.81	5,155.96
77.01	44.61	17.37	379.93	2,589.07	5,991.13
160.47	55.28	28.05	233.64	3,198.08	6,517.67
157.60	25.18	25.18	603.55	2,690.96	5,870.69
175.17	42.75	42.75	974.59	2,874.30	7,461.91
737.27	443.80	280.37	6,750.55	32,316.56	71,982.79
1.02	0.62	0.39	9.38	44.89	100.00

Figure 6.7).

Shredding System Total Operating Cost

The total monthly shredding system's operating costs, which include energy, wages, and supply expenses, are summarized in Table 6.4. The proportion of expenses incurred maintaining the shredding system operations in terms of labor, energy, and supply expenses is summarized in Figure 6.8. The primary shredder, secondary shredder, and conveyor consumed an average 43%, 41%, and 16% of the total shredding operation cost respectively. Thus, the shredders contributed to 84% of the total operating cost, leaving 16% to the conveying operation.

The relationship between the quantity of refuse processed and expenses incurred operating the shredding system was explored using regression analysis methods. The relationship can be expressed by the following linear regression model:

Total operating cost ($) = 3719 + (0.5674)(Refuse processed, in TONS/MO.)

$R^2 = 0.31$ $n = 12$

Standard error of
- a. Intercept 1104
- b. Slope 0.2704

The result of the relationship is shown in Figure 6.9. The total shredding operation expenses averaged $1.49 per ton during the one year period of study. Note that the R^2 value of 0.31 is relatively high, because the energy cost accounted for 44.89% of the total expense,

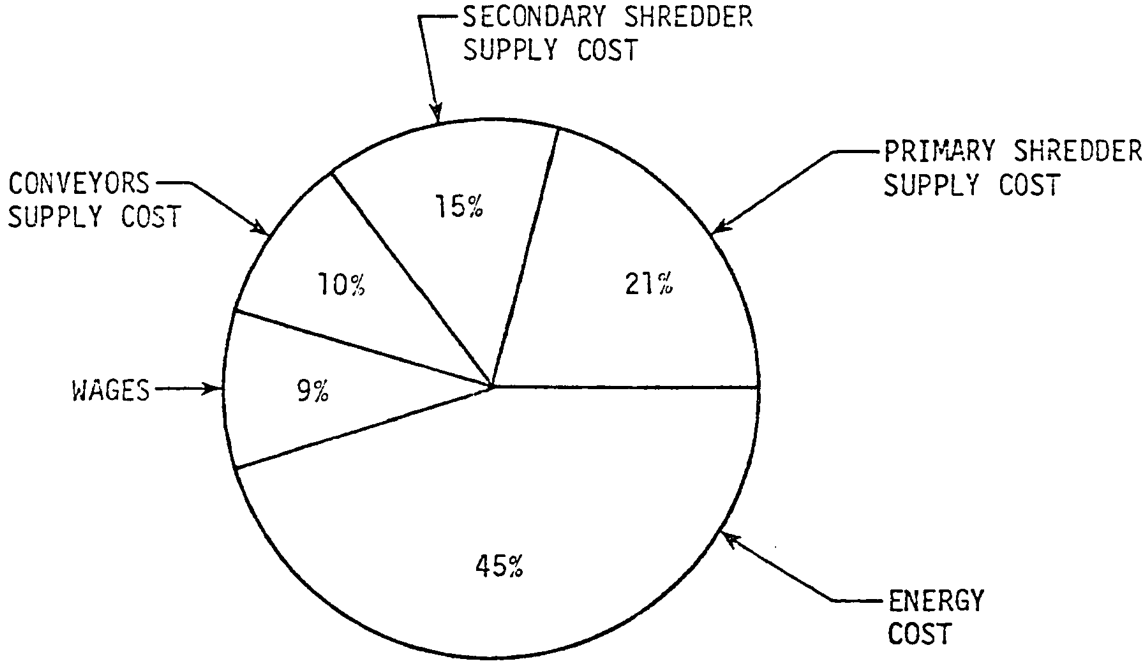

Figure 6.7. Shredding system operating cost distribution

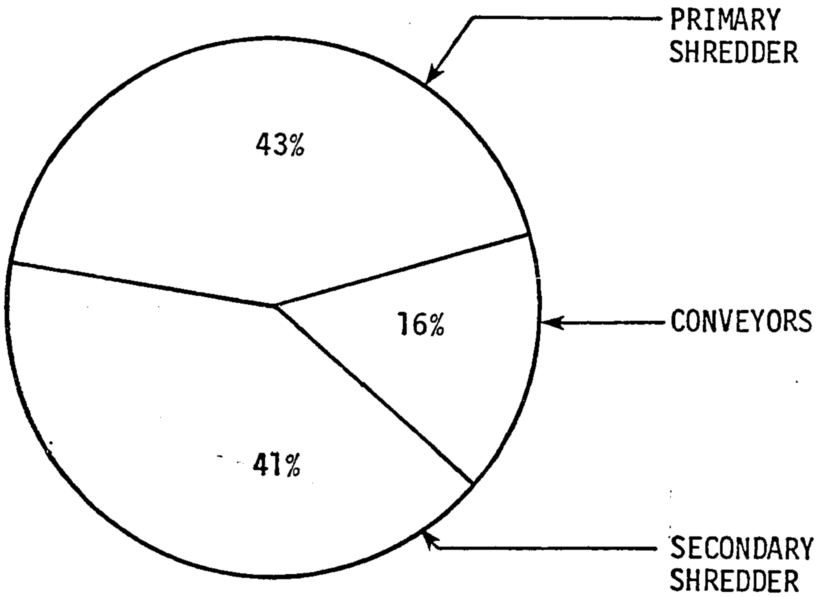

Figure 6.8. Shredding system total operation cost distribution

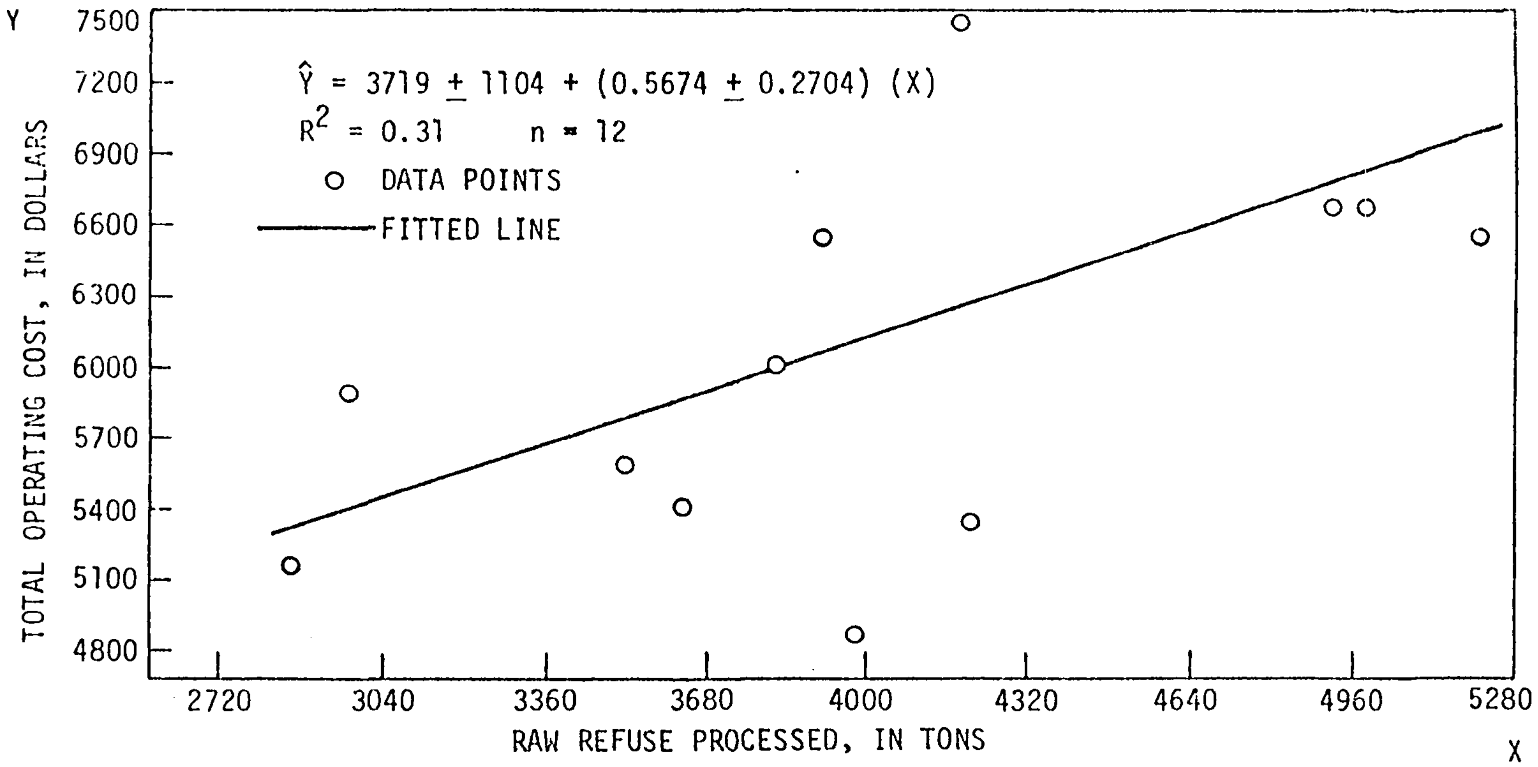

Figure 6.9. Shredding system total operating cost vs. raw refuse processed

which is highly correlated with the quantity of refuse processed.

Discussion

The electrical energy cost is the largest (45% of total operating cost) single operating expense in shredding system operations. The shredders are the main energy consumers, accounting for 90% of the energy consumption. The secondary shredder consumed an average 66% more energy than the primary shredder. Thus, the cost of shredding refuse to a smaller size requires more energy consumption, consequently increasing shredding energy costs. The primary and secondary shredders and the conveyors accounted for 43%, 41%, and 16% of the total shredding system cost, respectively. The shredding operation accounted for 84% of the total operating cost.

CHAPTER VII. AIR DENSITY SEPARATION SYSTEM

The air density separation system's (ADS) prime equipment components, are: the flight conveyor, vibrating feeder, rotary feeder, ADS chamber, ADS fan, cyclone, air return, and twin screw feeder. The refuse process flow through the ADS system is shown in Figure 7.1.

The main function of the ADS system is to separate the light aerodynamic fraction from the heavy fraction of shredded refuse. Refuse leaves the secondary shredder and is transported into the ADS system through conveyor (C-6). The refuse enters a storage or surge bin (flight conveyor) which serves as a temporary storage system in addition to feeding refuse to the ADS chamber at a constant rate. The refuse then enters a vibrating screen feeder which removes fine materials such as sand, glass, etc. before entering the ADS chamber. The fine materials are diverted into the rejected materials flow stream. The rotary air lock feeder conveys the refuse into the ADS chamber where the heavy and light materials are separated by density. Refuse enters the ADS chamber where air drawn by the ADS fan lifts the light materials up and then transfers them into the cyclone, which separates the air from the materials. These light materials are classified as RDF and transferred into the RDF transport system through a twin screw feeder. The screw feeder's function is to feed RDF into the transport system at an even rate. Meanwhile, the heavy materials fall to the bottom of the ADS chamber and are conveyed out on C-7. Then they are separated further into ferrous, nonferrous, and rejected materials.

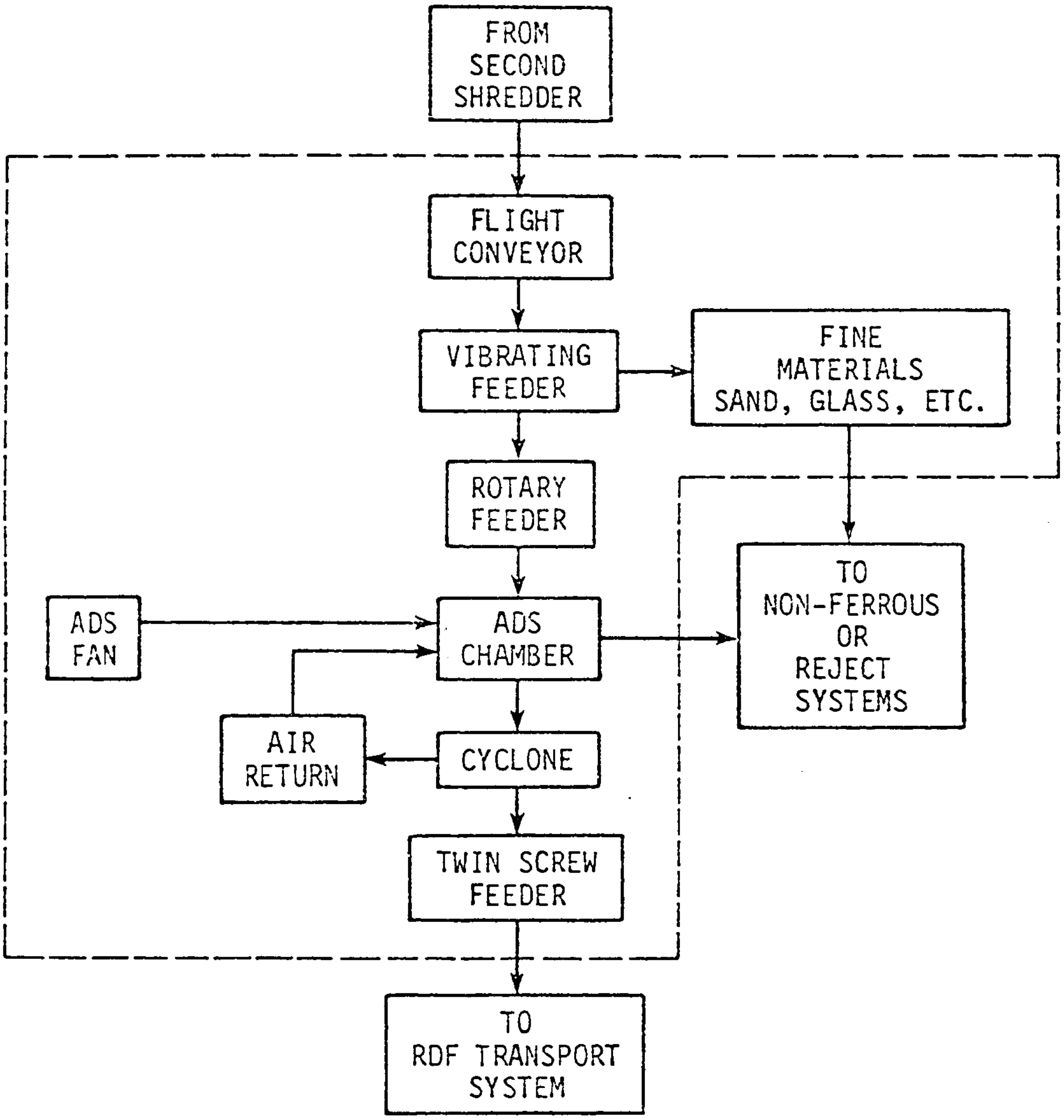

Figure 7.1. Air density separation process flow diagram

Labor Input and Distribution

The total monthly labor hours worked on the various pieces of equipment in the ADS system during the fiscal year is summarized in Table 7.1. The average proportion of time expended maintaining the various ADS system operations is summarized in Figure 7.2. The flight conveyor and the vibrating feeder conveyor consumed over 35% of the total labor hours worked. The flight conveyor encountered a major breakdown in December, 1977, that required flight repairs which consumed 162.50 labor hours. The amount of labor hours worked after this repair, however, has decreased. The vibrating feeder also faced frequent operation difficulties; when wet refuse is processed, the vibrating feeder often becomes congested, causing its motor to overload and burn out. The amount of labor hours expended maintaining the remaining pieces of equipment is due to refuse congestion in the system. No definite relationship can be shown between the quantity of refuse processed and amount of labor hours worked because equipment failure appears to occur at random times. However, the ADS system consumed an average of 0.02 labor hours per ton of refuse processed during the fiscal year.

The monthly labor hours varied considerably in the ADS system. This occurs because breakdowns do not occur at a fixed interval. Very little labor input is required until a major failure or maintenance work occurs. The ADS system consumed an average of 0.02 labor hours for every ton of refuse processed. A regression analysis of the labor input yields the following equation:

Table 7.1. Monthly labor hours input distribution for air density separation system

Year and month	Flight conveyor (HRS.)	Vibrating feeder (HRS.)	Rotary feeder (HRS.)	Cyclone (HRS.)	Air return (HRS.)	Twin screw feeder (HRS.)	Fan and chamber (HRS.)	TOTAL (HRS.)
1977								
July	2.00	18.00	13.50	-	0.50	-	7.00	41.00
August	-	13.50	2.50	-	0.50	-	-	16.50
September	-	27.00	14.00	6.00	4.50	4.00	5.00	60.50
October	0.50	29.00	1.00	1.50	1.50	-	19.00	52.50
November	29.00	.50	4.75	14.50	2.00	1.50	24.50	76.75
December	162.50	13.50	7.00	7.50	1.50	1.25	11.25	204.50
1978								
January	42.00	8.00	19.50	2.00	0.50	2.00	5.50	79.50
February	2.00	2.00	5.00	0.50	0.50	-	7.75	17.75
March	2.50	13.50	5.00	7.00	3.50	52.50	14.25	98.25
April	14.00	6.50	3.50	44.50	3.50	-	11.00	83.00
May	0.50	17.75	5.50	6.00	1.00	1.00	25.50	57.25
June	-	7.50	12.50	32.25	4.50	48.00	4.50	109.25
TOTAL	255.00	156.75	93.75	121.75	24.00	110.25	135.25	896.75
PERCENT OF TOTAL	28.44	17.48	10.45	13.58	2.68	12.29	15.08	100.00

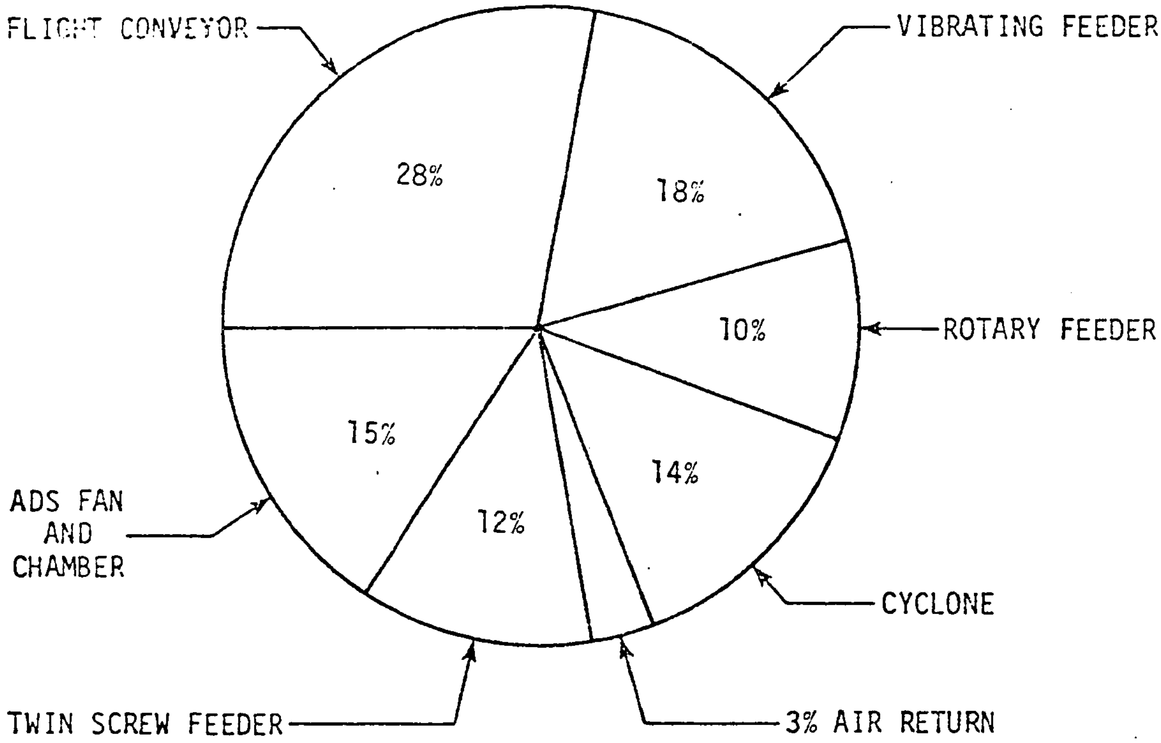

Figure 7.2. Air density separation system labor hours input distribution

Labor input (HRS./MO.) = 120 - (0.0113)(Refuse processed, in TONS/MO.)

$R^2 = 0.03$ n = 12

Standard error of
a. Intercept 85
b. Slope 0.0209

The analysis indicates that the linear model is not the best fit. The routine ADS maintenance is performed daily, thus independent of quantity of refuse processed.

Electrical Energy Consumption

The ADS blower has a 200 H.P. motor, while the remaining pieces of equipment which include the flight conveyor, vibrating feeder, rotary air lock feeder, and twin screw feeder have a combined equivalent of 63 H.P. The ADS systems's total energy consumption is summarized in Table 7.2. The blower and other equipment consumed an average of 64% and 36% of the total energy input respectively. A linear regression analysis is used to express the relationship between energy consumed and quantity of refuse processed. The analysis gives the following equation:

Energy input (KW-HRS./MO.) = 6901 + (5.2523)(Refuse processed, in TONS/MO.)

$R^2 = 0.51$ n = 12

Standard error of
a. Intercept 6705
b. Slope 1.6431

The above model shows that a positive relationship exists between the energy consumed and refuse processed. This result is shown in Figure 7.3. The ADS system used an average of 7 KW-HRS. of electrical energy with

Table 7.2. Monthly energy consumption and cost distribution for the air density separation system

Year and month	Energy Consumption: Blower (KW-HR.)	Energy Consumption: Other equipment (KW-HR.)	Energy Consumption: TOTAL (KW-HR.)	TOTAL[a] Energy cost ($)
1977				
July	15,350	9,288	24,638	1,007.69
August	21,730	13,706	35,436	1,403.27
September	19,520	12,349	31,869	1,386.30
October	20,410	11,830	32,240	1,276.70
November	16,670	10,260	26,930	1,117.60
December	14,180	8,743	22,923	949.01
1978				
January	15,410	9,754	25,164	1,094.63
Februray	14,410	8,610	23,020	948.42
March	16,490	10,313	26,803	1,144.49
April	29,390	9,570	38,960	1,846.70
May	12,994	7,687	20,681	1,054.73
June	17,281	10,099	27,380	1,188.29
TOTAL	213,835	122,209	336,044	14,417.83
PERCENT OF TOTAL ENERGY CONSUMPTION	63.63	36.37	100.00	

[a]Actual energy cost.

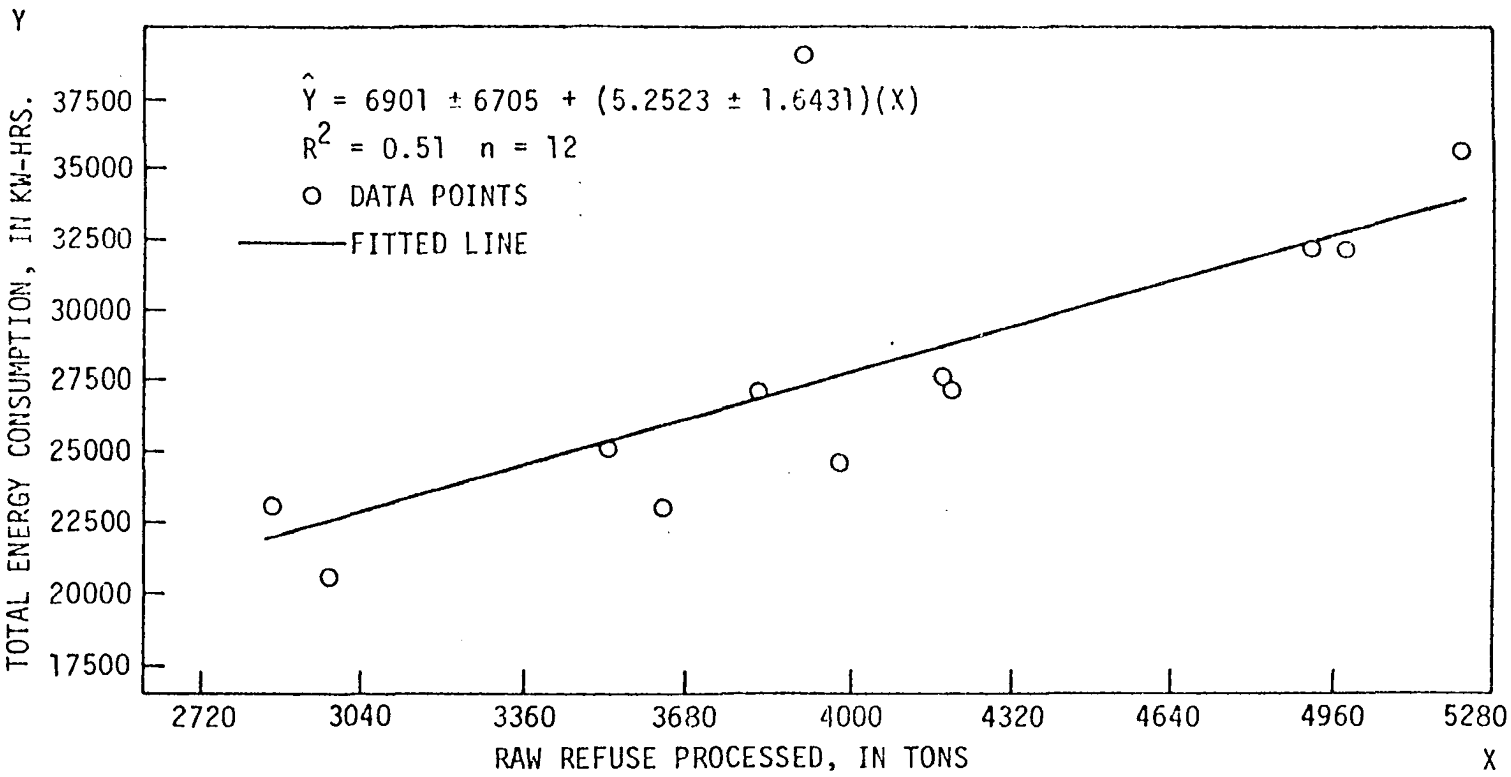

Figure 7.3. Air density separation system total energy consumption vs. raw refuse processed

an average cost of \$0.30 per ton of refuse processed.

Air Density Separation System's Total Operating Cost

The ADS system incurred an operating expense of \$28,555.79 during the 1977-1978 fiscal year, which is summarized in Table 7.3. Electrical energy expense accounted for 50.5% of the total operating cost, while wages, with 20.5% of the cost, ranked second to energy cost. The remaining 29% of the total cost was for supplies. Therefore, energy and wage expenses, with 71% of the total operation cost, also accounted for a large portion of the ADS system's maintenance costs. The proportion of expenses incurred in the various ADS system operation activities is summarized in Figure 7.4.

The total ADS system's operating expense is given by the following equation:

Operating expense (\$/MO.) = 4274 - (0.4716)(Refuse processed, in TONS/MO.)

$R^2 = 0.18 \quad n = 12$

Standard error of
- a. Intercept 1298
- b. Slope 0.3180

The ADS system has a large fixed cost. When the plant is in operation, employees monitor the ADS system's equipment visually, which increases the fixed cost.

Table 7.3. Monthly operating expenses distribution for the air density separation system

Year and month	Material Usage							
	Flight conveyor ($)	Vibrating conveyor ($)	Rotary feeder ($)	ADS & ADS fan ($)	General supplies ($)	Wages ($)	Energy ($)	TOTAL cost ($)
1977								
July	-	-	-	17.40	-	93.89	1,007.69	1,118.98
August	41.60	-	-	17.40	58.72	264.91	1,403.27	1,785.90
September	41.60	-	-	17.40	-	122.89	1,386.30	1,568.19
October	41.60	40.60	-	17.40	22.50	286.14	1,276.70	1,684.94
November	41.59	40.60	-	17.39	179.40	415.73	1,117.60	1,812.31
December	41.59	73.00	51.67	475.92	109.23	866.33	949.01	2,566.75
1978								
January	96.89	105.40	51.67	458.53	223.10	1,467.68	1,094.63	3,497.90
February	139.44	156.62	51.67	458.53	197.80	283.31	948.42	2,235.79
March	196.25	156.62	51.67	458.53	203.97	383.11	1,144.49	2,594.64
April	268.40	116.00	51.66	458.53	235.54	733.17	1,846.70	3,710.00
May	272.64	167.67	51.66	458.53	308.09	292.63	1,054.73	2,605.95
June	328.08	181.08	-	412.50	616.67	647.82	1,188.29	3,374.44
TOTAL	1,509.68	1,037.59	310.00	3,268.06	2,155.02	5,857.61	14,417.83	28,555.79
PERCENT OF TOTAL COST	5.29	3.63	1.09	11.44	7.55	20.51	50.49	100.00

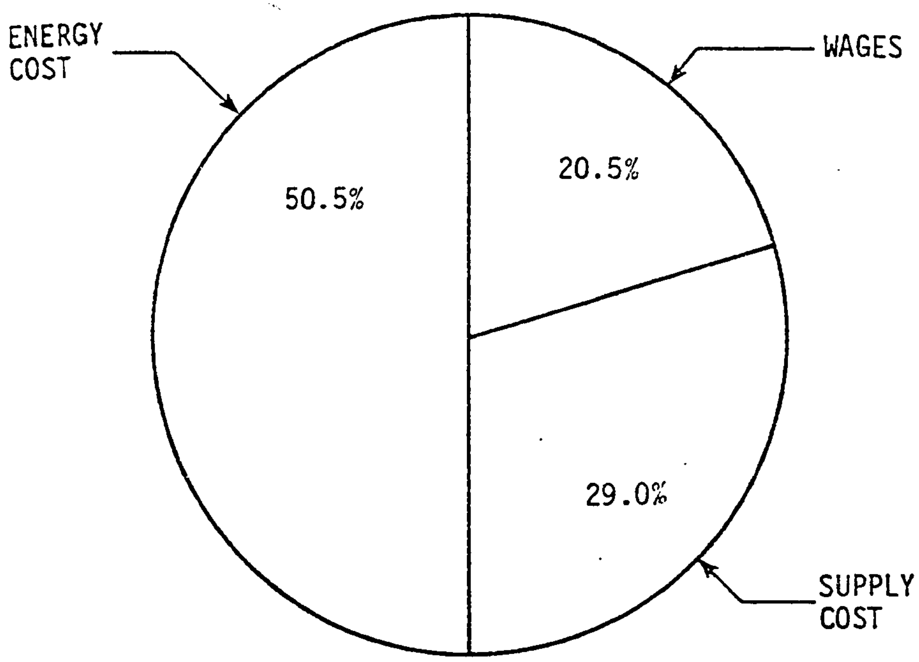

Figure 7.4. Air density separation system total operating cost

Discussion

The ADS system, designed to separate combustibles from noncombustibles, experienced frequent refuse congestion at its various processing stages, which contributed to processing interruptions. Earlier design difficulties caused the flight conveyor's drive motor to burn out three times during June and July of 1976. In August, 1976, flight conveyor design changes were made which improved the system's operation (Gheresus, 1977, p. 60). The facility's refuse processing interruption caused by the various sub-systems is discussed in a later chapter.

The ADS system is an important element of the plant operation because it determines the quality of the RDF. As shown earlier, the ADS chamber classifies some noncombustible materials (sand, glass, fine metals, etc.) as combustibles. The noncombustible materials cause rapid wear to the RDF transport system and increase ash handling work at the power plant. In addition, when the refuse is wet, the vibrating feeder's screen becomes covered with wet dirt; thus it is unable to remove the sand, glass, fine metals, etc. before these materials enter the ADS chamber.

CHAPTER VIII. REFUSE DERIVED FUEL TRANSPORT SYSTEM

The light fraction refuse classified as RDF is conveyed through the cyclone and twin screw feeder of the ADS system and then enters the RDF transport system through the air lock feeder. The RDF is then fed by means of the air lock into a 14" diameter steel pipeline located underground. The pipeline conveys the RDF by means of air supplied by a 200 H.P. blower into an RDF storage bin located 300 feet from the refuse processing facility (see Figure 8.1). The RDF is then withdrawn from the storage bin by the power plant as needed to be burned with coal in the plant's boilers. The power plant uses 4 underground steel pipes to transfer the RDF from the 550 ton capacity storage bin into the boilers; to date only 2 of these lines have been used.

Labor Requirement and Distribution

During the 1977-1978 fiscal year a total of 839 labor hours were expended in maintaining the RDF transport system. Over 84% of the total labor hours was used in replacing, rotating, or unplugging the RDF conveying pipeline. Sand, glass, and small ferrous metals, working as abrasive agents, cause pipe wear, thus necessitating the pipe change more often than desired. The pipe is rotated periodically to postpone its replacement. When the pipeline becomes congested with RDF, special equipment is required to clear the line.

Less than 16% of the total labor hours worked is used to maintain the blower and air lock feeder. The monthly labor hours expended main-

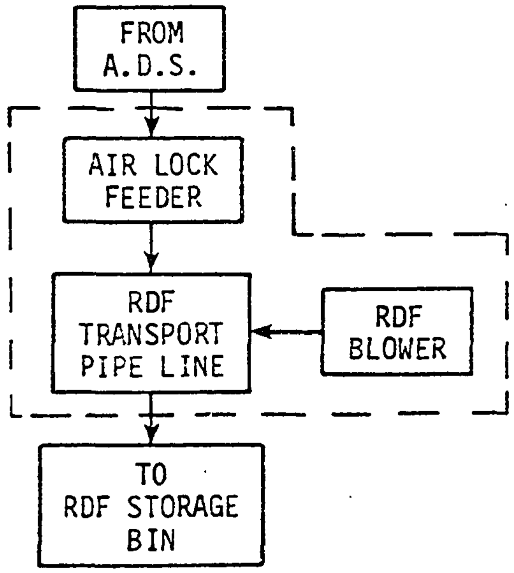

Figure 8.1. Refuse derived fuel transport system process flow diagram

taining the various pieces of transport equipment are summarized in Table 8.1. The RDF transport system consumed an average of 0.02 labor hours per ton with an average labor cost of $0.11 per ton of refuse processed. The total monthly labor hours varied from 547.25 hours during RDF pipeline replacement in December to 11.50 hours in September

Table 8.1. Monthly labor hours input distribution for the refuse derived fuel transport system

Year and month	Blower (HRS.)	Pipeline (HRS.)	Air lock Feeder (HRS.)	TOTAL (HRS.)
1977				
July	2.50	61.50	7.00	71.00
August	8.50	2.00	1.00	11.50
September	-	-	11.50	11.50
October	1.00	34.50	1.00	36.50
November	4.50	21.00	18.00	43.50
December	15.50	527.75	4.00	547.25
1978				
January	-	6.00	4.00	10.00
February	1.00	-	10.50	11.50
March	5.00	6.50	8.00	19.50
April	-	5.50	7.50	13.00
May	1.25	25.00	2.50	28.75
June	-	20.50	14.50	35.00
TOTAL	39.25	710.25	89.50	839.00
PERCENT OF TOTAL	4.68	84.65	10.67	100.00

and February. With the exception of the labor hours worked during December, the hours spent on the transport system were constant. The plot of total labor hours worked vs. the quantity of refuse processed is shown in Figure 8.2. This plot indicates that the hours worked were

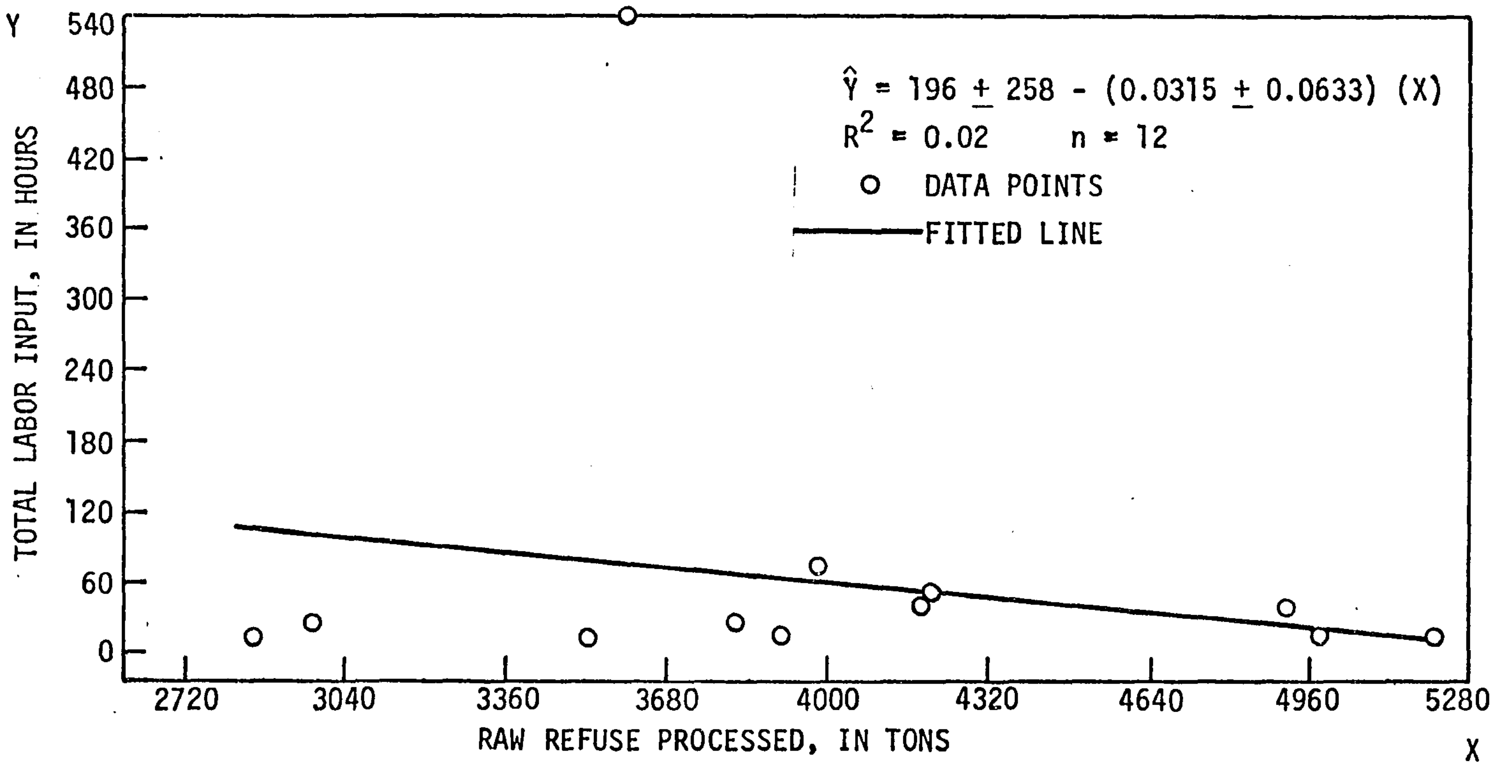

Figure 8.2. Refuse derived fuel transport system total labor input vs. raw refuse processed

constant regardless of the quantity of refuse processed with exception of one data point showing a high of 547.25 hours worked, which was caused by the pipeline replacement.

The monthly labor hours is constant except during major repairs of the pipeline. A linear regression analysis of the labor input gives the following equation:

Labor input (HRS/MO.) = 196 - (0.0315)(Refuse processed, in TONS/MO.)

$R^2 = 0.024$ n = 12

Standard error of
a. Intercept 258
b. Slope 0.0633

The labor hour input is decreasing as the quantity of refuse processed increases, because the monthly labor input is essentially constant.

Electrical Energy Consumption and Cost

Energy consumers in the RDF transport system are the RDF pneumatic blower with 200 H.P., and the 40 H.P. air lock feeder. The blower pushes the RDF through the 14" diameter pipeline into the storage bin. The air lock feeder is a buffer between the air density separator (discharging at atmospheric pressure) and the transport system (operating at pressures up to 6 PSI). The RDF blower and the air lock feeder consumed an average of 67% and 23% of the total transport system energy input. The monthly energy consumption by the RDF blower and air lock feeder, and total energy cost are listed in Table 8.2. The RDF

Table 8.2. Monthly energy consumption distribution and cost of the refuse derived fuel transport system

Year and month	Blower (KW-HR.)	Air lock feeder (KW-HR.)	Total energy usage (KW-HR.)	TOTAL[a] energy cost
1977				
July	10,390	5,461	15,851	648.31
August	15,540	8,058	23,598	934.48
September	14,480	7,260	21,740	945.69
October	14,700	6,955	21,655	857.54
November	12,820	6,032	18,852	782.36
December	10,090	5,140	15,230	630.52
1978				
January	10,590	5,735	16,325	710.14
February	10,280	5,062	15,342	632.09
March	12,510	6,063	18,573	793.07
April	13,120	5,626	18,746	888.56
May	9,847	4,519	14,366	732.67
June	12,637	5,938	18,575	806.16
TOTAL	147,004	71,849	218,853	9,361.59
PERCENT OF TOTAL ENERGY USAGE	67.17	32.83	100.00	

[a]Actual energy cost.

transport system required an average of 4.54 KW-HRS. of electrical energy per ton of refuse processed. The refuse processing energy cost averaged \$0.19 per ton.

The quantity of refuse processed and the total amount of energy consumed in the RDF transport system are related as shown by Figure 8.3. A linear regression analysis of this relationship gives the following equation:

Energy input (KW-HRS./MO.) = 3,452 + (3.6800)(Refuse processed, in TONS/MO.)

$R^2 = 0.87$ $n = 12$

Standard error of
a. Intercept 1823
b. Slope 0.4468

The equation reveals a fairly linear relationship between the quantity of refuse processed and the total energy consumed in the RDF transport system.

Supply Requirement

Material usage is divided into the following: blower, RDF pipeline, air lock feeder, and general categories. The monthly supply cost is summarized in Table 8.3. The RDF pipeline, general supply, and air lock feeder supply expenses accounted for 60%, 39% and 1% of the total supply cost respectively. Even though no supply cost is shown under the RDF blower, the general supply is used for the entire system which includes material used for the blower. However, the general supply category can not be identified with special pieces of equipment. The

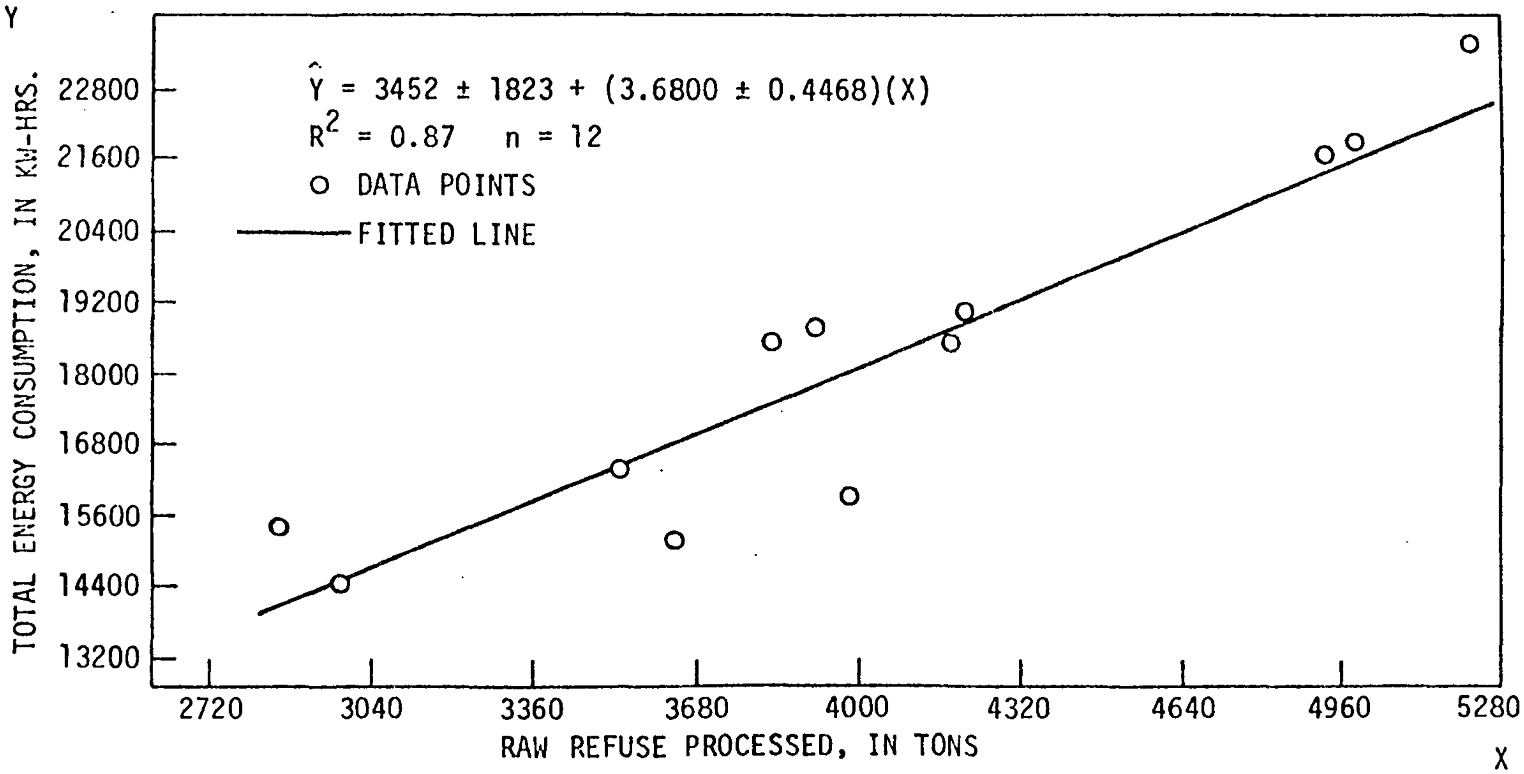

Figure 8.3. Refuse derived fuel transport system total energy consumption vs. raw refuse processed

Table 8.3. Monthly operating expense for the refuse derived fuel transport system

Year and month	Supply Cost				Wages	Energy cost	TOTAL cost
	Blower ($)	Pipeline ($)	Air lock feeder ($)	Total supply cost ($)	($)	($)	($)
1977							
July	-	811.79	-	811.79	140.33	648.31	1,600.43
August	-	811.79	-	811.79	531.93	934.48	2,278.20
September	-	811.80	-	836.12	86.54	945.69	1,868.35
October	-	811.80	-	811.80	304.16	857.54	1,973.50
November	-	811.80	-	811.80	64.14	782.36	1,658.30
December	-	811.80	-	813.82	2,404.94	630.52	3,849.28
1978							
January	-	541.44	-	750.95	6,166.50	710.14	2,627.59
February	-	591.86	-	635.42	258.54	632.09	1,526.05
March	-	591.86	23.16	615.02	-	793.07	1,408.09
April	-	591.86	23.16	665.79	32.20	888.56	1,586.55
May	-	591.86	23.17	665.80	167.57	732.67	1,566.04
June	-	591.86	-	5,626.49	381.23	806.16	6,813.88
TOTAL	-	8,371.52	69.49	13,856.59	5,538.08	9,361.59	28,756.26
PERCENT OF TOTAL COST		29.11	0.25	48.19	19.26	32.55	100.00

large RDF pipeline cost was primarily due to the cost of replacement. One half of the pipeline was replaced in June, 1977, and the other half in December, 1977.

Refuse Derived Fuel Transport System's Operating Cost

The RDF transport system incurred a total of $28,756.26 during the fiscal year of 1977-1978. This is an average cost of $1.01 per ton of refuse processed. The monthly supply, wages, and total expenses are summarized in Table 8.3. Supply, energy, and wage expenses consumed an average of 48.19%, 32.55% and 19.26% of the total operating cost respectively; these are illustrated in Figure 8.4. The high proportion of supply cost is due to the RDF transport pipeline replacement at a cost of $18.87 per lineal foot. The energy cost, accounting for over 32% of the total, is a major expense, with labor consuming the smallest portion (19.26%) of the total operating cost.

The total operating cost of the refuse derived fuel system is represented by the following equation:

Operating cost ($/MO.) = 1704 + (0.1724)(Refuse processed, in TONS/MO.)

$R^2 = 0.007$ $n = 12$

Standard error of
a. Intercept 2668
b. Slope 0.6539

The equation indicates that the operating expense is independent of the amount of refuse processed. This occurs because major repairs occur at one time and not continuously as the refuse is being processed. Thus,

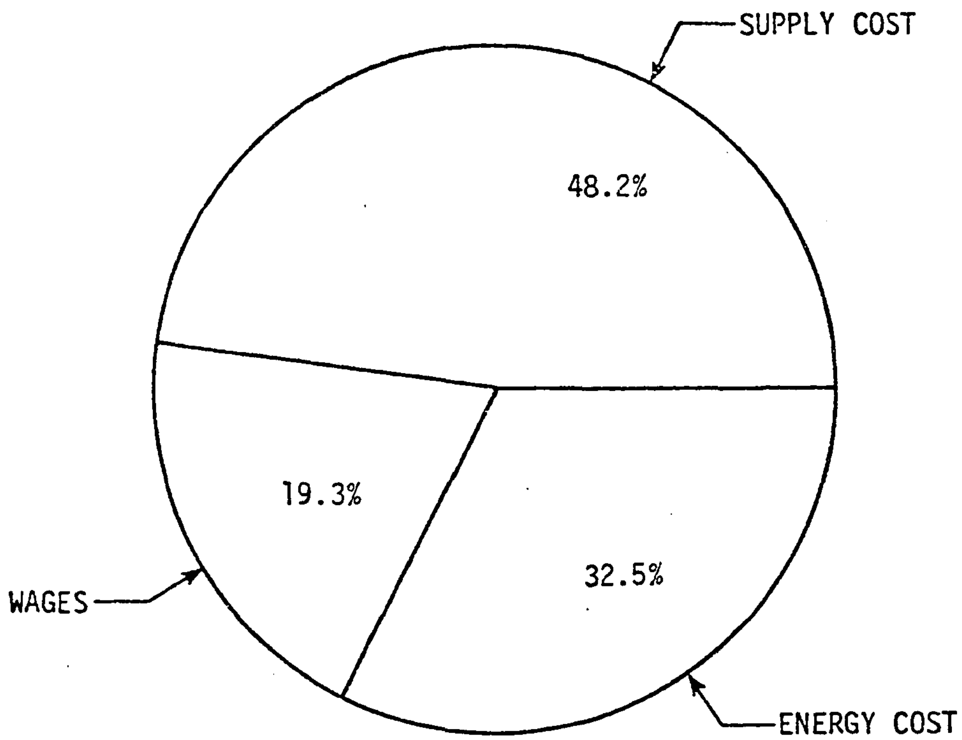

Figure 8.4. Refuse derived fuel transport system total operating expense distribution

the expenses vary from one month to another depending on the major repairs performed.

Discussion

The amount of labor hours expended in maintaining the RDF transport pipeline deserves careful evaluation. The entire pipeline is buried underground and is only accessible at one point in the middle of the pipeline system. Therefore, if wear occurs at either end of the line, an entire half of the pipeline must be pulled out from the center to be repaired. This task usually causes a plant shutdown for about one week.

Pipeline wear is caused by sand, glass, and small ferrous and nonferrous metals that function as abrasives. This problem was somewhat alleviated with the removal of sand, glass and other fine materials prior to entering the pipeline. Further research is needed in the area of RDF transport systems in order to improve on the operations and maintenance of these systems.

CHAPTER IX. FERROUS METALS SEPARATION SYSTEM

The ferrous metals separation activities can be divided into processed and nonprocessed operations. The nonprocessed metals are sorted at the tipping floor and then sold to a scrap metals dealer. These nonprocessed metals are composed of bulky items such as stoves, water heaters, refrigerators, and engine blocks. The remaining small metals and all ferrous metals are shredded and then extracted from the stream by a series of magnets. The metals removed in this manner are referred to as processed metals.

The first ferrous metal separation is accomplished by a magnet located between the first and second shredders. This recovers about 90% of the ferrous metal. Metal not removed by the first stage magnet is reclaimed by a second magnet which removes ferrous metal from the ADS heavy or rejected fraction. The final ferrous metal is extracted by a magnet before the heavy fraction is emptied into the reject bin. The processed ferrous metal from the three sources is then loaded into a semi-trailer for commercial sale. The ferrous metal separating process is shown in Figure 9.1.

Labor Requirement and Distribution

The processed and nonprocessed ferrous metal operation used a total of 1636.75 labor hours during the 1977-1978 fiscal year. The processed metal operation involves four magnets, five conveyors, and a ferrous storage trailer. The monthly amount of labor hours worked in

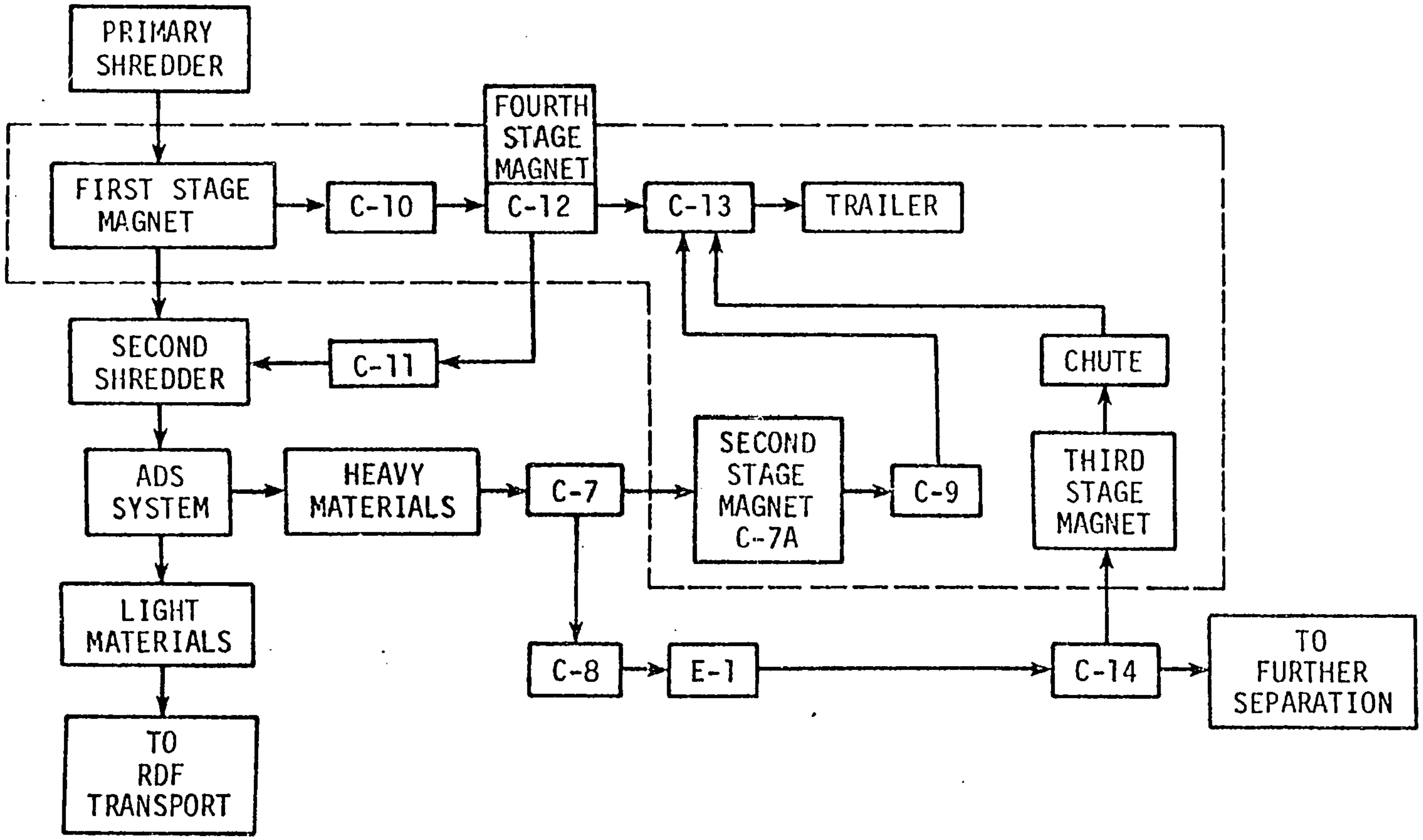

Figure 9.1. Processed ferrous metal flow diagram

maintaining the processed and nonprocessed metals is summarized in Tables 9.1 and 9.2 respectively. In the processed metal operation the conveyors, magnets, and ferrous trailer changes consumed 54%, 20%, and 36% of the total labor hours worked respectively. The processed metals operation used 88% of the total labor hours worked in maintaining the ferrous separation system. The remaining 12% of labor input was used in maintaining the nonprocessed metal operation on the tipping floor. The nonprocessed metal is gathered at the tipping floor, where the end-loader operator and the tipping floor attendant spend a portion of their time in sorting the nonprocessed metal from the refuse on the tipping floor. The processed and nonprocessed ferrous metals used an average of 0.03 labor hours per ton of refuse processed.

A linear regression analysis of labor input in the ferrous metal separation operation yields the following equation:

Labor input (HRS./MO.) = 161 - (0.0061)(Refuse processed, in TONS/MO.)

$R^2 = 0.005$ $n = 12$

Standard error of
a. Intercept 111
b. Slope 0.0272

The ferrous separation process labor input requirement varies from one month to another, depending on amount of equipment repair required. This is independent of the amount of refuse processed as indicated by the above equation.

Table 9.1. Monthly labor hours input distribution for the processed ferrous metal system

Year and month	First stage magnet (HRS.)	Second stage magnet (C-7A) (HRS.)	C-9 (HRS.)	C-10 (HRS.)	Fourth stage magnet (C-12) (HRS.)	C-13 (HRS.)	Third state magnet (chute) (HRS.)	Changing trailors (HRS.)	TOTAL (HRS.)
1977									
July	30.50	-	-	0.50	-	27.50	1.00	35.00	94.50
August	5.00	-	-	-	1.00	24.50	3.00	37.00	70.50
September	88.00	-	-	0.50	0.50	36.50	8.50	29.50	163.50
October	0.50	0.50	-	-	1.00	40.00	-	24.00	66.00
November	2.75	1.50	0.75	2.00	3.00	24.75	-	37.00	71.75
December	0.75	0.25	0.50	0.50	1.50	13.50	-	44.00	61.00
1978									
January	5.00	2.50	-	1.00	3.00	18.25	-	77.25	107.00
February	4.50	-	-	2.50	0.50	29.00	-	42.50	79.00
March	105.25	1.50	-	33.00	5.00	72.50	-	65.50	282.75
April	2.50	-	-	6.25	5.50	94.50	-	59.00	167.75
May	18.50	0.50	-	2.00	2.00	80.00	-	28.50	131.50
June	-	2.00	-	1.00	27.00	77.00	-	43.50	150.50
TOTAL	263.25	8.75	1.25	49.25	50.00	538.00	12.50	522.75	1,445.75
PERCENT OF TOTAL	18.21	0.61	0.09	3.41	3.46	37.21	0.85	36.16	100.00

Table 9.2. Monthly labor hours input distribution for the processed and nonprocessed metal operations

Year and month	Nonprocessed Metal: Endloader operator (HRS.)	Nonprocessed Metal: Tipping floor attendant (HRS.)	Nonprocessed Metal: TOTAL (HRS.)	Processed Metal (HRS.)	TOTAL labor hours worked (HRS.)
1977					
July	5.00	8.00	13.00	94.50	107.50
August	6.00	11.00	17.00	70.50	87.50
September	5.00	11.00	16.00	163.50	179.50
October	6.00	13.00	19.00	66.00	85.00
November	5.00	11.00	16.00	71.75	87.75
December	5.00	10.00	15.00	61.00	76.00
1978					
January	5.00	14.00	19.00	107.00	126.00
February	5.00	11.00	16.00	79.00	95.00
March	6.00	12.00	18.00	282.75	300.75
April	5.00	12.00	17.00	167.75	184.75
May	4.00	8.00	12.00	131.50	143.50
June	5.00	8.00	13.00	150.50	163.50
TOTAL	62.00	129.00	191.00	1,445.75	1,636.75
PERCENT OF TOTAL LABOR HOURS WORKED	32.46	67.54	11.67	88.33	100.00

Electrical Energy Consumption

The processed ferrous metal sorting operation is accomplished by a series of magnets and conveyors. The conveyor motors and magnets comprise an equivalent of a 12.5 horsepower motor. Conveyors C-7A, C-9, C-10, C-12 and C-13 each contain a 1.5 H.P. motor, while the first stage processed ferrous metal sorting magnet contains the equivalent of a 5.0 H.P. motor. The second, third, and fourth stage ferrous metals sorting magnets are located in the pulley of conveyors C-7A, C-14, and C-12. These are permanent magnets and require no energy to operate them. The ferrous metals extracted from conveyor C-14 travel by gravity through a chute into conveyor C-13, thus requiring no energy.

The amount of electrical energy consumed in extracting the processed ferrous metals and the cost of this energy during the 1977-1978 fiscal year operation are summarized in Table 9.3. The processed ferrous metals operation consumed an average of 0.65 KW-HRS. of electrical energy for every ton of refuse processed. A linear regression analysis is used to examine the relationship between the amount of refuse processed and energy consumed in extracting the processed ferrous metals. The analysis gives the following equation:

Energy input (KW-HRS./MO.) = 419 + (0.5448) (Refuse processed, in TONS/MO.)

$R^2 = 0.87$ $n = 12$

Standard error of
- a. Intercept 270
- b. Slope 0.0661

Table 9.3. Monthly energy input and cost for processed ferrous metal separation system

Year and month	Energy used (KW-HRS.)	TOTAL[a] charge ($)
1977		
July	2372	97.01
August	3500	138.60
September	3154	137.20
October	3021	119.63
November	2620	108.73
December	2233	92.45
1978		
January	2491	108.36
February	2199	90.60
March	2634	112.47
April	2444	115.85
May	1963	100.11
June	2579	111.93
TOTAL	31,210	1,332.94
MONTHLY AVERAGE	2601	111

[a]Actual energy cost.

The above equation gives a reasonable linear relationship between the amount of refuse processed and energy consumed in the nonprocessed refuse operation. This equation may be used as a predictor of this relationship within a reasonable range of the facility's refuse processing capacity. The result of this analysis is shown in Figure 9.2.

Ferrous Metals Separation System's Total Operating Cost

The processed metal operating expenses are divided into the following categories: supplies, equipment rental, wages, and energy costs. The monthly expenses incurred under these categories are summarized in Table 9.4. Expense for supplies includes all costs incurred in maintaining the processed as well as the nonprocessed ferrous metal operations. Over 95% of the supplies expense is attributable to the processed metals operation. The nonprocessed metal operation requires the use of the end-loader to load the metal from the tipping floor into the storage bin. The bin is provided by the purchaser of the metals.

The equipment rental includes the cost of the endloader and two trucks which pull the trailers that are used to ship processed ferrous metal. The wage expense covers all of the labor costs incurred in maintaining the entire ferrous metal operation, while the energy cost is applicable to the processed ferrous metal operation only.

Most of the repair requirements can not be predicted with certainty. In addition, the equipment rental expense is fixed on a

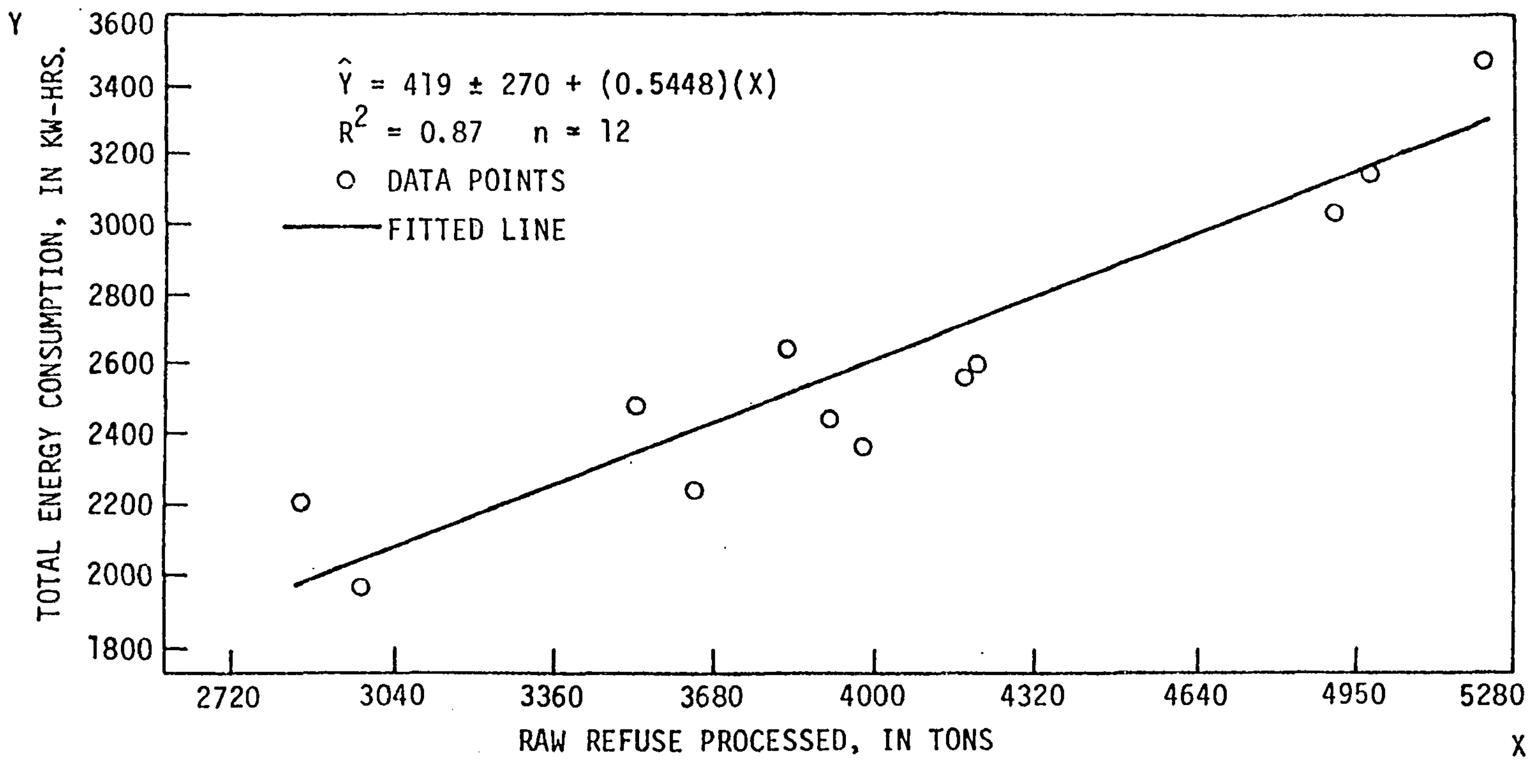

Figure 9.2. Processed ferrous metal total energy consumption vs. raw refuse processed

Table 9.4. Monthly operating cost for processed and nonprocessed metal separation system

Year and month	Tons processed ($)	Supplies Cost: Conveyors ($)	Supplies Cost: First stage magnet ($)	Supplies Cost: General ($)	Supplies Cost: Total supplies cost ($)	Equipment rental ($)	Wages ($)	Energy cost ($)	TOTAL cost ($)
1977									
July	3966	23.86	-	-	23.86	231.57	971.05	97.01	1,323.49
August	5218	51.80	-	37.46	89.26	283.13	832.55	138.60	1,343.54
September	4986	51.80	-	37.46	89.26	290.16	948.47	137.20	1,465.08
October	4925	42.11	-	66.31	108.42	495.84	821.47	119.63	1,545.36
November	4217	14.16	-	184.59	198.75	461.04	856.73	108.73	1,625.25
December	3637	24.84	-	244.65	269.49	469.34	821.17	92.45	1,652.45
1978									
January	3519	10.68	-	226.83	237.51	475.36	774.84	108.36	1,596.07
February	2859	10.69	-	171.07	181.76	461.04	852.77	90.60	1,586.17
March	3811	-	80.83	159.82	240.65	461.70	925.88	112.47	1,740.70
April	3916	105.57	80.83	159.83	346.23	540.14	1,231.77	115.85	2,233.99
May	2981	180.90	109.36	135.07	425.33	459.46	1,286.36	100.11	2,271.26
June	4179	262.93	109.36	147.63	519.92	460.44	1,673.96	111.93	2,766.25
TOTAL	48,214	779.34	380.38	1,570.72	2,730.44	5,089.22	11,997.01	1,332.94	21,149.61
PERCENT OF TOTAL COST		3.68	1.80	7.43	12.91	24.06	56.42	6.31	100.00

monthly basis and does not vary with the amount of refuse processed. Therefore, a wide range ferrous metal operation cost can be expected from one month to another for every ton of refuse processed.

The total cost of the ferrous metals operation averaged \$0.44 per ton of refuse processed. The proportional costs expended for supplies, wages and energy are summarized in Figure 9.3. The wages accounted for 57% of the total operating cost with equipment rental, supplies, and energy expenses accounting for 24%, 13%, and 6% of the total cost respectively.

The ferrous metal operation cost can be estimated by the following equation:

Operating cost (\$/MO.) = 2465 - (0.1748) (Refuse processed, in TONS/MO.)

$R^2 = 0.09$ $\quad$ $n = 12$

Standard error of
- a. Intercept 717
- b. Slope 0.1758

Note that 56.72% of the total operating cost is expended in labor which is fixed. In addition 24.06% of the total operation cost is used for equipment rental expense, which is also fixed. The labor and equipment rental expenses do not vary with the quantity of refuse processed as shown by the above equation.

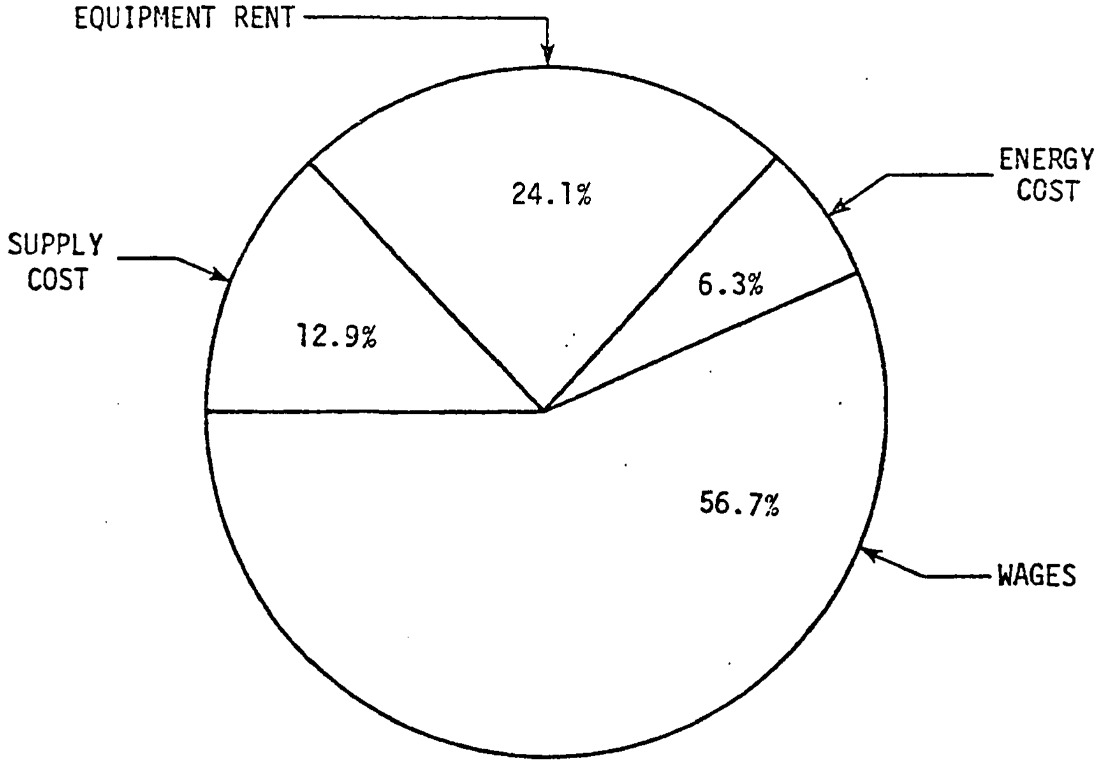

Figure 9.3. Processed ferrous metal total operation cost distribution

Discussion

In the Ames facility, revenue from the sale of ferrous metals accounted for 21.36% of the total revenues earned from the sale of recovered materials, including tipping fees (Gheresus, 1978, p. 60). The ferrous metals are sold commercially. The shipping cost for the processed ferrous materials consumed an average of 46% of the total metal revenue (Gheresus, 1977, p. 68). Therefore, the shipping cost should be evaluated before implementing a metals recovery system, especially in times of increasing shipping costs.

Labor and equipment rental costs accounted for 81% of the total ferrous metal operating cost, with labor comprising the largest portion of the expenses. Supplies and energy cost accounted for the remaining operating cost. Currently the processed ferrous metals are sold at an average price of $55 per ton, while the nonprocessed metals are sold at $10 per ton without any transportation cost (Hinderaker, P., 1979, City Records and personal communication, City of Ames, Iowa). Therefore, the ferrous metal operation is an important source of revenue in the Ames Solid Waste Recovery system.

CHAPTER X. NONFERROUS METAL SEPARATION SYSTEM

The nonferrous separation system classifies the heavy materials (noncombustibles) coming from the ADS system into: aluminum, other nonferrous (brass, copper, lead, bronze, etc.), glass rejects, and oversize materials. Heavy materials are accumulated in a bin (reject surge bin) and then fed into a cylindrical rotating screen (trommel screen) with 1/4", 5/8", 1-1/2", and 4" size holes. The materials which fall through all of these openings are classified as glass, rejects, nonferrous metals, and aluminum respectively (see Figure 10.1). Materials over 4" are classified as oversize and stored in a bin for later disposal at the landfill.

The nonferrous separators subject the shredded refuse stream to a high frequency (960 HZ) poly-phase magnetic field analogous to an eddy current linear motor. The magnetic field induces current into the metal which repels the field and pushes the nonferrous metal off the conveyor into a hopper. The nonferrous metal is then fed into a second eddy current source separator which (theoretically), further extracts aluminum from the nonferrous metal. Materials not sorted by the nonferrous separation system are classified as rejects and hauled to the landfill. The 1-1/2" and 4" size materials are processed by the nonferrous and aluminum separating systems respectively.

The sand, glass and oversize materials are disposed of in the landfill. The oversize and reject materials are buried, while the sand and glass are accumulated at this landfill for future sale. Aluminum

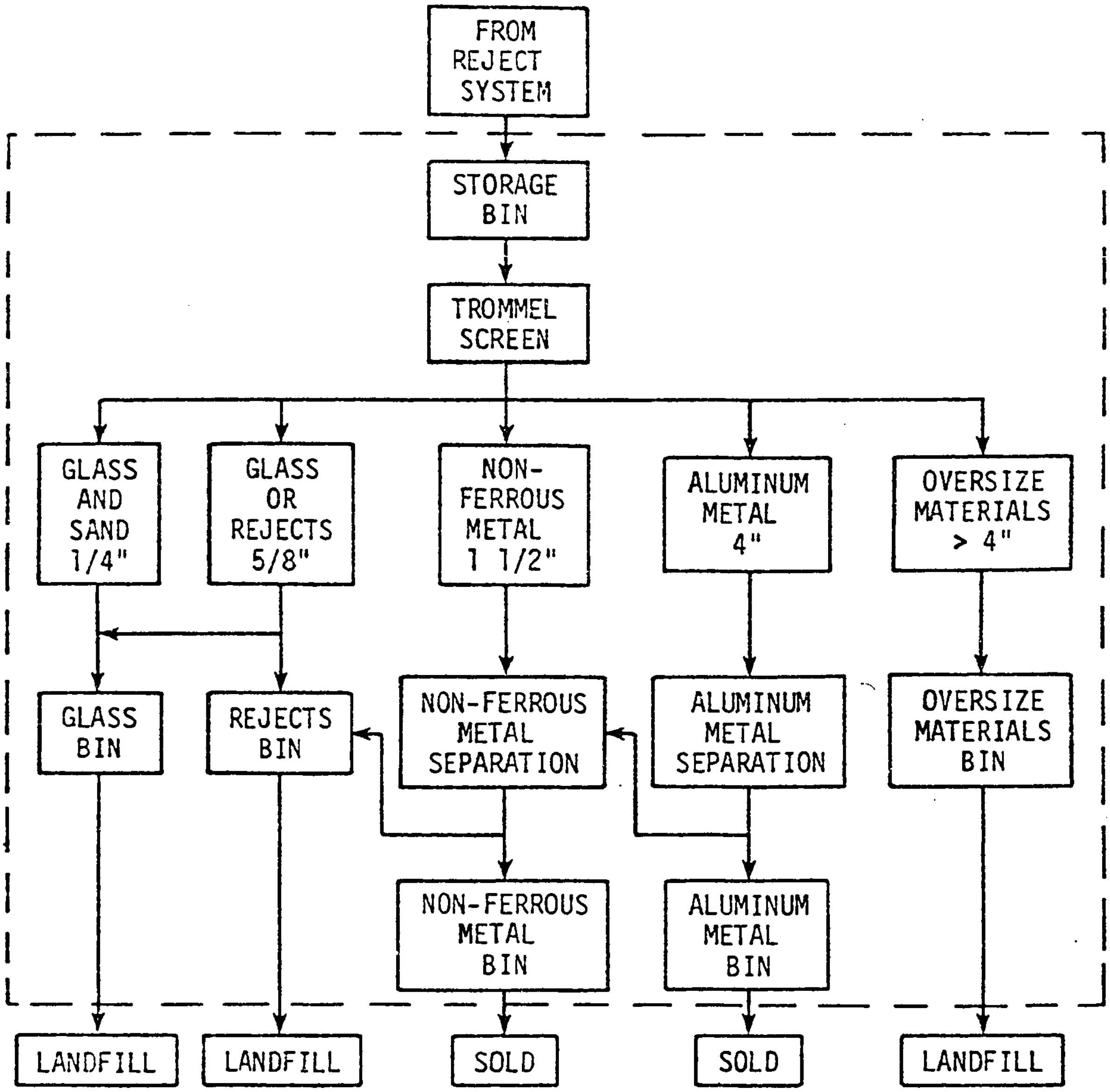

Figure 10.1. Nonferrous metal separation process flow diagram

and other nonferrous metals are sold commercially.

Operational Problems of the Nonferrous Metals Separation System

The nonferrous separation system had an initial investment of $251,130. The system has continued to experience operational problems. Early operations were hindered by corrosion problems which developed in the pipes carrying cooling water for the nonferrous separating magnets. After the pipes were replaced the magnets began to malfunction, which caused several nonferrous conveying belts to tear. During 1976, the system reclaimed a total of 5.07 tons of nonferrous metals (Gheresus, 1977, p. 72). In November, 1977, fire in the plant destroyed some of the nonferrous system wiring, further hindering its operation. The wiring has since been repaired, but the system requires considerable monitoring effort to keep it operational. All of the nonferrous metals sold after the 1976 operation were manually extracted. During the 1977-1978 fiscal year $24,420.39 worth of labor and materials was expended to repair and improve the system; however, the system was inoperable during this period. When the nonferrous system is not operated, the sand, glass, oversize and nonferrous metals are combined into a single flow stream and classified as rejects and then buried in the landfill.

Discussion

The nonferrous metals operation has continued to face difficulties. The potential of nonferrous metal recovery from the Ames Solid Waste remains unknown. Further research is needed to evaluate the effectiveness of the nonferrous metal recovery system. Because of high initial cost, the performance of the system prior to adaptation needs to be evaluated thoroughly. If the nonferrous metal separation system malfunctions, the principal and interest payments on this system alone contributes to making the entire resource recovery system's operation unprofitable.

CHAPTER XI. REJECTED MATERIALS DISPOSAL SYSTEM

Heavy material that falls to the bottom of the air density separation chamber constitutes the major portion of rejected materials. The rejected materials are introduced to two ferrous reclaiming magnets located at the end of conveyor C-7A, and the end of C-14. The disposal process flow diagram for the rejected materials is shown in Figure 11.1.

The rejected materials are conveyed into the nonferrous separation system through conveyor C-14. However, if the nonferrous metal separation system is not operated, the rejected materials bypass this system and are transported by conveyors C-15 and C-16 into storage bins for disposal at the landfill. When the nonferrous system is inoperable, sand and glass, and nonferrous metals are classified as rejected materials and buried at the landfill. Rejected materials are also removed from the tipping floor and hauled to the landfill by trailer.

Labor Input Requirement, Cost and Distribution

The rejected materials disposal system includes the following equipment: conveyors C-7, C-8, C-15, C-16, elevator E-1, and two storage bins. The rejected material disposal operations include maintaining the conveyors, elevator, and rejected material bins as well as hauling the rejected materials to the landfill. The labor hours allocated to the various rejected materials operations are summarized in Table 11.1.

Over 50% of the total labor input was expended in loading the

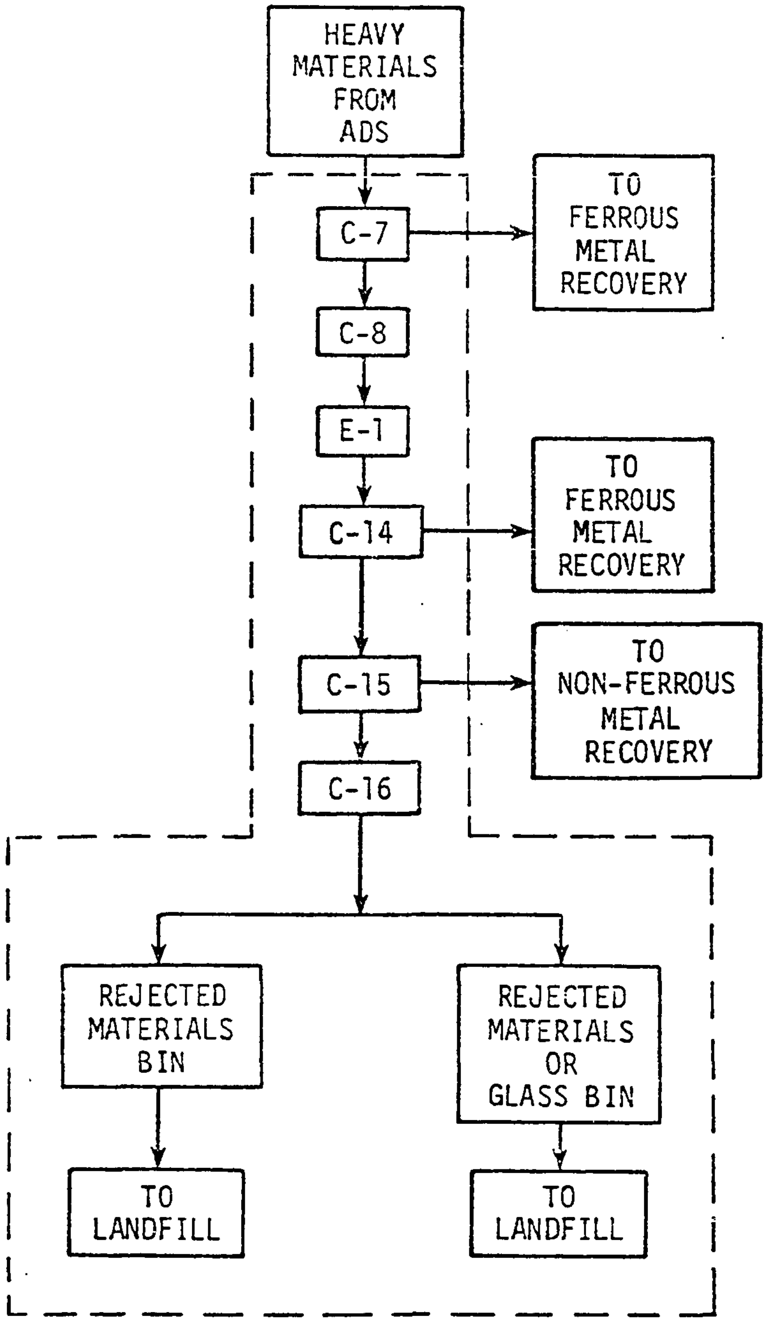

Figure 11.1. Rejected material process flow diagram

Table 11.1. Monthly labor input distribution for rejected materials disposal system

Year and month	Rejects storage bins and hauling (HRS.)	Conveyors C-7 (HRS.)	C-8 (HRS.)	C-14 (HRS.)	C-15 (HRS.)	C-16 (HRS.)	C-17 (HRS.)
1977							
July	106.50	14.50	-	4.00	-	-	-
August	232.00	44.00	-	6.00	0.50	0.50	-
September	246.50	76.00	-	6.50	-	0.50	-
October	208.00	25.50	2.00	3.00	-	-	-
November	94.00	2.50	1.50	4.75	1.50	1.50	1.50
December	59.00	0.50	0.50	0.50	0.50	0.50	0.25
1978							
January	93.00	4.00	2.00	9.00	21.50	-	-
February	46.00	1.50	4.00	17.00	12.50	-	-
March	88.50	7.50	1.00	10.50	-	-	-
April	102.50	15.00	-	7.00	5.00	10.50	-
May	68.50	8.00	-	20.00	-	1.50	-
June	155.00	29.50	6.50	4.50	6.50	-	-
TOTAL	1,499.50	228.50	17.50	92.75	48.00	15.00	1.75
PERCENT OF TOTAL LABOR HOURS WORKED	51.48	7.84	0.60	3.18	1.65	0.51	0.06

Elevators						
E-1 (HRS.)	E-4 (HRS.)	Total conveyors and elevators (HRS.)	End-loader operator (HRS.)	Tipping floor attendant (HRS.)	TOTAL labor hours worked (HRS.)
55.00	-	73.50	11.00	12.00	203.00
127.50	-	178.50	11.00	18.00	439.50
116.00	1.00	200.00	10.00	18.00	474.50
83.00	-	113.50	11.00	21.00	353.50
16.25	-	29.50	10.00	18.00	151.50
7.00	-	9.75	10.00	16.00	94.75
5.50	-	42.00	11.00	24.00	170.00
1.50	-	36.50	9.00	17.00	108.50
24.50	1.00	44.50	12.00	18.00	163.00
73.50	-	111.00	11.00	19.00	243.50
90.00	3.50	123.00	9.00	13.00	213.50
71.75	-	118.75	11.00	13.00	297.75
671.50	5.50	1,080.50	126.00	207.00	2,913.00
23.05	0.19	37.08	4.33	7.11	100.00

rejected materials from the reject storage bins into a truck and hauling them to the landfill. Unplugging and maintaining congested conveyors consumed 37.08% of the total labor input. Sorting rejected materials from the tipping floor and loading them into a trailer required 11.44% of the total labor input. The rejected materials operation required 0.06 labor hours per ton of refuse processed. As the quantity of refuse processed increased, so did the number of labor hours worked. This relationship is exemplified by the following linear regression equation:

Labor input (HRS./MO.) = -313 + (0.1384) (Refuse processed, in TONS/MO.)

$R^2 = 0.69 \quad n = 12$

Standard error of
- a. Intercept 120
- b. Slope 0.0293

The labor expenses incurred maintaining the rejected materials operation are summarized in Table 11.2. Over 89% of the labor cost was attributed to loading rejects from the storage bin into a truck, hauling, and working on conveyors. The sorting of rejected materials on the tipping floor and the disposing of processed rejected materials operations consumed 10.55% and 89.45% of the total operating cost. The overall rejected materials disposal operation cost an average of $0.43 per ton of refuse processed.

Table 11.2. Monthly labor cost distribution for rejected materials

Year and month	Rejects storage bins and hauling ($)	Rejects conveyor system ($)	End-loader rejects loading ($)	Tipping floor's rejects sorting ($)	TOTAL cost ($)
1977					
July	414.65	873.06	101.92	135.89	1,525.52
August	1,003.15	589.58	77.26	103.02	1,773.01
September	1,671.48	760.01	74.30	99.06	2,604.85
October	1,343.50	535.77	68.59	91.45	2,039.31
November	945.92	715.45	67.91	90.54	1,819.82
December	394.10	632.28	71.10	94.80	1,192.28
1978					
January	396.18	559.50	83.08	110.77	1,149.53
February	379.32	599.59	81.41	108.55	1,168.87
March	241.05	659.17	68.16	90.88	1,059.26
April	911.14	577.02	65.53	87.38	1,641.07
May	807.65	703.61	81.98	109.30	1,702.54
June	1,459.45	1,264.52	90.30	120.41	2,934.68
TOTAL	9,967.59	8,469.56	931.54	1,242.05	20,610.74
PERCENT OF TOTAL COST	48.36	41.09	4.52	6.03	100.00

Electrical Energy Consumption and Cost

Each rejected materials conveyor is driven by a 1.5 H.P. electric motor, while elevator E-1 is powered by a 3.0 H.P. motor. The conveyor and elevator motors thus have a total equivalent of a 10.5 H.P. motor. The monthly total energy consumption is summarized in Table 11.3. The quantity of refuse processed and the amount of energy consumed can be summarized by the following equation:

Energy input (KW-HRS./MO.) = 399 + (0.4481)(Refuse processed, in TONS/MO.)

$R^2 = 0.87$ n = 12

Standard error of
- a. Intercept 222
- b. Slope 0.0544

The above equation represents an important relationship between the amount of refuse processed and electrical energy consumed. The rejected materials disposal operation consumed an average of 0.53 KW-HRS. per ton of refuse processed with an average cost of $0.02 per ton of refuse processed.

Total Operating Cost

The expenses for the rejected materials disposal operation are divided into categories of supply, equipment rental, wages, and energy. Rented equipment includes two trailers and a dump truck that are used to haul rejected materials to the landfill. It also includes an end-loader which is used to load rejected materials from the tipping floor into a trailer. This equipment is rented on a monthly basis. The total

Table 11.3. Electrical energy consumption and cost for rejected materials disposal system

Month	Energy used (KW-HRS.)	Total[a] energy cost ($)
1977		
July	1952	79.84
August	2881	114.09
September	2595	112.88
October	2486	98.45
November	2156	89.47
December	1837	76.05
1978		
January	2049	89.13
February	1809	74.53
March	2169	92.53
April	2011	95.32
May	1616	82.42
June	2121	92.09
TOTAL	25681	1,096.80
MONTHLY AVERAGE	2140	91

[a]Actual energy cost.

Table 11.4. Operating cost distribution for rejected materials disposal system

Year and month	Tons Processed	Supplies Cost: Conveyors ($)	Supplies Cost: General ($)	Supplies Cost: TOTAL supplies cost ($)	Equipment rental ($)	Wages ($)	Energy cost ($)	TOTAL cost ($)
1977								
July	3966	16.70	-	16.70	845.00	1,525.52	79.84	2,467.06
August	5218	113.87	3.24	117.11	845.00	1,773.01	114.09	2,849.21
September	4986	113.87	24.40	138.27	845.00	2,604.85	112.88	3,701.00
October	4925	220.60	23.20	243.80	845.00	2,039.31	98.45	3,226.56
November	4217	239.82	20.14	259.96	845.00	1,819.82	89.47	3,014.25
December	3637	377.09	-	377.09	845.00	1,192.28	76.05	2,490.42
1978								
January	3519	312.03	-	312.03	803.06	1,149.53	89.13	2,353.75
February	2859	238.30	11.65	249.95	803.06	1,168.87	74.53	2,296.41
March	3811	223.33	-	223.33	803.06	1,059.26	92.53	2,178.18
April	3916	298.17	7.08	305.25	803.06	1,641.07	95.32	2,844.70
May	2981	275.27	83.00	358.27	803.06	1,702.54	82.42	2,946.29
June	4179	284.50	202.32	486.82	803.06	2,934.68	92.09	4,316.65
TOTAL	48,214	2,713.55	375.03	3,088.58	9,888.36	20,610.74	1,096.80	34,684.48
PERCENT OF TOTAL COST		7.82	1.08	8.90	28.51	59.42	3.17	100.00

operating expenses for rejected materials disposal are summarized in Table 11.4.

Wages, equipment rental, supplies, and energy costs accounted for 59.42%, 28.51%, 8.9% and 3.17% of the total operating expenses respectively. Labor constituted the largest expense, followed by equipment rental cost. These two expenses accounted for 87.93% of the total. The rejected materials overall operation cost an average of $0.72 per ton of refuse processed. The total operating cost for the rejected materials can be summarized by the following linear regression equation:

Operating cost ($/MO.) = 1,240 + (0.4107)(Total refuse processed, in TONS/MO.)

$R^2 = 0.24 \quad n = 12$

Standard error of
a. Intercept 944
b. Slope 0.2312

Discussion

Rejected materials comprise 9.32% of the total incoming refuse. If recovery of aluminum and other metals were made possible, the amount of rejected materials produced could be reduced. Due to the inoperable condition of the nonferrous metals separating system, the exact amount of these recoverable materials present in the Ames' refuse stream is not known.

Labor cost accounted for 59.42% of the total rejected materials disposal operating expenses, while 28.51%, 8.90% and 3.17% of the total operating cost was attributed to equipment rental, supply, and energy expenses respectively.

CHAPTER XII. AUXILIARY OPERATIONS

The paper baling, log chipping, used motor oil and newspaper collecting operations are separate from the refuse shredding system. These systems can be operated without interrupting the refuse shredding process. These recycling activities were added in order to provide additional materials reclamation opportunity to the facility's resource recovery effort.

Log Chipping Operation

The log chipper, with an initial investment of $32,319, grinds tree logs that are delivered to the plant by customers. The logs are stored at the landfill until needed and then delivered to the plant. They are then loaded by the end-loader into the log chipper, which is located on the tipping floor. The log chips are stored in a trailer and then sold to local customers at $20 per ton. The log chips are used for flower and animal bedding.

During the 1977-1978 fiscal year's operation 12.49 tons of log chips were produced and sold. The log chipping operation used 95.50 labor hours with a total operating expense of $2,281.44.

Paper Baling Operation

The paper baling operation began in 1976. The paper baler was purchased for $85,877 with an additional $100,348 spent to house the paper baling system.

The paper baling operation is located adjacent to the tipping floor. The tipping floor attendant's duties included sorting cardboard and other paper from the tipping floor. This paper is fed into the baler from the tipping floor and sold commercially. It took 445 labor hours and a total of $2,528.63 operating expenses which yielded 3.82 tons of baled paper during the 1977-1978 fiscal year.

Newspaper Collecting Operations

Newspapers and other bundled papers are delivered to the facility. These papers are collected in a separate bin located outside of the plant, providing customer service 24 hours a day. These papers are either baled or sold as delivered commercially. The newspaper collecting consumed 77.50 labor hours with an overall total expense of $2,706.75 during the one year period of study.

Oil Collecting Operations

Used oil delivered to the facility is accumulated in a 10,000 gallon underground container located at the plant. The oil is then sold locally for gravel road dust control.

Discussion

The baled paper and wood chips production are based on customer demand and market conditions. If management feels that the baled paper selling price is low, then all of the paper is shredded with the remaining refuse. Therefore, the operation of these systems is dependent upon customer demands and market conditions, and not upon the amount of refuse processed.

CHAPTER XIII. PLANT SUPPORT OPERATIONS

Various tasks can not be readily assigned to particular sub-system operations. These tasks are divided into 9 categories; the labor input in each activity is summarized in Table 13.1.

1. Operations and grates: The operation and grates task includes employees walking through the processing area and visually inspecting the refuse processing operations at various stages. When a problem occurs in the process area, the employees inform the refuse processing control operator by telephone about the problem and continue to communicate until the problem is corrected. Similarly, the process control operator dispatches employees to a problem area by means of loud speakers which are located in the process area. Since some of the refuse processing equipment can not be visually monitored directly or by a television camera, employees in the area are required to inspect this equipment periodically. The operations and grates activities required 7.38% of the total plant support operations labor input.

2. Cleaning process area: A cleaning crew works in the process area from 4 P.M. to 8 P.M. daily. These employees clean spilled materials and blow the dust off of the refuse processing equipment using compressed air. The plant, with no dust collecting system, generates dust which settles on the equipment. Removing the dust on a daily basis becomes an essential factor in the plant operation. Dust removal is necessary to the maintenance labor input requirement, and at the same time, prevents fire or explosions that can be caused by a

Table 13.1. Labor input distribution for the plant support operation

Year and month	Operations and grates (HRS.)	Cleaning process room (HRS.)	Process control room (HRS.)	Custodial (HRS.)	Miscellaneous (HRS.)
1977					
July	39.50	544.00	127.00	123.50	20.00
August	26.50	589.00	160.00	88.50	11.50
September	7.00	601.50	158.50	77.00	15.00
October	39.00	561.50	196.50	57.50	42.00
November	94.00	560.00	182.00	34.50	50.50
December	222.00	428.00	127.00	69.00	29.00
1978					
January	219.00	491.75	165.50	73.00	54.50
February	110.00	412.50	189.00	68.50	93.00
March	63.50	458.00	180.50	16.00	91.50
April	25.00	400.50	157.50	21.00	43.50
May	51.00	263.00	121.50	21.50	57.50
June	93.00	371.25	198.50	39.50	15.00
TOTAL	989.50	5,681.00	1,963.50	689.50	523.00
PERCENT OF TOTAL HOURS WORKED	7.38	42.39	14.65	5.14	3.90

Electrical control room (HRS.)	Fire prevention (HRS.)	General maintenance (HRS.)	Secretarial and tours (HRS.)	TOTAL hours worked (HRS.)
-	31.50	98.50	82.50	1,066.50
-	8.00	210.50	94.00	1,188.00
-	21.50	91.00	160.00	1,131.50
-	-	140.00	160.00	1,196.50
-	21.50	153.50	168.00	1,264.00
-	13.00	87.50	149.00	1,124.50
6.00	6.00	195.00	160.00	1,370.75
-	0.50	230.50	151.50	1,255.50
7.50	9.50	155.25	183.00	1,164.75
6.50	20.00	74.50	148.50	897.00
1.50	9.00	131.00	142.00	798.00
-	70.50	68.25	90.00	946.00
21.50	211.00	1,635.50	1,688.50	13,403.00
0.17	1.57	12.20	12.60	100.00

dusty environment. This operation consumed 42.39% of the total plant support labor hours requirement.

3. Process control room: The process control room houses the controls for the refuse processing equipment. The refuse process control operator monitors the refuse processing equipment and communicates with employees in the process area as well as on the tipping floor by means of telephone and loud speaker.

Whenever a problem occurs the operator dispatches employees to the troubled area. Conveyor operations, shredder bearing temperature, motor operating currents, and the remaining sub-system operations are monitored at the control room. The process controller also regulates the raw refuse feed rate. The control room, manned by a single person, used 14.65% of the total plant support operations labor requirement.

4. Custodial: The custodian's tasks involve cleaning the conference room, process control room laundry, the two bathrooms, and the hallways. This task required 5.14% of the total plant support operations labor hours input.

5. Miscellaneous, electrical control room, and general maintenance: Miscellaneous, electrical control room, and general maintenance operations used 3.90%, 0.17%, and 12.20% of the total plant support operations labor requirement. General maintenance activity covers tasks such as air compressor maintenance, light bulb replacement, door repair, yard work, etc. which are not associated with any particular sub-system operation.

The electrical control room houses the process equipment switching system. Transformers, switch circuit breakders, air conditioner, and the kilowatt hour meters are also located in the electrical control room. Miscellaneous operations activities include purchasing supplies, transporting employees, and other tasks.

6. <u>Fire prevention</u>: Fire breaks out in the process plant from time to time. Most fires originate at the shredders during the grinding operation. If the fire is not detected immediately, it is carried by the conveyors through the rest of the process equipment; it has been known to travel to the RDF storage bin. Fire in the RDF storage bin caused the plant to shut down two days in July and one day in November of 1977.

The facility is equipped with a water sprinkler fire suppression system. In the event of fire, employees fight the fire using fire extinguishing tanks. Fire prevention and fire fighting tasks consumed 1.57% of the total plant support labor hours during the 1977-1978 fiscal year operations.

7. <u>Secretarial and tours</u>: The plant employs one person to perform the secretarial and tour tasks. The plant is open to the public every Wednesday for tours. This portion of the task consumed 12.60% of the total plant support labor input.

8. <u>Plant support total labor hours input</u>: Total labor hours requirement: the plant support labor hours requirement can be estimated by the following linear equation:

$$\text{Labor input (HRS./MO.)} = 967 + (0.0373)(\text{Refuse processed, in TONS/MO.})$$

$R^2 = 0.03$ $n = 12$

Standard error of
a. Intercept 282
b. Slope 0.0691

Note that the above linear equation is a poor estimator of the labor requirement as a function of refuse processed. This result is to be expected since total monthly labor hours worked are fairly constant as shown in Table 13.1. The plant support operation required an average of 0.28 labor hours per ton of refuse processed.

Electrical Energy Consumption and Cost

The total electrical energy consumption and cost for the plant support operations during the 1977-1978 fiscal year are summarized in Table 13.2.

The facility's heating, air conditioning, lighting, and other electrical energy consuming equipment are included in the plant support operation system. Some of the 480V, 3 phase equipment used in the plant operation are: equipment hoist (19 H.P.), air compressor (15 H.P.), 3 sump pumps with total rating of 7.5 H.P., 7 heaters in the process area, each with 14.4 Amps rating, an air conditioner with 37.5 Amps rating, and 3 fans with 120V at 1.9 Amps.

A regression analysis of the energy consumption versus the quantity of refuse processed yields the following equation:

Table 13.2. Electrical energy consumption and cost distribution for plant support operation

Year and month	Energy used	TOTAL[a] energy cost
1977		
July	61,131	2,500.26
August	54,774	2,169.05
September	62,473	2,717.59
October	52,733	2,088.23
November	88,967	3,692.13
December	122,042	5,052.54
1978		
January	101,764	4,426.73
February	97,176	4,003.65
March	97,121	4,001.39
April	74,580	3,535.09
May	85,046	4,337.35
June	71,637	3,109.05
TOTAL	969,444	41,633.05
MONTHLY AVERAGE	80,787	3,469.00

[a]Actual energy charge.

Energy input (KW-HRS./MO.) = 163,029 - (20.4691)(Refuse processed, in TONS/MO.)

$R^2 = 0.51$ n = 12

Standard error of
a. Intercept 26,054
b. Slope 6.3843

The model indicates that as the amount of refuse processed increases, the average energy requirement for each ton of refuse processed decreases. This relationship indicates that the amount of energy consumption is relatively constant. The lighting, heating, and air conditioning energy requirement is expected to remain constant. The seven heaters located in the process area are turned on whenever the plant stops processing refuse; this is in order to prevent moisture collection in the equipment's motors. The energy consumption by these heaters thus adds to the facility's fixed energy consumption. The plant support operation consumed 20 kilowatt hours of electrical energy per ton of refuse with an average cost of $0.86 per ton of refuse processed.

Total Plant Support Operating Cost

The plant support expenses are divided into: wages, energy, supplies, equipment rental, insurance, water and sewage, and principal and interest payments. Monthly operating expenses for these categories are summarized in Table 13.3.

Wage expense includes the cost of labor for the various plant support operations listed in Table 13.1 and administrative cost. The plant support energy cost excludes the electrical energy expense of the other sub-systems. Supply expense includes cleaning supplies, uniforms, portable heaters, office, building and maintenance supplies. The facility rents vehicles and other equipment for its operation; this cost is included in the equipment rent category. Insurance is paid yearly while principal and interest are paid semi-annually.

Principal and interest constituted 65.94% of plant support operating expense, making it the largest expense item. Labor cost, with 15.04% of the total plant support expense, ranked second to the principal and interest expense. The remaining expenses accounted for 19.02% of the total plant support operating cost.

The total monthly plant support operating cost can be estimated by the following equation:

Total cost (\$/MO.) = 57,131 + (0.4135)(Refuse processed, TONS/MO.)

$R^2 = 0.004$ $n = 12$

Standard error of
a. Intercept 8773
b. Slope 2.1498

The equation is a poor estimator of the operating cost for the plant support operations per ton of refuse processed. The plant support operations has a large monthly fixed cost. An inspection of the total monthly operating cost shows that the monthly expense is fixed, with an average of \$58,792/MO. and a standard deviation of \$5,324 per month. The monthly equipment, insurance, and principal and interest expenses are fixed and account for 70.88% of the total plant support operation cost, therefore, making the fixed cost the largest portion of

Table 13.3. Total operating expense for plant support operation

Year and month	Wages ($)	Energy ($)	Supplies ($)	Equipment rental[a] ($)	Insurance premiums ($)	Principal and interest ($)	Water and sewage charge ($)	TOTAL cost ($)
1977								
July	8,269.00	2,500.26	2,137.35	411.00	2,398.00	38,779.00	182.32	54,676.93
August	9,762.41	2,169.05	2,501.34	411.00	2,398.00	38,779.00	175.39	56,196.19
September	7,820.87	2,717.58	9,104.38	411.00	2,398.00	38,780.00	397.97	61,629.80
October	8,945.93	2,088.23	2,055.21	411.00	2,398.00	38,780.00	173.85	54,852.22
November	8,271.70	3,692.13	6,100.55	411.00	2,398.00	38,780.00	122.26	59,775.64
December	11,734.24	5,052.54	3,152.87	411.00	2,398.00	38,780.00	109.17	61,637.82
1978								
January	7,295.93	4,426.73	2,584.72	373.36	2,627.00	38,758.00	71.90	56,137.64
February	10,589.85	4,003.65	4,452.97	373.36	2,627.00	38,758.00	90.50	60,895.33
March	8,300.76	4,001.39	2,813.96	373.36	2,627.00	38,758.00	107.63	56,982.10
April	9,118.98	3,535.09	2,456.50	373.36	2,627.00	38,758.00	136.89	57,005.82
May	5,277.00	4,337.35	1,910.13	373.36	2,627.00	38,758.00	168.46	53,451.30
June	10,719.55	3,109.05	16,470.31	373.36	2,627.00	38,758.00	216.68	72,273.95
TOTAL	106,106.22	41,633.05	55,740.29	4,706.16	30,150.00	465,226.00	1,953.02	705,514.74
PERCENT OF TOTAL COST	15.04	5.90	7.90	0.67	4.27	65.94	0.28	100.00

[a]Actual principal and interest paid by the city.

the operating expense, the plant support operation averaged $14.63 per ton of refuse processed during the 1977-1978 fiscal year. The principal and interest payment accounted for 65.94% of the average processing cost.

Discussion

The plant support operation is the most costly operation of the entire system. It consumed more labor hours and electrical energy than any other sub-system operation. Most of the labor input was used to clean the refuse processing equipment and the process area of dust and material spillage. However, the dust collection system installed in November of 1978 ought to reduce the labor requirement for the cleaning operation.

The plant support operation cost is essentially fixed. The fixed cost items include equipment rental, insurance, and principal and interest expenses. The average refuse processing cost is lower when the plant processes more refuse as opposed to less refuse, due to the fixed costs.

CHAPTER XIV. REFUSE PROCESSING INTERRUPTIONS

The facility encounters various refuse processing delays that are caused by internal or external difficulties. Interruptions of short duration create no refuse diversion to the landfill. But if the short duration delays are frequent, the plant processes refuse under overtime conditions to avoid refuse diversion to the landfill. Delays of long duration may or may not cause refuse diversion to the landfill. The facility's refuse receiving floor has a maximum capacity of 500 tons or three days' refuse delivery from its customers. Thus, a three days' or more continuous refuse processing interruption leads to refuse diversion to the landfill. A one to three days' continuous refuse processing delay necessitates refuse diversion to the landfill if management chooses not to process refuse under overtime conditions. The frequency and impact of the various refuse processing downtimes are an important factor that affects the facility's production and economic viability. Excessive downtime causes diversion of resources to the landfill with virtually no chance for future recovery of the material once buried at the landfill. The actual refuse processing times are logged whenever the facility processes refuse. Refuse is processed when the primary shredder's refuse infeed conveyor delivers refuse to the primary shredder. The infeed conveyor (C-1) operating time is monitored by an hour meter.

Another hour meter records the amount of time the RDF transport system is operating. During this time the RDF transport continues to operate whether or not there is RDF to be transported to the storage bin.

When the plant is temporarily delayed in processing refuse and the delay time is of short duration, the infeed conveyor is stopped until the problem is corrected. During this time the processing equipment, including the RDF transport system, is allowed to run. However, if the refuse processing delay is for an extended time, the entire refuse processing system is halted. During the 1977-1978 fiscal year the facility encountered various delay and shutdown times due to internal and external difficulties. These problems are discussed in this chapter.

Plant Idle Time

Idle time is defined as the difference between the RDF transport system running time and the refuse infeed conveyor (C-1) time. Temporary idle times are caused by minor equipment problems in the system. Refuse feeding is also halted during the ferrous metals trailer change until an empty trailer is parked under the ferrous metals discharge conveyor. The plant is scheduled to process refuse eight hours a day, five days a week, with plant maintenance scheduled to be performed in the evenings. The plant had 255 days (2040 hours) of potential processing time during the one year study period. The potential and actual refuse processing times, and the RDF transport operating monthly times for the 1977-1978 fiscal year are summarized in Table 14.1.

During the 1977-1978 fiscal year the facility processed refuse at an average rate of 4,017.87 tons per month. The facility, with 2040 hours (255 days) potential processing time, actually processed refuse for 1,377.7 hours or 172.21, 8 hour equivalent days. The actual refuse

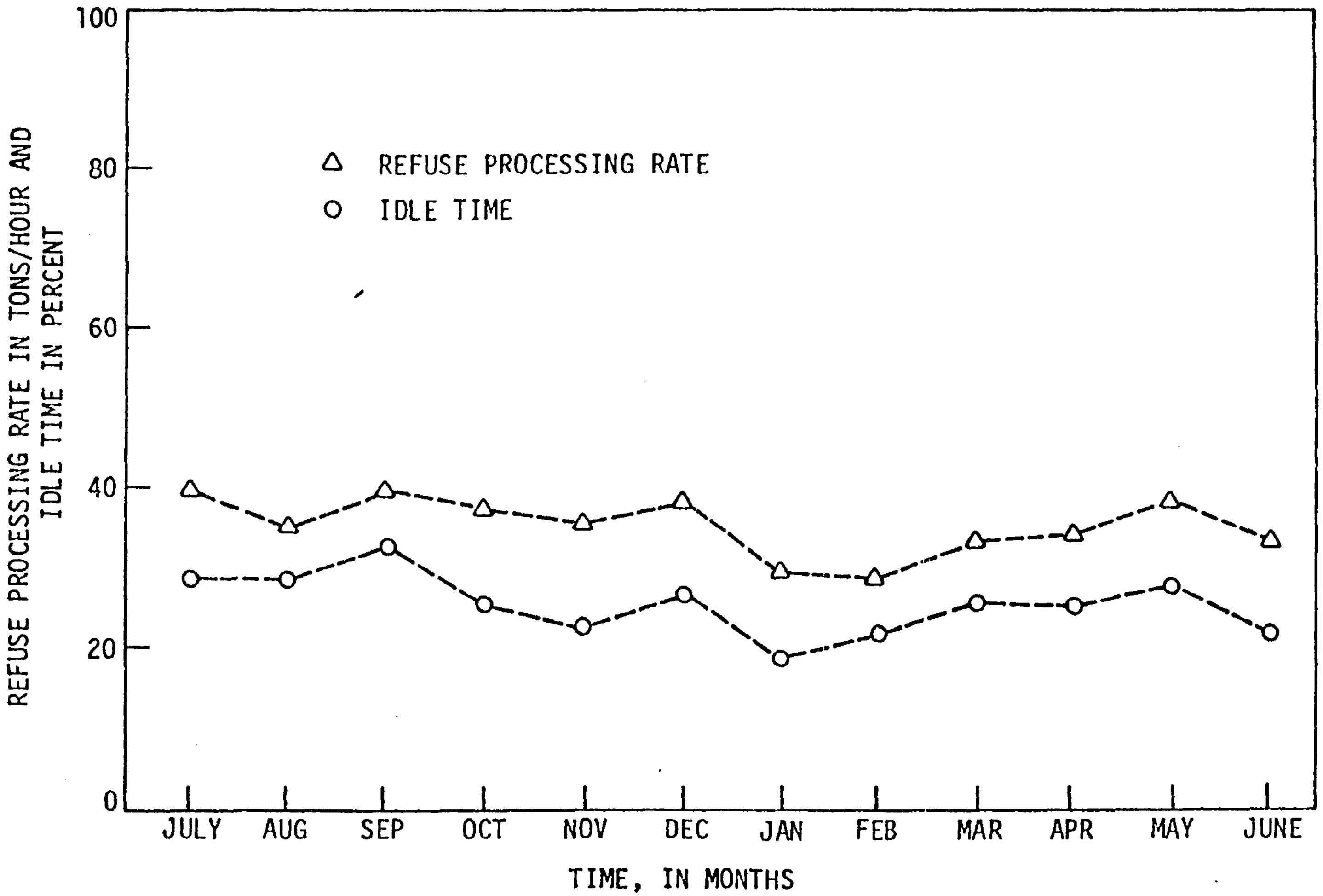

Figure 14.1. Idle time vs. monthly refuse processing rate (1977-1978)

processing time includes overtime. During the remainder of the time, which amounted to 32.47% (8 equivalent days) of potential time, the plant was unable to process due to minor delays for brief periods and process shutdowns for extended periods, both of which were caused by internal or external events. The RDF transport system operated for 1,852.8 hours, or 232 equivalent days during the fiscal year. Idle time amounted to 475.1 hours (1,852.8 - 1,377.7) or 60 equivalent days. The total idle time averaged 25.86% (60 days/232 days), based on the total RDF transport system's running time.

The idle time computation, which is discussed in a later section, does not include the plant shutdown time due to internal or external causes. The proportion of idle time varied from a high of 28.37% in July to a low of 19.37% in January with an overall average of 25.64% (see Table 14.1).

Refuse Processing Rate and Idle Time Relationships

The refuse processing idle time is attributable to equipment material handling limitations, refuse conditions (wet or dry) and composition, and refuse feeding rate. Under certain processing conditions various pieces of equipment accounted for most of the refuse processing delay time. For example, when the processed refuse is wet, elevator (E-1) is known to congest and plug, thus contributing to the idle time.

The idle time is also increased whenever the actual refuse processing rate (mass of refuse processed/actual refuse processing hours) is increased (see Figure 14.1). The refuse processing rate varied from 28.17 TONS/HR. in February to 39.66 TONS/HR. in July, with an average rate of 35.00 TONS/HR. An examination of the actual refuse processing rate and idle time data indicates that these two variables tend to move in the same direction. A plot of the relationship is shown in Figure 15.2. The plot of idle time versus feed rate indicates an inverse relationship between the refuse feed rate and idle time. The degree of relationship can be summarized by the following linear regression equation:

Idle time (%) = -3.16 + 0.817 (feed rate, in TONS/HR.)

$R^2 = 0.73$ n = 12

Standard error of	a. Intercept	0.586
	b. Slope	0.159

The result of this model is significant in that it demonstrates the presence of a strong relationship between the processing rate and idle time. Over 72% of the idle time can be explained by this model. A discussion with the process control operator also substantiated the fact that as the refuse processing rate is increased, the incidence of idle time also increases (Barber, D., 1979, The Ames Solid Waste Resource Recovery System, Ames, Iowa, personal communication). Idle time is caused by various pieces of equipment in the shredding, air classifying, RDF transport, ferrous reclaiming, and rejected materials systems.

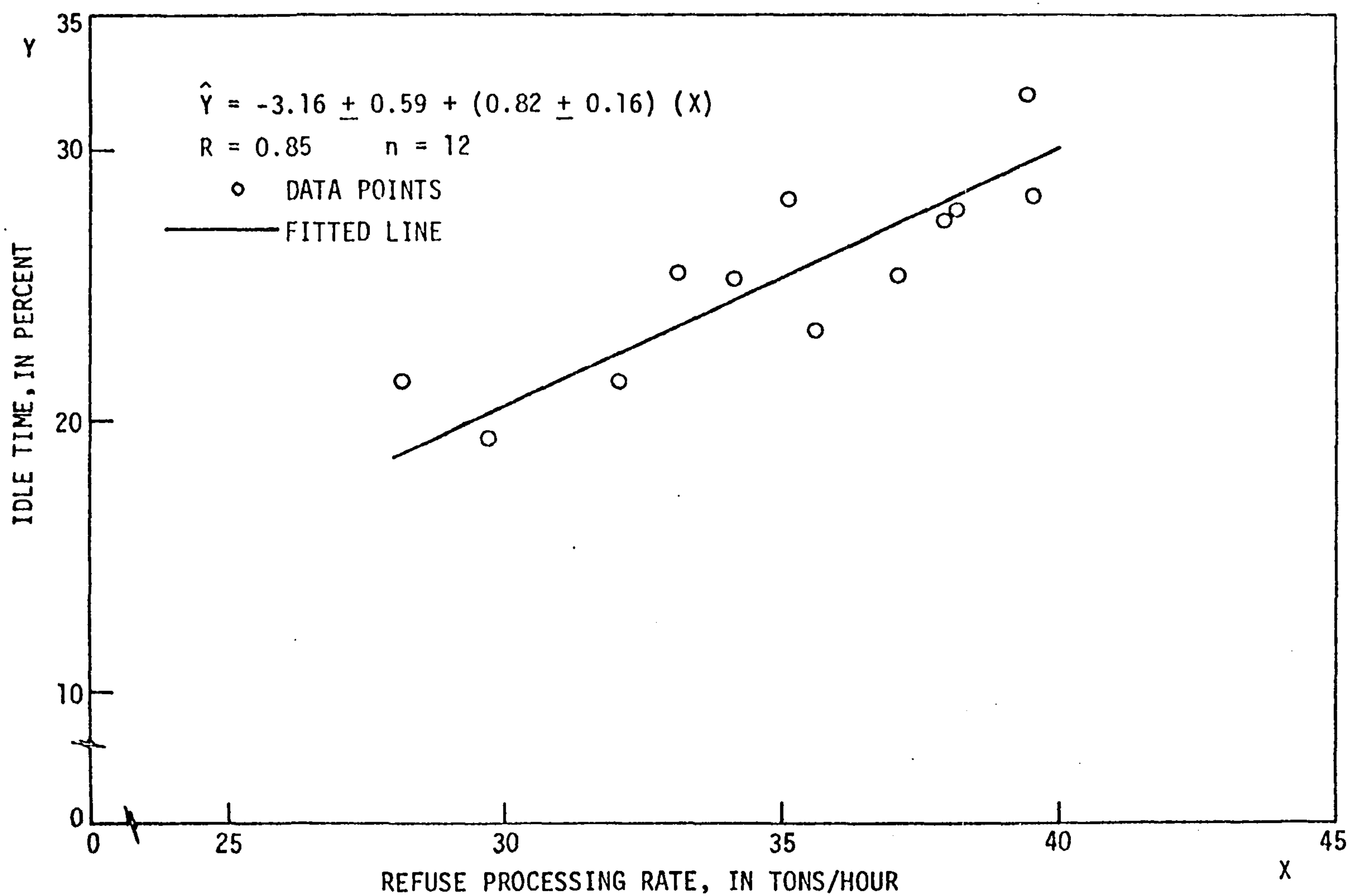

Figure 14.2. Idle time vs. refuse processing rate in percent

Table 14.1. Plant idle time and refuse processing rate summary

Month	Refuse processed (TONS)	Refuse Processing Time: Potential (DAYS)	Potential (HRS.)	RDF transport (HRS.)	Actual (HRS.)	Idle time (%)	Refuse processing rate TONS/HR.
1977							
July	3966.00	20	160	139.6	100.0	28.37	39.66
August	5218.05	23	184	206.0	148.1	28.11	35.23
September	4985.89	22	176	185.6	125.9	32.17	39.60
October	4924.76	22	176	177.8	132.7	25.37	37.11
November	4217.36	20	160	154.2	118.4	23.22	35.62
December	3637.64	20	160	131.4	95.5	27.32	38.09
1978							
January	3518.89	21	168	146.6	118.2	19.37	29.77
February	2858.86	20	160	129.4	101.5	21.56	28.17
March	3810.95	23	184	155.0	115.2	25.68	33.08
April	3916.08	20	160	153.4	114.3	25.49	34.26
May	2981.23	22	176	108.1	78.0	27.84	38.22
June	4178.73	22	176	165.7	129.9	21.61	32.17
TOTAL	48,214.44	255	2040	1,852.8	1,377.7	Avg. 25.64	Avg. 34.99

Plant Downtime

Downtime is the time when the plant's entire refuse processing equipment is shut down due to major internal or external problems. Some of the shut down periods are planned, while others are unscheduled. The total downtime distribution based on the 1977 calendar year operating experience is summarized in Table 14.2. The hammer changes and plant maintenance downtime were planned, while the downtime caused by the flood damage, air density separation system, RDF transport system and RDF storage bin system were unplanned. A portion of the power plant downtime is planned for annual scheduled maintenance. The unplanned downtime is caused by equipment failures in most cases.

Some of the major events that contributed to the plant downtime during 1977 were:

1. A flood caused by a main water pipe rupture in January, 1977, due to extremely cold weather. The water flooded the processing area floor and the plant was shut down for 4 days.
2. Shredders hammer changes and scheduled plant maintenance.
3. Boiler maintenance at the power plant in April, 1977, forcing 5 days' downtime.
4. Replacement of the RDF transport pipeline on December 16, 1977, resulting in 5 days' downtime.
5. A fire in the RDF storage bin on July 14, 1977, which prevented refuse processing operations for 3 days.

Table 14.2. Refuse processing plant downtime distribution by systems (1977)

Year	Internal Cuases of Downtime					External causes of downtime		TOTAL downtime	
	Flood damage (%)	Shredders hammers changes (%)	Planned plant maintenance (%)	Air density separating system (%)	RDF transportation system (%)	RDF storage system (%)	Power plant (%)	HRS.	DAYS
1977	5.25	6.27	1.31	8.22	17.73	52.19	9.03	601.60	76.20
PERCENT OF TOTAL	38.78%					61.22%		100.00%	

6. An RDF storage bin floor repair, which caused 7 days' downtime in June, 1977.
7. Air density separating system equipment failures (vibrating feeder conveyor, flight conveyor, air lock feeder, cyclone, air return, ADS chamber and fan).

During the 1977 plant operations, the process plant, RDF storage bin, and the power plant accounted for 38.78%, 52.19% and 9.03% of the total downtime respectively (see Table 14.2).

Discussion

The Ames facility, advertised as capable of processing refuse at a rate of 50 tons per hour (Funk and Sheahan, 1975, p. 215), does not attain this capacity. During the one year's study, the plant attained its highest refuse processing rate of 39.66 TONS/HR., 79% of its rated capacity in July, 1977. As shown earlier, when the feed rate increased, the downtime also increased. An inquiry into this relationship revealed that some of the equipment is unable to process refuse at the expected rate.

The shredders are able to shred refuse at 50 TONS/HR. However, the air density separating system is incapable of handling the rated 45 TONS/HR. necessary to keep up with this infeed rate (Moravetz, K., 1979, The Ames Solid Waste Resource Recovery System, Ames, Iowa, personal communications). Other systems may also be limited in their processing capabilities, but the air density separating unit appears to be the prime contributor to processing at lower rates.

The plant's experience of 25.64% average idle time due to material handling problems signifies serious problems deserving attention by management. Downtime results in lost revenues from RDF and materials that are buried in landfill that otherwise would have been recovered and sold. Whenever the plant stops processing and the landfill is used, the facility loses an average of $1,700/DAY in revenue due to loss of salable resources. These resources, once buried, have no chance of future recovery. In addition, the facility must continue to pay its fixed costs, which are not dependent upon the quantity of refuse processed. An intermittent refuse processing operation could lead to the cancellation of contracts for the marketable products.

In view of the preceding difficulties, the following recommendations are made:

1. A thorough investigation of the equipment processing capability should be made to determine the limiting system(s) and to adjust the feed rate to match the equipment's capacity. It may be more profitable to process at lower rather than higher feed rates, which seems to cause additional downtime due to congestion, plugging, and motor failures.
2. Even in a well-run plant, malfunctions of certain equipment occasionally occur. The chances of this happening can be minimized through an aggressive preventative maintenance program. The consequences of not having such a program will lead to severe operating economic difficulties. Therefore, a preventive maintenance schedule is to be encouraged.

CHAPTER XV. SUB-SYSTEMS SUMMARY

This chapter summarizes the result of this research concerning the Ames Solid Waste Resource Recovery System operations. The quantity of various resources reclaimed from the Ames solid waste are presented. In addition the amount of labor, energy, and the cost expended in maintaining each sub-system operation are summarized.

Resources Recovered

During plant operations in the 1977-1978 fiscal year, RDF, ferrous metals, nonferrous metals, baled paper, wood chips, and rejected materials were reclaimed from the Ames Solid Waste. These materials accounted for an average of 83.93%, 6.52%, 0.01%, 0.06%, 0.10% and 9.32% of the total refuse processed respectively. Ferrous metal and RDF accounted for 90.45% of the output based on the total incoming refuse. These two resources are the most important sources of revenue in the Ames system. Revenue from the sale of RDF and ferrous metal constitutes 71.48% and 21.36%, respectively, of the total revenues earned by the facility (Gheresus, 1978, p. 60).

Reclaimed ferrous metal, RDF, and rejected materials comprise an average of 99% of the total incoming raw refuse. The proportions of RDF, ferrous metal, and rejected materials recovered from the Ames Solid Waste during a 35 month period are summarized in Table 15.1. The linear regression equations given in Table 15.1 show that the magnitude of RDF, ferrous metal, rejected materials present in the Ames refuse is

Table 15.1. Proportions of RDF, ferrous metal, and rejected materials recovered from the Ames solid waste

Resource recovered (Type)	Quantity of Resources Reclaimed		Coefficient of determination (R^2)	Sample size[c] (month)
	Average[a] (%)	Estimator equation[b] (TONS)		
Refuse derived fuel	84	$\hat{Y} = 137 \pm 75 + (0.8061 \pm 0.0202)(X)$	0.98	35
Ferrous metal	7	$\hat{Y} = -21 \pm 36 \pm (0.0707 \pm 0.0096)(X)$	0.62	35
Rejected materials	8	$\hat{Y} = -134 \pm 69 + (0.1225 \pm 0.0187)(X)$	0.57	35

[a] Average of total refuse processed by weight.

[b] $\hat{Y}$ = Resource recovered in tons, X = refuse processed in tons.

[c] January 1976-December 1978.

significant. The equations indicate that for every ton of refuse processed we can expect to recover approximately 0.80 tons of RDF, 0.07 tons of ferrous metal, and 0.12 tons of rejected materials.

The amount of nonferrous metal, wood chips, and baled paper recovered from the Ames refuse has been minimal. Perhaps these operations can be performed profitably in other locations. Therefore, the market for these items needs to be studied prior to implementation of such systems in order to avoid economic difficulties.

The quality and quantity of recovered materials are important factors that determine the marketability of the reclaimed materials. The quality of the resources recovered from the Ames refuse is summarmarized on pp. 47-57. The RDF and ferrous metal products contain some contaminants, which can reduce their selling price. Therefore, more research is needed in the materials classification technology in order to improve the quality of resources recovered. For example, an inspection of the rejected materials composition on page 55 shows that valuable resources such as ferrous and nonferrous metals, wood, and paper are classified as rejected materials and buried at the landfill.

More than any other single factor, refuse derived fuel marketing determines the financial success of the Ames Solid Waste Resource Recovery system operation. The Ames RDF has an average heating value of 5197 BTUs per pound and an average moisture content of 22% by weight. The composition and quantity of resources present in solid waste may vary from one community to another. However, the results summarized in

Table 15.1 provide important information for management concerning the quantity resources that can be expected from the Ames solid waste. This result is also important to communities which are contemplating or in the process of implementing a solid waste resource recovery system, especially if their refuse profile is similar to that of Ames.

Labor Input Requirement

A total of 27,288.25 labor hours were expended in plant operations during the 1977-1978 fiscal year. The refuse processing operation consumed an average of 0.566 labor hours per ton of refuse processed. The plant support and refuse receiving floor operations consumed 67.06% of the total plant labor. The average labor hour input per ton of refuse processed in each of the sub-system operations is summarized in Table 15.2.

The method of linear regression was used to model the labor hour requirement per ton of refuse processed in each sub-system operation. The result of the analysis is summarized in Table 15.3. The linear equation in general indicates that the amount of labor hours worked is independent of the quantity of refuse processed. This can be explained by the fact that the number of hours worked by the 8 fulltime employees does not vary with the amount of refuse processed. That is, these employees work eight hours per day whether the plant processes refuse for eight hours or not. In addition, if the plant is shut down due to external problems caused by the RDF storage bin or the power plant, the

Table 15.2. Labor hours input distribution for sub-system operations

Sub-system operation	Labor Hours Requirement Total (HRS.)	Average[a] (HRS./TON)	Percent of total (%)
Refuse receiving floor	4,894.75	0.102	17.94
Shredder	2,087.00	0.043	7.65
Air density separation	896.75	0.019	3.29
RDF transport	839.00	0.017	3.07
Ferrous metal separation	1,445.75	0.030	5.30
Nonferrous metal separation	191.00	0.004	0.70
Rejected material disposal	2,913.00	0.060	10.67
Paper baler operation	445.00	0.009	1.63
Bundled paper collection	77.50	0.002	0.28
Log chipper	95.50	0.002	0.35
Plant support	13,403.00	0.278	49.12
TOTAL[b]	27,288.25	0.566[c]	100.00

[a]Average labor hour input per ton of refuse processed.

[b]Does not include plant superintendent's labor hour input.

[c]Average value for a 12 month period (July 1977-June 1978).

Table 15.3. Monthly labor hours requirement linear equation estimators for sub-system operations

Sub-system No.	Sub-system Operation	Monthly labor requirement[a] estimator equation (HRS./MO.)	Coefficient of determination (R^2)	Sample size (MO.)
1	Refuse receiving floor	$\hat{Y} = 318 \pm 70 + (0.0225 \pm 0.01722)(X)$	0.14	12
2	Shredder	$\hat{Y} = 186 \pm 87 - (0.0030 \pm 0.0213)(X)$	0.002	12
3	Air density separation	$\hat{Y} = 120 \pm 85 - (0.0113 \pm 0.0209)(X)$	0.03	12
4	RDF transport	$\hat{Y} = 196 \pm 258 - (0.0315 \pm 0.0633)(X)$	0.024	12
5	Ferrous metal separation	$\hat{Y} = 161 \pm 111 - (0.0061 \pm 0.0272)(X)$	0.01	12
6	Rejected material disposal	$\hat{Y} = -313 \pm 120 + (0.1384 \pm 0.0293)(X)$	0.69	12
	TOTAL I[b]	$\hat{Y} = 646 \pm 226 \pm (0.1270 \pm 0.0555)(X)$	0.34	12
7	Plant support[c]	$\hat{Y} = 967 \pm 282 \pm (0.0373 \pm 0.0691)(X)$	0.03	12
	TOTAL II[d]	$\hat{Y} = 1614 \pm 342 \pm (0.1643 \pm 0.0837)(X)$	0.28	12

[a] $\hat{Y}$ = Labor hours input per month, X = quantity of refuse processed per month.

[b] Includes sub-systems' 1 through 6 labor hours.

[c] Includes log chipper and paper baler labor hours.

[d] Includes sub-systems 1 through 7 labor hours.

fulltime employees work in plant maintenance. The parttime employees, however, work 4 hours per day and their working schedule can be adjusted according to plant operations. During the one year period, the total labor hours input averaged 2274 hours per month with a standard deviation of 233 hours per month. During the same period the plant was scheduled to process refuse 8 hours a day (255 days excluding overtime work); however, the facility averaged an actual refuse processing time of 5.4 hours per day.

The linear regression equation for the labor input in the shredder sub-system operation shows a poor fit. This is because major labor input occurs in the shredders when the hammers are being changed or major repair work is performed. Therefore there may be negligible labor until major work is required. This compounds the problem of trying to establish a reasonable functional relationship between the labor hours required and quantity of refuse processed. This problem, unfortunately, is common to many of the sub-system operations.

The linear regression equation for the labor hour requirement in the rejected material disposal operation gives reasonable results when compared with the remaining sub-system equations. The labor input in the rejected materials disposal sub-system is proportional to the quantity of refuse processed. A large portion of the labor hours worked in this system is expended in loading and hauling rejected materials to the landfill. The amount of rejected materials produced is proportional to the amount of refuse processed.

The plant support has the largest monthly fixed labor hours requirement than any other sub-system. The plant support labor requirement equation indicates that the amount of labor hours worked is essentially independent of the quantity of refuse processed. The plant support labor requirement equation gives a poorer linear fit when incorporated to the overall plant labor requirement equation as shown in Table 15.3.

The facility has several processing operations for which it is difficult to determine relationships between the quantity of refuse processed and the amount of labor hours required. The information presented in this report should provide a guide to current or future solid waste current or future solid waste resource recovery designers or operators in making a labor requirement estimation for plants similar to that of the Ames facility.

Electrical Energy Input Requirements

Electrical energy consumption is a factor that can affect the facility's economic viability as well as energy balance. The Ames' facility consumed a total of 2,377,806 KW-HRS. of energy, or an average of 49.32 KW-HRS. per ton of refuse processed. The plant support and shredder sub-systems on the average consumed 40.77% and 31.70% of the total energy input respectively. Thus over 72% of the total energy input is used by these two systems. The air density separation and RDF transport sub-systems consumed 14.13% and 9.21% of the total energy requirement. The average electrical energy consumption per ton of refuse processed for each sub-system is summarized in Table 15.4.

The plant support operation consumed an average of 40.77% of the total energy input. This includes electrical energy used to heat, light, and air condition the building, operate plant maintenance equipment, and provide electrical energy to the refuse process control room and electrical switchgear rooms. Seven heaters in the refuse processing area are turned on whenever the plant stops processing refuse in order to prevent moisture build-up in the electric motors.

The shredder sub-system consumed 31.70% of the total energy required; it is the second major energy user after the plant support. The air density separation sub-system ranked third with an average of 14.13% of the total energy input.

The relationship between the quantity of refuse processed and the amount of energy required was explored using linear regression analysis methods; the results for each sub-system are summarized in Table 15.5. The equations indicate that the amount of energy consumed is dependent upon the quantity of refuse processed. The linear relationship result appears to be reasonable, the energy consumption is related to the quantity of refuse processed except for the plant support operations. The plant support operation has a large monthly fixed energy requirement and this amount decreases by 20.47 KW-HRS. per ton of refuse processed. Tables 15.4 and 15.5 yield similar results on a sub-system energy consumption basis.

Table 15.4. Electrical energy requirement for sub-system operations

Sub-system operation	Electrical Energy Consumption		
	Total (KW-HRS.)	Average[a] (KW-HRS./TON)	Percent of total (%)
Refuse receiving floor	42,840	0.89	1.80
Shredder	753,734	15.63	31.70
Air density separation	336,044	6.97	14.13
RDF transport	218,853	4.54	9.21
Ferrous metal separation	31,210	0.65	1.31
Rejected material disposal	25,681	0.53	1.08
Plant support[b]	969,444	20.11	40.77
TOTAL	2,377,806	49.32[c]	100.00

[a] Average energy input per ton of refuse processed.

[b] Includes paper baler and log chipper energy consumption.

[c] Average value for a 12 month period (July 1977-June 1978).

Table 15.5. Electrical energy requirement linear equation estimators for sub-system operations

Sub-system No.	Sub-system Operation	Electrical energy requirement[a] estimator equation (KW-HRS./MO.)	Coefficient of determination (R^2)	Sample size (MO.)
1	Refuse receiving floor	$\hat{Y}$ = 3077 ± 315 + (0.1227 ± 0.0773)(X)	0.20	12
2	Shredder	$\hat{Y}$ = 16,662 ± 7562 + (11.4859 ± 0.4859)(X)	0.79	12
3	Air density separation	$\hat{Y}$ = 6,901 ± 6,705 + (5.2523 ± 1,6431)(X)	0.51	12
4	RDF transport	$\hat{Y}$ = 3,452 ± 1,823 + (3.6800 ± 0.4468)(X)	0.87	12
5	Ferrous metal separation	$\hat{Y}$ = 419 ± 270 + (0.5443 ± 0.0661)(X)	0.87	12
6	Rejected material disposal	$\hat{Y}$ = 339 ± 222 + (0.4482 ± 0.0544)(X)	0.87	12
	TOTAL I[b]	$\hat{Y}$ = 30,846 ± 14,220 + (21.5333 ± 3.4846)(X)	0.79	12
7	Plant support[c]	$\hat{Y}$ = 163,029 ± 26,054 - (20.4691 ± 6,3843)(X)	0.51	12
	TOTAL II[d]	$\hat{Y}$ = 193,875 ± 27,265 + (1.0641 ± 6.6811)(X)	0.03	12

[a] $\hat{Y}$ = energy requirement per month, X = quantity of refuse processed per month.

[b] Includes sub-systems 1 through 6.

[c] Includes log chipper and paper baler energy consumption.

[d] Includes sub-systems 1 through 7.

The end-loader is used extensively in the facility for various operations (see p. 63); therefore, it is an energy consumer. The end-loader consumes diesel fuel at a rate of 2.5 gallons per hour of use. During the 1977-1978 fiscal year plant operation, the end-loader used an estimated 7828 gallons of diesel fuel for 3131 hours of operation. The diesel fuel has an estimated heating value of 138,500 BTU/GAL., American Gas Association, Inc. (1965, pp. 2-34). One kilowatt-hour is equivalent to 3412 BTUs, Semioli (1974, p. 421). Thus, the 7828 gallons of diesel fuel is equivalent to 317,754 KW-HRS. of electrical energy.

This amount of energy is significant when compared to the plant's total energy requirement. During the 1977-1978 fiscal year plant operation consumed a total of 2,377,806 KW-HRS. of electrical energy, excluding the end-loader's energy input. The end-loader energy consumption on an equivalent basis averaged 13% (317,754 KW-HRS./2,377,806 KW-HRS.) of the plant's total electrical energy usage. The total diesel fuel expense for this period is estimated to be $4,070 (0.52/GAL.) or an average of $339 per month, or $0.84 per ton of refuse processed. In addition, a floor sweeper and a forklift each consume an average of 10 gallons of gasoline per month. The fuel cost for the end-loader, floor sweeper and the forklift is also included in monthly rental charge.

The Ames system is energy effective system. During the 1976-1977 plant operations the electrical energy generation to consumption ratio was 11.2 in the Ames system (Adams et al., 1979a, p. 640). The energy requirement equations can be used to estimate the amount of energy needed to process a ton of refuse. These equations provide useful information that can be used in making decisions concerning the Ames facility and other operations with a similar design.

Operating Cost

The Ames Solid Waste Resource Recovery system incurred a total cost of $997,237.71 or an average of $20.68 per ton of refuse processed during the 1977-1978 fiscal year operations. The average refuse processing cost for each of the facility's sub-systems is summarized in Table 15.6. The plant support, with an average refuse processing cost of $14.63, accounted for 70.75% of the total facility's opeating cost. Ten sub-systems incurred an average refuse processing cost between $0.05 and $1.55, while the plant support sub-system averaged $14.63 per ton of refuse processed.

The expected operating cost per ton of refuse processed per month in the various sub-systems is estimated using linear regression equations; the results are summarized in Table 15.7. The goodness of fit is affected by the dominant cost operation in a given sub-system. For example, the energy expense accounted for 44.89% of the total operating cost in the shredder sub-system. The amount of energy consumption in the shredder system is dependent upon the quantity of refuse processed, as shown in Table 15.5. Therefore, the shredder operating cost per ton of refuse processed is affected by the energy input and its cost.

The plant support operation cost equation exhibits a poor linear

Table 15.6. Refuse processing cost distribution for sub-system operations

Sub-system No.	Sub-system Operation	Operating Cost[a] Total ($)	Operating Cost[a] Average[a] ($/TON)	Operating Cost[a] Percent of Total II (%)
1	Refuse receiving floor	74,656.83	1.55	7.49
2	Shredder	71,982.79	1.49	7.22
3	Air density separation	28,555.79	0.59	2.86
4	RDF transport	28,756.26	0.60	2.88
5	Ferrous metal separation	21,149.61	0.44	2.12
6	Nonferrous metal separation	24,420.39	0.51	2.45
7	Rejected material disposal	34,684.48	0.72	3.48
8	Paper baler operation	2,528.63	0.05	0.25
9	Bundled paper collection	2,706.76	0.06	0.27
10	Log chipper operation	2,281.44	0.05	0.23
	TOTAL I[b]	291,722.97	6.05	29.25
11	Plant support	705,514.74	14.63	70.75
	TOTAL II[c]	997,237.71	20.68[d]	100.00

[a] Average cost per ton of refuse processed.

[b] Includes sub-systems 1 through 10 operating cost.

[c] Includes sub-systems 1 through 10 and number 11 operating cost.

[d] Average value for a 12 month period (July 1977-June 1978).

Table 15.7. Monthly processing cost linear equation estimators for sub-system operations

Sub-system No.	Sub-system Operation	Operating cost estimator equation[a] ($/MO.)	Coefficient of determination (R^2)	Sample size (MO.)
1	Refuse receiving floor	$\hat{Y}$ = 2,664 ± 1952 + (0.8853 ± 0.4783)(X)	0.26	12
2	Shredder	$\hat{Y}$ = 3,719 ± 1104 + (0.5674 ± 0.2704)(X)	0.31	12
3	Air density separation	$\hat{Y}$ = 4,274 ± 1,298 - (0.4716 ± 0.3180)(X)	0.18	12
4	RDF transport	$\hat{Y}$ = 1,704 ± 2,668 + (0.1724 ± 0.6539)(X)	0.01	12
5	Ferrous metal separation	$\hat{Y}$ = 2,465 ± 717 - (0.1743 ± 0.1758)(X)	0.09	12
6	Rejected material disposal	$\hat{Y}$ = 1,240 ± 944 + (0.4107 ± 0.2312)(X)	0.24	12
	TOTAL I[b]	$\hat{Y}$ = 18,091 ± 6249 + (1.5480 ± 1.5314)(X)	0.09	12
7	Plant support[c]	$\hat{Y}$ = 58,793 ± 8,773 + (0.4135 ± 2.1498)(X)	0.004	12
	TOTAL II[d]	$\hat{Y}$ = 75,222 ± 13,805 + (1.9614 ± 3.3828)(X)	0.03	12

[a] $\hat{Y}$ = Operating cost per month, X = quantity of refuse processed per month.

[b] Includes sub-systems' 1 through 6 operating cost.

[c] Includes log chipper and paper baler operating cost.

[d] Includes sub-systems 1 through 7 operating cost.

fit; this can be explained by the fact that the plant support operation has a large fixed cost. Equipment rent, insurance, principal and interest, administrative wages, lighting, air conditioning, and a portion of direct labor expenses are essentially independent of the quantity of materials processed. Principal and interest, and insurance payments alone accounted for 47% and 3% of the plant's total operating cost respectively. The effect of the large fixed cost in the plant support operation is reflected in the linear regression equation.

The attempt to establish a reasonable operating cost model for each sub-system is hindered by plant downtime and also the method of accounting used. When downtime occurs and refuse processing ceases, some of the costs continue to accrue. In addition, the timing of expense recognition and payment are important factors that can affect the operating cost model results. In the Ames system expenses are recognized at the date of payment; the city makes no attempt to allocate the expenses over time or quantity of refuse processed. However, in this research, whenever the cost of the item was available, it was charged to the proper operation. Even though the total operating cost for the fiscal year is included in this report, it was difficult to obtain a complete expense breakdown for each sub-system. Therefore, the operating cost models are estimators and can provide useful information for the Ames operation and other similar facilities. Principal and interest, and insurance payments accounted for 50% of the facility's total operating expense. This expense is a major factor

factor that needs to be considered for communities which are contemplating building a facility that is similar to the Ames system.

CHAPTER XVI. CONCLUSIONS AND RECOMMENDATIONS

A solid waste resource recovery plant may not provide a remedy for the solid waste disposal problems of every community. However, when a proper combination of waste disposal costs and energy demand exists, the energy/material recovery plant can be cost effective.

Conclusion

Based on the Ames Solid Waste Resource Recovery System's operating experience, the following conclusions may be made:

1. The Ames solid waste contains a significant amount of refuse derived fuel and ferrous metals that are valuable. RDF and ferrous metal constitutes 84% and 7% of the total incoming refuse, respectively.
2. The critical parameters that control the economics of the plant operations are: capital, energy, labor, maintenance costs, downtime, quantity and quality of the recovered materials.
3. The overall labor hours requirement and total plant operation cost remain essentially independent of the quantity of refuse processed. However, the labor input and operating cost of an individual sub-system may be dependent upon the quantity of refuse processed.
4. The amount of electrical energy consumption is dependent upon the amount of refuse processed.

5. The principal and interest payment, accounting for 47% of the facility's total operating expenses, has a significant effect on the economic viability of the system.

6. The Ames Solid Waste Resource Recovery System has not eliminated the need for a landfill. Some materials that have no value are hauled directly to the landfill. In addition, between 7% and 8% of the processed refuse is classified as rejected materials and hauled to the landfill.

7. The economic viability of the Ames Solid Waste Resource Recovery is determined by the prices received from the sale of RDF and ferrous metal. During April, 1979, the Ames Power Plant spent $35.81/TON for Western coal and $23.77/TON for Iowa coal (Riggs, D., 1979, Power Plant, City of Ames, Iowa, personal communication). The transportation cost accounted for 54% and 29% of the total cost for the Western and Iowa coal respectively. In view of the increasing fuel cost, the price of coal can be expected to rise. The Ames Solid Waste Resource Recovery system, located only 900 feet from the Power Plant that uses the RDF, has a transportation advantage that can make it a competitive fuel producer. Therefore, the Ames Solid Waste Resource Recovery system can operate economically by maintaining its current operations especially if the price of alternate fuel and materials costs continues to rise.

Recommendations

The experience of the Ames Solid Waste Resource Recovery system's operations revealed many unforseen challenges that need to be discussed. Based on the Ames system experience, the following recommendations are made.

1. The Ames refuse processing operations are arranged in series. Therefore, an equipment failure at the processing facility, RDF storage bin, or power plant forces the refuse processing operation to halt. As a result, equipment operating performance should be studied in order to provide an alternate way to process and handle the refuse. For example, the RDF is pneumatically transported into the RDF storage bin through an underground pipeline. The pipeline faces frequent congestion and pipe wear in one section requires the removal of half of the pipeline to repair a small hole. The RDF storage bin has also caused many processing shutdowns due to floor wear and mechanical wear. In view of these problems, a study of alternative methods of RDF transportation and storage should be investigated.
2. This research was concerned with the refuse processing plant operations only. However, the RDF storage bin and power plant are an integral part of the entire refuse processing operations. The operating economics of these systems can affect the refuse processing operation. Further research should be conducted on these systems in order to evaluate their economic implications

in the entire refuse processing operation.

3. Human factor considerations should be taken into account when implementing a solid waste resource recovery system. These include equipment noise level, dust, odor, and fire problems that can cause health problems to employees. The plant has installed a dust collection system that alleviates this problem. A proper control panel design is important in any system's operation. The refuse processing control operator in the Ames system monitors refuse processing equipment by means of meters, television cameras, and flashing lights which are considered too numerous for a single person to monitor adequately. Thus, the impact of a solid waste resource recovery system on its employee must be researched.
4. The RDF quantity produced is determined by weight difference. Since RDF is the major salable product of the Ames system, a scale should be incorporated in order to weigh the amount of RDF produced with accuracy.
5. The state of Iowa has implemented a beverage depository law in 1979. The impact of this legislation on the amount of ferrous metal recovery needs to be examined.
6. During the 1977-1978 fiscal year 23,596 private customers delivered refuse to the facility. This is an average of 1,966 customer trips per month. This service primarily established for customers without commercial refuse service, is also used by other customers. Fuel conservation can be

realized when the refuse can be hauled in large loads rather than by having each individual customer hauling his/her refuse. In view of the energy shortage and the need for energy conservation, an alternative energy efficient means of refuse collection system should be considered for the private customers.

7. The operating economics of the solid waste resource recovery system is important in the making of alternative decisions. The economy of scale for such operations is an important factor that should be considered. The separation of variable and fixed operating costs provides valuable economic information. Thus further research in the refuse processing operations is recommended.

Finally, the complexity of the resource recovery project extends beyond the system's hardware. The refuse processing operation requires cooperation of the facility owner, the refuse derived product purchaser, and the community which produces the refuse. With these complicated interrelationships a clearly defined objective with a single program manager may be desirable in order to keep the tasks on schedule and within budget. The importance of cooperation in such a project can be best summarized in the following quotation by Lehtho (1972, p. 37).

> The home owner says: "I would gladly separate paper from other refuse, but no one will take it off my hands." The paper stock dealer says: "I'd gladly collect the paper as long as the mills will buy it." The mills say: "We would gladly use all the paper stock we could, but there is no market for the end product." The consumer says: "I would gladly buy products with recycled fiber content but I don't see any around to buy."

As Pogo, the cartoon character stated,

"We have met the enemy and they is us."

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ACKNOWLEDGMENTS

This report could not have been written through the author's efforts alone. Many people have guided my work and lent me support from the beginning to the closing chapters. Although I can not acknowledge each individually, I extend my sincere appreciation to everyone.

Thanks must go to Mr. Arnie Chantland and Mr. Paul Hinderaker for very generously furnishing me with all of the cost information. Thanks to Mr. Kenny Moravetz, Mr. David Barber and the rest of the Ames Solid Waste Resource Recovery system's employees for providing me with valuable information concerning the facility's operation.

I would like to extend my sincere appreciation to my committee members, Dr. S. K. Adams, Dr. H. A. Cowles, Dr. D. F. Cox, Dr. J. C. Even, Jr., Dr. C. H. Meyer, and Dr. G. M. Montag. Special thanks to Dr. McRoberts for his untiring effort in encouraging me to pursue my educational objectives as well as for providing me with financial aid throughout my graduate study. I am most grateful to my advisors, Dr. Cowles, Dr. Even, Dr. Adams for their constructive criticism, patience, and guidance. I would also like to thank Debbie Ross for the valuable time and effort she spent helping me compile this report. Many thanks to Mary Fry who helped me in editing the report.

Acknowledgment is also due Professor Alfred Joensen from mechanical engineering, Dr. Paul W. Peterson, Director of the Engineering Research Institute, Iowa State University and the United States Environmental Protection Agency for providing me with the opportunity to work on the Ames Solid Waste Resource Research Project. Much appreciation is expressed to Debbie Ross, David Gheresus, David Joensen, Susan Even, Marlin Eiben, and Mesfin Yohannes from the Iowa State University Engineering Research Institute for helping me to gather the necessary data.

Finally, I am indebted to my mother, Akberet Teaghes, my brothers, David, Daniel, and Habtom, my sponsors, Mr. and Mrs. Hohanshelt, the Sandager family, and Mr. and Mrs. Richard Hoppe, who have supported me unselfishly throughout my academic career and made the attainment of this goal possible for me.