Business Plan: New York Municipal Solid Waste

Capstone Design Project- University of Oklahoma
Spring 2003

By:
Jessica Beard
Brant Bennett
Jason Black
Adam Bymaster
Alex Ibanez

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In 2001, the United States generated 208.4 million tons of Municipal Solid Waste (MSW), or 5 pounds per person per day.[1] By weight, 15% is burnt, 30 % is recycled and 55 % is put into landfills.[2] Municipal solid waste consists of product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances and batteries. Materials such as construction demolition debris, municipal liquid waste (MLW) treatment sludges and non-hazardous industrial wastes are not considered MSW.[2] Institutional wastes, such as waste products from prisons, hospitals, and schools are considered MSW.

Several cities facing disposal problems were considered for a new disposal method of municipal solid waste. The decision was made based on: current disposal costs, trends in disposal costs, trends in waste production, population growth and the severity of the problem with current method of disposal. The four locations analyzed were New York City, New York; Los Angeles, California; Detroit, Michigan; and Hilo, Hawaii. Although each location has significant problems processing municipal solid waste, New York City was selected based on the aforementioned criteria. It produces the largest amount of MSW per day, pays a high cost to dispose of its MSW, and it maintains a large population growth.

I. MSW in New York City

Everyday New York City and its surrounding area generate approximately 47,303 tons of waste. The New York Department of Sanitation (DOS) manages 40% of this waste, and private corporations handle the other 60%. In the year 2000, 35% of the amount that the DOS managed was recycled, 34% was deposited at the Fresh Kills Landfill, and 31% was exported out of the city. However, the Fresh Kills Landfill closed in April of 2001. On average, New York City pays an average $63.30 per ton to landfill their municipal solid waste[3].

Present Methods of Disposal

In New York City, approximately 10,500 tons of MSW need processing daily[4]. As previously mentioned, the amount not recycled is transported out of the city to several neighboring landfills. However, landfilling is a decreasing option for several reasons. In a high density area such as New York City, health problems stemming from landfill contamination have prompted the passage of state laws that prevent landfilling in the municipal area[5]. The laws have long since placed a constraint on MSW disposal in the vicinity of New York City, particularly the state of New York.

New York currently has nine privately owned landfills and twenty-three publicly owned sites where the combined capacity is 60 million tons. Currently, 98 percent of New York's commercial landfill space is located in western New York State. If New York City sends all trash to state landfills, they would be filled to capacity within four years.

In New York City, proposals have been made that tried to gain support for incineration as a solution to its MSW problem. None have had any success, however. Incineration has many disadvantages. First, building and operation costs for incineration are considerably high because of the energy required. Also, disposal costs can range from $120/ton to $175/ton in some cities that use incinerators. The two biggest disadvantages, however, are the air emissions and toxic ash produced by incinerators. NYC residents point out the fact that a 3,000 tons/day incinerator with emission controls still releases about 2 million pounds of smog-forming nitrogen oxides into the air each day (similar to adding more than 300,000 cars to the road) as well as the fact that burning 5,000 tons per day of garbage could add about 300 pounds of mercury to NYC's air each year[6].

Pyrolysis is believed to be the only option that is feasible in the New York City metro area because of restricted biomass processing rates and land constraints. It shares similar disposal issues with incineration, however, the emissions are considerably less than incineration and modern technology has indicated that new air exhaust filters can reduce toxic emissions even more significantly. The slag left over from the pyrolysis must be landfilled or can be used as an aggregate in asphalt.

With the integration of a separation process to keep pollutants out of the stack and facilitate recycling, the goal of this approach – reducing disposal fees while operating within EPA guidelines - is closer than simply implementing a nondiscriminatory waste disposal facility. Three major benefits of pyrolysis all have their root in savings that make it more marketable than the other options. The reduction of landfill volume – ranging from 85 to 92 % - makes landfill disposal of waste cheaper.[7] Transporting less material from the plant to the landfill will also be less costly. The heat released while pyrolyzing may be used to make steam and generate electricity, a profit-making enterprise. Finally, it is possible to produce synthetic gas which may then be upgraded to valuable end products, some of which include synthetic fuels, hydrogen, ammonia, alcohols, aldehydes, and carboxylic acids.

II. Pyrolysis Process Overview

Union Carbide Corporation (UCC) developed the PUROX pyrolysis system to convert solid wastes to synthetic gas - a mixture of CO, CO_2 and H_2. This gas can be used as a medium value heating fuel, but because of the inefficient nature of using syngas for combustion, syngas is used to develop an end product such as ammonia, hydrogen, or synthetic fuel. Below is a figure depicting the general pyrolysis process.

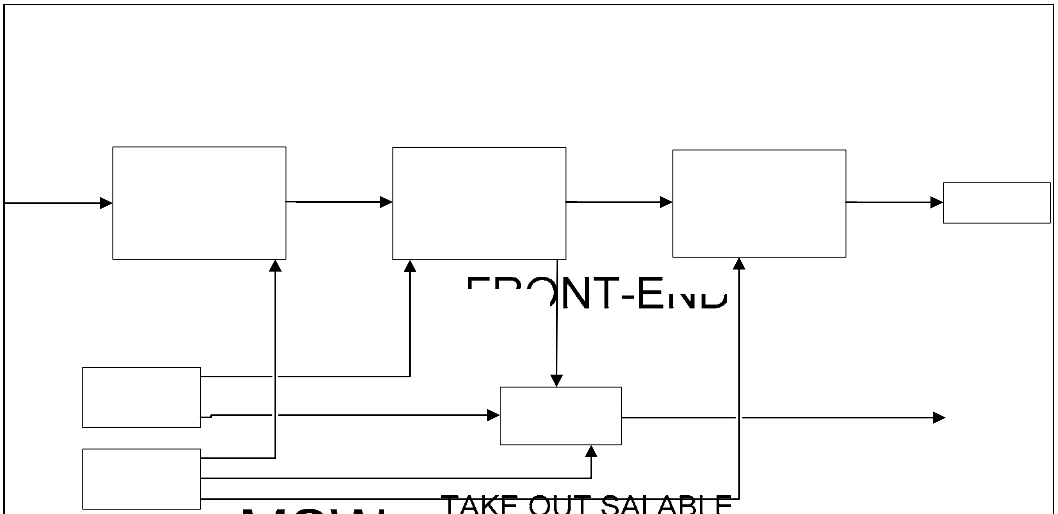

Figure 1: Pyrolysis Process Overview

The process is scalable to allow the integration of several plants throughout a region. The optimization of a plant network that can meet the changing constraints of the New York City municipal area is one goal of this project. A secondary goal of the project is to keep material from being burned or landfilled.

The constraints on the facility follow: it must be large enough to handle the specified waste stream during the life of the project, it must be small enough to operate efficiently, and it must cost as little as possible. It must also have emissions control equipment - baghouses and desulfurization - and facility ambient air control equipment such as covered conveyors and ventilation leading to the baghouses.

Front-End Design

Separation before the pyrolysis reactors allows the recovery of salable products, enhances product purity, and reduces problems with emissions controls. All of these things enhance the overall aesthetic of the process, which in turn increases the community's acceptance of the operation.

Separation is accomplished with a set of equipment known as the 'front end'. The front end begins the process. It only has one materials shredder and it includes an aluminum separator. The aluminum separator is essential to the profit of the process because of the high price of recycled aluminum. This design is chosen because of the commercial availability of the components.

The front end is operated six days a week for two shifts – sixteen hours – a day. Because the gasifiers will be operated continuously, the average waste processing rates must be turned into hourly processing rates for the front end for accurate sizing and pricing. This is a rate of 1750 tons/day. It is important that the front end have a day for maintenance because it is handling a coarse mixture of material. The front end can be scaled in proportion to the plant in order to save capital and allow the addition of fractional plant capacity.

PUROX Pyrolysis Unit

The purpose of the PUROX system is to turn solid waste into a synthetic gas. The oxygen and trash are fed to the reactor with slag and syngas coming out. The basic reactions driving the production follow:

$C + O_2 \rightarrow CO_2$ ΔH = -405 kJ/mol (1)

$C + H_2O \rightarrow CO + H_2$ ΔH = 131 kJ/mol (2)

$C + CO_2 \rightarrow 2CO$ ΔH = 173 kJ/mol (3)

The negative sign for reaction (1) indicates that it gives energy away as heat. Because this reaction gives away more than enough heat for the other reactions, the reaction is self-sustaining as long as the oxygen feed is present.

Pyrolysis Equipment

The heart of the Purox system is a vertical column heterogeneous-phase gasifier. The UCC-standard reactor sizes can process up to 350TPD of waste feed. The reactor operates continuously in order to maintain steady state operation, minimizing costly start ups and shut downs. This means that the facilities associated with the plant: electricity conditioning, oxygen production, water treatment and cooling also have to operate continuously or, in the case of the oxygen plant, operate with an excess stored in case of cyclic shutdown or emergencies.

There are three regions within the reactor: the drying zone at the top, the pyrolysis zone in the middle, and the hearth zone at the bottom. The oxygen is fed to the hearth zone, and this is where combustion takes place. Organic solid waste, heavy non-metallic components and glass are fed into the top of the unit. As it falls it is heated until it is completely dry in the drying zone. After it is dry, it begins to char. In the absence of oxygen (it is all consumed in the lower zone of the reactor), the cellulose is pyrolyzed until it is reduced to char and oil. It continues to fall and settles on a grate. With oxygen blowing on it, all of its volatile components are vaporized and eventually it falls through, landing in the bottom of the reactor and mixing in with other molten waste such as glass. A slag aggregate forms and oozes out of the bottom of the reactor where it is collected on a conveyor and taken to an elevated frit container for loading onto trucks and sold as cinder block material.

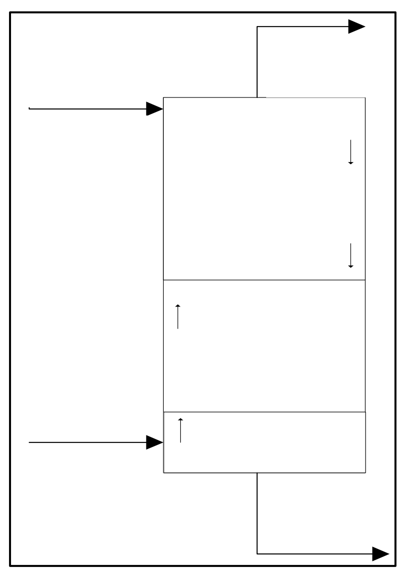

Figure 2: Purox

As the waste falls, it is dried by hot syngas coming from the pyrolized matter below it. Once the waste feed is completely dry, it begins to char and release the syngas. The char and residual oils that fall to the bottom ignite upon contact with the oxygen feed, providing heat for the reaction to continue. All of the oxygen is used up in this hearth zone, making carbon oxides, hydrogen gas, and hydrocarbon gases. The hearth zone is approximately 1650 ^{o}C, which is hot enough to melt the glass and encapsulates the other heavy constituents.

A scrubber is used to keep the syngas leaving the purox reactor within EPA standards due to the fact that it has particulate emissions and sulfurous compounds in it. The scrubber cools the vapor to the point where the moisture drops out and some effluents are removed. The condensate from this process is very high in biochemical oxygen demand (BOD), and the EPA regulates these levels, too. The water is sent to a sewage treatment plant that utilizes the oxygen left over from the plant – not used in the pyrolysis.

From the scrubber, the vapor passes through a knock out (KO) tank where solids and more liquid precipitate due to pressure drop. The gas moves on to a wet electrostatic precipitator. The electrostatic precipitator uses electrical fields in the moist vapor to collect and precipitate particles from the vapor. The electrical fields stimulate the formation of ions, namely ozone, that bond to everything that needs to be separated. When the vapor has the appropriate amount of moisture, the gas is then transported to the desulfurization facility.

Table 1 shows the capital costs scaled up from the 1975 EPA report. The construction costs take into account all capital costs for the front end and Pyrolysis system including those of the wastewater plant and oxygen plant.

Table 1: Capital Cost Requirements for Purox System

Item	1975 $ millions	2004 $ millions
Construction	47.08	126.93
Interest during construction	4.30	11.59
Startup Costs	2.56	6.90
Working Capital	1.56	4.21
TOTAL	55.50	149.63

Oxygen Plant

280 TPD of 99% oxygen is required for every four purox reactors, as well as the wastewater treatment plant. Also, if the plant expands, up to twice that number is possible. The oxygen used in the Purox system and the wastewater treatment plant is produced in an on-site cryogenic oxygen plant where oxygen is separated from air. First, the air is compressed to liquefy it. Then, at temperatures below 90 K, the liquefied air is fractionally distilled to separate it into a top vapor nitrogen stream and a bottom liquid oxygen stream. Nitrogen, having a lower boiling point, is more volatile and rises to the top of the column, while the more dense liquid oxygen falls to the bottom of the column. The liquid oxygen can be stored or allowed to vaporize and used immediately. The nitrogen also has several uses. It is may be stored or used for purging reactors, and it is a critical to the plant safety program.

The major cost that is associated with the air separation process is the cost of electricity to compress the inlet air. This generally comprises the biggest change in the utility cost of the cryogenics plant. However, the cost of refrigerant for each of the columns is an expensive commodity. The goal of the design is to minimize the cost of compression.

Wastewater Treatment Plant

Before wastewater from the solid-liquid separator can be released into the municipal sewage system, it must be treated to reduce Biochemical Oxygen Demand (BOD) to local city regulation limits. Union Carbide provides a UNOX wastewater treatment facility with its PUROX pyrolysis unit. Most sanitation departments do not allow high BOD discharge into sewage lines.

The UNOX wastewater treatment system, developed by the Union Carbide Corporation, uses feed oxygen in a sludge process to reduce BOD. The feed of 40 tons per day of pure oxygen is provided to the microorganisms that remove the pollutants from the wastewater. If air were used instead of oxygen, these microorganisms would not receive enough oxygen to survive, and the pollutants would not be removed. The UNOX system is a covered three-stage process that accepts wastewater and oxygen and discharges treated wastewater, off gas, and excess biomass, or sludge. This is illustrated below in Figure 3. The UNOX plant is designed to handle a wide range of throughput of wastewater, the necessary amount to process up to 3,000 TPD of MSW.

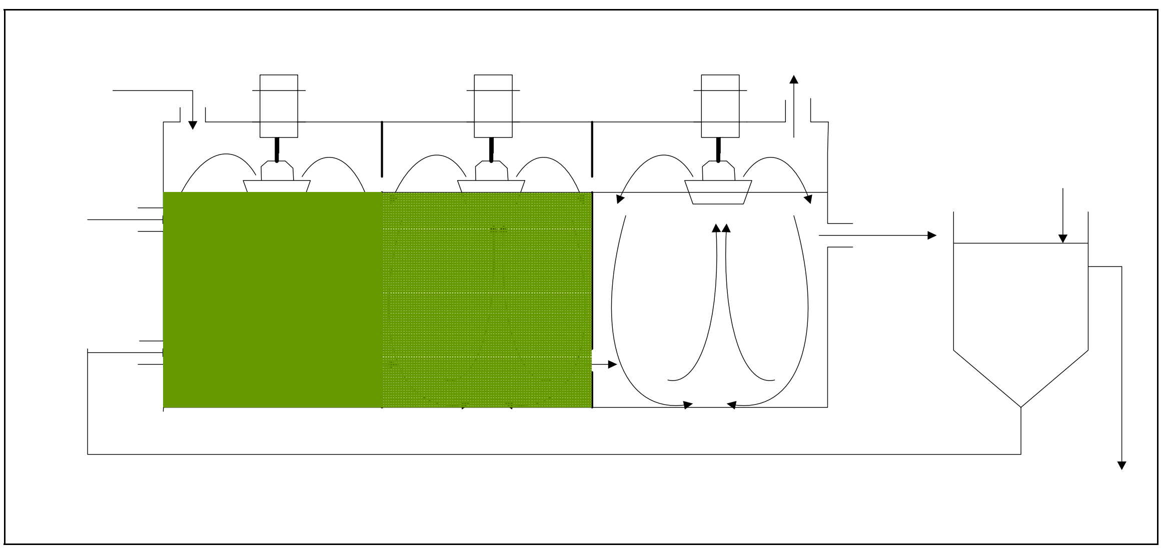

Figure 3: Wastewater Treatment Plant

Desulfurization

The dry gaseous effluent from the pyrolysis unit has a major problem with sulfur contamination. Sulfur presence will poison catalysts if the concentration is far above 1 ppm, so the target removal of sulfur will produce a gas with less than 1 ppm sulfur compounds. Desulfurization is required to prepare the syngas for synthetic preparation. The removed sulfur can be used to produce sulfuric acid or elemental sulfur, both salable products.

SURFACE AERATORS

O_2 FEED
40 TPD

An industry standard for the removal of hydrogen sulfide is the gas shift zinc oxide-hydrogen sulfide reaction below. The porous zinc oxide spheres absorb the sulfur in the hydrogen sulfide.

$$ZnO + H_2S \rightarrow ZnS + H_2O$$

The zinc can then be regenerated with oxygen gas.

$$2ZnS + 2O_2 \rightarrow 2ZnO + 2SO_2$$

According to an article in Oil & Gas Journal, regeneration can reduce sulfur levels in spent catalyst to below 1% and can recover over 95% of the available surface area.[8] The catalysts can be regenerated in situ (on site) or ex situ (off site). Ex situ generation is the more economical option. The cheapest way to remove 600 ppm sulfur particulates is with ZnO dry-bed absorption with ex situ regeneration and disposal every two years.

For the lifespan of the 20 year project, a catalyst bed will cost $150,000 with an average annual catalyst cost of 2.4 million with an additional cost in the first year of 2.6 million and in the second year of 2.4 million, yielding an average of 2.9 million. With fresh catalyst, ex situ regeneration (~20% of catalyst price) will cost $800,000.

III. End Product Comparison

The pyrolytic synthetic gas produced from the pyrolysis process can be upgraded to valuable end products. The end products considered were hydrogen, ammonia, synthetic fuel, methanol, acetic acid, dimethyl ether, and polycarbonates. After careful investigation of all end product possibilities, hydrogen was selected as the most feasible product with the highest profit per ton of waste processed. This conclusion was found using material balances and selling prices of each end product. Hydrogen was estimated to sell for $107 per ton of MSW processed. The synthetic fuel was approximately $72 per ton of MSW, with an additional income from government tax credits. Assuming there exists a market to sell all or most of the hydrogen produced, hydrogen will be the most profitable end product. Synthetic fuel production is the next best option.

Figure 4: Product comparison of profit per ton of waste

IV. Hydrogen Processing Plant

The production of hydrogen from synthetic gas involves four major systems: steam reformation, water-gas shift conversion, carbon dioxide removal, and pressure swing adsorption. Steam reformation converts the 11 molar percent composition of hydrocarbons in syngas to hydrogen and carbon dioxide. The next phase uses the water-gas shift to further convert carbon monoxide and steam to hydrogen. Then, Selexol solvent selectively absorbs most of the remaining CO_2 and H_2O. Finally, a pressure swing adsorption purifies the hydrogen to industrial quality levels.

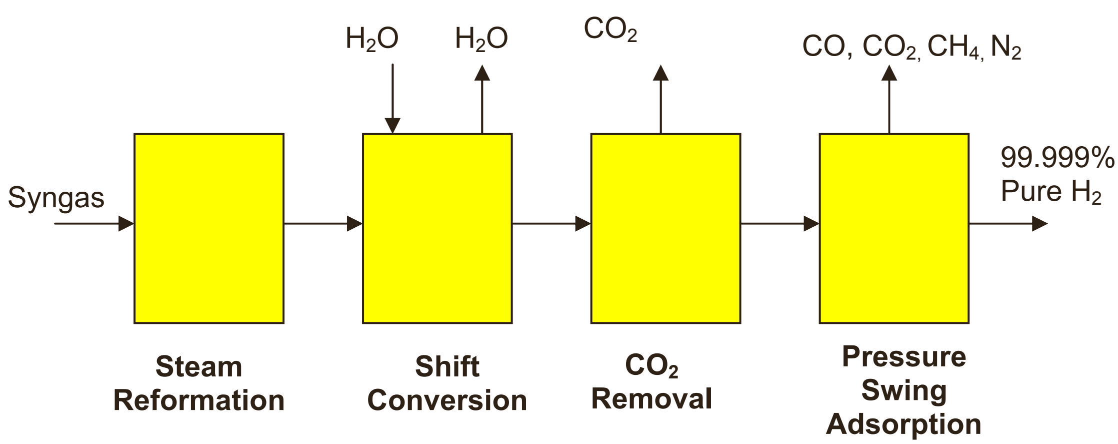

Figure 5: Hydrogen Processing Plant Overview

Table 2: Capital breakdown of hydrogen processing plant.

Direct Costs			
	Total Equipment Costs		$22,050,976
		Total	$79,383,512
Indirect Costs			
		Total	$31,753,405
Fixed Capital Investment			$111,136,917
Working Capital			$19,625,368
Total Capital Investment			$130,762,286

V. Transportation

Transport of MSW

The feasibility of purchasing municipal solid waste garbage/dump was evaluated. Semi trucks with dump trailers were investigated. The cab for this truck has a cost of approximately $95,000.00 while the dump trailer has a capacity of approximately 15 tons and a cost of $30,000[9]. These trucks get an average of 6 miles per gallon. Using the price of diesel fuel, the price per mile to transport the municipal solid waste from a transport station to the plant site was 31 cents.

Transport of Hydrogen

Liquid hydrogen should be transported with special double-walled insulated tanks to prevent boil-off. The capital costs of liquid hydrogen transport will consist mainly of the insulated tank trailer, plus the cost of the cab for truck transport. The same transportation costs from the semi-trucks for MSW are used for the hydrogen. The cost of the tanker for the transport of hydrogen is found to be $350,000. The cost of the truck and chassis is found to be $90,000.

VI. The Mathematical Model: Formulating a Business Plan

A mathematical model was developed to be used as an engineering tool that assists in the logistic planning of the New York City waste management system. The model incorporates cost minimization of the waste management process by evaluating all possibilities from an economic perspective. This includes consideration of all possible investments, waste management disposals and technologies, locations, amounts of waste processed, and ownership options. The deterministic model developed for this project was designed to incorporate the following objectives:

- Implement and control the most efficient and cost-effective flow of materials in relation to time
- Account for current MSW disposal contracts
- Encompass transport of MSW and final products
- Execute the right number, location, and capacity of plants
- Incorporate expansions in relation to time, money, and the amount of trash available
- Evaluate ownership options

Scale Up of Pilot Plant Data

In order to formulate the mathematical model, it is necessary to extrapolate data from the already developed pilot processing plants. The pilot plants were all quoted for a MSW processing capacity of 1500 TPD because they are based on the 1975 EPA report that used the same capacity. This information may be scaled up in order to accurately represent the processing capacities that are required of each individual location.

The model was programmed to account for the increasing capital investment and operating cost associated with expansion. Also, the model was programmed to take into account the fact that it must have one hydrogen plant for every 4 purox reactors. Basically, if the model must take in more than 1500 TPD, it will build another purox reactor. For each purox reactor, the hydrogen plant needs one water-gas shift reactor, but it must build a new CO_2 removal system and a new PSA system. Figure 6 provides a broad estimate for the entire processing plant if it were to process the entire city of New York's municipal solid waste.

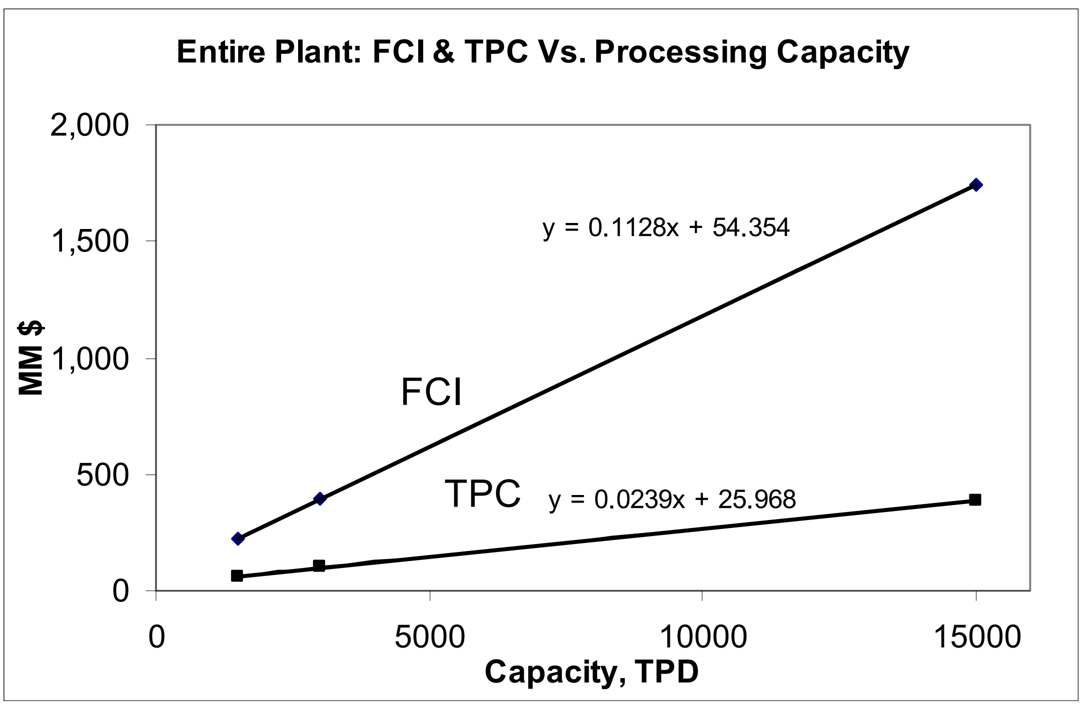

Figure 6: Entire Plant Fixed Capital Investment and Total Production Costs

Analysis of Private Ownership with Strategic Planning

The model was built to incorporate the private aspect of ownership for the disposal and processing of New York MSW. The objective was not to process the maximum amount of MSW available, but to select the optimal amount of MSW to maximize the net present worth (NPW) over the lifetime of the 20 year project. A disposal fee of $45/ton of MSW was chosen in order to be well below the average disposal fee of $63.3/ton. This price offers the freedom and reality to select and win bids on available contracts from the city, to process this optimal amount of MSW from the desired transfer stations.

Of the above 13 possible plant locations input into the model, the model selected 6 plants to be built over the lifetime of the project. The locations chosen by the model were all in the NYC vicinity and are as follows: Oxford, NJ; Charlespoint, NY; Huntington, NY; Babylon, NY; Islip, NY; and Hempstead, NY. Six consumer locations were entered into the model, all of which were used. The six consumers were refineries in New Jersey (no refineries are in the state of New York), which were chosen since the main consumers of hydrogen, at this time, are refineries. These refineries were located as follows: Port Reading, NJ; Perth Amboy, NJ; Paulsboro, NJ; Westville, NJ; Linden, NJ; and Paulsboro, NJ.

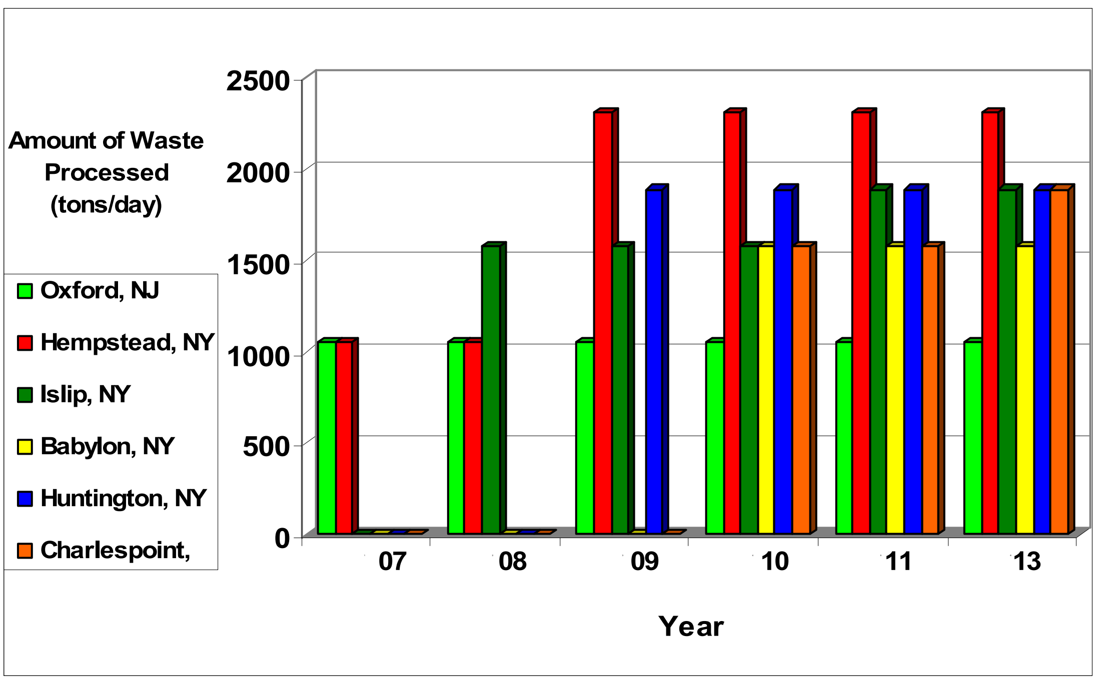

Figure 7: Waste processed by each plant in relation to time for private ownership

The figure above depicts the amount of waste processed by each plant in relation to time. The years included in the figure represent the years where major changes occurred in total processing capacity, either through additions of new plants or expansions to existing ones. From the figure it can be seen that two plants start-up in year 2007 and by 2013 all six plants are operating at full capacity. Figure 8 below compliments the above figure, illustrating the amount of total MSW processed by all plants in relation to time of the project. Also depicted in the figure is the amount of waste available from all transfer stations (including those not free from contracts). By the year 2013, the company is handling 86% of the amount of MSW handled by the NY

Department of Sanitation. Over the lifetime of the project, the company processes about 78% of the waste available. At this fee of $45/ton, processing 78% of the waste available over the lifetime of the project saves the city an average of $54.7 million (MM) per year. This calculation assumes that the remaining 22% of the MSW is disposed of at the average fee of $63.30/ton.

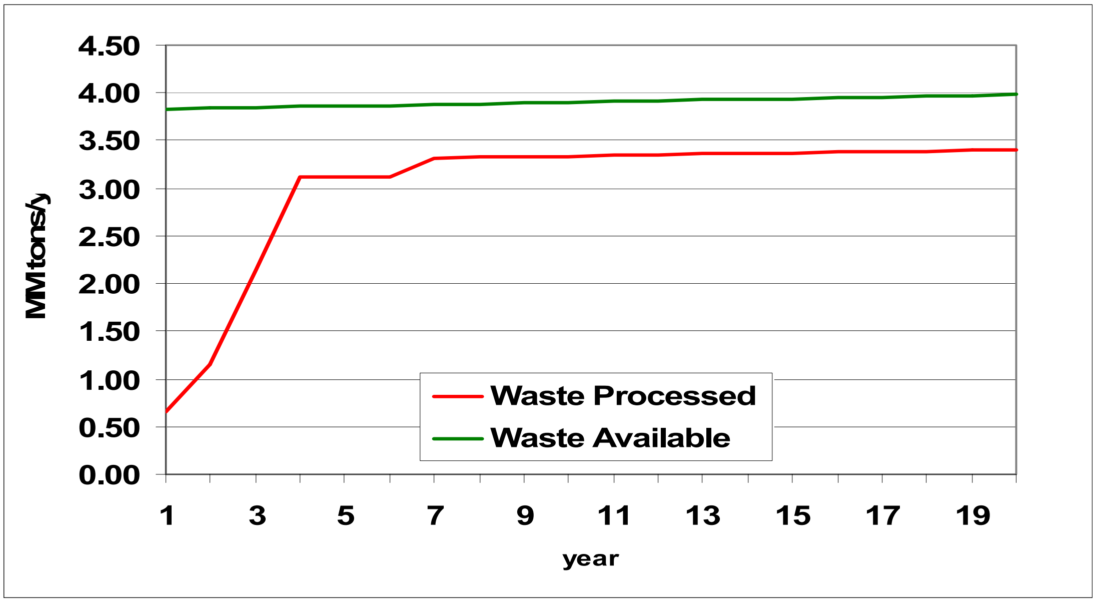

Figure 8: Waste processed by all plants: time, expansions, and available waste

The model was also programmed to determine the number of MSW semi-trucks needed to transport waste from the transfer stations to the 6 plants (see equation below). As more plants are added and expansions take place, more trucks are required.

$$\#Trucks_{MSW} = \frac{(wasteamount)}{(\#trips)(capacity_{truck})}$$

The number of trucks needed to transport all the hydrogen was determined just as the MSW trucks were calculated, in relation to the amount of product to be transported between plant and consumer, the number of trips that can be made in one operating day per truck, and the capacity of each truck. The tables below show the distribution of the number of trucks needed at each of the plants (at full capacity), based on the equation above.

Table 3**:** MSW trucks from transfer stations to plant.

Location	**No. MSW Trucks**
Oxford,NJ	20
Hempstead,NY	33
Islip, NY	36
Babylon, NY	36
Huntington, NY	36
Charlespoint, NY	36

Table 4: H_2 trucks needed from plant to consumers

Location	No. H2 Trucks
Oxford,NJ	45
Hempstead,NY	99
Islip, NY	90
Babylon, NY	90
Huntington, NY	94
Charlespoint, NY	90

At the start-up of operation in 2007, there is a revenue of $175 MM and an operating cost of $137 MM. As the total operating capacity increases to over 9,000 tons of wastes per day, the gap between the revenue generated and the operating costs increases. By 2027, an operating cost of about $790 MM is required, and a revenue of $1.1 billion is generated.

Over the the lifetime of the project, the total capital investment of all plants and trucks totaled $2.0 billion. Dividends were factored into the model and represent 10% of each year's profits. According to the results from the model, the project recovers from all investments in year 2015. By 2027, a total cumulative cash of $4.1 billion is predicted. A net present worth over the 20 years is $198 million, with a favorable return on investment of 12.5%.

Analysis of Private Ownership with Strategic Planning

A model based on public ownership was also built for investigation. The major difference between the public model and the private model is that the public model has the added constraint that all the MSW should be processed. To account for the money needed for investment of the project, bonds were also added to the model. The equations below are the basic equations added to the model to account for the issuing of bonds.

$$\begin{aligned}\text{Cumulative Cash (t)} &= \text{Cumulative Cash (t - 1)} + \text{Revenue(t - 1)} - \text{Operating Costs(t - 1)} \\ &- \text{Capital Investment (t)} - \sum_{b=1}^{b=3} \text{Bond Repayment10(t, b)} + \sum_{b=1}^{b=3} IssuedBond10(t,b) \\ &- \sum_{b=1}^{b=5} \text{Bond Repayment5(t, b)} + \sum_{b=1}^{b=5} IssuedBond5(t,b)\end{aligned}$$

$$\text{Bond Repayment n (t, b)} = \text{Issued Bond n (t - 10)} * ((1+0.04)^{n}\ )$$

where n = 5 or 10 (depending on lifetime of bond—5 or 10 years)

Unfortunately, when trying to force the model to take all the MSW available, the model faced difficulties in converging to a solution. Therefore, to understand and demonstrate the process of how the public ownership would be executed with the issuing of bonds, a model run was recorded and analyzed that did not process all the waste of New York. The analyzed results are summarized below.

Similarities between the two models were achieved in some results. The plant locations chosen were the same as those chosen for the private business. However, the amount of waste processed, as well as the amount processed at each plant and expansions, etc. were different. A disposal fee of $35 per waste ton was chosen as the lowest fee that the city of New York could charge to its people without losing money. This fee would be charged by the city to its residents through taxes.

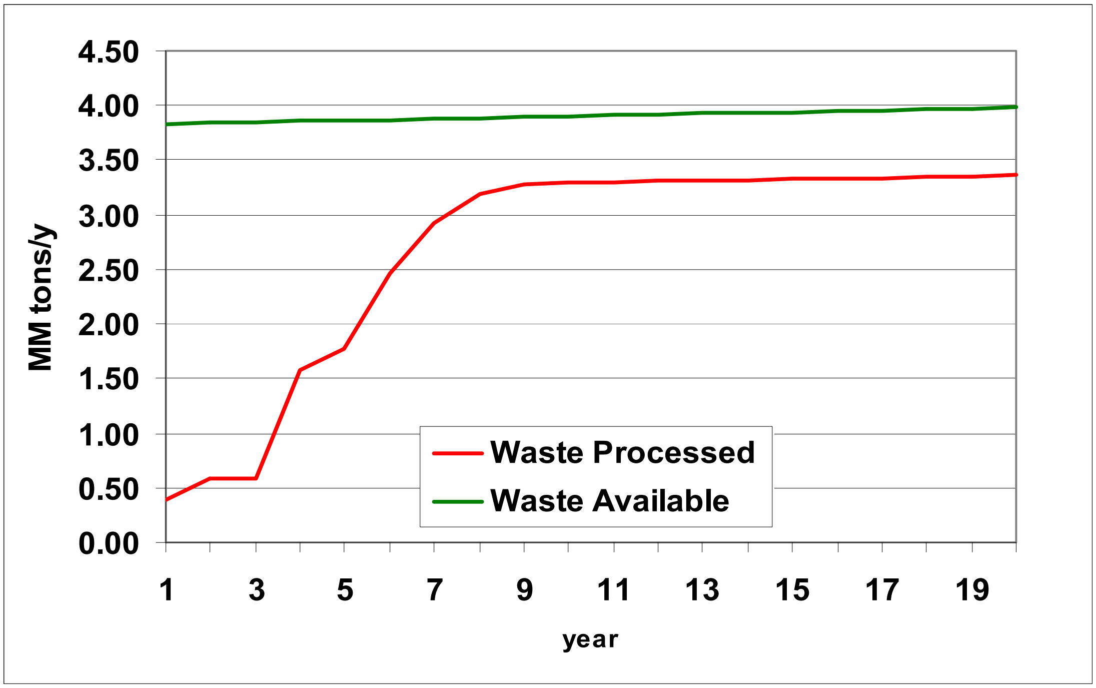

Figure 9: waste processed by all plants: time, expansions, and available waste

The figure above illustrates the amount of MSW processed by all plants during the project. Figure 10 below shows how much each individual plant processes in relation to time and shows what years plants were built or expanded. By the year 2015, the company is handling 84% of the amount of MSW handled by the NY Department of Sanitation (compared to 86% by the year 2013 for the private). When comparing the numbers from the public ownership to those found in the previous section over private ownership, it is easy to see that less waste is processed over the lifetime of the project. In comparison to the private ownership, the public option processes approximately 69% of the MSW available over the lifetime of the project (private processes over 79%). Obviously, from the public perspective, this is not acceptable as it is desirable to process all the waste available.

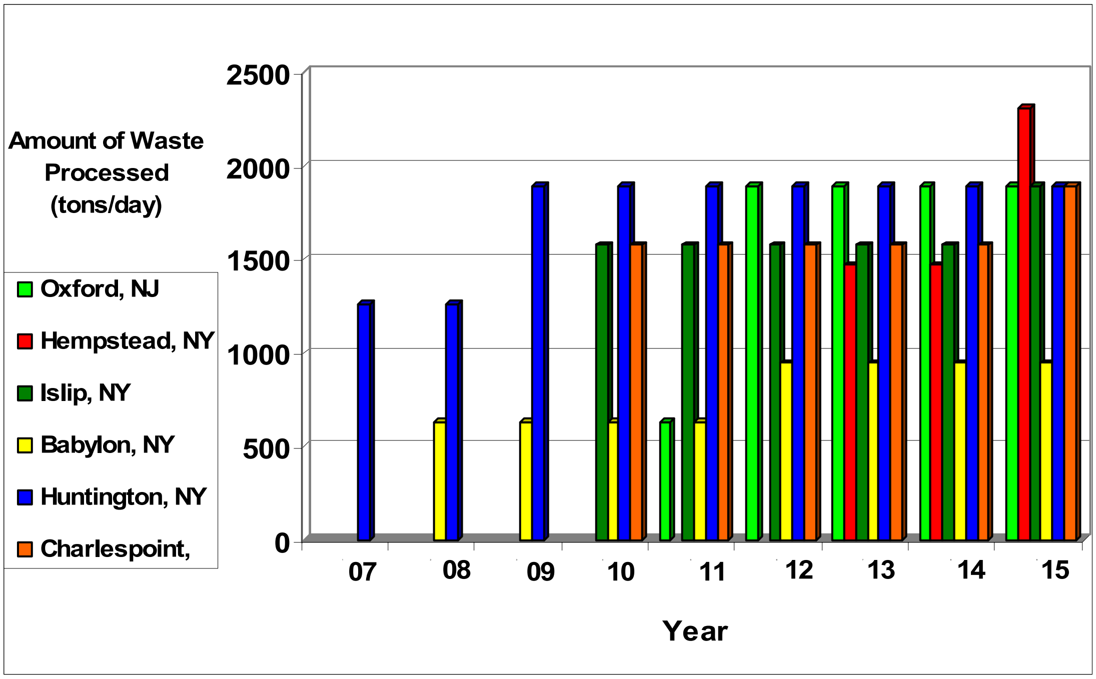

Figure 10: waste processed in relation to time for public ownership

The number of MSW and hydrogen semi-trucks was found using the same equations as those for the private. By 2027, 195 MSW trucks are needed between the six plants. Table 5, below shows the distribution of the number of MSW trucks needed at each plant. Table 6 demonstrates that at full capacity, 492 hydrogen trucks are required.

Table 5: MSW trucks transfer station to plant

Location	No. MSW Trucks
Oxford,NJ	36
Hempstead,NY	33
Islip, NY	36
Babylon, NY	18
Huntington, NY	36
Charlespoint, NY	36

Table 6: H_2 trucks needed from plant to consumers

Location	No. H_2 Trucks
Oxford,NJ	81
Hempstead,NY	99
Islip, NY	90
Babylon, NY	45
Huntington, NY	87
Charlespoint, NY	90

The total capital investment of all plants and trucks totaled $2.48 billion over the 20 years of the lifetime of the project. A total of $1.14 billion is issued in bonds to cover the capital investment (profit pays for remainder of capital investment not paid for by bonds). All three bonds were 10 year bonds at 4% interest. Bond 1 is issued in 2007 for $974 million, Bond 2 in 2011 for $136 million, and finally Bond 3 in 2014 for $30 million. The bond repayment totals $1.69 billion between the 3 bonds after a payback period of 10 years for each bond. By 2027 the cumulative cash reaches over $2.72 billion dollars. All taxes were taken out of the model as the public enterprise is exempt.

VII. Conclusions

The drawback to the city of New York when considering the private enterprise is that a privately owned company will not process all of the city's solid waste. The mathematical model has been programmed to only accept trash from transfer stations and in quantities that output the maximum net present value and thus profitability. However, results from the model indicate that for years beyond 2013, approximately 86% of the waste can be disposed, therefore saving the city millions of dollars each year.

From a public perspective, processing all the waste would be very attractive to the city of New York. This option is especially attractive if the private enterprise is too risky or cannot attract investors for the project. A publicly owned MSW disposal plant that produces hydrogen potentially offers the best option, allowing the city to minimize the waste disposal fees while gaining profit from the hydrogen to pay for other services for the city of New York. Finally there exists the possibility of managing some combination where a fraction of the profitable aspects of the proposal is privately owned and the remainder is run by the city of New York.

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[1] Total U.S. Population. Fact Monster. 4 May 2004. <http://www.factmonster.com/ipka/A0004997.html>

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[3] . "The Waste Stream Managed by the NYC Department of Sanitation". February 2001. 4 May 2004. http://www.ibo.nyc.ny.us/iboreports/nycwastemanagement.pdf

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