New York Municipal Solid Waste

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"One man's trash is another man's treasure."
-Unknown

I. Introduction

Municipal solid waste (MSW) consists of many different products, such as product packaging, grass clippings, furniture, clothing, food, and newspapers. The most preferred method for taking care of the municipal solid waste is source reduction, people producing less trash. However, reduction cannot reach 100%. Therefore, cities resort to landfilling, incineration, and pyrolysis.

a. New York City

There are many different cities that have problem with too much trash, but New York City has the biggest problem. New York City has about 19 million people in only 47,200 square miles. In 2000, New York City produced 46,000 tons of waste each day, where the Department of Sanitation (DOS) only took care of 40% and private sectors took care of 60%. DOS used to take 34% of the trash to Fresh Kills landfill on Staten Island; however, in March 2001, Fresh Kills landfill closed. Fresh Kills closing required complete exportation of the trash. Since all of the trash had to be exported, the cost of removing the trash ended up being $300 million a year, while it cost New York City about $100 million a year when Fresh Kills was open.

Landfilling is no longer a feasible option for New York City, mainly because there is no land. But on top of the lack of land, landfills are environmentally hazardous. Landfill produces a gas through anaerobic decomposition which produces 54% methane and 46% carbon dioxide. This results in about 1.5 million tons of carbon released into the air every year. This contributes to about 2% of the total United States Green House gases. On top of the gas produce by landfills, landfills also produce a liquid called leachate. At the very best, leachate is similar to very strong sewage water, but at its worst, leachate carries hazardous material to the bottom of the landfill. While newer landfills have a synthetic liner to keep the leachate in, there is still the possibility that the leachate will get into the ground reason. For these three reasons, landfilling will not be used.

Incineration, or direct combustion, is not longer a popular method for disposing of municipal solid waste. The main reason is due to the fat that the process is not environmentally friendly. For example, processing 3,000 tons/day of MSW, an incinerator with emission controls still releases about 2 million pounds of smog-forming nitrogen oxides into the air each day. Also, it costs about $925/MW for an incinerator to be built only to produce electricity, which electricity only sells for about $55/MW.

Contrary to incineration, full conversion of CO_2 does not take place with pyrolysis. Instead, waste is converted into a valuable intermediate, mainly syngas. Pyrolysis's air emissions are very similar to incineration; however, the amount is significantly lower than incineration. Syngas is made up mainly of carbon monoxide and hydrogen (85%) with smaller amounts of carbon dioxide and methane. This syngas can be converted into useful end products like methane, methanol, ammonia, hydrogen, and other chemicals. When producing hydrogen from pyrolysis, it costs about $0.15/kg of hydrogen to build the plant and the selling cost of Hydrogen is between $2.30/kg and $3.00/kg.

II. Pyrolysis Plant

The entire process was divided into four main parts, with each part designed independently from the other.

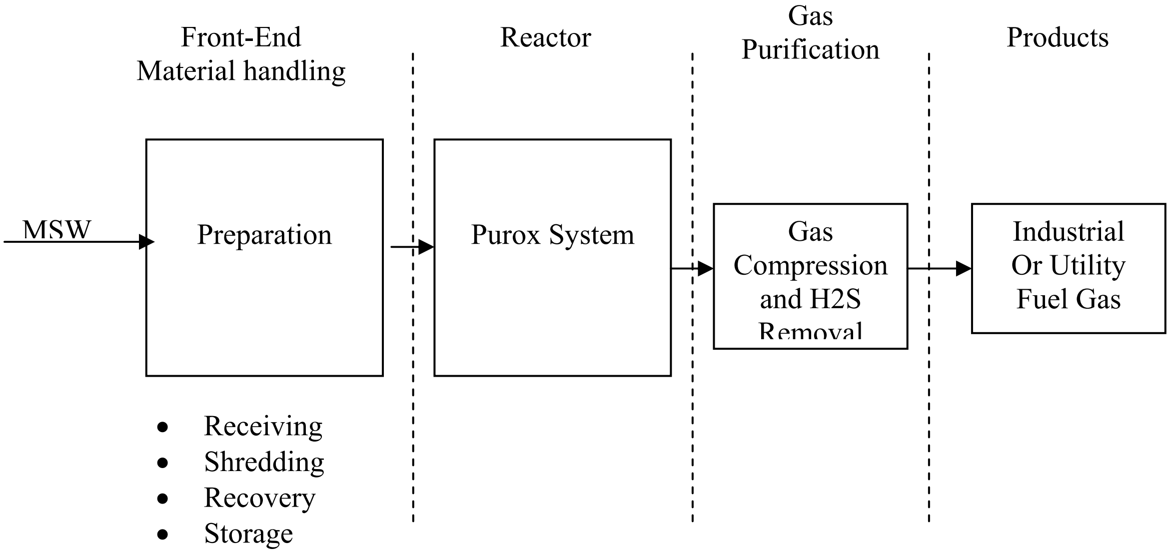

Figure 1: Pyrolysis Process System

a. Front-end Processing Plant

A front-end processing plant capable of handling 1500 tons per day of MSW was designed. This plant is capable of removing the valuable items such as aluminum and iron, while staying environmentally friendly. After removing the valuable items, the feed is reduced to 1363 tons per day. This feed is then sent to the reactor where pyrolysis and production of syngas take place.

b. Purox Plant

Three types of reactors were considered to carry out pyrolysis: (1) Bubbling Fluidized Bed Reactor, (2) Circulating Fluidized Bed Reactor, and (3) Fixed Bed (Purox Reactor). In order to determine the best reactor, three basic criteria were considered. These criteria are: (1) Capital cost associated with the reactors, (2) Ability to handle municipal solid waste, and (3) Ability to produce hydrogen. The capital cost of the Purox reactor was found to be 1.5 times smaller than the other two reactors. Also, the ability of the Purox reactor to handle the municipal solid waste was found to be much higher than the other two reactors. In addition, the syngas composition needed to obtain the desired final product, hydrogen, could easily be obtained without any major changes to process. Therefore, based on the above three properties, the Purox reactor was found to be the best option. The biggest Purox reactor in the industry is capable of handling maximum feed of 350 tons per day; therefore, four reactors were required to carry out the process. However, one extra reactor was added for emergency situations and for regular maintenance. Each reactor includes gas clean-up equipment, an oxygen plant, and a waste water treatment plant. The reactor and the associated equipment are known as a module. After the gas clean-up, syngas is obtained and sent to the hydrogen plant. The figures below represent the front-end processing plant and the Purox Plant.

The capital cost associated with the front-end processing plant and Purox pyrolysis unit capable of handling 1500 tons per day was found to be $126 million and the operating cost was found to be $23 million a year.

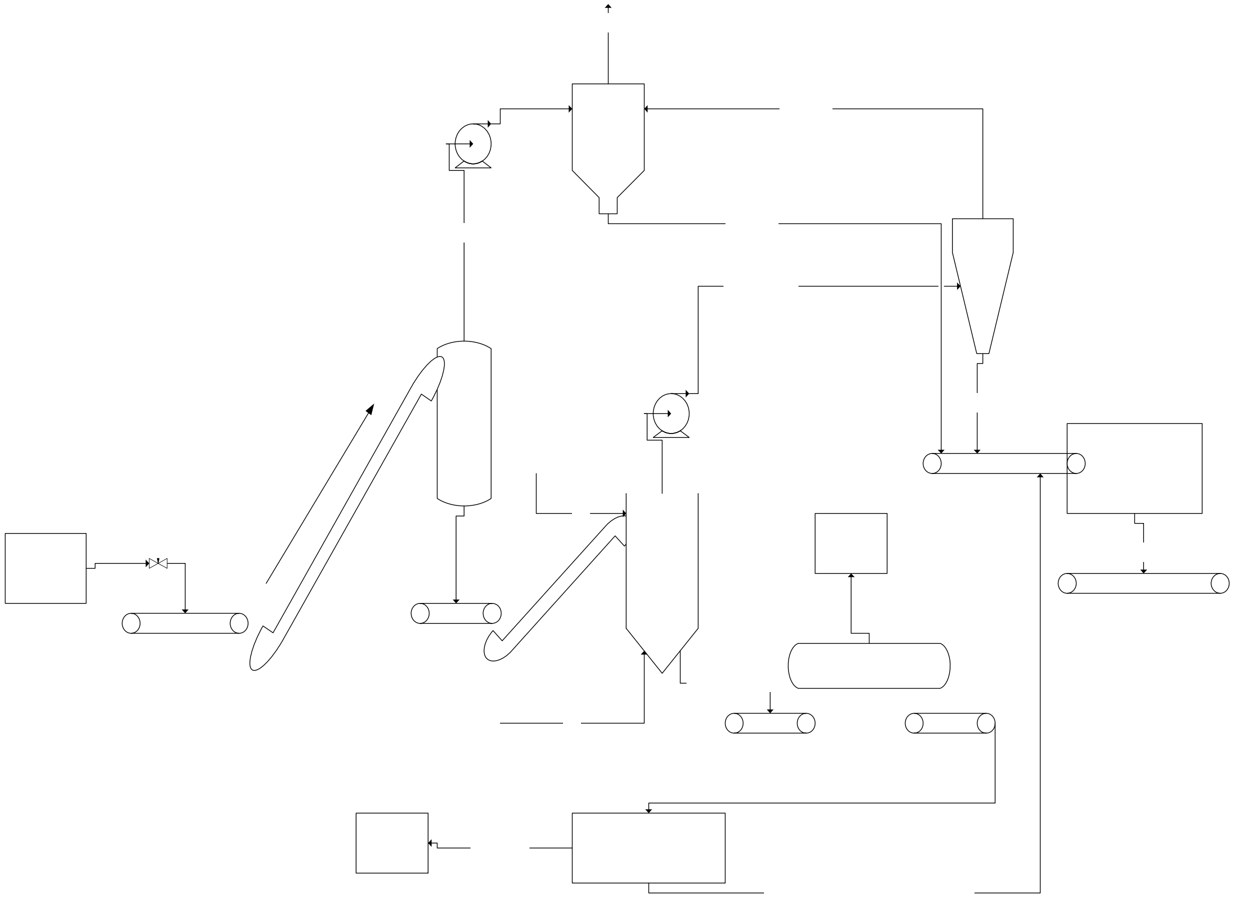

Figure 2: Front-end Processing Plant

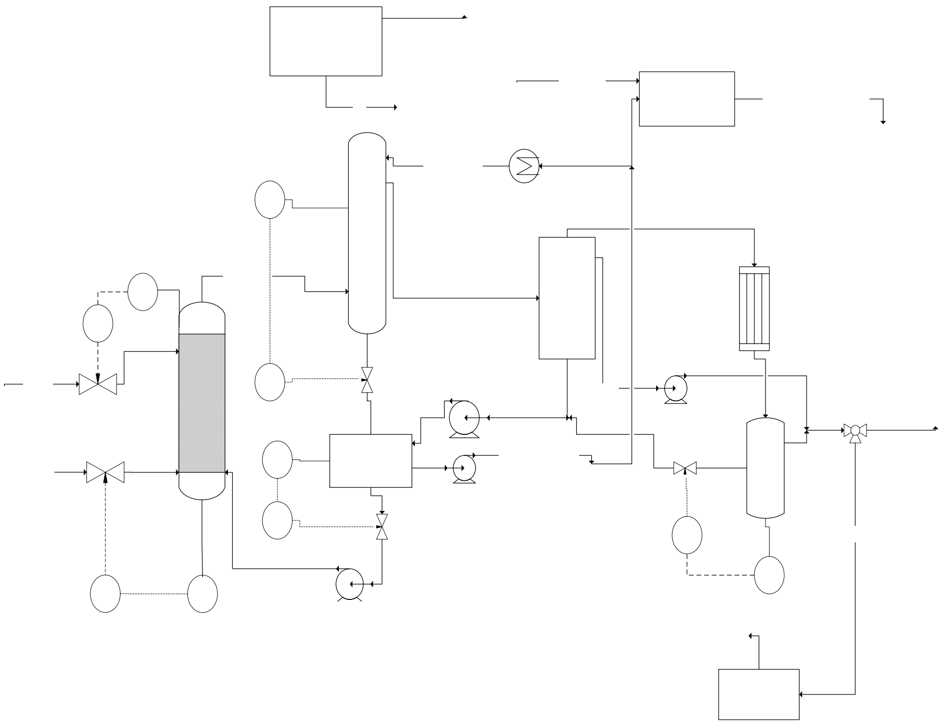

Figure 3: Purox Plant

III. Sulfur Removal

After exiting the pyrolysis unit, the 600 ppm hydrogen sulfide in the syngas must be reduced before entering the hydrogen plant. This amount of H_2S cannot be tolerated in the hydrogen production process and must be decreased to less than 1 ppm. There are several methods of removing hydrogen sulfide, however these methods produce elemental sulfur and have large capital and operating costs. Due to the low amount of sulfur production, combined with the low future market value of sulfur, it is not feasible to add a sulfur production unit to our process.

The method selected to remove the hydrogen sulfide consists of a sulfur absorbent metal oxide catalyst, specifically designed to purify feed streams for hydrogen production. The sorbent consists of porous zinc oxide spheres that absorb the sulfur in the hydrogen sulfide by the following reaction.

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

Zinc sulfide and water vapor are produced from the reaction. After the sorbent has reached breakthrough, it will be regenerated. Regeneration occurs by adding oxygen to zinc sulfide by the following reaction.

$$2\,ZnS + 3\,O_2 \rightarrow 2\,ZnO + 2\,SO_2$$

The method of ex situ, or offsite, regeneration was selected over in situ, or onsite, regeneration due its many advantages. Ex situ regeneration removes fines and chips from the catalyst which could contribute to pressure drop problems in the reactor and also obtains better catalyst activity recovery than in situ.

The reactor specifications were determined from information provided by a zinc oxide catalyst manufacturer. Using a void fraction of 0.29 for the zinc oxide catalyst, the volume of the reactor was determined to be 13100 ft^3, with a fluid volume of 3800 ft^3. Assuming a L/D ratio of 4, the reactor length and diameter were determined to be 64 ft and 16 ft, respectively. Using the syngas flowrate into the reactor of 28 million scfd, the gas velocity was determined to 1.6 ft/s.

There will be two reactor beds with one operating while the other catalyst is being regenerated off site. With a catalyst cost of $5/lb and 400 tons needed per year, and a regeneration cost of 20% of the fresh catalyst cost, the capital and annual operating costs for the entire H_2S removal process, including ex situ regeneration, are $ 8 million, and $1.2 million, respectively.

IV. Conversion to Products

Methanol, ammonia, hydrogen, and synthetic fuel were evaluated as end products from syngas. Methanol's second highest end use is Methyl Tertiary-Butyl Ether, or MTBE, which is blended with gasoline to enhance octane. It has been tentatively classified as a possible human carcinogen by the EPA, and will be phased out of use by 2006. This will result in zero growth in methanol demand over the next few years. Due to the small increase in demand, and methanol's low growth market, it will not be a reasonable final product.

The economics of ammonia was evaluated due to its large future market growth as a result of the fertilizer market. From the EPA's Office of Research and Development, an ammonia plant processing 28 million scfd of synthesis gas, producing 345 tpd, and selling ammonia at the price of $350 per ton, will have capital and operating costs, and income from sale of $211 million, 24 million, and 38 million, respectively.

Synthetic fuel was also evaluated further as an end product due to its demand as an alternative fuel source and its future market growth. From a report titled *Process Economic Evaluation Over 1,000 bpod Fisher-Tropsch Synthesis Plant*, the capital and operating costs, and income from sale for a plant that processes 28 million scfd of synthesis gas, produces 790 bpod, with a price of synthetic fuels of $0.95 per gallon, will be $23 million, 11 million, and 11.5 million, respectively.

Hydrogen is an essential component of many industrial processes such as petroleum refining and ammonia manufacturing. In efforts to achieve a cleaner environment, hydrogen is being looked to as the long-term energy source of the future. The U.S. Department of Energy states that hydrogen has the potential to solve two major energy challenges that confront America today: reducing dependence on petroleum imports and reducing pollution and greenhouse gas emissions. Hydrogen has recently been also used as alternative clean automotive fuels. In the near future, there will be more and more fueling stations built inside of State of New York. Additionally, hydrogen will be used in fuel cells for both mobile and stationary applications. With a forecasted market growth rate of 15% per year and the government's vision for a hydrogen-driven economy, hydrogen will be a viable option for an end product of the pyrolysis plant.

V. Hydrogen Production

The method of manufacturing hydrogen is to enrich its content in the synthesis gas mixture (CO_2, CO and H_2) and purify it. Additional hydrogen is produced by exothermic reaction of carbon monoxide with water by the water-gas shift reaction, high temperature and low temperature reactors. To reduce the greenhouse gas emission, CO_2 coming out of the water-gas shift reactors is scrubbed by using the physical solvent of Selexol, which is a mixture of dimethyl ether and polyethylene glycol. The solvent is regenerated in the process. The rich CO_2 stream will be captured and stored under the deep saline formation locations near New York State. The hydrogen stream is left with a small portion of CO, which will be absorbed in the absorbents in the pressure-swing absorption (PSA). Since the produced hydrogen will end up in the fueling stations and hydrogen fuel-cell power plants, it should be compressed to 7,500 psi by utilizing the multi-stage compressors and transported in composite cylinders by truck. The cylinders are made of aluminum and thermoplastic lining with glass or carbon fiber strengthening and each can contain 120 kg of H_2. Both the equipment cost and capital investment cost are calculated. The equipment cost comes out to be \$ 9,383,000, and the capital investment cost is \$ 24,370,000. The operating cost of compressing hydrogen to high pressure is a big part of the total operating cost, which turns out as \$ 5,974,000. The income from selling hydrogen is also determined at the price of \$3.00/ kg. The following figure shows the process flow diagram of hydrogen production unit.

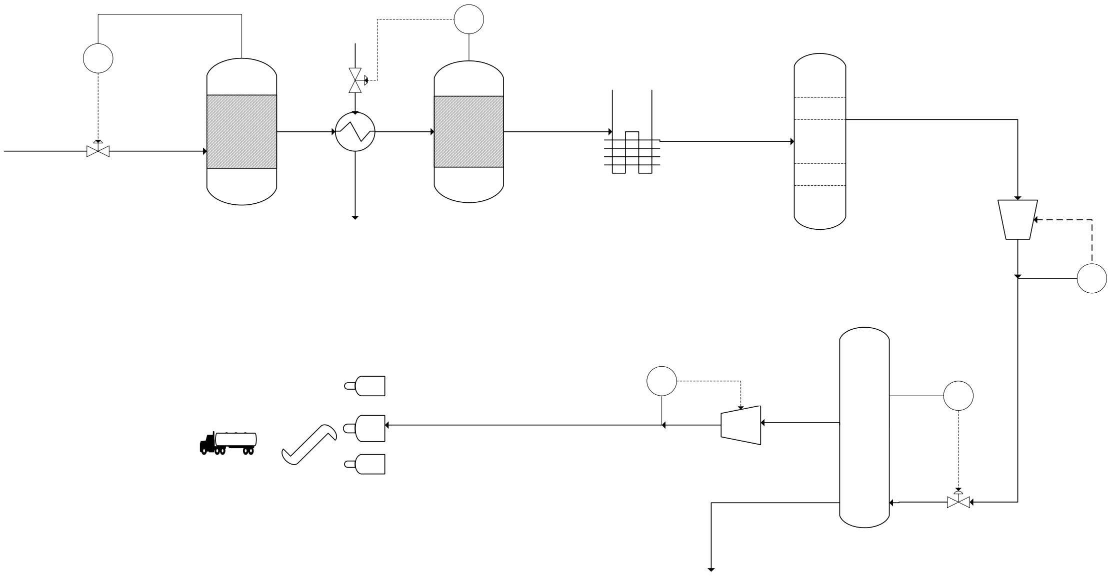

Figure 4: Hydrogen Production

Net present worth is the profitability criteria to determine the final product of processing MWS. The total capital investment consists of capital costs for land, pre-treatment, Purox, hydrogen production, CO_2 scrubbing and sulfur removal unit. The total operating cost includes transportation cost to delivery the trash from New York City to the plant location, Purox and final production unit operating costs. The operating time of each project is 20 years from now. The operating rate is 90 percent or 347 days per year. The method of straight-line depreciation is applied in all of the calculation. The inflation rate is assumed as 4 percent. The discount rate is 8.0 percent. Eventually, the calculation shows that hydrogen option is the most feasible due to a high positive NPW with the lowest required initial capital investment while the NPWs of both ammonia and synthetic fuel productions are negative. Table 1 shows details of the costs used to calculate NPW.

Table 1:

Items	Hydrogen	Synthetic fuel	Ammonia
Total capital investment	$167,463,000	$147,780,000	$335,759,000
Total operating cost	$55,900,000	$25,270,000	$38,745,000
Income from sales	$103,803,628	$42,105,000	$65,011,000
Net present worth	**$134,006,412**	**-$2,975,000**	**-$102,252,000**

VI. Business Plan

The information acquired pertaining to capital investment, process parameters, operating cost, and revenue allowed the formulation of relationships in a mathematical model, which then optimized the process. The goal of the mathematical model was to create a time line for the construction and subsequent expansion of the Purox facilities at the eight possible locations over the next 20 years. In doing so the mathematical model maximized the net present worth (NPW) of the entire solution. The model consists of three sections: Data, Model, and Solution.

The Data section of the model contains all of the known parameters of the system, where they are defined, and set equal to their respective values. In this section sets are defined, which allow the user to easily input and understand the data. The model for this project uses three sets:

i = New York City MSW transfer stations (NY1-NY15)
j = Possible site locations (L1-L8)
t = time periods (t1-t20)

Once the sets are defined, different parameters can be created for each set or a combination of sets. An example of a one dimensional parameter used in the model is the land cost per acre at the eight respective site locations, which is represented by lc(j). For parameters with two or more sets, a Table can be used to input data. A two dimensional example is the distances between the transfer stations (j) and site locations(i), this is represented by dist(i,j). The third form of data entry, Scalar, can be used to input values that will be constant through out the model examples are the disposal fee charged to NYC, pdis, and the Federal Tax rate, fedtx.

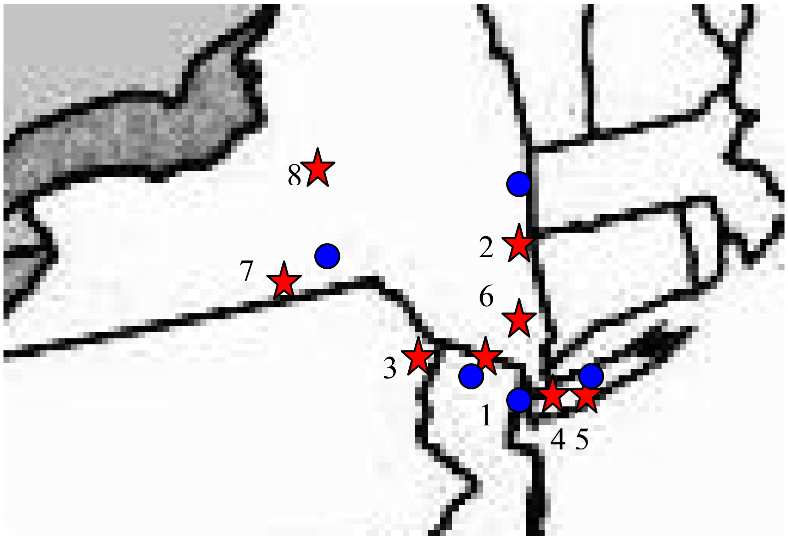

Figure 5: Map of Possible Site Locations (★) and Hydrogen Consumers(●)

The Model portion of the model contains two sections, one for Variables and another for Equations. Variables represent values changed as the model attempts to maximize a particular value. The main variable for this model Q(i,j,t), which represents the amount of trash sent from a transfer station I to a site location j in year t, plays a significant role in calculation of the other variables. In order for Q(i,j,t) to be positive, a plant must be built, representing a Capital Investment, and the plant must have an operating cost and revenue. The variables along with the parameters are used in equations that lead to the calculation of the NPW of each site. The Solution then solves the model for the maximization of the sum of all NPW, while following each of the constraints.

The model contains several important equations, each of with is either involved with the capital investment, revenues, and operating cost. Examples of these equations are:

Disposal Fee Revenue = disposal fee ($/ton) * amount of trash processed
CIpurox = 54.3*350*NU(j,t) +13000*Y(j,t)

Where, CIpurox = capital investment for purox portion
NU(j,t) = number of units built at site j in year t
Y(j,t)= Construction at site j in year t

$$NPV = \sum_{t=1}^{n} \frac{CF_i}{(1+r)^{t-1}} - TCI$$

Where, NPV = net present value of site j
CF= cash flow of year t
r=rate of return
TCI=Total Capital Investment of site j

The model solution provides a wealth of information about the overall solution to the MSW problem faced by NYC. The most important piece of data taken from the solution is the construction time table. This table tells when a facility should be built and how many modules the facility should have. This model is also able to take into consideration making expansions at an existing plant as opposed to starting a completely new facility. This is represented in Table 2.

Year:	**1**	**2**	**3**	**4**	**8**	**10**	**12**
Oxford, NJ	5		5				
Taylor, PA						2	1
Hempstead, NY		5	5				
Islip, NY	4			5			
Poughkeepsie, NY	1				3		
Hudson Falls, NY			1	2			

Table 2: Construction and Expansion Timeline

This figure shows that site four is the first to reach the maximum capacity limit, which means that according to the model site L4 (Hempstead, NY) is the most favorable location.

Another result given by the model is the capital investment cost at each of the selected sites. Table 3 displays this information.

Oxford, NJ	$340,300,000
Taylor, PA	$102,300,000
Hempstead, NY	$342,200,000
Islip, NY	$308,970,000
Poughkeepsie, NY	$173,320,000
Hudson Falls, NY	$103,000,000
Total	**$1.24 Billion**

Table3: Total Capital Investment per site

Although the total investment cost over the first 10 years is nearly $1.2 billion, the model also proves the process is both cost effective and profitable with net present worths are:

Oxford, NJ	$198,980,000
Taylor, PA	$6,810,000
Hempstead, NY	$196,600,000
Islip, NY	$167,900,000
Poughkeepsie, NY	$40,000,000
Hudson Falls, NY	$21,070,000
Total	**$631,370,000**

Table3: Net Present Worth

The net present worth was calculated using discounted cash flows for 20 years, with a return on investment rate of 12%. A table showing the trash flow rates from the transfer stations to the site locations is attached to the end of the file.

VII. Conclusion

The MSW produced by New York City is a significant problem that must be answered. Eventually there will not be enough room in the country for landfilling to continue to be a feasible solution and methods like incineration have detrimental effects on the environment. By proposing to charge NYC a disposal fee that is half of what is currently being paid, the city will save nearly $163 million by year 10. The net present value of the savings over the twenty year span will be $878,000,000. The MSW will be processed so that the effects to the environment are kept to a minimum.

The solution also creates a new supply of Hydrogen gas which is an important factor for the expansion of hydrogen fuel cell use. By the 10th year, the project will produce 160 million scf of hydrogen gas annually. The Hydrogen will have possible use in hydrogen refueling stations that are to be built in NYC and the surrounding area.