UNIVERSITY OF NEVADA, RENO

SYSTEM AND ECONOMIC ANALYSIS OF A MUNICIPAL SOLID WASTE TREATMENT PLANT

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN MECHANICAL ENGINEERING

BY

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ABSTRACT

The Municipal Solid Waste treatment plant involves mechanical thermal and chemical processing of solid waste for the separation of MSW into in-organic and organic materials and for production of biogas. The purpose of this study is to perform an economic analysis to examine the viability of a Municipal Solid Waste Treatment System (MSWS) in Northern Nevada. A Reno, Nevada company, Comprehensive Resources, Recovery and Reuse, Inc. (CR3), has developed a system design and tested a prototype. However, the economic feasibility of using the CR3 system design in Northern Nevada has not been established. Two scenarios of economic analysis of the four unit plant have been carried out. In the first case, the economic analysis of the plant with biogas production was calculated. In the second case, the economic analysis of the plant without biogas production was carried out. The results indicated that the plant with biogas production is more economically viable than the plant without biogas production. In fact, it is not feasible to operate the plant unless biogas is produced.

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Vitech Corporation had been a great help in making me understand CORE concepts.

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INTRODUCTION

1.1 BACKGROUND:

Municipal Solid Waste (MSW) is the waste generated in a community with the exception of industrial and agricultural wastes [1]. Hence MSW includes residential waste (e.g., households), commercial (e.g., from stores, markets, shops, hotels), and institutional waste (e.g., schools, hospitals). Paper, paperboard, garden and food waste can be classified in a broad category known as organic or biodegradable waste.

The organic compound fraction of MSW in the US represents 70% of the waste composition and consists of paper, garden waste, food waste and other organic waste including plastics. The biodegradable fraction (garden, paper and food waste) accounts for 53% of waste composition [2]. Treatment of this waste is an important component of an integrated solid waste management strategy and reduces both toxic and volume of MSW requiring final disposal in the landfill.

The biodegradable fraction of MSW contains anywhere from 15%-70% water. Themelis and Kim (2000) [3] showed that a representative average molecular formula for organic wastes, excluding nitrogen and other minor components, is $C_6H_{10}O_4$. The anaerobic decomposition of organic materials yields principally Methane (CH_4), Carbon-dioxide (CO_2) and a solid compost that can be used as soil conditioner.

In the United States over 200 million tons of municipal solid waste is generated every year [4]. About two thirds of this material finds its way to the landfills. Landfills, apart from the space they take up, create significant environmental issues such as gas emissions to the atmosphere and leachates into the groundwater.

Comprehensive Resources Recovery and Reuse (CR3), a small technological company, has been addressing better ways to recover and recycle products from MSW. It has developed a system of steam conditioning that allows the organic portion of the solid waste to be separated from the inorganic fraction. Sufficient testing has been completed at the Comprehensive Resources demonstration plant in Reno, Nevada to confirm the viability of the steam conditioning system to separate materials. The pilot plant in Reno has one autoclave in the steam conditioning system. The pilot demonstration unit was based on six feet diameter with a shortened tube length, providing a rated volume per batch of two tons. Using the dimension of the pilot plant the solid waste behavior regarding the pulping dynamics is very credible.

Four ten foot diameter autoclaves are recommended for the commercial plant to condition a 25 ton batch of solid waste each cycle. The combined production output on a 24 hour day basis is 1000 tons. With the CR3's technology a first small commercial plant was constructed in Minnesota in 2004 and has been in operation since then.

A national company, Waste Management, with operations in Nevada, has stated that the MSW treatment is not economical. Consequently, this study involves economic analysis to establish economic feasibility wherein the raw MSW is been paid to store it and the waste material from the processed MSW can be sold to the paper industry for manufacturing recycled paper. Given the capital costs, revenue streams and the annual

O&M costs, the study investigates the economic feasibility of a plant for which the raw materials and the resulting output are revenue sources.

1.2. ADVANTAGES OF BIOGAS:

It is a known fact that fossil fuels cause environmental pollution so that investigating into different sources of energy that reduces the pollution problem that we are facing are being conducted. Biogas is one such way in which energy can be produced without causing much pollution. The main constituents of Biogas are Methane (50-60%), CO_2 (30-40%) and small quantities of residues. Biogas energy offers many advantages [7].

1. Biogas powered electricity plants can be built quickly, simply, and for much less money per kilowatt than coal, oil or nuclear power plants.
2. Unlike these other current resources, biogas is a renewable resource.
3. Biogas provides an excellent source of energy that is helpful to the environment.
4. The residue from burning biogas, called activated sludge, can be dried and used as fertilizer.

1.3. OBJECTIVES AND APPROACH:

The objective was to determine the performance, economic feasibility and environmental benefits of processing the MSW using CR3's technology. The study of MSW System, consisting of a Steam Conditioning (SC) Subsystem (autoclaves, eductor, oil heaters, and trommel), and Digester Subsystem (DS) (High Rate Anaerobic Digester and High Solids Anaerobic Digester) used CORE software (a systems engineering design and analysis tool) to design and analyze the MSW system, model by comparing the CORE simulated results with the theoretical results. The CORE software provides a great deal of flexibility, not only in modeling a system but also in configuring the CORE environment.

The approach used the following steps:

- Model the Steam Conditioning system using CORE
- Verify the CORE model by comparing the theoretical results with the simulated results.
- Optimize the system, *i.e.* to compare the viability of the four unit system which produces biogas gas as the end product against the plant where the short fibers are sent to the land fill without being processed further and long fibers being sent to the paper manufacturing industry.
- Determine the economic viability of the Municipal Solid Waste Treatment plant.

CORE DESCRIPTION [6]

The goal of System Engineering is to design/specify a balanced system that satisfies the customers' needs and requirements. CORE is a tool that is used to solve model-based systems engineering problems. The CORE software synchronizes system requirements, behavioral models, architectures and design solutions with system specifications and test procedures. The resulting integrated executable architecture can be simulated using CORESIM, a discrete event simulator, to gain insight into potential performance issues enabling better risk and contingency management for any size project. The way that CORE was used in this research was to compare the theoretical time cycle with the simulated time cycle.

CORE was used to:

- Develop and document the MSW Functional Architecture.
- Develop and document the MSW Physical Architecture.
- Develop and document the MSW Operational Architecture..
- Simulate the MSW Performance based on the MSW Operational Architecture Model the Operational Architecture of the MSW system.

1.4. SYSTEM OVERVIEW:

MSW is received at the landfill and loaded into steam conditioner (SC) for reforming these heterogeneous products to facilitate sorting. Steam Conditioning permits expanded recovery and reuse using various recycling methods in a more innovative manner. The treatment recommended for MSW is a steam pressure and vacuum process that starts off by sanitizing the MSW in a propriety arrangement of rotary pressure vessels that act as steam autoclaves with repulping features. Steam autoclaving conditions the MSW such that downstream sorting can be efficiently carried out in a safe environment producing uniform clean products for downstream use. Following separation into organic and non-organic materials, further processing is accomplished by the digester subsystem. Inorganic items shown as recyclable are recovered by conventional methods. The long fiber available is marketable to the paper industry and represents a high quality pulp more valuable than normal waste paper feedstock obtained by curbside programs.

Table 1.1 shows the constituents in an average MSW stream and how they can be separated after the steam conditioning treatment. Splitting by size is shown by percentages for each of the materials present when passed over a ½”screen. Representation on the sector chart, Figure 1.1, indicates these percentages, 66 percent passing with 34 percent retained, and more importantly shows the components available for recycling or as organic sludges suitable for biogas or synthetic gas production.

TABLE 1.1 Municipal Solid Waste Constituents[13]

1,250 Tons (including 250 Tons water)
Material Balance 1,000 Tons Dry

Source:CR3

Type of Materials	Tons	½” Size Splitting		Remarks
		Pass	Retain	
Paper	500			
Cellulose long	260	260	0	Marketable
Cellulose short	185	185	0	Gas production
Minerals- inks	30	30	0	
Starch furnish	25	25	0	Gas production
Food	75			
Food – misc.	75	75	0	Gas Production
Glass and others	210			
Glass	60	20	40	Partial Use
Leather – carpets	20	0	20	
Buildings debris	20	0	20	
Wood – Yardwaste – dirt	70	25	45	
Rags – Fabrics	40	0	40	
Metals	100			
Aluminum	15	0	15	Recyclable
Steel, etc.	85	0	85	Recyclable
Plastics	115			
Film – LDPE	60	40	20	
PET – HDPE	25	0	25	Recyclable
PVC – HD Plastic	30	0	30	
TOTAL	**1,000**	**660**	**340**	N/A

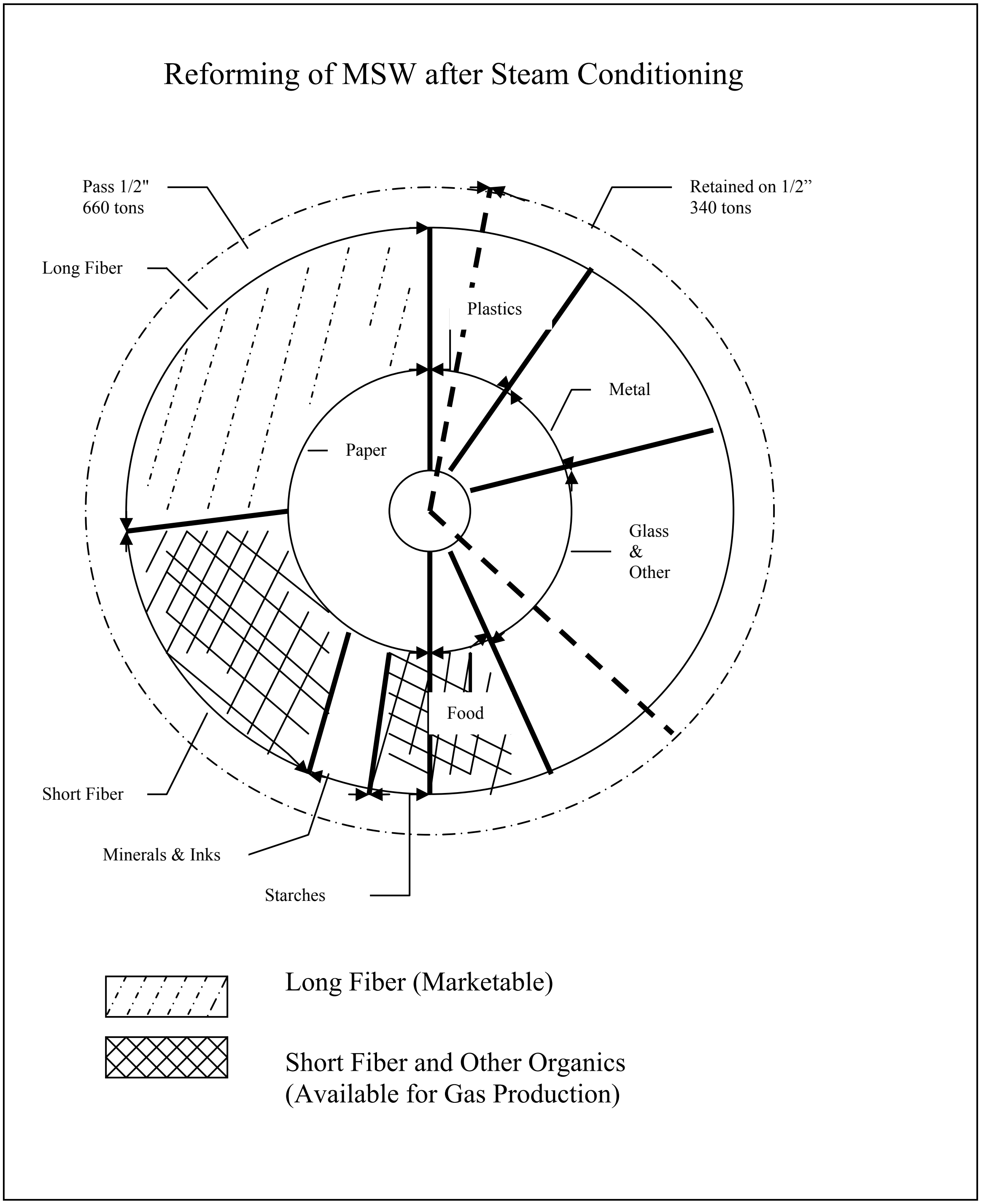

Figure 1.1 Sector Diagram [13]

Biogas produced from this phase will be available for green power electrical generation and using a cogeneration feature will also supply the process heat required in this system with the remainder of the electricity made available for sale. The above approach would divert organics away from landfills greatly reducing the harmful effects on the environment. In addition landfill diversion would be greatly increased as this organic portion which is presently being deposited in the landfills is recovered and reused.

Chapter 2

OPERATIONAL CONCEPT

2.1. RECEIPT OF MSW

All residential, institutional and commercial MSW is accepted at the MSW plants where it is received on a standard transfer station floor where removal of bulks can be carried out permitting at first inspection. Loading equipment moves the MSW to the receiving pit where the sliding floor conveyors feed the inclined conveyors supplying each of the four autoclaves. A further visual inspection is made of the material on the belt as it is loaded into the autoclaves. The operator inspects each delivery on a thirty minute cycle time and can stop the belt in order to remove objectionable objects escaping in the initial inspection. All the accepted material now enters the autoclave for further processing.

2.2 STEAM CONDITIONING SYSTEM SEPARATION

Initially the autoclave is loaded in the raised position having the MSW fed into the vessel with the wetting agent concurrently. The autoclave rotates during the filling compacting the MSW into the body of the vessel as it becomes saturated. The wetting agent is preheated so that the mixture attains a known temperature of about 92 degrees Fahrenheit prior to the door on the autoclave being fastened. At this point the eductor removes air from the vessel, creating a negative pressure in the autoclave and improving the steam condensing capacity of the contents.

The process description discussed below is based on a four unit grouping of autoclaves using the interconnecting piping and valving concept. This plant is sized to handle 1250 tons per day of MSW which on a dry weight basis is 1,000 tons. All the charts for both material balance and energy requirements are applied to these four 25 ton capacity autoclave units. The steam process steps are shown on Figure 2.1 and Table 2.1 for the four autoclaves where point F corresponds to the fully loaded position at the start of the 120 minute cycle at time zero for autoclave 1. It is now loaded with 25 tons of MSW, plus 6.25 tons of inherent water and 11.25 tons of a wetting agent. It is also assumed that the four unit plant is in a state of steady operation and given below is the detailed operational process steps of autoclave 1.

TABLE 2.1 OPERATIONAL ACTIVITIES AND HEAT TRANSFER FOR AUTOCLAVE 1 [13]

(120 Minute Cycle Time)

Node	Activities (Related to autoclave 1)	Time Min. Temp ^oF	Remarks	Heat Transfer x 10 M BTU		
				Oil	Steam	
				In	In	Out
F-G	Autoclave 1 receives 3.5 tons steam from autoclave 3	0-10 92-200	Autoclave 3 into cool down mode	-	8.10	-
G-H	Autoclave 1 receives 1.5 tons steam from autoclave 4	10-15 200-247	Hot oil mobilized at 10 minutes	0.75	3.45	-
H-A	Autoclave 1 continues heat rise with hot oil exchange only	15-45 247-292		4.20	-	-
A-B	Autoclave 1 releases 1.5 tons steam to autoclave 2	40-45 292-262	First flash from autoclave 1 contents	0.75	-	3.45
B-C	Autoclave 1 regains heat from hot oil exchange	45-60 262-292		2.20	-	-
C-D	Autoclave 1 releases 3.5 tons of steam from cool down to autoclave 3	60-70 292-212	Hot oil cut off at 70 minutes	1.50	-	8.10
D-E	Autoclave 1 connected to eductor to complete cool down and drying releasing 2.0 tons steam	70-90 212-152	Condensate and heat collected in eductor tank for recovery		-	4.30
E-X	Autoclave 1 door removed and contents emptied into trommel loading bin	90-105 152-62	Not in closed pressure loop			
Y-F	Autoclave 1 refilled with 25 tons MSW, 6.25 tons inherent water and 11.25 tons wetting agent. Door close and air extracted	105-120 62-92	Not in closed pressure loop			

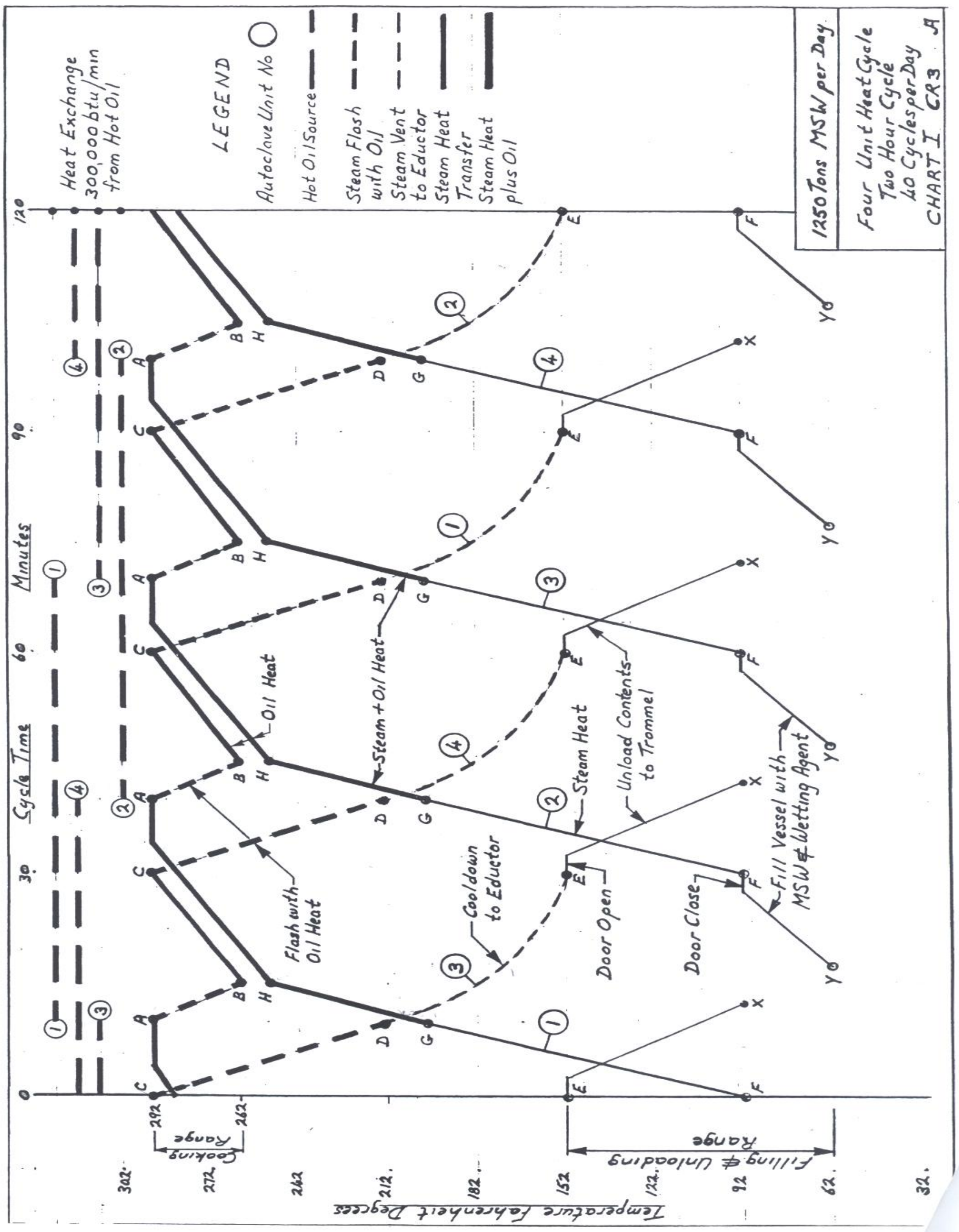

Figure 2.1. Cycle Diagram [13]

Air is first extracted from the sealed autoclave using the eductor jet and then 3.5 tons of steam is immediately transferred from a second autoclave that is previously heated, i.e. autoclave 3, at a full pressure and temperature (45 p.s.i and 292 degrees Fahrenheit). In this sequence the first flash is autoclave 3 traveling from point C to point D (refer to Figure 2.1). It has a duration of ten minutes allowing the temperature in autoclave 3 to drop to 212 degrees Fahrenheit. This in turn raises the temperature of autoclave 1 to about 200 degrees Fahrenheit. The steam transfer from this flash takes autoclave 1 from point F to point G.

A second flash sustained for five minutes is released from autoclave 4 also previously heated to 292 degrees Fahrenheit. Autoclave 1 again receives this flashed steam amounting to 1.5 tons and at the same time, 10 minutes into the cycle, hot oil is mobilized. This now gives a total transfer of 5 tons of steam combined with the oil heat which raised autoclave 1 to 252 degrees Fahrenheit at cycle time fifteen minutes corresponding to point H. using oil heat alone the temperature continues to rise to 292 degrees Fahrenheit and the contents are raised with the maximum water content for pulping (40 percent consistency). This part of the cycle continues to point A for twenty five minutes in the cooking zone for a total elapsed cycle time of forty minutes.

Autoclave 1 is now ready to give the first flash for a five minute duration traveling from point A to B. The temperature is allowed to drop from 292 degrees to 262 degrees Fahrenheit with a corresponding pressure drop from 45 p.s.i to 20 p.s.i. This first flash from autoclave 1 transfers 1.5 tons of steam to autoclave 2 as it travels from point G to H. Oil heat continues through the flash and on to point C fifteen minutes later when the temperature is restored to 292 degrees.

Having reached point C on autoclave 1 this autoclave is sixty minutes into the time cycle and is ready for its second flash and the beginning of the drying and cool down phase. The starting consistency at point C is 42 percent having lost 2 percent of the moisture with the first flash. Over a ten minute period the second flash is completed to 212 degrees Fahrenheit. Steam amounting to 3.5 tons is being transferred to autoclave 3 with the consistency in autoclave 1 further reduced now to 47 percent. Oil heat exchange is disconnected at point D now seventy minutes into the cycle time which has provided a total of sixty minutes one half of the total cycle time established at two hours.

The final part of the cool down and drying is carried out by connecting autoclave 1 to the eductor jet from point D to point E. During this stage an additional 2.2 tons of condensate is extracted from the contents. Both water and heat are collected in the eductor tank for reuse as makeup water and preheat for the wetting agent. Contents are now cooled down to 152 degrees Fahrenheit at a consistency of 50 percent are metered through the trommel for size separation. At this point residual heat is considered lost to ambient with the exception of the fine biomass fraction which enters the went phase at 92 degrees Fahrenheit.

The cycle time from node E to node F which is for a total of thirty minutes takes the autoclave 1 out of the closed pressure loop. By node X the vessel is now empty and brought back to the raised position node Y for refilling with MSW and the preheated wetting agent. Table 2.1 shows ambient and cooking temperatures used in the heat balance. The heat available from the D-E phase of 4.3 million Btu as sensible heat is approximately doubled that required to preheat the wetting agent from a 62 degree Fahrenheit ambient to the 92 degree Fahrenheit starting temperature.

Treated materials are now removed from the autoclave after the door is opened and transferred to the rotary trommel for size separation. The SC system reforms the MSW to a consistency that permits a size separation through one half inch screen. STEP I is the over fraction representing the materials predominantly inorganic. In case of STEP II, the fraction passing over one half inch screen, there is over eighty percent of the organic material including a similar percentile for water. The wetting agent that is added to the 1250 tons of MSW in the autoclave is a low quality water. It amounts to 450 tons per day and where logistics permit can be activated sludge from an adjacent waste water treatment plant. This water is handled in STEP II by the process water treatment plant and is suitable for reuse as process water.

STEP I includes steam processing, size separation and the normal recycling of metals, plastics and glass. This is carried out on a 510 tons of material retained on the one half inch screen and will allow recovery for 165 tons of normal recyclables. In addition a further 740 tons is diverted to STEP II processing. The residuals for landfilling from STEP I is 245 tons which includes 50 tons of water of a material essentially free from organics and leachable constituents.

Consequently to the flexibility of this technology STEP I and STEP II can be operated independently if desired. The amount transferred to STEP II is 1190 tons which includes the 450 tons of wetting agent. Recycling of this fraction is initiated in a wet pulping process where density and size separation equipment removes the contaminants from the fiber. After a series of rinsing 300 tons of a pulp substitute is available as a recycled product for sale to a paper mill.

TABLE 2.2 MASS BALANCE FOR 1250 TONS PER DAY PLANT, NON-SOURCE SEPARATED [13]

Type of Materials	Tons	STEP I Ret. ½ in. Screen			STEP II Pass ½ in. Screen		
		Total	Recycle.	Landfill	Total	Recycle	landfill
Paper	**500**	**20**	**-**	**20**	**480**	**405**	**75**
Cellulose long	300	-	-	-	300	300	-
Cellulose short	145	20	0	20	125	80	45
Minerals-Inks	30	-	-	-	30	-	30
Starch Furnish	25	-	-	-	25	25	-
Foods	**75**	**-**	**-**	**-**	**75**	**75**	**-**
Foods-misc.	75	-	-	-	75	75	-
Plastics	**115**	**75**	**25**	**50**	**40**	**-**	**40**
Pet-HDPE	25	25	25	-	-	-	-
Film-LDPE	60	20	-	20	40	-	40
PVC-HD	30	30	-	30	-	-	-
Metals	**100**	**100**	**100**	**-**	**-**	**-**	**-**
Aluminum	15	15	15	-	-	-	-
Steel, etc	85	85	85	-	-	-	-
Glass and Others	**210**	**165**	**40**	**125**	**45**	**-**	**45**
Glass	60	40	40	-	20	-	20
Leather-carpets	20	20	20	-	-	-	-
Building debris	20	20	20	-	-	-	-
Wood-YW-Dirt	70	45	-	45	25	-	25
Rags-Fabrics	40	40	-	40	-	-	-
Water Inherent	**250**	**150**	**100**	**50**	**100**	**-**	**100**
Total	**1250**	**510**	**265**	**245**	**740**	**480**	**260**

2.3 WET PROCESS SEPARATION

The predominance of the paper fiber included in this biomass gives its appearance of a gray to brown pulp which is carrying significant particulates ranging from glass shards to plastic balls along with various other granular waste particulates. Because of the steam atmosphere and elevated temperature, the thermoplastic materials are exposed to they become deformed and assume globular shapes but they are not damaged in terms of recyclability. However plastic film and plastic coatings are transformed into very small pellets. Styrofoam behaves in similar manner converting to polystyrene pellets all combining to produce a large stream of commingled pellets that could be isolated for further treatment. In order to separate the above particulates from the paper fiber along with the grit, dirt, paper furnishes and ink which are also present, the second part of the process has to be a wet process. The process was developed along traditional paper pulp industry standards and modified to suit the unique characteristics of the biomass generated by the Steam Conditioning System.

The fine or biomass fraction of the trommelled material carries over 90 percent of the moisture remaining in the autoclaved waste stream. The moisture is approximately equal in weight to the dry weight of the biomass and it contains the soluble substrates from the food waste and paper coatings. A series of pulping tanks are arranged to receive the biomass and the material is slurried to a 3 percent consistency in water at 120 degrees Fahrenheit. Due to these pulping tanks the contaminants to be removed using gravity separation, size screening and dilution washing in order to prepare the cellulose as a replacement pulp. The rejects from the cleaning and the screening devices allow glass and plastics to be recovered for further processing. Dilution washing and rinsing permits the balance of the biological material in solution to be separated from the paper fiber as fine solid contaminants are removed. The final washing and rinsing step carried out classifies the fiber product to a specified freeness and cleanliness to meet replacement pulp standards. The pulp is now thickened and dried to a wet lap and baled for shipping. The rinse water remaining still carries large amounts of colloidal and suspended fibers in addition to containing a highly concentrated solubilized fraction. Slipstreaming of the rinse or process water is carried out using cleaners continuously which allows then an internal waste water treatment system to recycle the process water for reuse in the plant.

2.4 WATER TREATMENT BIOGAS PRODUCTION

Rinse water after being treated through a series of cleaners now produces a thickened reject effluent which is extracted for waste treatment. The thickened effluent carries the full organic contaminant load remaining consisting for solubilized food, fine paper fiber and other inert solids such as inks, clays and dirt particles. Now this effluent is ready for biological remediation and Table 1.1 and the Figure 1.1 quantifies the significant portion this represents of the total solid waste stream. Two anaerobic digesters and an aerobic filter form the main body of the treatment which produces the biogas as s product.

Prior to entering the digesters, the effluent passes through a series of settling tanks for clarification which when combined with a dissolved air flotation system prepares and separates the two streams for biological treatment. The soluble fraction free from solids is treated in a high rate contact digester which quickly produces the biogas for collection.

The second stream carrying the solids fraction is fed into a continuously stirred digester where transformation to biogas at a much slower rate is generated.

TABLE 2.3 Municipal Solid Waste Constituents[13]
1,250 Tons (including 250 Tons water)
Material Balance 1,000 Tons Dry

Type of Materials	Tons	½" Size Splitting		Remarks
		Pass	Retain	
Paper	500			
Cellulose long	260	260	0	Marketable
Cellulose short	185	185	0	Gas production
Minerals- inks	30	30	0	
Starch furnish	25	25	0	Gas production
Food	75			
Food – misc.	75	75	0	Gas Production
Glass and others	210			
Glass	60	20	40	Partial Use
Leather – carpets	20	0	20	
Buildings debris	20	0	20	
Wood – Yardwaste – dirt	70	25	45	
Rags – Fabrics	40	0	40	
Metals	100			
Aluminum	15	0	15	Recyclable
Steel, etc.	85	0	85	Recyclable
Plastics	115			
Film – LDPE	60	40	20	
PET – HDPE	25	0	25	Recyclable
PVC – HD Plastic	30	0	30	
TOTAL	**1,000**	**660**	**340**	N/A

Note: The above Table 2.3 is a repetition of Table 1.1

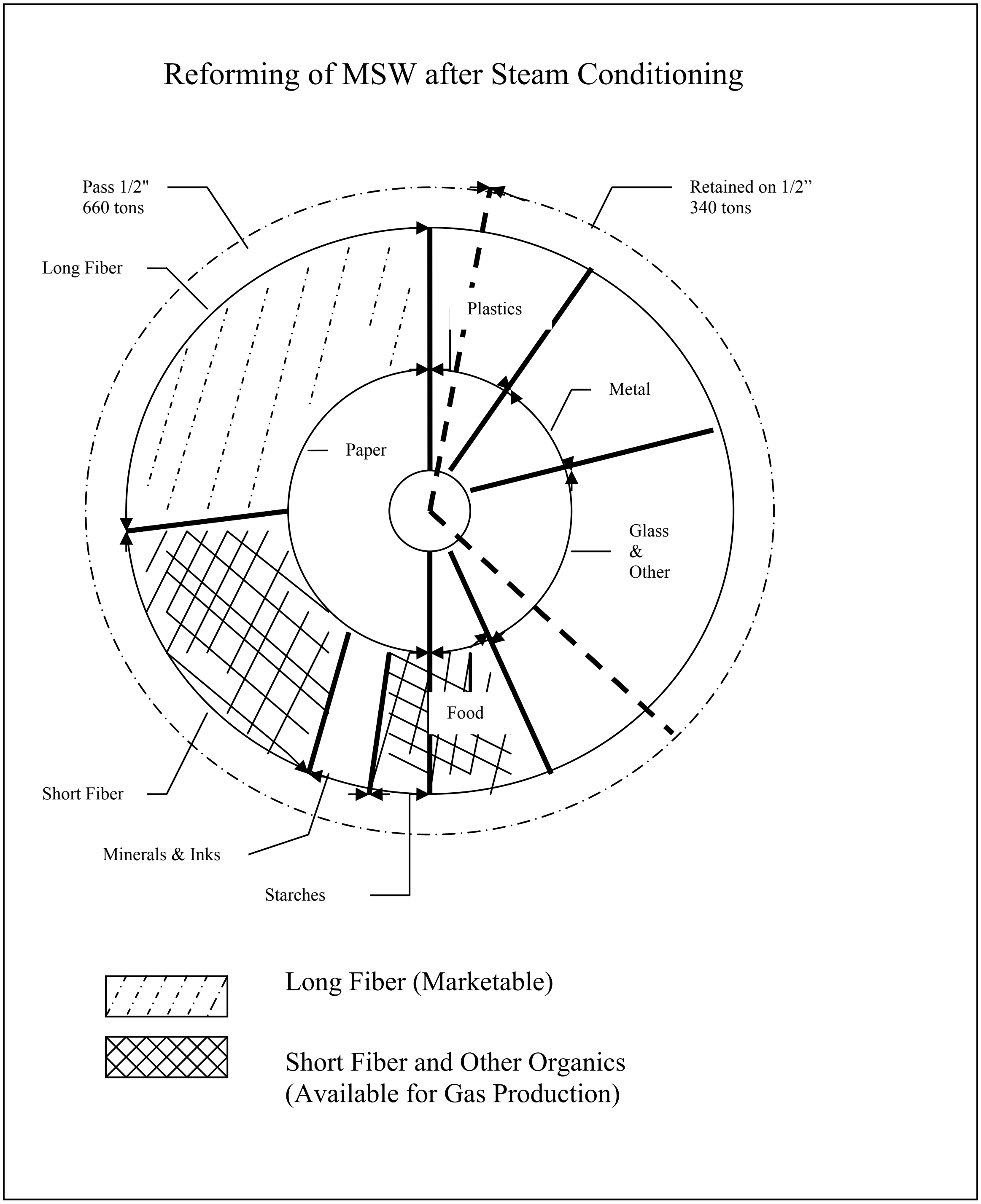

Figure 2.2 Sector Diagram [13]

Note: The Figure 2.2 is a repetition of Figure 1.1

The combined effluents from the anaerobic digesters are now passed into an anaerobic type filter. Here the water receives a final polish prior to being made available to the pulping plant as process water makeup. On a site specific basis demineralization or other tertiary treatments may be necessary at this final step depending on the value or availability of water in the region involved.

Biogas produced will be captured and with relatively simple treatments such as hydrogen sulphur removal along with carbon dioxide entrapment the quality of biogas available is improved as fuel. The preferred method to use this biogas would be as shown in Figure 2.3 where a gas turbine electrical generation plant would receive the biogas supply. By having this plant in close proximity to the waste processing units an excellent cogeneration feature can be tied into the waste heat. Maximum temperature at the autoclave is 300 degrees Fahrenheit with the pulpers at 120 degrees Fahrenheit and the digesters at 100 degrees Fahrenheit. Additional drying of the wet lap pulp processed could also be a used of waste heat.

A backup natural gas supply would allow a larger generating plant to be installed which would also firm up the electricity supplied. Early energy calculations indicate a 40 percent energy requirement required for this total waste recycling plant with 60 percent available for electricity sale.

Another feature that can be integrated with the steam autoclaving, providing the siting logistics can be accommodated, is to use effluents from waste water treatment plants. The wetting agent required in the steam autoclaving can be a very low quality water as this system does not require a steam generating boiler with boiler quality water specified. Tests using activated sludge have been carried out very successfully as a wetting agent. An additional benefit received is that the nutrients provided in the sludge improve the food diet fed to the fermenting bacteria which in turn increases the biogas yield. The benefits to a waste water treatment plant in disposing of this activated sludge is considerable and should be encouraged in the siting of these solid waste plants.

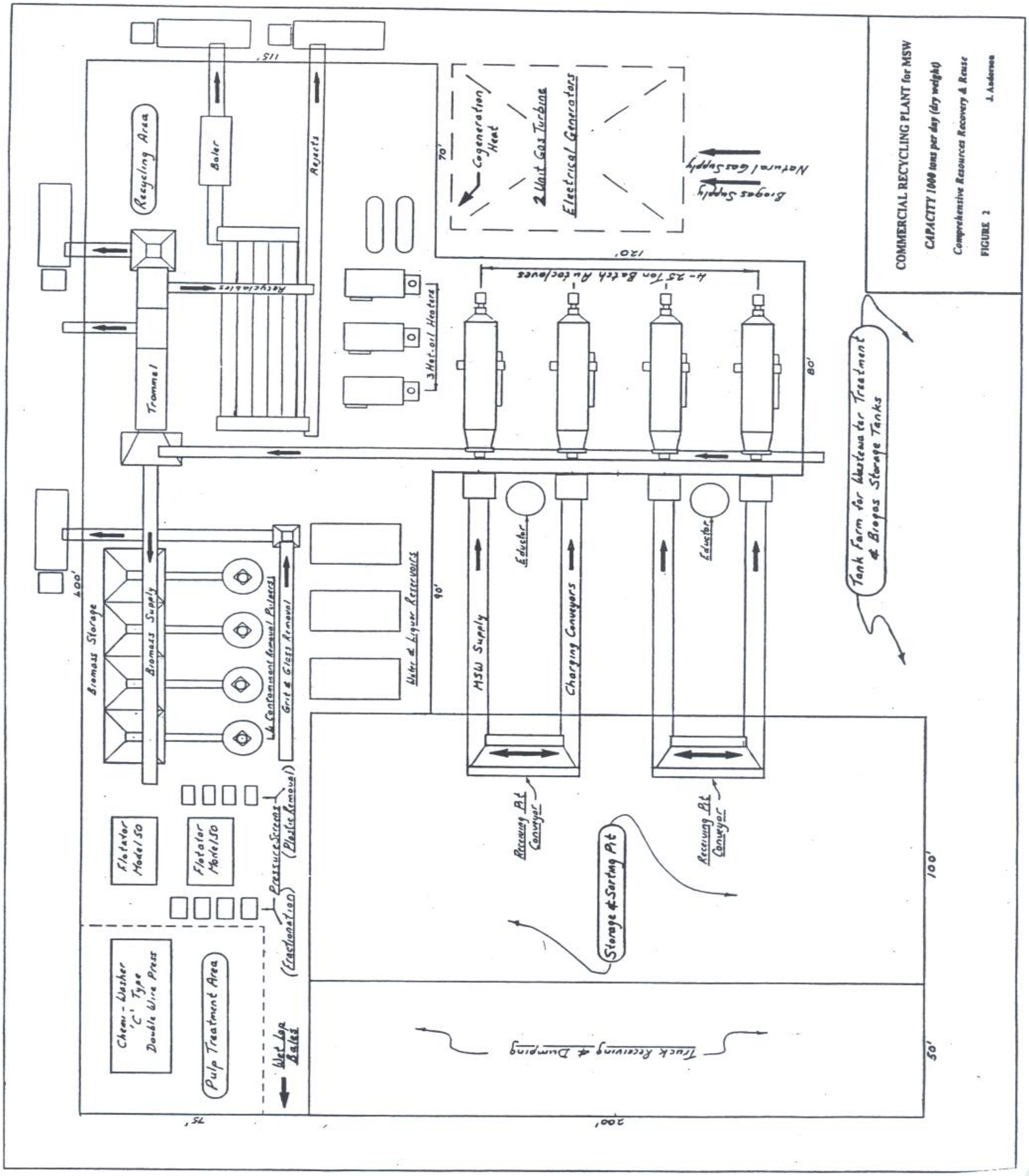

Figure 2.3. Plant Diagram [13]

Chapter 3

SYSTEM AND SUBSYSTEM REQUIREMENTS

Three kinds of system requirements are discussed in this chapter.

1. System Level Requirements: These requirements specify the system as a whole. System level requirements specify the quantities such as cost, reliability maintainability, the inputs, the outputs and the energy requirements of the whole plant.

2. Steam Conditioning Subsystem Requirements: Steam Conditioning is a subsystem in the whole MSW system. The requirements specify the cost of the SC system, the temperatures that the autoclaves can withstand, and the pressures inside them.

3. Digester Subsystem Requirements: Digester subsystem as SC system is a subsystem in the MSW system. The requirements specify the cost of the digester system, the maintainability of the digester system, the temperature to be maintained in the digester system and the number of days that would take for the digester system to produce biogas.

3.1. SYSTEM LEVEL REQUIREMENTS:

1. The whole plant shall cost no more than $57 million.
2. The plant shall operate for 20 hrs in a day.
3. The annual maintenance cost of the plant shall be no more than $25 million.
4. The plant shall take raw MSW as its input.

5. The plant shall produce recyclable non-organic materials, non-organic landfill materials, short fibers (used for the production of biogas gas) and long fibers (marketable for paper manufacturing) as the end products.
6. The plant shall be self powered.
7. Using the 1250 tons per day module approximately 9 MW of energy shall be generated
8. 3 MW of this energy shall be used for the Steam Conditioning plant including the wet process stage.
9. The remaining excess electricity shall be sold.

3.2. STEAM CONDITIONING SUBSYSTEM REQUIREMENTS:

For the SC system to function, all the components in the system should satisfy the following requirements:

1. The steam conditioning system shall cost no more than $17 million.
2. The annual maintenance of the SC system shall be more than $6.8 million.
3. The autoclave vessel shall withstand a temperature of 300^{o} F.
4. The autoclave vessel shall withstand a pressure of 50 psig.
5. The autoclave shall accommodate 25 tons per load.
6. The water reservoirs shall have a capacity of storing 900 tons of water.
7. The oil heaters shall heat the oil to a temperature of 360^{o}F so as to transfer the heat to the contents in the autoclave.
8. The trommel shall have a one half inch screen and shall separate the organic part of MSW from the inorganic part of the MSW.

9. System controller
    a. The system controller shall have startup, operating, shutdown, standby, and emergency shutdown modes.
    b. All control functions shall be hosted on a PC
    c. The system process diagram and operating data shall be displayed on a PC monitor to provide clear and unambiguous control.
10. The conveyor belt shall be able to withstand the weight of the MSW to transfer it to the trommel for size separation.

3.3. DIGESTER SUB-SYSTEM REQUIREMENTS:

1. The cost of the digesters shall be no more than $7 million
2. The temperature in the digester system shall be not more than 58^{o}C and shall not drop below 50^{o}C.
3. The retention time in the digester shall be 20 days.
4. Short fibers shall be fed in HSAD (High Solids Anaerobic Digester).
5. The water from repulping shall be fed in HRAD (High Rate Anaerobic Digester).
6. The retention time in the HRAD shall be one day.

Chapter 4

SYSTEM DESCRIPTION AND DESIGN

4.1. SYSTEM DESCRIPTION

The steam conditioning system's unique characteristics are embodied in an articulating steam autoclave that pressure cooks solid waste in a gentle rotating mode. During this process paper is repulped and food is solubilized as the mass is rolled and kneaded together in the steam environment. The process allows for the efficient recovery of paper and other valuable recyclables destined for landfills having been overlooked or ignored by present recovery programs. After cooldown and partial drying of the reformed waste, separation is carried out using a rotary trommel screen which size classifies the mixture into three groupings. Each of these groups are treated independently by further processing systems.

The process begins when residential, office, and light commercial wastes are gathered from existing collection systems and received on the tipping floor. The waste is first inspected for hazardous or oversized items and then conveyed into the steam autoclave vessel as it rotates slowly allowing the interior helices to compress the waste ingredients to a smaller volume. While loading, a low grade water is added to the autoclave with the MSW in order to provide the optimum moisture content for repulping. The autoclave door is shut sealing the vessel with its contents. Steam is led into the autoclave from a second vessel that is already cooked and ready to enter the venting and cooldown phase. The SC system obtains maximum efficiency on both cycle time and heat recovery when two or more autoclaves are operated in the system. Using a multiple unit plant the total cycle time including loading and unloading is approximately two hours for each unit in the system.

The SC system in addition to incorporating a patented autoclave vessel embodies a propriety multiple unit concept that assumes two or more autoclaves to be jointly operated. Although this requirement allows significant energy savings to be realized more importantly all steam used is generated in the autoclaves using the heat exchange features. This avoids the need for boiler quality water and allows heat buildup to be carried out much faster between the autoclaves reducing the unit cycle time.

4.2. SYSTEM DESIGN:

The system design includes decomposition and definition of both the requirements, or the statement of the design problem, and the architectures, functional architecture and physical representation of the system. The operational architecture addresses which physical resources of the system are going to perform which functions, but also includes a mapping of all the requirements to the physical resources of the system.

4.2.1 Functional Architecture

The functional architecture of a system contains a hierarchical model of the functions performed by the system, the system's components, and the system's configuration items. The functional context diagram (Figure 4.1 Functional Context Diagram below) identifies the relationship and interfaces between the SC system and its environment.

1. Provide for MSW processing

- This function provides for the transformation of the raw MSW into its constituent parts i.e., long fibers, short fibers, metals, glass, plastics, biogas, and wood.

2. Provide for system control

- This function provides signals to system components

3. Provide electrical power

- This function uses biogas to generate power and also provides external electrical power for sale as available.

4. Use MSW end products

- This function uses the end products such as grit, glass, metal and long fiber that are marketable and provides them to the MSW product users.

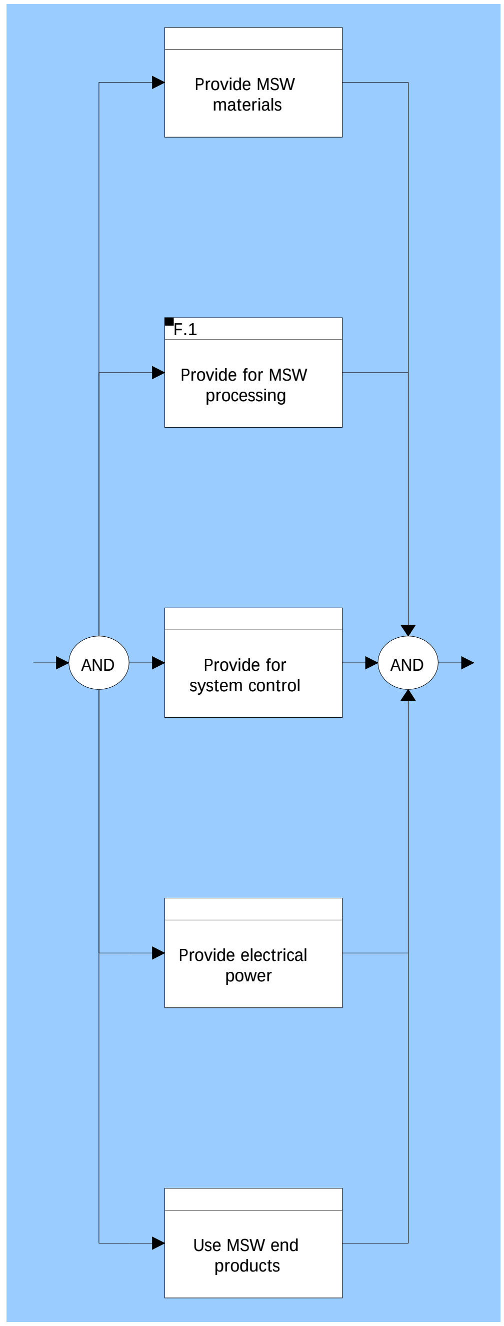

Figure 4.1. Functional Context Diagram

The Figure 4.2 is the Functional block diagram of the MSW treatment plant.

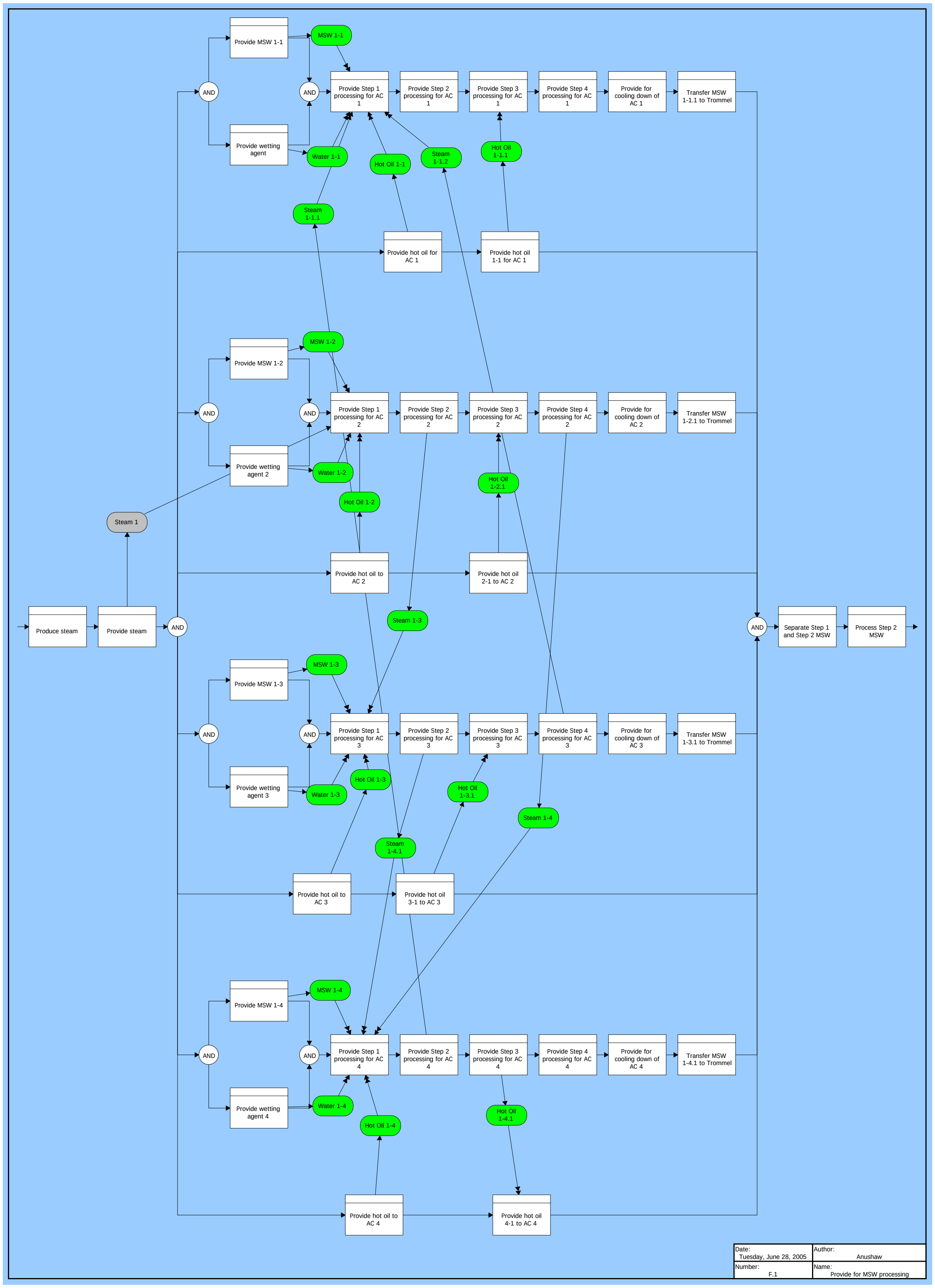

Figure 4.2. Functional Block Diagram of the MSW Treatment Plant

The functions that comprise of the top level “provide for MSW processing” function are

1. Produce steam – Autoclave 1 is used as a steam boiler to produce steam for the first half an hour of the cycle.
2. Provide steam – This function provides steam to autoclave 2 and the duration would be fifteen minutes.
3. Provide MSW 1-2 – This function provides MSW to autoclave 2 and the duration would be fifteen minutes.
4. Provide wetting agent 2 – This function provides 11.25 tons of wetting agent for duration of fifteen minutes. Both the functions “provide wetting agent” and “provide MSW” start at the same time.
5. Provide hot oil 2 – This function provides hot oil to the contents in the autoclave and the duration is 55 minutes.
6. Provide Step 1 processing for autoclave 2 – In this function all the components i.e. MSW, wetting agent, steam and the heat from the hot oil are combined.
7. Provide Step 2 processing of autoclave 2 – Autoclave 2 is ready for its first flash and it transfers 1.5 tons of steam to autoclave 3 and the duration is 5 minutes
8. Provide Step 3 processing of autoclave 2 – Autoclave 2 receives heat from the hot oil for half an hour and raises the temperature of the unit to 292^{o}F.
9. Provide Step 4 processing of autoclave 2 – Autoclave 2 is ready for the second flash and it releases 3.5 tons of steam to autoclave 4 and the duration is 10 minutes. Temperature drops to 212^{o}F.

10. Provide cooling down for autoclave 2 – Autoclave 2 is now connected to the eductor for complete cool down. The duration is 20 minutes and the temperature drops to 152°F.
11. Transfer MSW to 1-2.1 to Trommel – This function transfers the conditioned MSW to the trommel for size separation.
12. Separate Step 1 and Step 2 MSW– This function separates the organic matter from the inorganic matter.
13. Process Step 2 MSW – This function sends the step 2 MSW for further processing.

All the other autoclaves also go through the same processes. The cycle time for each autoclave, starting from the loading of MSW till the emptying it into the trommel, is 120 minutes.

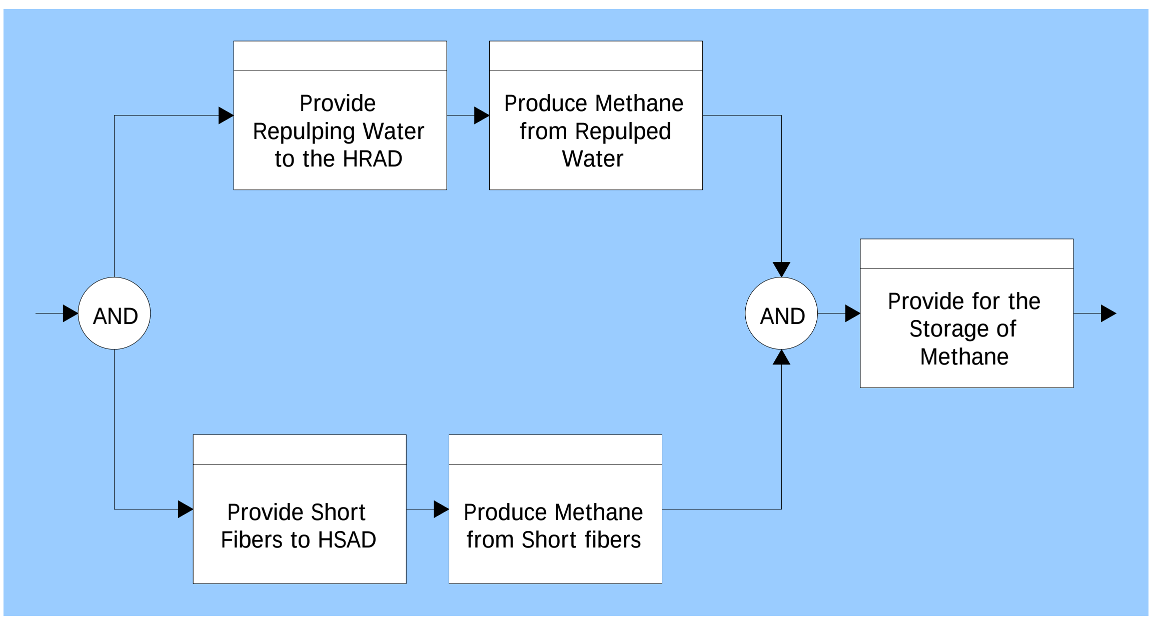

Figure 4.3. Functional Block Diagram for Biogas Production

The above Figure 4.3 is the functional diagram for Biogas production.

1. Provide Repulping water to HRAD: This function provides the water from wet process to HRAD for biogas production
2. Produce Biogas from Repulped water: In this function the organic matter in the repulped water is converted to biogas gas in the High Rate Anaerobic Digester. The retention time in this digester is one day
3. Provide Short Fibers to HSAD: This function would provide the short fibers that are separated from the long fibers in the wet process
4. Produce Biogas from Short Fibers: In this function biogas is produced from the short fibers in High Solids Anaerobic Digester. The retention time in this digester is 20 days.

4.2.2 Physical Architecture

The physical architecture of a system is a hierarchical description of the components that comprises the system. This hierarchy begins with the system context diagram and the system's top-level components and progresses down to the configuration items that comprise each intermediate component. The physical architecture provides resources for every function identified in the functional architecture.

Figure 4.4 is MSW System Context Diagram that illustrates the relationships among the MSW system and its environment. MSW system context diagram is built from the components MSW system, MSW suppliers and MSW product users.

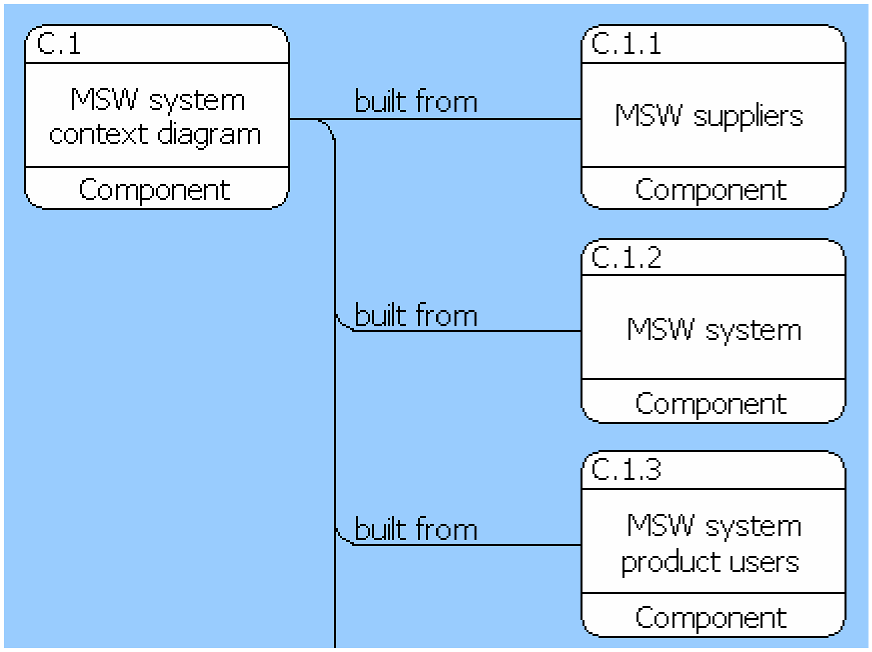

Figure 4.4 MSW System Context diagram

In the Figure 4.4 "MSW supplier" component is allocated to the function "provide MSW". "Provide MSW" is a function that provides MSW, which is brought from the transfer station to the MSW treatment plant, for processing. "Provide MSW for processing" is a function that is allocated to the component MSW system. "Provide MSW for processing function" performs all the functions starting from the loading of autoclaves till the treated MSW comes out of the autoclaves and is separated in the landfill, recyclables, long fiber pulp and biogas.

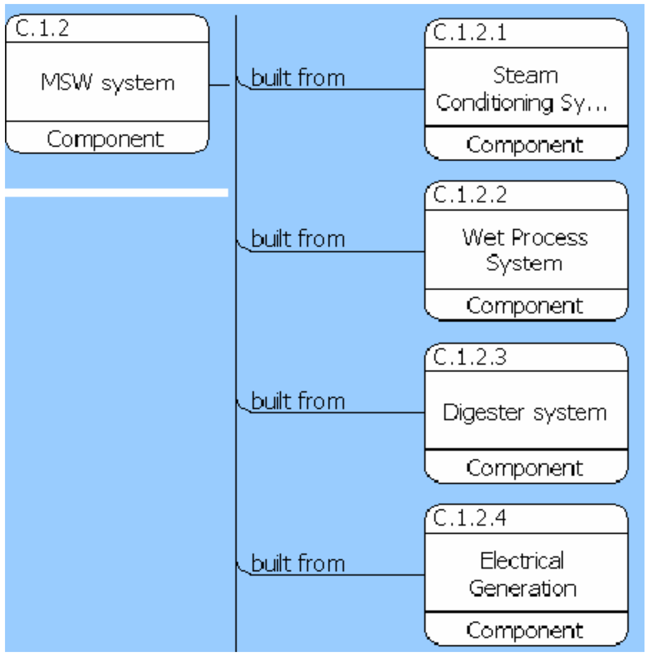

Figure 4.5. MSW System Diagram

The MSW system is built from the components Steam Conditioning System, Wet process system, Digester system and Electrical Generation.

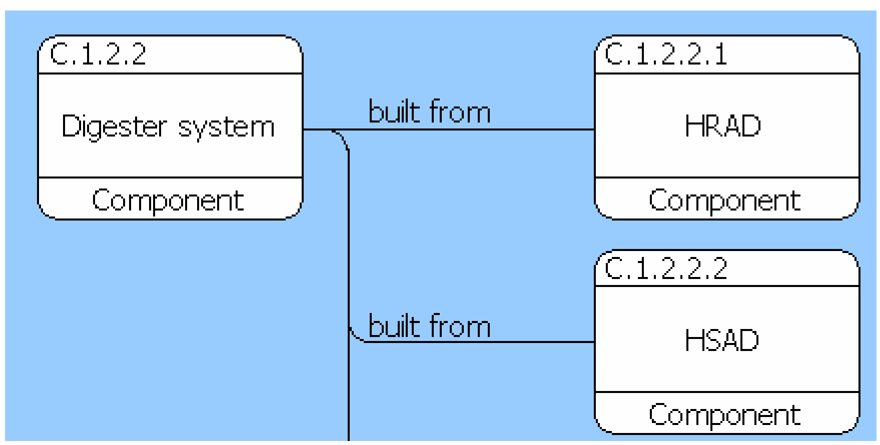

Figure 4.6. Digester System

The Digester System is built from two different types of digester, High Rate Anaerobic Digester (HRAD) and High Solids Anaerobic Digester (HSAD). Waste water after the wet process is fed into the HRAD and the short fibers from the wet process are fed into HSAD.

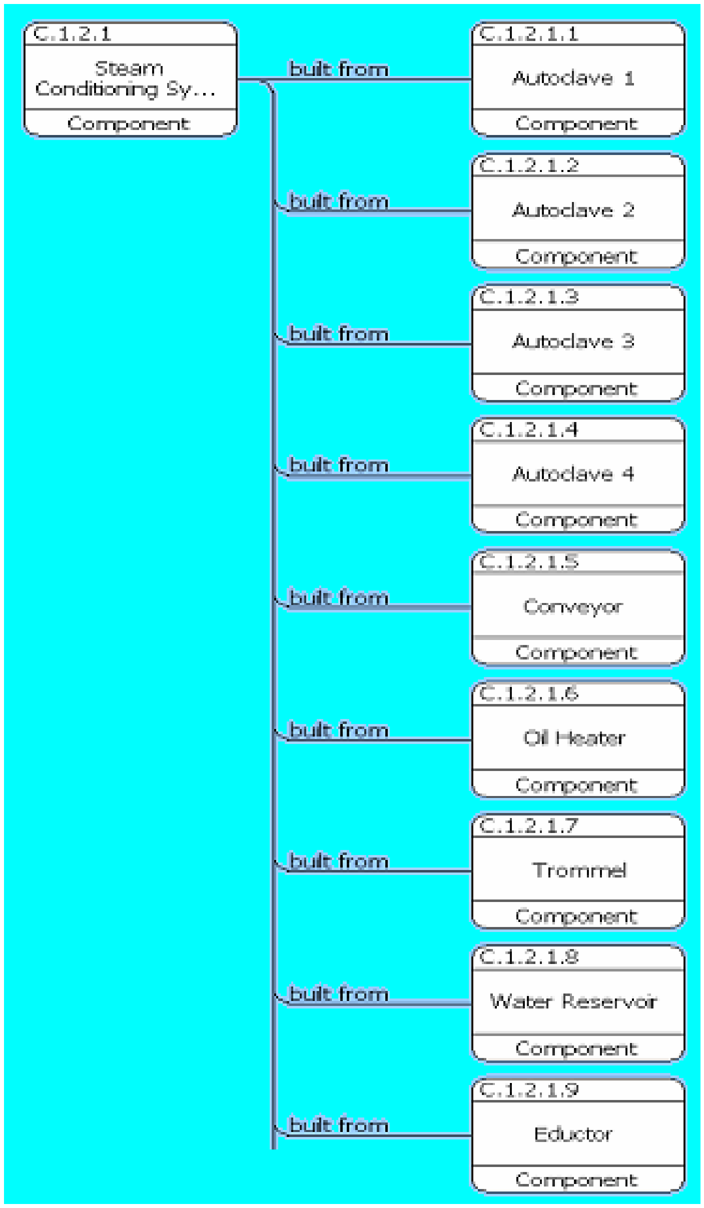

Figure 4.7. Steam Conditioning System Diagram

Figure 4.7 is the SC system diagram. It is built from the components: autoclaves, conveyor, oil heater, trommel, water reservoir and trommel. Each of these components is allocated to perform certain functions.

4.2.3. Operational Architecture:

The development process for the operational architecture is the activity during which the entire design comes together [5]. The operational architecture integrates the requirement decomposition with the functional and physical architectures. The process of developing the operational architecture provides the raw materials for the definition of the system's external and internal interfaces and is the only activity in the design process that contains the material needed to model the system's performance and enable trade-off decisions.

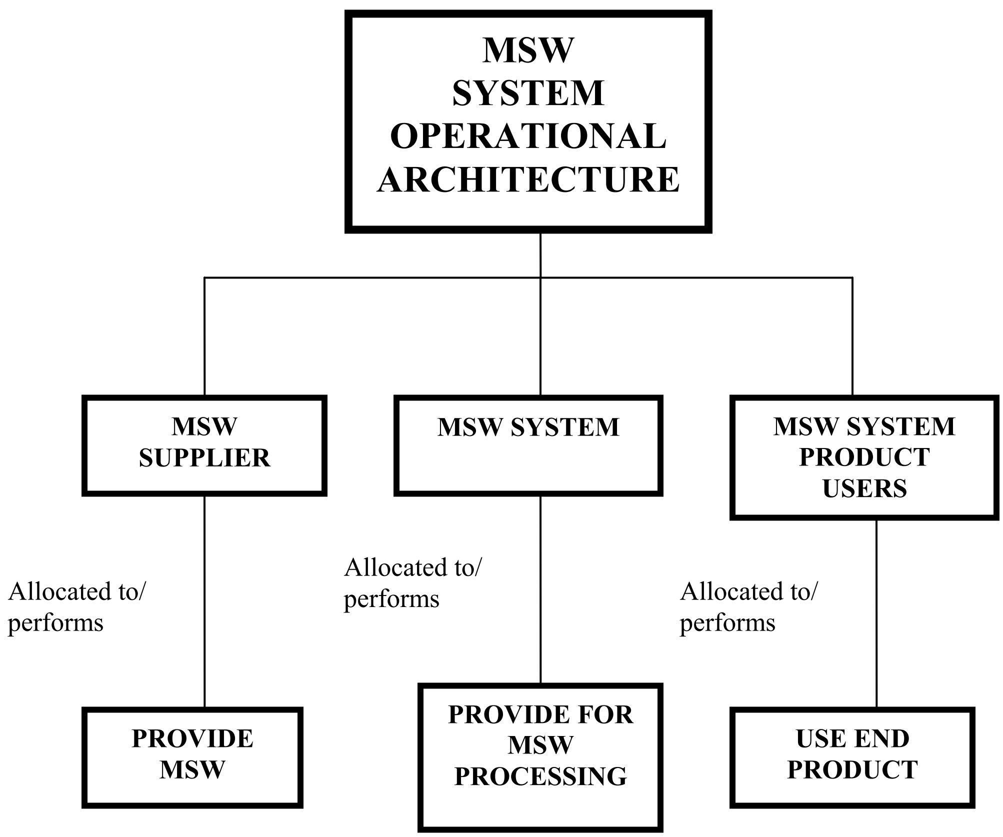

Figure 4.8. MSW Operational Architecture Diagram

The MSW system is built from the components Steam Conditioning System and Digester system.

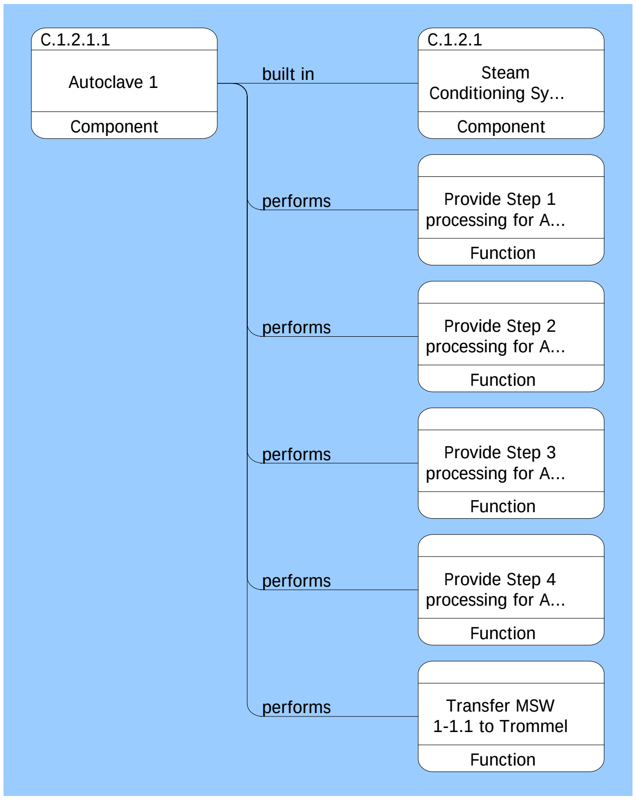

Figure 4.9. Functions Associated with Component "Autoclave 1"

For example for the component "autoclave 1" the functions that are associated with it are:

1. Provide for Step 1 to 4 processing for autoclave 1
2. Transfer MSW 1-1.1 to Trommel

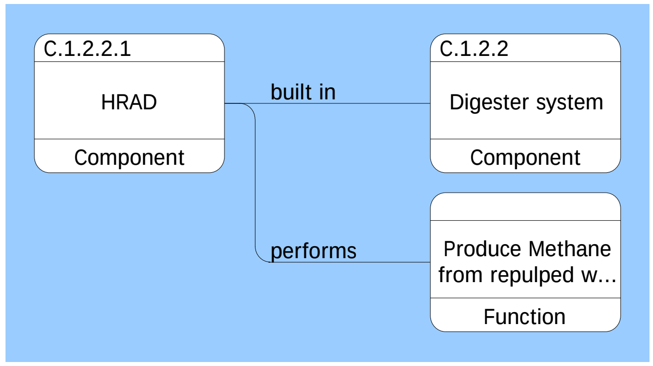

Figure 4.10 Function associated with HRAD

Figure 4.10 illustrates the function that is associated with High Rate Anaerobic Digester which is “Produce Biogas from repulped water”

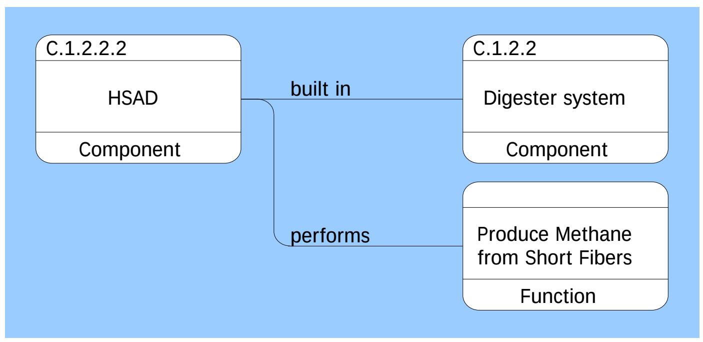

Figure 4.11 Function associated with HSAD

Figure 4.11 illustrates the function that is associated with High Solids Anaerobic Digester which is “Produce Biogas from Short Fibers”.

Results of CORESIM:

The functional block diagram, Figure 4.2, was executed in CORE with all the requirements of the functions. The Figure 4.12 below is the result of the simulation with CORE.

Comparison of theoretical results with the simulated results:

The theoretical cycle time for all the four autoclaves, starting from loading the MSW till emptying the contents into the trommel, is 240 minutes. The cycle time obtained from CORE simulation was 289.72 minutes. The difference in 49 minutes is because the simulated time also includes the times of the functions “Separate Step 1 and Step 2 MSW” and “Process Step 2 MSW” whereas the theoretical time does not include the times of these steps. The High Rate Anaerobic Digester takes 24 hrs to produce biogas from the repulping water. The High Solids Anaerobic Digester takes 20 days to produce biogas from short fibers.

NOTE: The time taken for HRAD to produce biogas is one day and the time taken for HSAD to produce biogas is 20 days. The result could not be shown in the form of CORE result.

The dark green color in the above diagram specifies that the function against it is been carried out for the amount of time shown on the black bar. When there is a yellow color against a function it means that the function is waiting for another function to pass on the information and the fluorescent green indicates that there are many triggers that are specified to that function and that function is waiting for all the other triggers to enable it. For example, the function “produce steam” is been carried out for 30 minutes. The function “process Step 1 for AC 2” should be triggered by “Produce Steam” unless “produce steam” function is not carried out “Process Step 1 for AC 2” cannot be carried out.

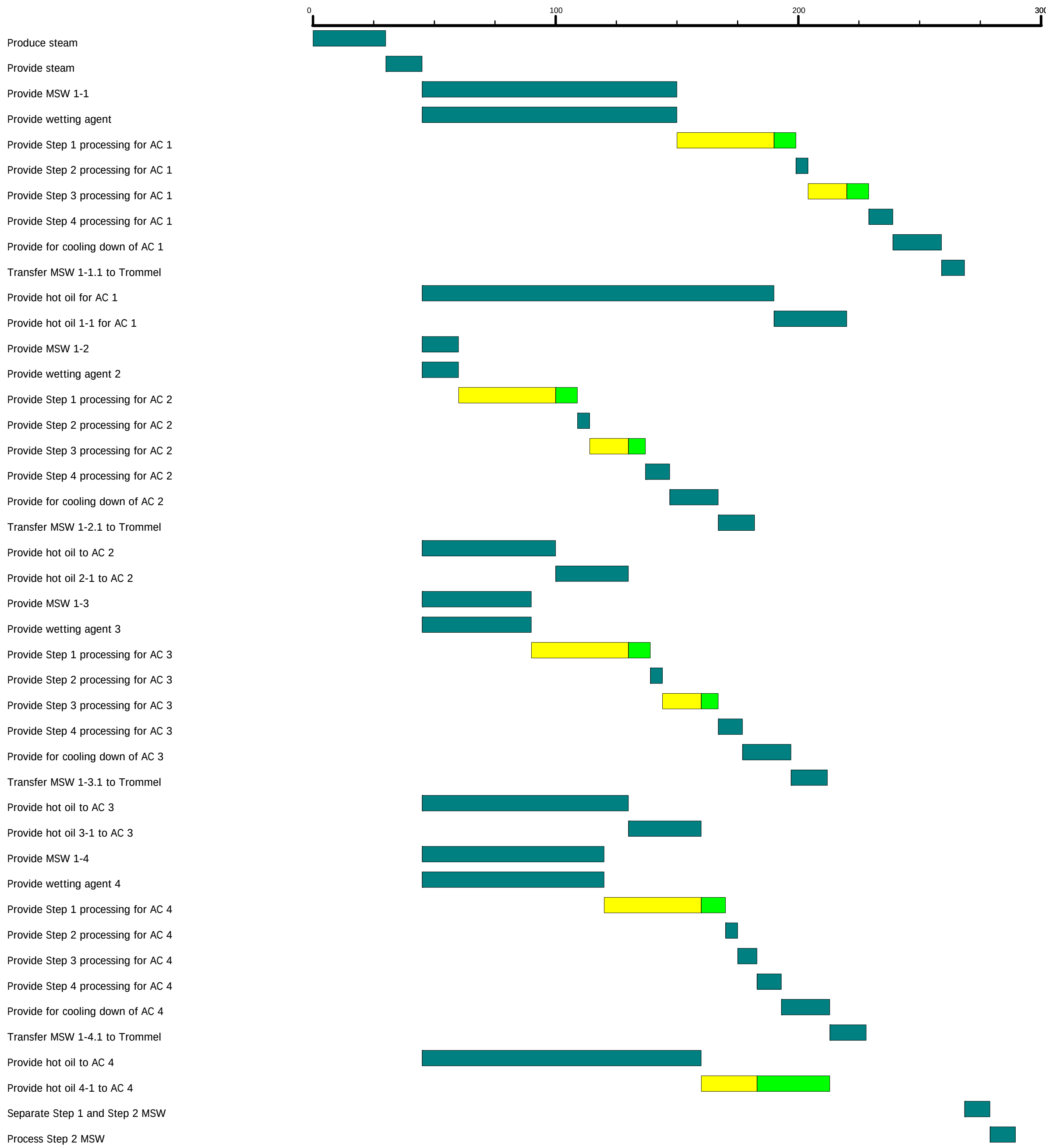

Figure 4.12. Result of CORESIM

Chapter 5

SYSTEM OPTIMIZATION

The economic comparison of the four unit plant producing biogas as the end product is compared to the four unit plant without producing biogas.

5.1. ECONOMIC ANALYSIS FOR A FOUR UNIT AUTOCLAVE SYSTEM WITH BIOGAS PRODUCITON.

For any project to be successful it is necessary for it to be technically efficient and effective and also, it has to be economically viable. Economic analysis is an important aspect to make capital investment decisions and to estimate the return on investment.

Tables 5.1, 5.2, and 5.3 give an overview of the capital costs, the annual revenue and the annual O&M costs for the MSW Treatment plant.

MSW SYSTEM
Economic Model Summary 1250 Tons per Day [13]
TABLE 5.1

CAPITAL COSTS	
Steam Conditioning	$17 Million
Repulping Process	$18 Million
Wet process-Power production-Industrial heat	$22 Million
TOTAL	**$57 Million**

TABLE 5.2

ANNUAL REVENUES	
Diversion Fee ($50/ton)	$19.9 Million
Water and Green Energy	$9.8 Million
Repulping ($120/Ton)	9.1 Million
TOTAL	**$38.8 Million**

TABLE 5.3

ANNUAL O&M COSTS	
Steam Conditioning	$6.8 Million
Repulping	$14.2 Million
Water-Power-Heat	$4.0 Million
TOTAL	**$25.0 Million**

NOTE: These cost tables were given by CR3 Technology [13].

The operating income for the Municipal Solid Waste Treatment plant would be $13.8 Million.

The $50.00 Diversion Fee is based on the Sacramento City Department of Sanitation in arrangement with a company called BLT. BLT would deliver the MSW to the landfill which is owned and operated by the Waste Management.

The Life Cycle Cost of the plant is calculated based on the above tables. The period of time that has been taken into consideration is 20 years because most of the components in the plant have a life span of 20 years.

Life Cycle Cost (LCC) - The LCC is commonly applied to alternatives with cost estimated over the entire system life span. This means that costs from the very early stage of the project through the final stage of the project are estimated [10].

Therefore, LCC is calculated with the following formula [11]

$$LCC = C + M_{pw} + R_{pw} - S_{pw}. \qquad (5.1)$$

Where, C is the capital cost of the plant includes the initial capital expense for equipment, the system design, engineering, and installation. Capital cost is always considered as a single payment occurring in the initial year of the project, regardless of how the project is financed.

Maintenance (M) is the sum of all yearly scheduled operation and maintenance (O&M) costs. O&M costs include such items as an operator's salary, inspections, insurance, property tax, and all scheduled maintenance.

Replacement cost (R) is the sum of all repair and equipment replacement cost anticipated over the life of the system. Normally, these costs occur in specific years and the entire cost is included in those years. 15 percent of the capital cost is spent for the replacement of the motors in the plant.

The salvage value (S) of a system is its net worth in the final year of the life-cycle period. It is common practice to assign a salvage value of 20 percent of original cost for mechanical equipment that can be moved. This rate can be modified depending on other factors such as obsolescence and condition of equipment.

The formula for the single present worth (P) of a future sum of money (F) in a given year (N) at a given discount rate (I) is

- $P=F/(1+I)^N$ (5.2)

The formula for the uniform present worth (P) of an annual sum (A) received over a period of years (N) at a given discount rate (I) is

- $P=A[1-(1+I)^{-N}]/I$ (5.3)

Depreciation rate is calculated from the following formula

- $d_{max}= 2/N$; where N is the number of years

In this case N = 20 therefore $d_{max} = 2/20 = 0.1$; so depreciation rate is 10%.

The LCC cost calculated from the above formula is 286 Millions for this plant for a span of 20 years.

The payback period (n_p) is the number of years it will take for the estimated revenues and other economic benefits to recover the initial investment and a stated rate of return.

Payback can take two forms: one for i>0 (also called discounted payback analysis) and the other for i=0% (ignores the time value of money)

The formula for n_p=P/NCF; where P is the initial investment and NCF is the Net Cash Flow. This formula is used for the scenario i=0%.

When this formula is used the payback for i=0% for the MSW plant was n_p=57,000,000/13,800,000 = 4.1 years.

5.1.1 Weighted Average Cost of Capital (WACC) and Debt-Equity Mix

Weighted Average Cost of Capital: Corporations create value for shareholders by earning a return on the invested capital that is above the cost of that capital. WACC is an expression of this cost and is a blend of equity and debt cost. It is used to determine if intended investments or strategies or projects or purchases are worthwhile to undertake and is expressed in percentage. The cost of the capital for any investment, whether for an entire company or for a project, is the rate of return capital providers would expect to receive if they would invest their capital elsewhere [12].

The debt-to-equity mix identifies the percentages of debt and equity financing for a corporation. A company with 55-45 D-E mix has 55% of its capital originating from debt capital sources (bonds, loans, mortgages) and 45% derived from equity sources (stocks, retained earnings)

5.1.2 Calculation of Payback Period, n, Including the Time Value of Money (i> 0%)

The weighted average cost of capital (WACC) is estimated by the relative fractions from debt and equity sources.

WACC= (equity fraction) (cost of equity capital) + (debt fraction) (cost of debt capital)

The D-E ratio for a MSW plant is 60:40 [8]

The cost of debt capital 7 3/8% [9]

The cost of equity capital was assumed to be 10%

Hence, WACC = 8.42%

With the above data, the number of years taken to repay the 57 million capital cost with 8.42% compound interest is 5.3 years.

5.1.3 Sensitivity Analysis

Sensitivity analysis is used to determine the sensitivity of the outcomes of an alternative to changes in its parameters and to test the impact of assumptions (as opposed to the changes in the environment). If a small change in a parameter results in relatively large changes in the outcomes, the outcomes are said to be sensitive to that parameter. This may mean that the parameter has to be determined very accurately, or that the alternative has to be redesigned for low sensitivity, or that assumptions may need to change.

The sensitivity analysis of the four unit plant was calculated and is shown with the help of Boxplots.

Several different assumptions were made to test the sensitivity. Depending on the nature of the costs the standard deviation was varied. The diversion fee taken was $50/ton of MSW and this was given by the city of Sacramento. As this cost is almost the exact cost, it would not vary much. Therefore, the standard deviation taken for this cost was 1.67% of the annual diversion fee. For Water and Green energy cost and Repulping Costs the standard deviation was taken as 3.33 of Annual Water and Green Energy and Annual Repulping costs. These were the assumptions taken for the Annual Revenue costs. The Annual O&M costs can have significant uncertainty, and hence the standard deviation of 5% was assumed. Annual O&M cost is the expenditure cost for the MSW plant. Expenditure can be varied to perform a sensitivity analysis as this cost is an assumption. For the Annual Capital Cost a standard deviation of 3.33% was assumed for each of the costs. All the costs are varied according to their standard deviations.

Normal distributions were assumed for the above costs to identify the sensitivities of payback periods to cost assumptions. The normality assumption is grounded on the central limit theorem because the various costs are the sum of a number of costs. Each individual cost may or may not be normally distributed, but their sum tends to be normally distributed.

Boxplots are used to summarize information about the shape, dispersion (variation or spread in the data) and the center of the data. They can also help to spot the outliers (A value that is very different from the others in a distribution).

- The lower portion of the box represents the first quartile, Q1 (This statistic is also referred to as 25th percentile because data from 25% of observations are less than or equal to this value), while the upper portion of the box represents the third quartile, Q3 (this is also referred to as 75th percentile because data from 75% of the observations are less than or equal to this value). Thus the box portion of the plot represents the interquartile range (IQR), or the middle 50% of observations.
- A line drawn through the boxplot represents the median of the data.
- The lines extending from the box are called as whiskers. The whiskers extend outward to indicate the lowest and highest values in the data set (excluding outliers).
- Extreme values, or outliers, are indicated by dots. A value is considered an outlier if it is outside the box (greater than Q3 or less than Q1) by more than 1.5 times the IQR.

Assessing the symmetry of the data using boxplots:

- If the data are fairly symmetric, the median line will be roughly in the middle of the IQR box and the whiskers will be in similar length.

- If the data are skewed, the median may not be in the middle of the IQR box and one whisker will likely be noticeably longer than the other.

TABLE 5.4 SUMMARY OF BOXPLOT Δ PAYBACK/ Δ COST SENSITIVITIES

		First Quartile (Q1)	Median	Third Quartile (Q3)
Annual Revenue Cost Sensitivity (years/$M)	Diversion Fee	0.37	0.43	0.55
	Water and Green Energy	0.40	0.43	0.55
	Repulping	0.43	0.49	0.56
Annual O&M Cost Sensitivity (years/$M)	Steam Conditioning	0.32	0.42	0.52
	Repulping	0.42	0.49	0.58
	Water-Power-Heat	0.33	0.56	0.85
Capital Cost Sensitivity (years/$M)	Steam Conditioning	0.09	0.15	0.24
	Repulping	0.09	0.13	0.16
	Water-Power-Heat	0.07	0.10	0.14

Note: The figures that are given above are the ratios of Δ payback to Δ cost change.

The detailed explanation of the above table can be seen in the boxplot figures below. In the boxplot of the precipitation data the median is centered in the IQR box, and the whiskers are the same length. This indicates that except for the outlier (asterisk), the data are symmetric. This is a good indication that the outlier may not be from the same population as the rest of the sample data.

Thus, from the below boxplots, it can be inferred that the variation in the Annual Revenue costs boxplot and the Annual O&M costs boxplot is greater than the variation in the Capital cost boxplot. It can be inferred that the payback period is more sensitive to the operating income than the capital cost as the variation in the operating income is greater than the variation in the capital cost. Thus, change in Operating Income has larger effect on the payback than Capital Cost.

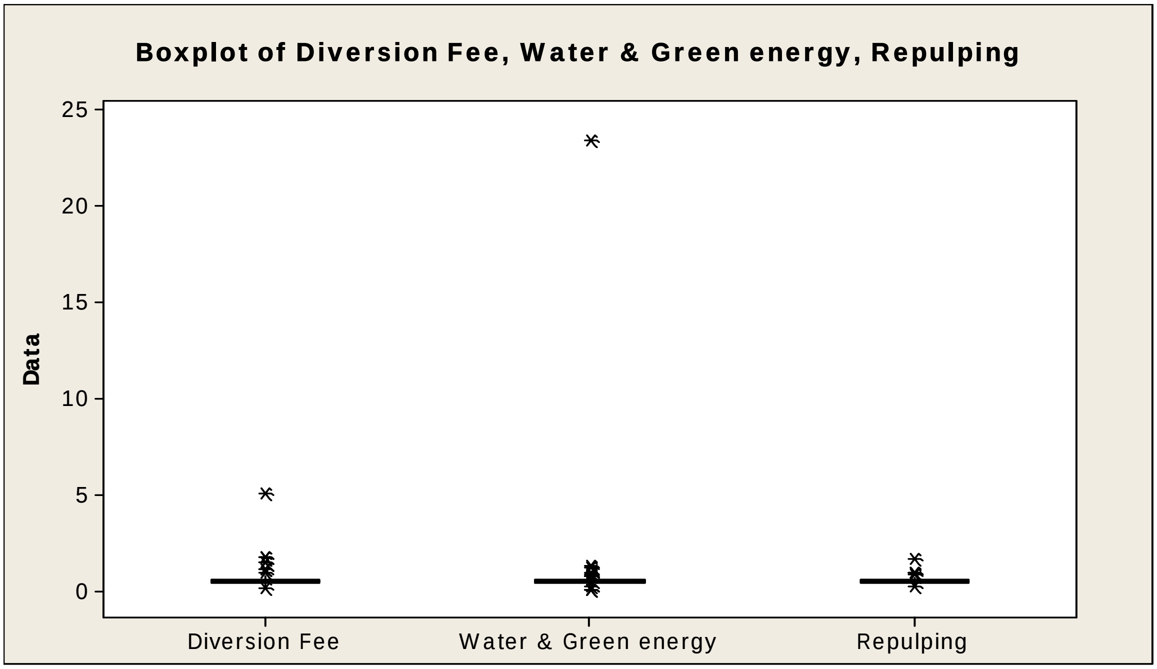

Figure 5.1 Boxplot for Annual Revenue Cost Sensitivity Δ payback/ Δ cost

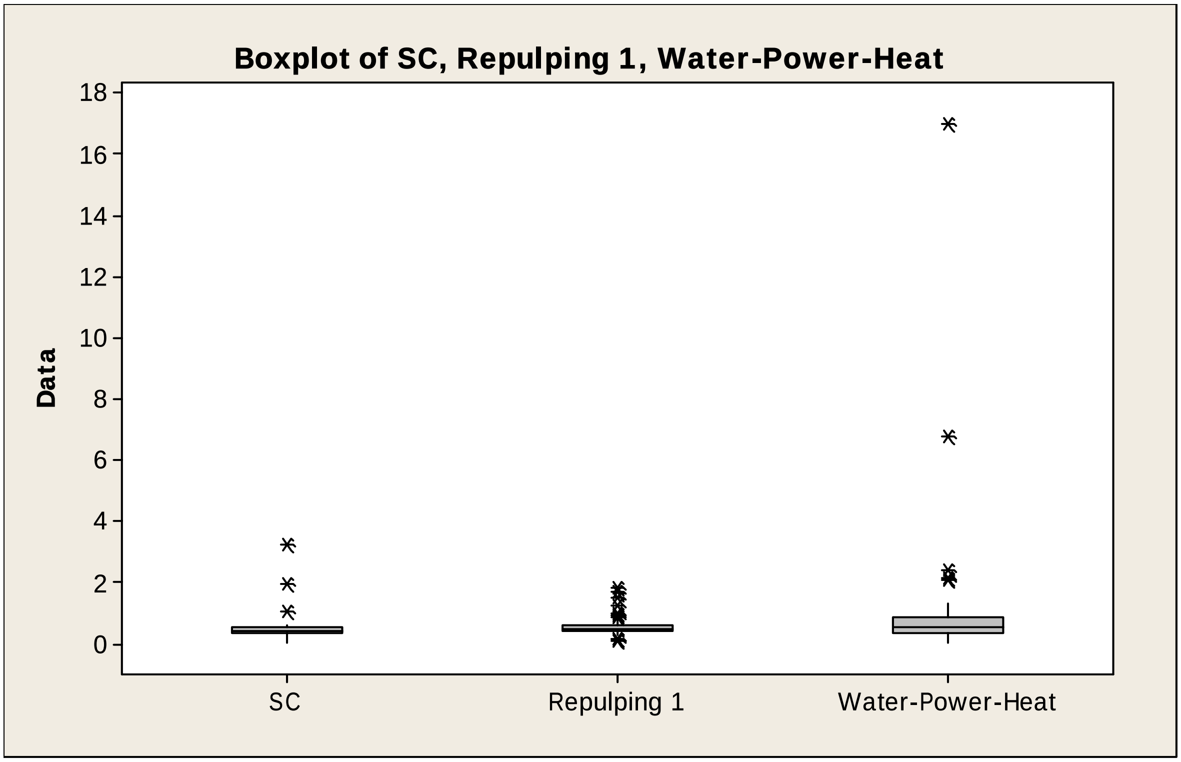

Figure 5.2 Boxplot for Annual O&M Cost Sensitivity Δ payback/ Δ cost

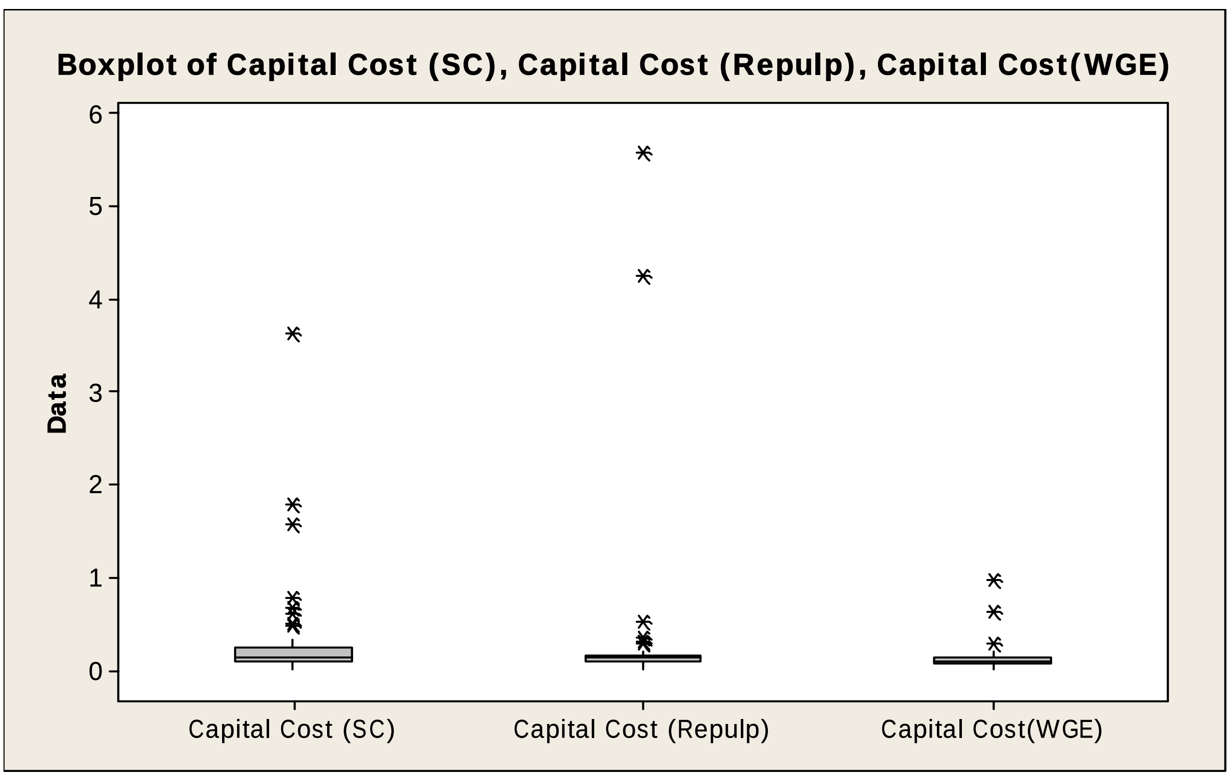

Figure 5.3 Boxplot for Capital Cost Sensitivity Δ payback/ Δ cost

Note: The y-axes in the boxplots represent the ratio of Δ payback to Δ cost change.

It can be seen from the above boxplot figures and also table 5.4 that the variation of Annual Revenue Costs and the Annual O&M Costs is greater than the variation in the Capital Cost. Therefore the Operating Income *i.e.* the difference between the Annual Revenue Costs and Annual O&M Costs has greater impact on the payback period than the Capital Cost.

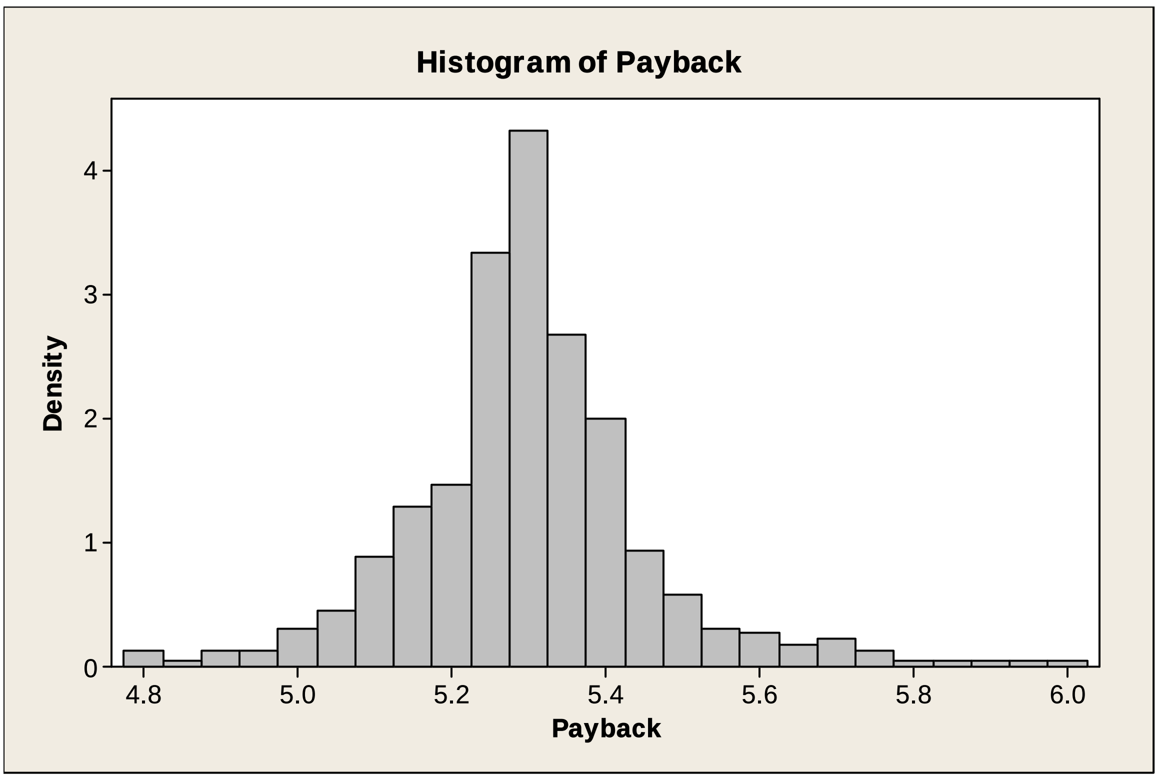

Figure 5.4 Histogram of Payback

The Histogram of Payback shows the variation of payback time with the change in the operating income. It can be seen from the Histogram (Figure 5.4) that the payback period varies from 4.7 years to 6.1 years. The table below shows the payback period and the operating income associated with it.

TABLE 5.5 SUMMARY OF HISTOGRAM

Payback period (years)	Operating Income ($)
4.8	14.5 M
5.0	14.2 M
5.2	13.8 M
5.4	13.5 M
5.6	12.9 M
5.8	12.6 M
Histogram Average	5.3 years
Histogram Standard deviation	0.16 years

The histogram was drawn with several different combinations of the payback period. As the costs were fluctuated and as the distribution was considered a normal distribution the result i.e. the payback period also came out to be a normal distribution. It can be seen that when different combinations of Annual Revenue stream, Annual O&M costs and the capital costs were changed the payback period also changed accordingly. The number of years taken to repay was 4.8 years when the operating income was 14.5 years. And on the other hand when the payback period is at its maximum it implies that there was a large variation in the Operating Income *i.e.* the operating income is less compared to the capital cost. From this histogram the optimum payback period can be determined. Depending upon the change in the capital cost and the change in the operating income the payback period can be determined.

5.2. ECONOMIC ANALYSIS FOR A FOUR UNIT AUTOCLAVE SYSTEM WITHOUT BIOGAS PRODUCITON

Tables 5.6, 5.7, and 5.8 give an overview of the capital costs, the annual revenue and the annual O&M costs for the MSW Treatment plant without the production of biogas. $7 million from the capital cost is deducted as it represents the cost for the digesters.

TABLE 5.6

CAPITAL COSTS	
Steam Conditioning	$17 Million
Repulping Process	$18 Million
Wet process-Power production-Industrial heat	$15 Million
TOTAL	**$50 Million**

TABLE 5.7

ANNUAL REVENUES	
Diversion Fee ($50/ton)	$19.9 Million
Repulping ($120/Ton)	9.1 Million
TOTAL	**$29 Million**

TABLE 5.8

ANNUAL O&M COSTS	
Steam Conditioning	$6.8 Million
Repulping	$14.2 Million
Water-Power-Heat	$4.0 Million
TOTAL	**$25.0 Million**

The operating income for the Municipal Solid Waste Treatment plant would be $4 Million. The payback period for this plant with interest rate i=0 (excludes time value of money) would be 12.5 years

The plant with $4M operating income will not be able to pay back $50M with 8.95% compound interest. The plant should have a minimum operating income of 8M in which case the pay back, with 8.95% interest rate, would be 9.57 years. Therefore, the plant without biogas production is not viable. This can also be seen with the help of IRR vs. $(C_i-C_o)/I$ where C_i-C_o is the cumulative difference between the cash inflow and cash out flow and I is the initial investment or the capital cost.

Internal Rate of Return (IRR) – IRR is the rate of interest which discounts the net cash flow over time of net revenue generated by an investment, such that the present value of the net cash flow is equal to the capital sum invested. IRR is the discount rate at which the NPV (net present value) is zero.

$$NPV = I - \Sigma(C_i-C_o)/(1+IRR)^N \quad (5.4)$$

When NPV is zero, the above equation becomes

$$I = \Sigma(C_i-C_o)/(1+IRR)^N$$

$I/\Sigma(C_i - C_o) = 1/(1+IRR)^N$

$(1+IRR)^N = \Sigma(C_i - C_o)/I$

$IRR = ((C_i - C_o)/I)^{1/N} - 1$

Figure 5.1is a graph corresponding to variations of IRR vs. $\Sigma(C_i - C_o)/I$ with respect to N, where N is the number of years.

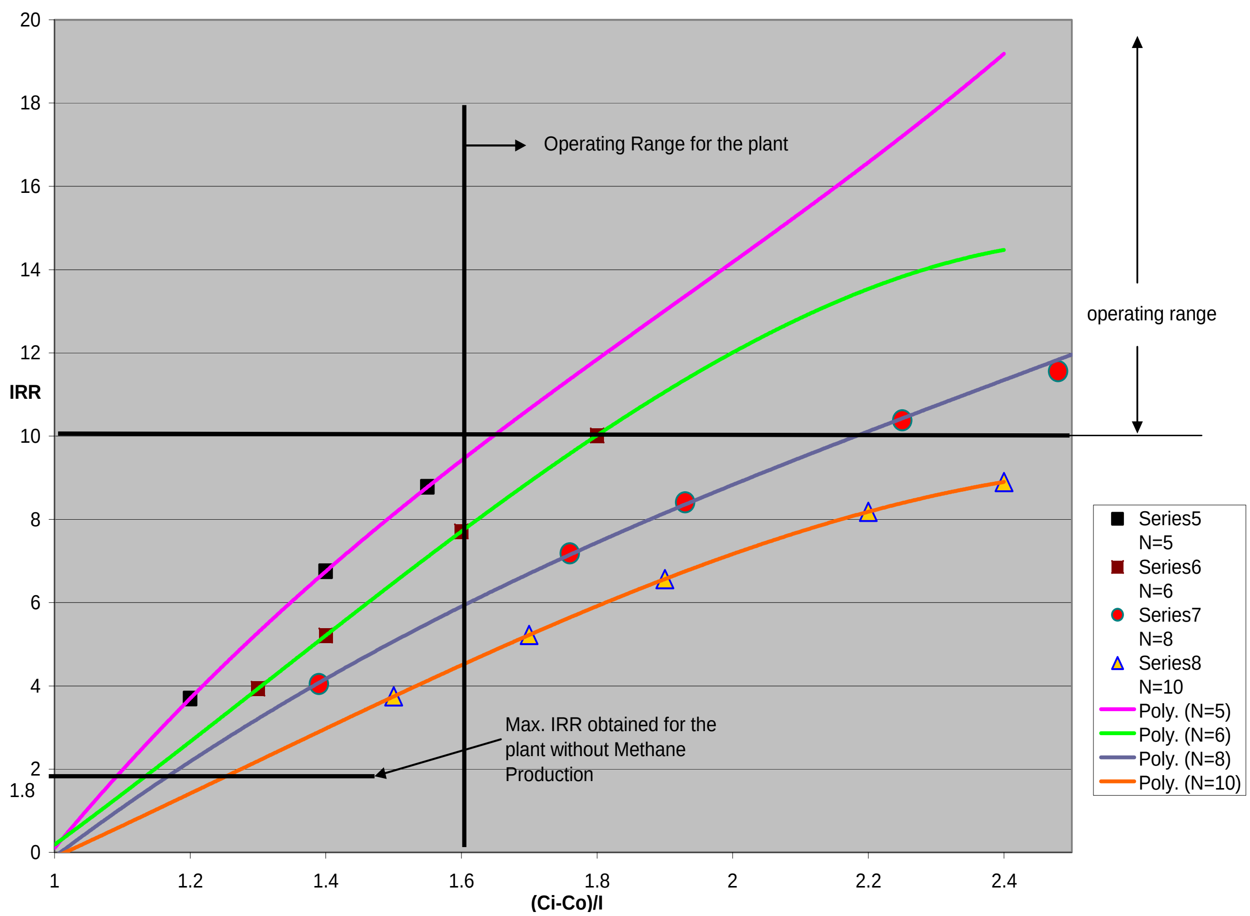

Figure 5.5 IRR vs. $(C_i - C_o)/I$

Based on the sensitivity analysis results, a graph (Figure 5.5) between IRR and $\Sigma(C_i - C_o)/I$ has been plotted. From the Figure 5.5, it can be inferred that above 10% IRR the operation of the plant with biogas production is feasible. Below the 10% IRR line the plant operation is not recommended. And similarly the plant operation would be feasible with the Σ $(C_i-C_o)/I$ ratio to be at least 1.6. Below 1.6 the plant operation is not recommended. The Maximum IRR that was obtained for the plant without biogas production was 1.8% which is well below the operating range of 10%. This implies that the plant to operate without biogas production is not viable. It is noted 10% IRR is a generally low standard for project evaluations. Many companies use 20% as the IRR threshold.

Chapter 6

CONCLUSIONS AND RECOMENDATIONS

From the sensitivity analysis results it is clear that the fluctuation in the operating income has more impact on the payback period than the capital cost. The major conclusion drawn from the economic analysis is that biogas production and long fiber production are essential for economic feasibility, given the capital and operating cost estimates provided. The plant would be marginally economically viable under the conditions that the IRR is greater than 10% and the $\Sigma (C_i-C_o)/I$ ratio should be atleast 1.6. If the plant is operated without using the short fibers for the generation of biogas it would not only be an economic loss but also an environmental issue. If the short fibers were sent to the land fill, as the short fibers contain organic substance, they would undergo an aerobic digestion process and considerable amounts of CO_2 (60%), CH_4 (30%) and other gases would be produced which would be fed into the atmosphere. With the above drawn conclusions, it is recommended to use the short fibers and the repulped water to generate biogas, then, to, use that biogas for the power generation and for plant heat. Environmentally and economically the four unit plant with biogas production is significantly more viable than the plant without biogas production.

Future work in this area would be to use the short fibers to produce hydrogen rather than to produce biogas. Hydrogen production can be carried out in the anaerobic digesters where photosynthetic bacteria could be used for the production of hydrogen.

These bacteria can help in increasing the quantity of Hydrogen being produced. In this study the anaerobic digestion process used was DRANCO process for the production of biogas. The DRANCO process is a single staged Anaerobic Digester (AD) system.

Other digester systems such are sequential batch can be taken into account for the production of biogas. The sequential batch process comprises two or more reactors. The leachate from the first reactor, containing a high level of organic acids, is re-circulated to the second reactor where methanogenesis occurs. Batch processes offer the advantages of being technically simple, inexpensive and robust. However, they require a large land footprint as compared to single-stage reactors. Other disadvantages are settling of material to the bottom thus inhibiting digestion and the risk of explosion while unloading the reactor. If these disadvantages can be handled, then sequential batch anaerobic digesters can be used for the production of biogas. They can take larger volumes of short fibers as a result can increase the quantity of biogas being produced when compared to the single stage AD system, time being the same for both the processes.

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