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Systems Analysis for the Development of Small Resource Recovery Systems

Description of Solid Waste Modular Simulator

Final Report
October 1980

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Prepared for:

U.S. Department of Energy

Assistant Secretary for Conservation and Solar Energy

Office of Buildings and Community Systems

Under Contract No. AC01-77CS 20026

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Description of Solid Waste Modular Simulator

Final Report
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ABSTRACT

In response to the increasing need for small-scale solid waste processing facilities, the U.S. Department of Energy (DOE) contracted with Systems Technology Corporation (SYSTECH) to identify the technologies that should be developed to make such facilities attractive to and viable for small municipalities with solid waste between 50 and 250 tons per day (TPD). In addition to identifying candidate technologies, SYSTECH applied a set of criteria to them to determine those that could best satisfy the existing market conditions. The criteria included costs of the alternative landfill disposal, material and energy prices, developmental status of the technology, and environmental impact of the systems. The system types studied included those with mechanical separation, thermal and thermochemical energy recovery, and bioconversion processes. For these studies, the performance of each system was simulated by a mathematical model. After the systems were evaluated, the most promising were analyzed to determine which components and operating parameters had the greatest impact on system viability. Accordingly, the research and development (R&D) needs to advance the state-of-the-art for small-scale solid waste processing facilities were identified.

The study results are documented in four volumes: (1) Executive Summary, (2) Description of Solid Waste Modular Simulator, (3) Research and Development Needs, and (4) System Performance Data.

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SECTION 1

INTRODUCTION

This report describes the Solid Waste Modular Simulator (SWIMS), a computer program for simulating the performance of solid waste processing/resource recovery systems. The current program data enables the simulation of systems with design throughput rates of 100 and 200 TPD of solid waste. Systems with larger throughput capacities can also be simulated by supplying the program with their performance data.

The main line of this program is basically an accounting routine which totals the costs, revenues, and mass balances for all components in a simulated waste processing line. In addition, the main line controls the input of all information required to execute the program and the output of the resultant system performance data.

In addition to the main line, there are 13 subroutines. Of these subroutines, each of nine is for a discrete functional system module such as waste receiving. While each of these subroutines can accommodate any one of several components performing the given module function, it can only simulate one at a time. In the computer simulation, each of the module subroutines calculates the cost, revenue, and mass balance for the specific component in the subroutine. In addition, each component is simulated so that the output of any subroutine may be the input to any of the other eight subroutines. Consequently, the operational sequence of the components in a processing line may be varied to investigate the effect of these variations on the system performance.

Each of the remaining four subroutines performs a specific calculation such as the capital cost amortization for the specific component within any of the nine module subroutines.

Parameters which can be changed to reflect site-specific conditions include the following: labor and operating costs, amortization rates, selling prices for recovered products, and the composition and tonnage of the incoming waste.

The program has outputs at three levels: Level 1 presents a total plant operational and cost summary including a detailed mass and energy balance and a complete economic evaluation. For each component, Level 2 presents the operating and maintenance labor hours, direct operating costs, maintenance material costs, electrical usage, operating time, and cost per ton of refuse

processed. Level 3 presents a summary report of the plant operations and total cost. Level 1 includes all the information presented in both Level 2 and Level 3.

SWIMS is a first-generation model and is based on available equipment performance data.

SECTION 2

PROGRAM LOGIC

As mentioned before, SWIMS contains a subroutine for each of nine functional system modules. In a given computer run, each subroutine may simulate any one of several components performing the module function. In addition, the output of any one of the nine subroutines may be the input to any one of the other eight subroutines. Consequently, SWIMS permits a wide variation in the system simulation. Moreover, as new processes evolve, other functional modules may be added in the SWIMS simulation by simply preparing the appropriate subroutines for them and adapting the program's main line for their incorporation in the program. Further, the SWIMS logic was designed in a straightforward format so that an experienced programmer could readily follow its flow.

The entire SWIMS program is written in a version of the Fortran language that meets or exceeds all ANSI standards. Originally developed on the Sperry-Univac Series 70/7 at the University of Dayton, the program was available in a multiuser environment on a time-sharing basis. The program running on a system other than the Univac would require very little, if any, modification. However, a terminal with 132 print positions should be used because of the long line length of the program output. Moreover, since the unit numbers of the input-output devices vary among computers, the program was designed such that Device 2 would be the output line to the terminal, and Device 5 would be the input line from the terminal.

As mentioned previously, the main line of the program is basically an accounting routine which totals the costs, revenues, and mass balances for all components in a simulated waste processing line. In addition, the main line handles all decision-making activities introduced by user interaction. After computing the foregoing totals, the main line directs the summary information to the computer output device. The main line also governs the printout data for each component in the solid waste processing line.

The program contains, in addition to the main line, 13 subroutines: 1 set of 9 to calculate the cost, revenue, and mass balance for the specific component in the respective 9 modules; and 1 set of 4 to perform specific calculations, 2 for the given component in each of the 9 modules and 2 for the entire system.

The nine modules are as follows: (1) receiving, (2) size reduction, (3) combustible materials separation, (4) refuse derived fuel preparation,

(5) thermal processing and fuel densification, (6) fuel storage, (7) ferrous recovery, (8) aluminum recovery, and (9) glass recovery.

The specific calculations performed by the second set of subroutines are as follows: those for the particular component in each module are (1) the higher heating value and chemical composition of the separated material streams and (2) the capital cost amortization of the given component. Those for the entire system are (1) the cost of the building to house the system and (2) the recoverable heat value of the fuel fraction at the end of the process line after accounting for boiler and other heat losses. The program logic is illustrated in Figure 1.

While the program has much flexibility, the following data items for each component are fixed: (1) capital cost, (2) tons per hour (TPH) capacity, (3) labor cost, and (4) supply cost.

INPUTS

Figure 1. SWIMS program flow.

SECTION 3

INPUT PARAMETERS

This section is primarily for the user and the programmer. The following instructions describe how to execute the run time decisions in the program.

MODES OF OPERATION AND INPUT/OUTPUT CAPABILITIES

The SWIMS program was designed to be run in either the foreground (interactive) or the background (batch) modes. The program is very versatile in the foreground mode since the user can interact with the program when using it. In the background mode, however, the user must determine all the input parameters before the run initiation. The user should choose his mode of operation according to the number of desired runs and the amount of data to be generated. If the user plans to make several runs, he should choose the background mode since it will produce the results quickly and will require little programmer time.

Foreground Mode

The foreground mode permits the user to supply data from the terminal as it is required or to read in the data from a disc file. In this mode, the user supplies data from a disc file as the program is executed unless a disc file link has been established. The program is currently directed to read the data from I/O Device 65. However, this device may be changed to accommodate any operating system by internally changing the value of the variable INPUT in the main program. If a link to I/O Device 65 is not established, the program will read from I/O Device 5 which is the terminal on the University of Dayton Univac 70/7 system.

The user can change any or all I/O devices and/or the operation mode by answering "yes" to the question "do you wish to change the mode or any of the I/O devices?" The valid response is three two-digit numbers with the first two numbers being the values to be used when linking to the devices for input and output. The third two-digit number represents the operation mode, that is, 01 for the foreground mode and 02 for the background mode.

The user can perform the I/O functions with whatever I/O devices are available to his system. When choosing values for I/O devices, the user must choose the device numbers supported by his system.

Background Mode

This mode requires an input disc file, a link to I/O Device 65, and characters 1 and Y as the first and second data records. The third data record will contain the output device number. When the user establishes all links between the selected I/O devices and this program, the simulation data base will be a direct input.

DATA BASES

The data bases for all executions of the SWIMS program are identical. All data bases must contain a "plant name," an output level assignment, and a process line description. An optional input may be programmed in by inserting appropriate data after the process line description. Tables 1 and 2 present a data base coding sheet and a sample data base, respectively. All economic data inputted during program execution is based on mid-1979 cost estimates and is expressed in mid-1977 dollars.

Plant Name

The plant name is any alphanumeric string of 60 characters or less that identifies a particular simulation. When performing a large number of simulations, the user should use very descriptive plant names. The plant name must appear in the first line of the data base.

Output Levels

Any one of three output levels may be chosen by entering a one-digit number (1, 2, or 3) in the second line of the data base. The program performs the same number of calculations regardless of the output level; however, the Level 1 output has more information than either the Level 2 output or the Level 3 output. The only direct monetary savings gained by a partial output is in the time required to write to the relatively slow output device. Section 6 illustrates the various output levels in a sample simulation and details the program output.

Level 3, which resembles a balance sheet, summarizes the system operations and includes the processing descriptions and operating parameter changes. This level is selected when the user wishes to compare identical plants while varying the values of the optional input variables (discussed later).

Containing information only for the components in the individual modules, Level 2 summarizes the module operations. The information includes the following: operating and maintenance hours required, operating and maintenance costs, initial equipment cost, electrical usage, operating time, and cost per ton of waste processed. The information for the separation modules includes (1) a mass balance of the processing stream before and after separation and (2) partial descriptions of the recovered materials. This level is selected when the user wishes to compare the component operating times and costs per ton of processed refuse.

TABLE 1. SWIMS DATA INPUT FORM

Plant Name 1 Card										
Level of Output	(1) All; (2) Module Summary; (3) Plant Summary									
Process Descrip- tion	(1)	(2)	(3)	(1) Sequence No. (2) Module No. (3) Process No.						
	0,1									
	0,2									
	0,3									
	0,4									
	0,5									
	0,6									
	0,7									
	0,8									
	0,9									
Optional	1,0									
	1,1									
	1,2									
	1,3	0	0	0	Coded Processing Line					
	VARIABLE PARAMETER VALUES									
	ASSIGNED VALUE			DESCRIPTION				DEFAULT VALUE		
	0,1			Paper				0.42		
	0,2			Organic				0.241		
	0,3			Wood				0.025		
	0,4			Iron				0.067		
0,5			Aluminum				0.009			
0,6			Metals				0.004			
0,7			Glass				0.100			
0,8			Plastics				0.035			
0,9			Textiles				0.024			
1,0			Inerts				0.045			
1,1			Fines				0.03			
1,2			Tons/Day Input				100.			
1,3			\$/Hr. Operator Salary				15.00			
1,4			Maintenance Salary \$/Hr.				18.00			
1,5			Fuel Price \$/MMBTU				1.48			
2,2			Landfill Cost \$/Ton				10.00			
2,3			Plant Life Yrs.				10.00			
2,4			Rate of Interest				.10			
2,5			Boiler Efficiency				.80			
2,6			Print/Boiler Data				0			
2,7			\$/Kw Demand				.08			
2,8			\$/Kwh Energy				.025			
2,9			Ferrous Price \$/Ton				32.00			
-11021										

$$\{ \dots \}$$

1

(1)	(2)	(3)
0, 1	0, 1	0, 2
0, 2	0, 2	0, 2
0, 3	0, 7	0, 4
0, 4	0, 2	0, 2
0, 5	0, 3	0, 4
0, 6	0, 6	0, 4
0, 7	0, 7	0, 4
0, 8		
0, 9		
1, 0		
1, 1		
1, 2		
-1, 1	0, 0	0, 0

Coded Processing Line

-	1	0	0	0	0
---	---	---	---	---	---

Optional:

Level 1 includes the information of Level 2 and Level 3 and, therefore, all the program-generated data. This level is generally selected when the user wishes an initial overview of a new system.

Processing Line Description

The next set of data to be entered in the program defines the processing line to be simulated. Table 3 lists the components that may currently be simulated in each module. The processing line codes are three two-digit integers. The first two-digit number is the sequencing code. When the last piece of equipment is entered, a -10000 is inserted to terminate the processing line assignment command.

The second two-digit number identifies the functional module in which a specific component may be selected for simulation. In the processing of the separated material streams, the program first processes the light fraction of a stream and continues doing so until it encounters a storage module. Then the program processes the heavy fraction. For example, if a simulated system contains an air classifier and subsequently magnetically separates the heavy fraction, the magnetic simulation cannot function until the light fraction has been processed to a storage module.

The subroutines for the aluminum and glass recovery modules, with codes of 08 and 09, respectively, were not simulated during the small system evaluation since the recovery of aluminum and glass is currently not profitable in small-scale operations. These two subroutines, therefore, are not included in Table 3.

The third two-digit number in the processing line code identifies the component that may be simulated in a module. In a given run, the user may simulate any one of several components in a module. As shown in Table 3, the number of available components for the respective modules ranges from 4 to 13. These components were selected on the basis of the research for systems with waste capacities in the 100-to 200-TPD range.

Variable Parameter Values

There are 23 operational parameters whose values may be changed to represent the particular characteristics of the various system simulations. To change the value of any of these parameters, the user must supply its code as well as its new value. When the program is run in the foreground (interactive) mode, it instructs the user when to make these insertions. When the program is run in the background (batch) mode, the user adds the changes before the run initiation, starting on the line after the final processing line code -10000. If the parameters are not changed, the user simply supplies a -10.0 at this point, and the program uses the "default" values, i.e., the standard program values shown in Table 1. The format for the variation of each of the 23 operational parameters is a two-digit parameter code followed by the selected value.

TABLE 3. SIMULATED PROCESSING COMPONENTS

MODULE	SYSTEMS	
01. RECEIVING	01. TIPPING FLOOR	100 TPD
	02.	200 TPD
	03. CONVEYOR PIT	100 TPD
	04.	200 TPD
	05. CRANE/PUSH PIT	100 TPD
	06.	200 TPD
	07. CRANE	100 TPD
	08.	200 TPD
	09. DOZER PIT	100 TPD
	10.	200 TPD
02. SIZE REDUCTION	HAMMERMILLS	
	01. HORIZONTAL-RAW	100 TPD
	02.	200 TPD
	03. HORIZ. POST TRON	100 TPD
	04.	200 TPD
	05. VERTICAL-RAW	100 TPD
	06.	200 TPD
	07. VERT. POST TRON	100 TPD
	08.	200 TPD
	09. FLAIL MILL	100 TPD
	10.	200 TPD
	11. SHEAR SHREDDER	100 TPD
	12.	200 TPD
03. COMBUSTIBLE SEPARATION	AIR CLASSIFIERS	
	01. ALLIS CHALMERS	100 TPD
	02.	200 TPD
	03. RADER	100 TPD
	04.	200 TPD
	05. VIBROELUTRIATOR®	
	OTHER	
04. RDF PREP	06. COARSE R. SCREEN	100 TPD
	07.	200 TPD
	01. FINE R. SCREEN	100 TPD
	02.	200 TPD
	03. MAGNET	100 TPD
	04.	200 TPD
	05. SEC. SHRED. HORIZ.	100 TPD
	06.	200 TPD
	07. SEC. SHRED. VERT.	100 TPD
	08.	200 TPD

(continued)

TABLE 3 (continued)

05. DENSIFICATION AND THERMAL PROCESSING	01. PELLETIZER	100 TPD
	02.	200 TPD
	03. CUBETTER	100 TPD
	04.	200 TPD
	THERMAL MODULES	
	05. ROTARY KILN INCIN.	100 TPD
	06. CONT. AIR INCIN.	200 TPD
	07. REFRAC. LINED INCIN.	100 TPD
	08. ANDCO TORRAX	250 TPD
	09. ANDCO TORRAX	200 TPD
	10. CENTURY RESEARCH	200 TPD
	11. REDKER YOUNG	200 TPD
	12. WALLACE ATKINS	200 TPD
	13. ECOLOGENICS	200 TPD
06. STORAGE	01. LIVE CENTER BIN	100 TPD
	02.	200 TPD
	03. ATLAS SILO	100 TPD
	04.	200 TPD
	05. TRANSFER TRAILER	100 TPD
	06.	200 TPD
	07. BUNKER	100 TPD
	08.	200 TPD
	09. FREE STORAGE	
07. FERROUS RECOVERY	01. DRUM MAGNET	100 TPD
	02.	200 TPD
	03. MUL. STG. BELT MAG	100 TPD
	04.	200 TPD

LEVELS OF ANALYSIS

- 01. COMPLETE MASS BALANCE
- 02. SUMMARY OF EACH MODULE
- 03. SUMMARY OF ENTIRE PLANT ONLY

PLEASE GIVE THIS PLANT A NAME (LESS THAN 60 CHARACTERS)

Parameter codes 01 through 11 represent various refuse compositions. The default values represent a national "average" solid waste composition. To change the composition ratios, the user needs only to specify the parameter code and to supply the appropriate value. However, to ensure that the refuse composition totals 100 percent, the user must adjust the other variables accordingly. Parameter Code 12 represents the system throughput in tons per day. While the user may vary this rate, only the operating time changes since the system capacity remains constant.

The next two Parameter Codes, 13 and 14, are the labor rates for the operating and maintenance personnel, respectively. These rates include salary and the company overhead. Therefore, if an operator's salary is \$5.00/hour and the overhead rate is 130 percent, the labor rate for this person would be \$11.50/hour.

Fuel prices (Code 15), which represent dollars per million Btu, and landfill costs (Code 22) must be varied according to local market values to ensure the validity of the simulation.

The plant life (Code 23), expressed in years, is the same as the period for the plant amortization. The "rate of interest" (Code 24) is simply the interest rate at which the plant is amortized.

The code for the boiler efficiency, namely 25, need only be used when a thermal module is incorporated in a system. To estimate the amount of heat energy that could be recovered by burning the fuel product, the value of Parameter Code 26 is changed from 0.0 to 1.0. This estimate is based on the composition of the fuel in the storage module. Although such an estimate has a limited accuracy because of the uniqueness of various thermal processing systems, it reasonably represents what might be expected in an actual facility.

The price of the electricity for the plant operation is expressed as the cost of dollars/KW for the peak power demands (Code 27) and as dollars/KWH for the normal operational requirements (Code 28).

The final variable is the dollars per ton for the recovered ferrous product (Code 29), which also must be varied according to local market conditions. In this program, the scrap iron value was assumed to vary linearly as a function of the product purity.

After any desired variable changes have been made, the index may then be set to -10.0 for the immediate program execution.

SECTION 4

PROGRAM OUTPUT

The program output, which is easy to execute and generally self-explanatory, provides enough information to readily assess the viability of a hypothetical plant.

The data common to all three output levels are the plant name, the operational parameter changes, and the process line description. The rest of the data output will be discussed under the Level 2 and Level 3 outputs (as mentioned above, the Level 1 output is a combined printout of the Level 2 and Level 3 outputs).

LEVEL 2 OUTPUT

This output summarizes the module operations with a detailing of the pertinent information for the component simulated in each module. The information format for the individual modules varies somewhat with the function performed by each module.

The information for each module includes operating and maintenance costs, initial equipment cost, operating time, operating and maintenance hours required, electrical usage, and cost per ton of processed refuse. The output for all modules except the receiving module gives the amount of refuse processed and the operating time for its processing. The information for the receiving module includes the higher heating value (HHV) and the moisture content of the incoming waste stream.

In addition to the foregoing data, the output for the separation modules includes a mass balance of the waste stream before and after separation to permit assessing their separation efficiency. The additional data for the magnetic separation modules include the total tonnage recovered, the purity of the product, and the market value of the product. All other separation modules analyze only the light fraction of the waste stream; and their data include the tonnage recovered, the higher heating value, and the moisture content of the waste stream at the point of separation.

If boiler data is requested, the output presents a boiler heat balance analysis based on the fuel in storage. This output includes a proximate and an ultimate analysis of the fuel. These analyses indicate the percentages of carbon, hydrogen, oxygen, nitrogen, sulfur, ash, and moisture. The output also presents a boiler heat loss analysis along with the factors used in this

analysis, namely the excess air, the unburned carbon, the flue gas temperature, the ash temperatures, and the air-fuel ratio. The total dry gas loss is the sum of losses due to carbon dioxide, nitrogen, oxygen, and sulfur dioxide in the gas stream. The total water loss is the sum of losses due to the humidity of the ambient air, the moisture in the waste, and the water resulting from combustion. Other losses accounted for are the radiation and convection heat losses, the heating value of the ash, and the sensible heat lost in the ash. The sum of all these losses appears with the higher heating value of the fuel on a dry basis and is followed by the estimated boiler efficiency.

LEVEL 3 OUTPUT

This output, which is the plant summary, is divided into two sections -- costs and revenues. In the costs section, the required operator and maintenance hours, electrical usage, and initial plant cost are first expressed in non-dollar terms. Then the actual costs with a breakdown for direct labor and maintenance costs, total electrical costs, overhead expenses (other costs), daily rate of capital amortization, and landfill costs are summed to yield the total cost.

The revenues section presents the income generated by the various processes. Revenues from the sale of refuse derived fuel (RDF) and ferrous metals are calculated separately. Although the SWIMS program has provisions for calculating aluminum and glass recovery revenues, these provisions were not used in this evaluation, as mentioned above. In addition to the total revenues, the output includes the net costs both per day and per ton of waste processed.

Section 6 presents a sample computer printout with the outputs for all three levels.

SECTION 5

PROGRAM THEORY

INTRODUCTION

This section explains the theory of the SWIMS program, that is, the equations developed to simulate the performance of a solid waste processing plant. The equations for the plant operation are based on extensions of data from manufacturers and system developers, and those for the plant economics are based on general accounting principles.

The factors used to define the component in each module are operating time, operator and maintenance requirements, and energy usage.

Since the separation modules divide the processing stream into light and heavy fractions, they have an additional factor. Values for these fractions are stored until they are used to compute a system mass balance. The data for the fractions include values for fuel, ferrous material, and landfill material constituents. An energy balance is calculated from the system mass balance and the input parameters.

The plant economics are calculated from linear relationships in which the input data on system costs are combined with the output data for the mass and energy balances.

PERFORMANCE CALCULATIONS

The first calculation, the daily operating time (t) of each component, is performed by dividing the daily refuse input (C_D) by the hourly capacity (C_H) of the given component:

$$t \text{ (hours)} = \frac{C_D \text{ (tons)}}{C_H \text{ (TPH)}} \quad (5-1)$$

However, each successive component must run at least as long as the preceding one. Any increase or surge in the material flow between two components is assumed to be handled by a system storage capability.

The operating and maintenance labor hours are computed by multiplying either the operating time (t) by the operating and maintenance labor hours required per operating hour (α) or the daily refuse throughput tonnage (T) by

the operating and maintenance labor hours required per ton of refuse processed (β). The selection of one multiplication or the other to compute the hours depends on how the manufacturer or systems developer expresses the labor requirement. Therefore,

$$\text{labor hours} = t\alpha \text{ or } T\beta \quad (5-2)$$

Similarly, the electrical consumption (P) is computed by multiplying either the operating time (t) by the kilowatt hour consumption per operating hour (p_1) or the daily refuse throughput tonnage (T) by the kilowatt hour consumption per refuse throughput ton (p_2). Again, the selection of one multiplication or the other depends on how the manufacturer or systems developer expresses the kilowatt hour consumption. Therefore,

$$P = tp_1 \text{ or } Tp_2 \quad (5-3)$$

The material separation efficiency of each of the system separation modules is defined as the percentage of material separated in each of 11 types, or categories, of refuse (paper, organic, wood, iron, aluminum, metals, glass, plastics, textiles, inerts, and fines). In this study, the efficiencies were determined according to available literature and vendor data. The weight of the material recovered, such as lighter combustible materials and ferrous materials, in each refuse category is calculated as follows:

$$R_c = (E_c)(M_c) \quad (5-4)$$

where R_c = weight of material recovered for each refuse category in the waste stream

E_c = efficiency of recovering material in each refuse category

M_c = weight in tons of incoming material in each refuse category

Then the total weight (W_t) of the recovered materials is calculated as follows:

$$W_t = \sum_{i=1}^{11} R_i = R_1 + R_2 + \dots + R_{11} \quad (5-5)$$

where the subscript "i" refers to each waste category

The weight of the rejected materials, such as the heavier and nonferrous materials, is computed by simply subtracting the total weight of the input refuse from the weight of the recovered materials:

$$X = \sum_{i=1}^{11} I_i - W_t \quad (5-6)$$

where X = weight of rejected materials

I_i = initial weight of materials in each refuse category

The simulated processing of the fuel fraction (light fraction) from each of the separation modules continues until a fuel product enters a storage module. Then the heavy fractions from each of these modules are summed and "processed" to produce a ferrous product stream and a rejected material stream. The composition and weight of each of these two streams, along with those of the input stream, make up the mass balance for the system.

The output data for the energy balance summarizes the energy flows within a processing system. The calculations for the energy balance are based on the data in the mass balance. The summary is based on the HHV of the processed refuse. The HHV and the moisture content of the entire refuse stream are calculated by summing the HHV and the moisture content for each of the 11 refuse categories:

$$HHV = \frac{\sum_{i=1}^{11} (M_i \times H_i)}{\sum_{i=1}^{11} M_i} \quad (5-7)$$

$$\bar{X} = \frac{\sum_{i=1}^{11} (M_i \times X_i)}{\sum_{i=1}^{11} M_i} \quad (5-8)$$

where M_i = mass of the i th refuse type (lb)

H_i = dry HHV of i th refuse type (Btu/lb)

X_i = average fractional moisture content of the i th refuse type ($X \leq 1.00$)

$\bar{X}$ = average moisture content

The resultant HHV represents an as-received (not a moisture-free) condition.

ECONOMIC ANALYSIS

The operating and maintenance costs are apportioned to each module and then summed for the entire system under the following cost classifications:

operating and maintenance labor, supplies, power consumption, residual materials landfilling, and capital amortization.

The operating and maintenance man-hours for each component are rounded off to the nearest 8-hour multiple to realistically account for the number of 8-hour employees. Then the man-hours for each labor category are multiplied by the respective hourly rates which include overhead. The labor costs include the costs for the plant operation and maintenance.

The cost of the supplies, maintenance parts, and other expendable items for each component is computed in terms of dollars per ton per day. These expendable items are identified as "other supplies." The total cost of these items is calculated by multiplying the daily throughput by the dollars per ton per day given by the respective vendors and then summing these products.

The electrical cost for a system is the sum of the energy and demand costs for the individual components. The individual energy and demand costs are incorporated in the program input when each component is characterized. These costs are based on 100 percent of the electrical load. The costs for peak or surge loads are not included since they would introduce errors larger than those obtained when average costs are used.

The capital cost for each component includes estimates for the original equipment, its operational auxiliaries, and the installation of these items. For example, the estimate for a hammermill would include the costs for the following: an in-feed conveyor, a magnetometer, a shredder (with its motor and the shredder-motor coupling), and a discharge conveyor.

In addition, the sum of the capital costs for each component is increased by 55 percent* to yield a total capital cost that accounts for such factors as administration, overhead, profit, and contingencies. For this study, the cost estimates are based on the costs for mid 1977.

The capital cost of a facility is amortized according to the selected plant life and interest rate. Then the annual capital cost is divided by 260 days for a 5-day week schedule to yield daily capital costs. These costs were based on the assumptions that the entire cost of a facility would be financed and that the type of financing would not appreciably affect the costs for a long-term financing. However, the costs exclude the interest charges during construction because of the wide variance in construction periods.

The cost for the landfill disposal of the residual waste is computed by multiplying the tonnage of the rejected material by the per ton disposal charge which includes the landfill tipping fee as well as the transportation cost.

*Building Construction Cost Data 1977, 35th Edition, Robert Snow Means Co., Inc., 1976.

The potential revenues for the recovered energy are based on the higher heating value and the quantity of the fuel expressed in terms of 10^6 Btu. Of the various materials in the waste stream, only ferrous metals are recovered in the processing simulation. The recovery of other materials, such as aluminum and glass, has not as yet proven economical on a small-scale basis.

The revenue from the sale of a recovered fuel is based on the fuel quantity in tons and the HHV of the fuel. The price received for the fuel is expressed in \$/million Btu and includes the cost for the fuel transportation to the buyer's site. The fuel revenue is calculated by Equation (5-9).

$$R = Q \times \text{HHV} \times P \times 10^{-6} \quad (5-9)$$

where R = revenue (\$/day)

Q = fuel produced (TPD)

HHV = higher heating value (Btu/ton)

P = price (\$/ 10^6 Btu)

The revenue from the sale of recovered ferrous material is based on the material purity (percentage of iron) and quantity in tons. In this study, the price for the ferrous materials was based on buyer quotations for ferrous scrap during January, 1978. This price, however, is FOB the resource recovery facility. The price for ferrous material is calculated by Equation (5-10), which is reasonable in view of the information available:

$$R = P \times Q(2p - 1) \quad (5-10)$$

where R = daily ferrous revenue (\$/day)

P = ferrous price (\$/ton)

Q = ferrous metal produced (TPD)

p = purity of the ferrous metal ($p \leq 1.00$)

The factor $(2p - 1)$ is applied to reflect that at 50 percent purity the recovered stream has no value and that the increase in value between 50 percent and 100 percent purity is roughly a linear relationship.

SUMMARY

Systems characterized in SWIMS have to be simulated somewhat differently because of the variations in the form and completeness of the data supplied by the equipment and system vendors. To complete the system characterizations and the simulations, the simulated systems are generally based on combinations of actual, scaled, and hypothetical data. Such data combinations were typical in characterizing the mechanical separation components in the mechanical

processing modules. For example, whenever a vendor of a thermal processing system did not supply the data for the refuse preprocessing components, the mechanical processing system had to be simulated to derive the total operational cost. In this simulation, the components making up the simulated system were selected so as to prepare the refuse derived fuel according to the vendor specifications.

SECTION 6

SAMPLE SIMULATION

The RDF facility in Ames, Iowa, was chosen for the sample simulation because of its current 250-TPD capacity and its substantial amount of operational data that would permit readily comparing this plant with similar facilities. Data for this simulation is taken in part from reports generated by Midwest Research Institute under EPA Grant No. R83931.

THE AMES, IOWA, FACILITY

The Ames plant consists of seven major components which are depicted by the flow chart in Figure 2. Refuse is received on a tipping floor and conveyed to a horizontal primary shredder. The material then passes under a belt magnet which recovers ferrous materials to be sold as scrap iron. The nonferrous waste stream then goes through a secondary shredder identical to the first shredder. The finely shredded material passes through an air classifier, and its light fraction is stored for sale as refuse derived fuel. The heavy fraction passes under another belt magnet which also recovers ferrous materials to be sold as scrap iron. The nonferrous materials are ultimately landfilled.

PROGRAM INPUT

Since the SWIMS program was only applied to systems with 100- or 200-TPD operating capacities in this evaluation, the simulated input tonnage had to be adjusted to be representative of the throughput rate at Ames. Although the Ames facility was designed to process 400 TPD, its actual capacity is only 250 TPD and it has been operating at 63 percent of capacity or 157 TPD. Consequently, since a 200-TPD plant was chosen for the simulation, the operating capacity was proportionately reduced to 125.6 TPD.

The coded processing line entered in the computer is shown in Table 2. For this simulation, some of the standard parameter values were changed to reflect the actual operating conditions at the Ames plant. They are also shown in Table 2. The waste stream has a high concentration of paper since the plant services the Iowa State University and other commercial "waste paper" generators.

Operator and maintenance salaries were set at \$12 and \$16.29 per hour, respectively. The price of the recovered fuel was calculated to be \$1.22 per 10^6 Btu. Landfill costs were estimated at \$1 per ton. The plant was

Figure 2. Ames process flow chart.

amortized over 20 years at an interest rate of 10 percent. The selling price for the recovered ferrous product was \$45 per ton.

The computer printout for this simulation is presented in Table 4.

PROGRAM OUTPUT

The major outputs of the sample problem simulation are the net daily cost and the net per ton cost of processing the waste stream. The \$14.20 per ton cost calculated in this simulation with "average" performance data closely approaches the \$15.15 per ton cost presented in the United States Environmental Protection Agency report prepared by Midwest Research Institute and Iowa State University. Other results of the simulation presented as part of the program output are presented in the following paragraphs.

The computer printout is in the standard Level 1 format, and its length is approximately 400 lines. The plant name appears as the first line of output information, and the operational parameter changes follow. The summary for the first component, that is the tipping floor in this simulation, includes the following information: (1) daily operating and maintenance hour requirements, (2) daily labor costs, (3) initial equipment costs, and (4) daily electrical power requirement. The next two lines of output after this information present the HHV and the moisture content of the incoming waste stream. The final data line for this component presents the operating cost, including the capital amortization and cost per ton of refuse processed.

Except for the waste stream characteristics, the summaries for the subsequent components include the foregoing information and the operating time for each component. The data for the separation components provide information on the material splits. This information is expressed as a mass balance such as that given for the multistage magnet in the third component. The mass balance is applied to each of the 11 waste stream categories. The input tonnage is separated into two output streams, magnetics and nonmagnetics, with the magnetic stream held in storage and the nonmagnetic stream processed through succeeding process steps.

The hammermills, the second and fourth components, are only involved in the economic calculations since they do not perform a separation function. The air classifier, the fifth component, divides the input stream into a light and a heavy fraction. The mass balance gives an overview of the processing systems and is a part of the simulation output that ultimately presents the product streams.

The data for the sixth component, which is a storage module, includes an estimated boiler heat balance along with the standard output data for the storage module. The program calling for a storage module indicates that an acceptable fuel product was generated. The boiler heat balance presented in this section provides the means for estimating the heat that can be recovered from the fuel product. As the final information for the boiler balance, the printout lists the HHV of the fuel product and an estimated boiler efficiency. After the fuel product data, the printout shows the results of the simulated processing of the heavy fraction.

TABLE 4. AMES SIMULATION LEVEL 1 PRINTOUT

1	

AMES IOWA SIMULATION	

DEFAULT VALUE CHANGES	
1	PAPER 0.700
2	ORGANICS 0.125
3	WOOD 0.013
4	IRON 0.035
5	ALUMINUM 0.305
6	METALS 0.002
7	GLASS 0.052
8	PLASTICS 0.018
9	TEXTILES 0.012
10	INERTS 0.023
11	FINES 0.015
12	TONS/DAY INPUT 125.60
13	OPERATOR SALARY 12.00
14	MAINT. SALARY 16.29
15	FUEL PRICE 1.22
22	LANDFILL COST 1.00
23	PLANT LIFE 20.00
26	PRINT B01.DAT 1.00
29	FERROUS PRICE 45.00

TIPPING FLOOR=200 TPD	
1 2	
TO PROCESS 125.600 TONS REQUIRES	
OPERATOR HOURS	5.02 HRS.
MAINTENANCE HOURS	1.51 HRS.
OPERATING & MAINT. COSTS	\$ 112.47
INITIAL COST	\$ 403000.
ELECTRICAL USAGE	35.17 KW-HR
INPUT STREAM HAS A HHV OF 5169 BTU/LB.	
MOISTURE CONTENT IS .211	
THE COST TO OPERATE THIS MODULE IS \$ 2.35/TON	

HORIZ. RAW HAMMERMILL-200 TPD	
2 2	
(continued)	

TABLE 4. (continued)

MACHINE TIME REQUIRED IS 4.10HRS

TO PROCESS 125.600 TONS REQUIRES

OPERATOR HOURS	2.51 HRS.
MAINTENANCE HOURS	3.77 HRS.
OPERATING & MAINT. COSTS	\$ 217.12

INITIAL COST	\$ 357500.
ELECTRICAL USAGE	1256.00 KW-HR

THE COST TO OPERATE THIS MODULE IS \$ 3.36/TON

MULTI-STAGE BELT MAGNET-200 TPD

74

MASS BALANCE

	INPUT	MAGNETIC	NONMAGNETIC
PAPER	87.920	0.440	87.460
ORGANICS	15.700	0.016	15.684
WOOD	1.633	0.000	1.633
IRON	4.396	4.176	0.220
ALUMINUM	0.628	0.006	0.622
METALS	0.251	0.000	0.251
GLASS	4.898	0.000	4.898
PLASTICS	2.261	0.000	2.261
TEXTILES	1.507	0.000	1.507
INEFFS	2.889	0.029	2.860
FINES	3.517	0.000	3.517

MACHINE TIME REQUIRED IS 4.10HRS

TO PROCESS 125.600 TONS REQUIRES

OPERATOR HOURS	0.21 HRS.
MAINTENANCE HOURS	0.04 HRS.
OPERATING & MAINT. COSTS	\$ 7.80
INITIAL COST	\$ 71800.
ELECTRICAL USAGE	75.36 KW-HR

MAGNETIC MATERIAL:

AMT. RECOVERED	4.67 TONS
PURITY	0.895
VALUE	\$ 165.86

THE COST TO OPERATE THIS MODULE IS \$ 0.34/TON

(continued)

TABLE 4. (continued)

HORIZ. RAW HAMMERMILL-200 TPD

2 2

MACHINE TIME REQUIRED IS 4.19HRS

TO PROCESS 120.933 TONS REQUIRES

OPERATOR HOURS		2.42 HRS.
MAINTENANCE HOURS		3.63 HRS.
OPERATING & MAINT. COSTS	\$	209.06
INITIAL COST	\$	357500.

ELECTRICAL USAGE 1209.33 KW-HR

THE COST TO OPERATE THIS MODULE IS \$ 3.41/TON

RADER A.C.-200 TPD

3 4

MASS BALANCE

	INPUT	LIGHT	HEAVY
PAPER	87.480	80.482	6.998
ORGANICS	15.684	7.842	7.842
WOOD	1.633	0.816	0.816
IRON	0.220	0.011	0.209
ALUMINUM	0.622	0.124	0.497
METALS	0.251	0.013	0.239
GLASS	3.674	0.184	3.490
PLASTICS	2.261	1.809	0.452
TEXTILES	1.507	1.356	0.151
INEFTS	2.860	0.143	2.717
FINES	4.741	2.845	1.897

MACHINE TIME REQUIRED IS 4.19HRS

TO PROCESS 120.933 TONS REQUIRES

OPERATOR HOURS		1.05 HRS.
MAINTENANCE HOURS		1.05 HRS.
OPERATING & MAINT. COSTS	\$	38.40
INITIAL COST	\$	317700.
ELECTRICAL USAGE		435.41 KW-HR

(continued)

TABLE 4. (continued)

LIGHT MATERIAL:

AMT. REMOVED	95.63 TONS
HHV	5982. BTU/LB.
MOISTURE CONTENT	0.202

THE COST TO OPERATE THIS MODULE IS \$ 1.63/TON

ATLAS 5710-200 TPD

0.604

MACHINE TIME REQUIRED IS 6.38HRS

TO PROCESS 95.625 TONS REQUIRES

OPERATOR HOURS	3.19 HRS.
MAINTENANCE HOURS	6.38 HRS.
OPERATING & MAINT. COSTS	\$ 168.30
INITIAL COST	\$ 871600.

ELECTRICAL USAGE

1632.00 KW-HR

THE COST TO OPERATE THIS MODULE IS \$ 6.48/TON

BOILER HEAT BALANCE

FUEL PROPERTIES	FRACTION
-----------------	----------

CARBON	0.3498
HYDROGEN	0.0464
OXYGEN	0.3405
NITROGEN	0.0036
SULFUR	0.0016
ASH	0.0572
MOISTURE	0.2020

(continued)

TABLE 4. (continued)

EXCESS AIR IS	0.3000
UNBURNT CARBON IS	0.1000 LB/LB
FLUE GAS TEMPERATURE IS	400. F
ASH TEMPERATURE IS	300. F
LB-AIR/LB-FUEL IS	5.979
LOSS ANALYSIS COMPONENT	BTU/LB
CARBON DIOXIDE	94.
NITROGEN	377.
OXYGEN	17.
SULFUR DIOXIDE	0.
TOTAL DRY GAS LOSS	487.
HUMIDITY	11.
BOUND MOISTURE	242.
COMBUSTION WATER	517.
TOTAL WATER LOSS	771.
R/C LOSS	120.
ASH LOSS	493.
ASH SENSIBLE LOSS	4.
TOTAL LOSS	1875.
HIGHER HEATING VALUE	5982. BTU/LB (DRY BASIS)
BOILER EFFICIENCY 68.6605 PERCENT	

MULTI-STAGE BELT MAGNET-200 TPD	7 4

(continued)

TABLE 4. (continued)

MASS BALANCE			
	INPUT	MAGNETIC	NONMAGNETIC
PAPER	6.998	0.035	6.963
ORGANICS	7.842	0.008	7.834
WOOD	0.816	0.000	0.816
IRON	0.209	0.198	0.010
ALUMINUM	0.497	0.005	0.492
METALS	0.239	0.000	0.239
GLASS	3.490	0.000	3.490
PLASTICS	0.452	0.000	0.452
TEXTILES	0.151	0.000	0.151
INERTS	2.717	0.027	2.690
FINIS	1.897	0.000	1.897

MACHINE TIME REQUIRED IS 4.19HRS

TO PROCESS 25.308 TONS REQUIRES

OPERATOR HOURS		0.21 HRS.
MAINTENANCE HOURS		0.04 HRS.
OPERATING & MAINT. COSTS	\$	7.80
INITIAL COST	\$	71800.
ELECTRICAL USAGE		75.36 KW-HR

MAGNETIC MATERIAL:

AMT. RECOVERED		0.27 TONS
PURITY		0.726
VALUE	\$	5.55

THE COST TO OPERATE THIS MODULE IS \$ 1.69/TON

15000 SQ FT BUILDING

THE BUILDING REQUIRES

INITIAL COST	\$610000.00
OPERATING & MAINT. COST	\$ 70.38

THE COST TO OPERATE THIS MODULE IS \$345.96/DAY

(continued)

TABLE 4. (continued)

WASTE MATERIAL TO LANDFILL

PAPER	6.963
ORGANICS	7.834
WOOD	0.816
IRON	0.010
ALUMINUM	0.492
METALS	0.239
GLASS	3.490
PLASTICS	0.452
TEXTILES	0.151
INERTS	2.690

FINES 1.897
ASH 0.000

WASTE MATERIAL:

AMT. REMOVED	25.03 TONS
HHV	3054. BTU/LB.
MOISTURE CONTENT	0.326

FUEL:

AMT. RECOVERED	95.63 TONS
HHV	5982. BTU/LB.
MOISTURE CONTENT	0.202
BOILER EFF. (EST.)	0.69
ASH CONTENT	5.72 %
GLASS CONTENT	0.19 %
FINES CONTENT	2.97 %

***** PLANT SUMMARY *****

THESE FIGURES INCLUDE CONSTRUCTION, ENGINEERING, AND INFLATION :	\$\$\$\$\$
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TO PROCESS 125.600 TONS OF REFUSE PER DAY

COSTS

(continued)

TABLE 4. (continued)

A TOTAL OF 14.61 OPERATOR AND 16.41 MAINTENANCE HOURS ARE REQUIRED		
LABOR	16.00 HOURS AT \$ 12.00 PER HOUR	\$ 192.00
MAINTENANCE	24.00 HOURS AT \$ 16.29 PER HOUR	\$ 390.96
ELECTRICAL USAGE		
	4718.63 KW-HR OF ENERGY AT \$0.025 PER KW-HR	\$ 117.97
	993.25 KW OF DEMAND AT \$0.080 PER KW	\$ 79.46
	TOTAL (AVERAGE COST \$0.042 PER KW-HR)	\$ 197.43
OTHER COSTS		\$ 388.75
INITIAL COST OF PLANT AMORTIZED OVER 20. YEARS AT 10.0 PERCENT INTEREST		\$ 4775000 \$2157.20
LANDFILL COSTS	25.03 TONS AT \$ 1.0 PER TON	\$ 25.03
** TOTAL COST **		\$ 3351.37
REVENUES		
FUEL PRODUCT:		
RDF	95.63 TONS @ \$ 1.22/MMBTU	\$ 1396.7
TOTAL FUEL		1396.79
FERROUS METALS	4.94 TONS @ \$34.70/TON	171.41
ALUMINUM	0.00 TONS	0.00
GLASS	0.00 TONS	0.00
** TOTAL REVENUE **		\$ 1568.20
NET COST IS \$ 1783.17		
***** COST PER TON IS \$ 14.20 *****		

(concluded)

The data for the seventh component, another multistage belt magnet that operates on the heavy fraction, includes all the ferrous material recovered for sale. This material includes the ferrous material recovered by the third as well as the seventh component.

The next items in the printout present the size, capital cost, operating and maintenance cost, and daily total cost of the building. This information is followed by a brief analysis of the material to be landfilled, including the material composition, tonnage, HHV, and moisture content.

The next section in the Level 2 output is a brief fuel analysis. The data for this analysis includes the weight; HHV; and moisture, ash, glass, and fines content of the recovered fuel. This analysis also includes the estimated boiler efficiency.

The plant summary, which is the Level 3 output, consists of two major sections, costs and revenues. The costs section summarizes the costs for operating labor, maintenance labor, electrical power consumed, overhead expenses, plant amortization, and landfill disposal. The total cost per day is the last item presented in this section.

The revenues section includes income from the sale of the refuse derived fuel and the recovered ferrous material. The total revenue per day is the last item presented in this section.