De-inking HDPE Plastic Film

DeMark Inc.

Elizabeth Beaudoin
Kristin Fraser
Beverly Pate

May 2, 2005

Executive Summary

DeMark Inc. proposes to build a plant in Englewood, New Jersey in 2006 to process recycled plastic removing its ink deposits and restoring it to a state where it can replace virgin raw plastic. With a NPW of $1.75 million, a pay out time of approximately 4 years, and a return of investment of 16%, DeMark Inc. proves to be a profitable company.

De-inking is not presently done in the plastic industry. The de-inked plastic has comparable quality to that of virgin resin, but is sold for a lower price, making it an ideal choice for plastic producers.

The process developed by DeMark Inc. removes ink from the surface of HDPE film. The proposed venture will be based on the collection and de-inking of 5000 tons per year of high density polyethylene film (HDPE), specifically Wal-Mart bags collected from the northeast region of the US. Based on financial data of labor costs, equipment costs, cost of raw materials, and operating costs, a net profit of $900,000 will be generated in the first year. This is based on an assumed selling price of $0.70 per pound of de-inked plastic pellets.

With the amount of plastic bags recycled increasing every year, there is a larger demand for recycled plastic than can be met. By de-inking high density polyethylene, the quality of recycled plastic can be improved, allowing recycled plastic to be used for uses usually reserved for virgin resin.

Table of Contents

Figures

Tables

1. Introduction

Nonrenewable natural resources (e.g. petroleum) used to make plastic are being depleted, and an alternative to throwing away these resources is needed. One alternative is to recycle the plastic, but it has been found that recycled plastics containing ink can no longer be used for applications requiring high strength and elongation. Ink present on the surface of the plastic is the main cause of the decline in physical and mechanical properties. Therefore, de-inking the plastic before recycling can correct such a problem.

A surfactant-based separation process has been used experimentally to de-ink plastic. The process consists of the deprotonation of ink binder, surfactant adsorption onto plastic and ink, detachment of ink, and solubilization and stabilization of detached ink. In the first step, the carboxylic acid groups on the ink binder are deprotonated at a high pH. Surfactant monomers then adsorb onto the surface of the plastic and attach to the anionic carboxylates in the ink binders.[4] The surfactant adsorption decreases the surface tension between the plastic/film and ink/film. When the summation of the surface tension of plastic/water and ink/water is less than the surface tension of the ink/polymer, the ink can detach from the plastic surface. The electrostatic binding between the surfactant and ink binder molecules allows for solubilization into micelles. This prevents the reattachment of ink onto the surface of the plastic.[3] The surfactant-based separation process will be further explained in the Process Design.

Because no actual experiment is being conducted for this project, all information is gathered from literature. Experiments performed by Chotipong et al. show that a plastic bag was cut up into 2.5cm by 2.5cm square sheets and placed into a 20mL surfactant solution.[3,4] The plastic film was pre-soaked in a pH 12 surfactant solution for two hours and agitated at 200 cycles/min for 30 minutes in a 25mM water/surfactant solution that removes nearly 100% of the ink. The surfactants used in the experiment was alkyltrimethylammonium bromides.[3]

In this project, we propose a plan for an industrial size de-inking process. This will be accomplished by creating an economic planning model by using excel that minimizes process costs by incorporating plant location, plant capacity, and transportation costs of plastic film.

2. Process Design

2.1 De-Inking Mechanism

2.1.1 Attachment of Ink

In order to understand how the de-inking mechanism works, a clear understanding of how the ink is attached is needed. The two most important factors in de-inking are pH and surface tension. Ink is attached to the plastic by first treating the surface of the plastic with a corona discharge. The corona discharge raises the surface tension of the plastic so that the ink will wet the surface. Corona discharge is an electrical discharge characterized by a corona (glowing region) and occurring when one of the two electrodes has a shape causing the electric field at its surface to be significantly greater than that of the other electrode. One electrode is highly curved (such as the tip of a needle, or a narrow wire) and the other low curvature (such as a plate, or the ground). In the case of attaching ink to plastic films, coronas are used to generate a charged surface, by placing one of the electrodes directly below the surface of the film (the ground) and the other above it. Corona discharge leaves reactive functional groups on the surface of the plastic. The functional groups are reacted with oxygen in the air to form hydra peroxides. The hydra peroxides further decompose and react with the air to produce various oxygen based groups. [4] These oxygen based groups have a stronger pull than the original hydrocarbon, creating a stronger surface tension. This is explained more completely in the next section.

The pH is lowered causing the binder to agglomerate and attaching the ink pigment to the plastic. How the pH effectively does this is explained below.

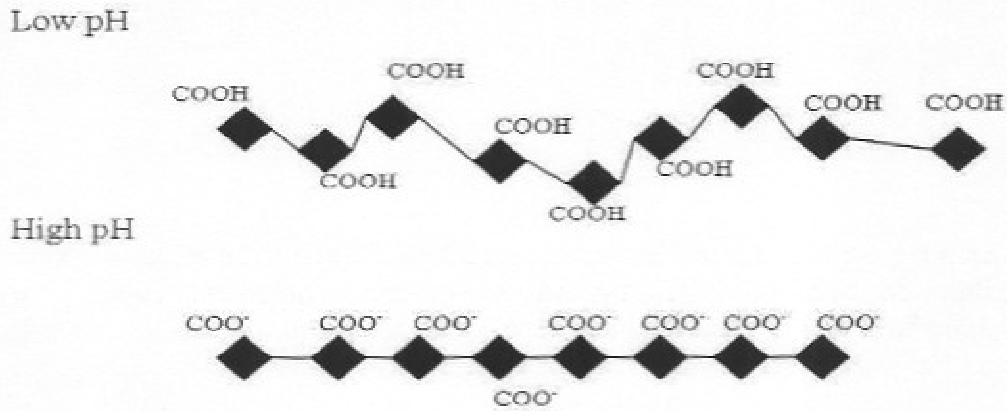
2.1.2 Role of Surface Tension in De-inking

Surface tension is caused by cohesion forces between surface molecules. The surface molecules are not surrounded by as many molecules as the interior molecules, so the surface molecules are more strongly attracted to each other. An effect of surface tension is that the surface is harder to overcome than the force needed to move around in the interior (fully submerged). Surface tension conventionally refers to the tension between a substance and the atmosphere although it is synonymous with interfacial tension. Interfacial tension refers to the tension between any two phases. The surface tension of water can be observed when a glass is filled and the water is rounded up above the top of the glass. When surface tensions are decreased, the water molecules at the surface move more freely, causing the surface to be less rounded. Lower surface tension also causes better "wetting". Wetting refers to the ability of a solution to soak into the pores and fissures of a substance, rather than making a bridge across them.

The cohesion forces can be overcome when a stronger force is applied to pull the molecules apart. These cohesion forces are commonly Van der Waal bonds. In the case of water, the Van der Waal forces hold the molecules together because of the dipole moment between the water molecules. One way to overcome surface tension is increasing the temperature, causing agitation between the molecules eventually leading to the force of agitation overcoming the force of cohesion. The temperature that causes the force of agitation to be greater than the force of cohesion is called the boiling point. Surfactants also create an atmosphere where surface tension can be overcome. How surfactant is used to overcome surface tension is described below.

2.1.3 Deprotonation

The first step in ink detachment is deprotonation of the ink surface. The ink must have a negative charge for the surfactant to adsorb on the surface. When the ink and plastic are submerged in a basic solution, the carboxylic groups in the acid acrylate binding deprotonate. Deprotonation of an acid occurs at the isoelectric point. The isoelectric point is the pH where the zeta potential of an amphoteric substance is zero (also known as zero point charge, ZPC). ZPC occurs because the concentration of the cationic form is equal to the concentration of the anionic form. Therefore below the pH of 3.1 there are more molecules of carboxylic acid than carboxylate ions, but as the pH rises above a pH of 3.1 the concentration of carboxylate increases. The more basic the solution, the more negative the charge of the ink particles become, by the formation of more carboxylate ions. The carboxylic acid in the binder starts to deprotonate at a pH of 3.1.[12] The isoelectric point for carboxylic acid is approximately the same as the experimental value of 3.3 found for the ink by Chotipong, et al.[3] In moderately to highly basic solutions the carboxylic groups deprotonate and the binder is fully extended, as is shown in Figure 1. As the binder extends the ink particles disperse causing some initial de-inking.[4]



*Gecol, Hatice , Colloid Polymer Science 2004

Figure 1: Water-based ink binder structure at different pH levels.[4]

2.1.4 Surface Adsorption

Once the deprotonation process is complete, the plastic is moved to basic solution with surfactant. The cationic head of the surfactant attaches to the carboxylate ions via electrostatic interaction.

In the case of de-inking Wal-Mart bags, the surfactant used is hexadecyltrimethylammonium (CTAB). CTAB adsorbs on the surface of the plastic and the ink. CTAB has a hydrophilic cationic head and a hydrophobic anionic tail. The tail of the surfactant adsorbs on the surface of the plastic, because it is hydrophobic and wants to get away from the water. The head of the surfactant adsorbs on the anionic surface of the ink, leaving the hydrophobic tail sticking out in the water. This can be seen in Appendix A. Since the hydrophobic ("afraid of water") tail does not like being exposed to the water, it compromises and unfavorably attaches itself to other exposed anionic surfactant tails in the water. This gives a double layer of surfactant on the surface of the ink. There are parts of the surface of the ink that are not anionic. On the non-anionic surfaces the tail of the surfactant adsorbs directly on the surface. Adsorption ceases when the surfactant fully covers the surface of the ink.[3]

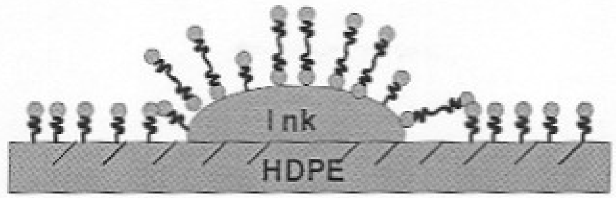


Figure 2: Surface adsorption

2.1.5 Detachment of Ink

Chotipong et al, showed the more the surface of the plastic is saturated with surfactant the more hydrophilic the surface becomes, which further decreases the surface tension between the plastic and the water.[3] Chotipong et al. also showed that as the tail length increases the hydrophobicity of the tail group increases. This occurs because the tail length of the surfactant, and the stronger the pull of Van der Waal's interactions.[3] The second layer of surfactant acts as a longer tail length causing stronger interactions and more force to overcome surface tension.

Chotipong, et al, proposes two explanations for the de-inking mechanism. The first is caused by the combination of electrostatic repulsion and the pull of the hydrophilic head to the water. The two forces cause the interfacial tension between the ink and the plastic to decrease. The electrostatic repulsion force between the plastic and the ink occurs because there is a positive charge on the surface of both. The combination of the repulsion between the ink and plastic and the pull of the hydrophilic head to the water cause the ink to detach from the plastic. Once the edge starts to detach, the carboxylic acid groups deprotonate and more surfactant adsorbs on the newly exposed surface, causing more electrostatic repulsion and pull. This continues until all the ink detaches.

The second explanation is that the negative charge of the carboxylate groups caused by deprotonation lessens the interaction with the hydrophobic HDPE surface encouraging detachment. Like the first hypothesis, as the ink starts to detach, more surfactant accumulates on the surface until the ink eventually detaches completely.[3]

Theses explanations are essentially the same, except in the first the head groups of the surfactants repulse each other and in the second the negatively charged surfaces repulse each other. The second seems less plausible since the ink would just completely detach during the deprotonation process, if it were only the negative charge of the surface and not the pull of the surfactant. It is probably a combination of the two, since it is known that some de-inking occurs during deprotonation.

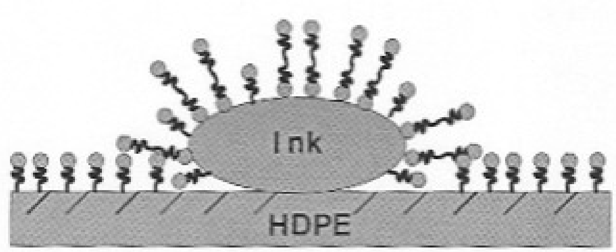


Figure 3: Ink detachment

2.1.6 Solubilization and Stabilization

Once the ink completely detaches, the newly uncovered plastic surface becomes saturated with surfactant. The electrostatic repulsion from the heads of the surfactant repels the heads of the surfactant exposed on the surface of the plastic, preventing reattachment of the ink on the surface of the HDPE.

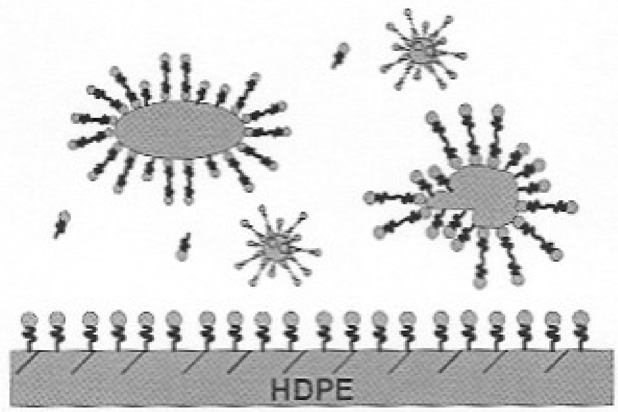


Figure 4: Solubilization and stabilization of detached ink

2.2 Raw Materials

The raw materials consist of HDPE plastic film, deionized water, strong base, and surfactant. A flow chart of the raw materials can be found in Figure 5.

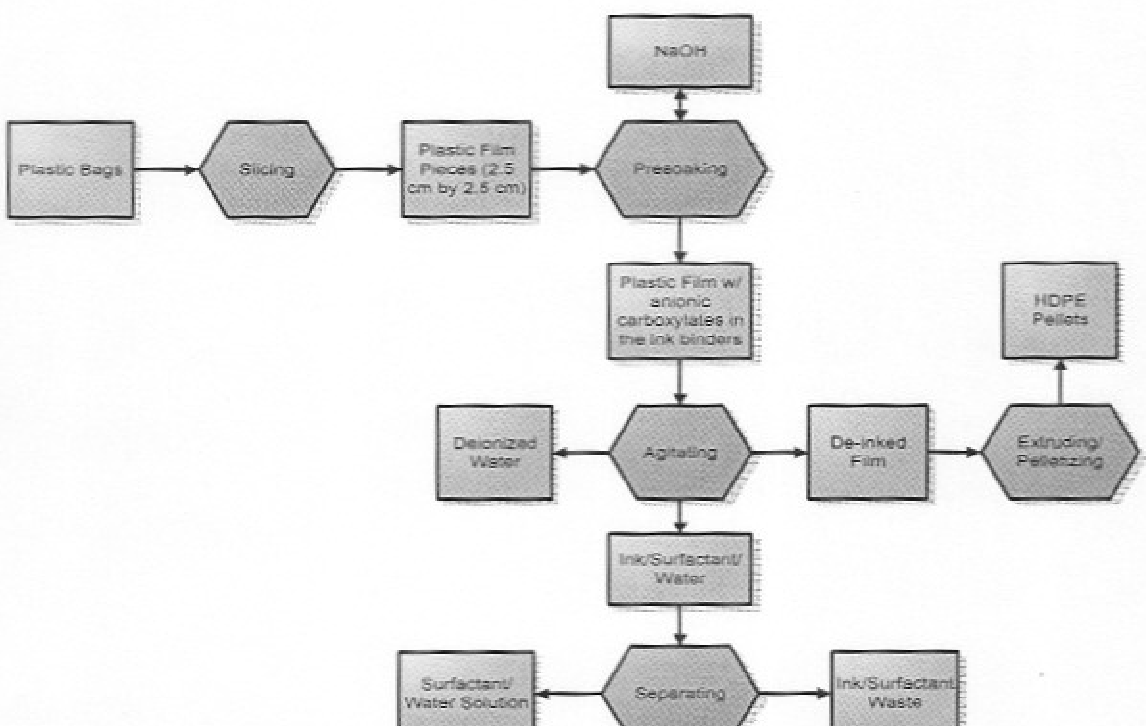


Figure 5: Raw Materials Flow Chart

2.2.1 Plastic

Most plastic film is composed of HDPE, LDPE, or a combination of HDPE and LDPE.[4] Wal-Mart plastic bags were chosen for three reasons:

1. Wal-Mart has a recycling bin for plastic bags outside its stores and donates the bags to recycling companies.
2. HDPE plastic film is Wal-Mart's only bagging source.
3. The ink on Wal-Mart bags is water-based, and the bags are not dyed. This makes it easier to remove the ink.

The de-inking process for all plastic film remains the same as long as the ink is water-based; the plastic is not dyed, and is HDPE.

Ink is composed of four main components:

1. Pigments-give color and influence its fluidity
2. Binders-low MW resins that disperse the pigments and retain them on plastic film
3. Carriers-used to help print on plastic film
4. Additives-enhance drying, finish, and durability (e.g. waxes, surfactants, drying agents)

There are two types of ink used on plastic film: water-based and solvent-based ink. Water-based inks stay on the surface of plastic. Therefore, water-based inks are not chemically bonded with the surface, but instead an adhesive process. Solvent-based inks contain glue that enters the surface of the plastic binding the ink and plastic. For that reason, solvent-based inks are chemically and physically bonded with the plastic.[12]

The ink to plastic volume ratio in Wal-Mart bags was found to be 2%. The volume capacity of plastic to be processed is 5360 tons per year. This is a capacity that comes from the market analysis, which is explained in the economics section.

2.2.2 Deionized Water

Ordinary water contains ions such as calcium and magnesium that affect the pH. By using deionized water, any ions that could react with the deprotonated carboxylic acid groups are eliminated. This is important in the process because it allows the surfactant to bind to all deprotonated carboxylic acid groups prompting detachment.

2.2.3 Base

A basic solution of pH 12 is needed to completely deprotonate the carboxylic acid groups, which allows the surfactant to attach to the binder.[4] For a soaking time of two hours, a pH lower than 12 will not completely deprotonate the carboxylic acid. Sodium hydroxide was chosen because it is a strong base and relatively cheap. A more detailed explanation of how pH effects deprotonation can be found in *2.1.3 Deprotonation*.

2.2.4 Surfactant

A surfactant is a linear molecule that modifies surface tension. A surfactant is composed of a hydrophilic head that is a polar or ionic group, and a hydrophobic tail that is a hydrocarbon or long fatty chain. There are four types of surfactants:[5]

1. Cationic which has a positive charge
2. Anionic which has a negative charge
3. Amphoteric which can act as a positive, negative, or zero net charge
4. Nonionic which has no charge

A longer alkyl chain length or higher surfactant concentration increases the de-inking efficiency. However, a shorter alkyl chain length requires a higher surfactant concentration than a longer alkyl chain length. For instance, 24 times more dodecyltrimethylammonium bromide then hexadecyltrimethylammonium bromide is needed for complete de-inking.[3]

The ink is negatively charged when the carboxylic groups deprotonate. This means that a cationic surfactant would be attracted to the anionic carboxylates. Hexadecyltrimethylammonium bromide was chosen as the best surfactant because it is cationic, has a long tail group, and is inexpensive compared to similar surfactants.[4]

2.3 Product

The product produced by the de-inking process is recycled plastic with properties comparable to virgin resin. Our process is based off of experiments conducted by Chotipong et al. that remove almost 100% of the ink on plastic bags. Without de-inking the plastic film, the physical properties are not maintained when recycled. These include yield strength and elongation, which are very important factors when dealing with plastic film. Due to the reduction in these properties, recycled plastic with ink is used for such things as lawn furniture, compost bins, trash cans, detergent bottles, agricultural pipes, pallets, curbside recycling crates, where these reduced physical properties are not as important. Recycled de-inked plastic can be used for almost anything that virgin resin may be used, including crinkly shopping bags, freezer bags, milk and cream bottles, shampoo and cleaner bottles, milk crates. The only aspect that separates recycled de-inked plastic from virgin resin is a slight beige discoloration. The beige color is due to reactive functional groups created on the surface of the plastic during corona discharge at the time of ink attachment.

2.4 Process

The following is a description of the process used to de-ink plastic and clean the dirty solution. The weight percentage of bags in solution of any instance mentioned below is 26.5%. A detailed process flow diagram is shown in Figure 6.

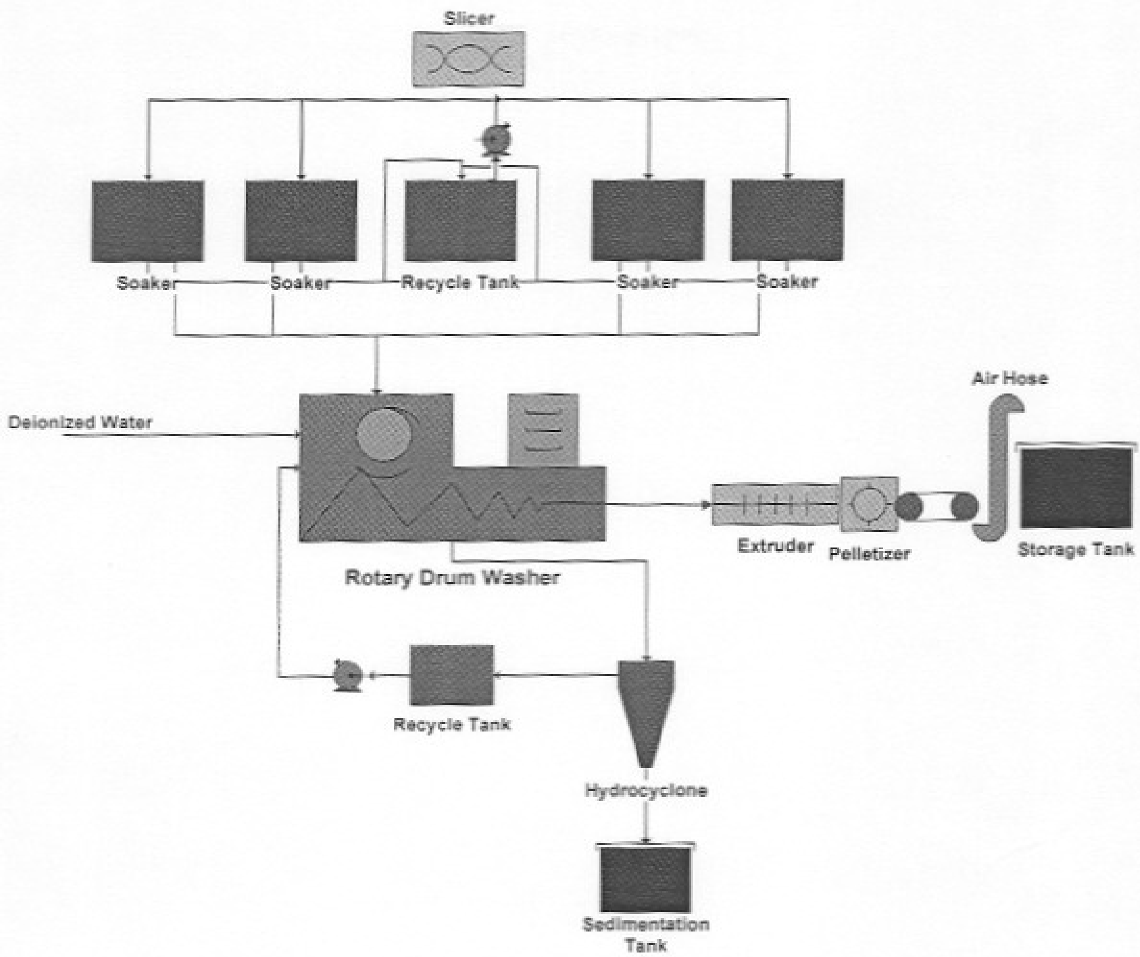


Figure 6: PFD of the De-inking Process

2.4.1 Slicing

Before the bags can be processed they must be sliced into small squares. In the soaking and de-inking process, the entire surface of the plastic must be in contact with the liquid. This is why the bags are sliced into squares. The size of the squares is fairly arbitrary, so 2.5 cm × 2.5 cm squares was chosen.

2.4.2 Soaking

Once the bags have been sliced, they are transferred by a mesh net to four large tanks containing deionized water with added base to a pH of 12.

The bags are soaked for two hours per batch. At the end of the two hours, the bags are removed and the tanks are drained. Each tank is equipped with a filter to remove dirt and debris from the solution. The solution is then recycled and pumped back to the four tanks. Finally, at the end of each day, 1.6 liters of base is added to maintain the solution at a pH of 12.

2.4.3 Agitation

After the bags have been soaked, they are transferred to a rotary drum washer via a mesh net which they were originally placed in after slicing. One worker takes the bags out of the mesh net and places them into the rotary drum washer which is capable of processing

6700 lb/hr. The washer then cleans the plastic of ink using deionized water and surfactant for 30 minutes. The water is drained and the bags are automatically fed to a conveyer belt. The conveyer belt runs the plastic squares through a dryer and feeds them to an extruder.

2.4.4 Extrusion

The bags fall from the conveyer belt into the hopper of a pug mill extruder. The extruder melts the plastic and feeds it to a pelletizer.

2.4.5 Pellitization

The extruded plastic and water are fed to the pellitizer. The function of the water is to cool the plastic so that it is no longer molten. The solid plastic is then ground into pellets by powerful gears. After the plastic has been ground into pellets, the pellets are dropped onto a conveyer belt suspended over a trough. The conveyer belt serves three main purposes:

1. It has holes to allow the water and any dirt to drop down to the trough.
2. It vibrates to make the pellets dislodge as much water as possible.
3. It transports the plastic to the air hose where the pellets are sent to the storage silo.

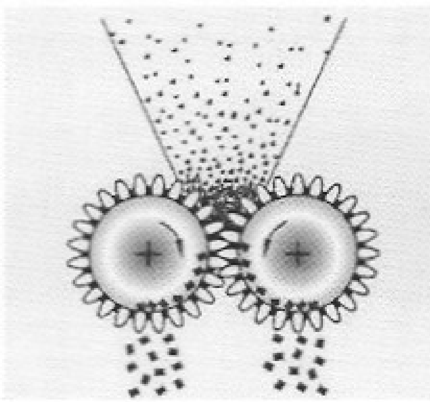


Figure 7: Pelletizer (www.hosokawamicron.com/.../GEARPELLETIZER.HTM)

2.4.6 Solution Cleaning

In order to save money, the dirty solution from the rotary drum washer is recycled into a hydrocyclone, which is a density separator. Hydrocyclones contain a single feed stream where the light and heavy components are introduced to the device. The hydrocyclone then uses the velocity of the fluid stream to provide centrifugal force to the stream by guiding it into a spiral flow. This spiral flow creates a tendency for the heavy components to be forced in the tangential direction of the flow which translates to the outer wall of the hydrocyclone. As the stream travels down the hydrocyclone and the heavy components are forced to the outer portion of the stream, the lighter components are forced to the inner portion of the stream and a secondary vortex composed of the lighter components is created. This lighter component vortex is forced out of an exit located at the top and center of the hydrocyclone while the heavier component is forced out through an exit stream at the bottom. For streams with a low concentration of heavy components, such as the one which we are processing, the exit stream for the heavy components can be difficult to size because if the size is set to large, light components are lost and if the size is set to high, the flow can get clogged causing a backup of the streams. To resolve this problem a hydrocyclone can be fitted with an accumulation chamber. An accumulation chamber essentially solves the problems of sizing the exit stream for the heavy component by allowing the heavy component to accumulate in this chamber and to be purged based on a timer or turbidimeter (or other sensor).[6]
Figure 8 shows a picture of the inside of a modified hydrocyclone.

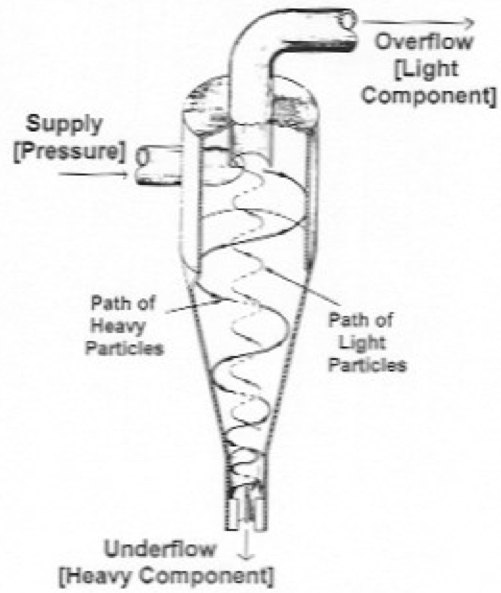


Figure 8: Hydrocyclone

Not all surfactant can be recovered. Any surfactant that formed a micelle on the ink will be lost. This surfactant loss is estimated to be 5% volume of the total original surfactant. The clean solution is transferred to a recycling tank, which pumps the solution back into the rotary drum washer. The ink-surfactant waste is deposited into a sedimentation tank. Once a day, the waste tank is emptied into barrels.

3. Location Model

Plant location plays a crucial role in making the process profitable. The transportation to collect bags and the amount of bags that can feasibly be collected are both important variables associated with location. Included in optimizing location is maximizing the amount of plastic recovered while minimizing travel distances.

The optimal plant location for the de-inking plant was determined using excel simulations. The three possible plant locations considered include Englewood, NJ, New Rochelle, NY, and Greenwich, CT. The twenty most populous cities from Pennsylvania, New York, New Jersey and Connecticut were considered as possible collection sites. To find the best plant location, the net present worth of the plant in each location was compared.

First, the distance from every collection site to each plant location was calculated. Then, the initial transportation cost was calculated by multiplying the distances found by the price of traveling per mile. The price per mileage is a function of gasoline prices, maintenance of the vehicle, and load.

Next, the revenue generated from each collection site was found. The revenue was calculated by multiplying the amount of bags available from each collection site by the price of pellets sold by DeMark Inc. The amount of bags available from each collection site was determined using the population of the city, the population of the U.S. and the total amount of bags available in U.S. Based on the fact that the demand for recycled plastic is so much higher than the supply can meet, it was assumed that we would collect all possible bags available from each collection site. The selling price of pellets is $0.70 per pound.

The profit of each collection site was then calculated by subtracting the transportation cost from the revenue generated. If a negative profit was found, that collection city was not considered in the total transportation cost. The total transportation cost was found by summing the transportation costs of all the collection sites that generated a positive profit.

The NPW (net present worth) of each possible plant location was compared to determine the best location. The NPW takes into consideration the total transportation cost, the cost of land, and state tax rates. The optimal plant location using the excel simulation was found to be Englewood, New Jersey. Englewood had the lowest net present worth, as well as the lowest land costs and state tax rates. The NPW for the Englewood, NJ plant is $1.75 million. Tables 9, 10, 11, and 12 in Appendix A summarized these results. Equations used to determine plant location can be found in Appendix B.

4. Business Plan

4.1 Organization

DeMark Inc. is made up of a president, three executive engineers, operation specialists, sorters, truck drivers and a business consultant. The president has overall responsibility of the plant. The president will also approve final process designs and oversee the installation of all equipment.

The executive engineers will assist the president in the process management and oversee general daily production in the plant. Any technical problems are to be directed to the executive engineers for analysis and repair. The executive engineers will also oversee the operation of other employees such as operation specialists, sorters, and truck drivers.

Operation specialists are required to operate the process equipment during daily operation. Sorters are used to sort through collected bags prior to de-inking. They are looking for objects that may obstruct or disrupt the process at any stage, including receipts or other items often left in plastic grocery bags. It was determined that six workers are needed per shift, for three shifts to sort through the bags before processed in the de-inking process. Each worker is expected to sort through approximately 5 bags per second. The truck driver is responsible for the collection and transportation of the materials brought into the plant.

The business consultant is responsible for all business decisions including marketing, advertising and selling the product. They will also oversee the changes in recycling trends and how they will affect the supply and demand of the product

4.2 Marketability

The use of HDPE increases annually. Currently, there is a larger demand for recycled plastic than can be met. Nonrenewable natural resources (e.g. petroleum) used to make plastic are being depleted, and an alternative to throwing away these resources is needed. One alternative is to recycle the plastic, but it has been found that recycled plastics can no longer be used for applications requiring high strength and elongation. Ink present on the surface of the plastic is one cause of the decline in physical and mechanical properties. Therefore, de-inking the plastic before recycling can correct such a problem.

It is estimated that in the year 2006, 96 thousand tons of plastic can be recovered for recycling. Of this, 45% is plastic film, and 70% of the plastic film recovered is HDPE. It is assumed that DeMark Inc. can recover 15% of this amount. Therefore, we will process approximately 5000 tons per year.

4.3 Plastic Recovered

Before the equipment can be sized, an estimate of the amount of plastic that is recoverable has to be determined. A graph of the thousands of tons of plastic generated, percent of total plastic generated, and thousands of plastic recovered for 1990, 1995, 1999-2001 were generated.[7] Each graph was then extrapolated so an estimate could be made for 2005. These graphs are shown below. 1808 thousand tons of plastic was estimated to have been recovered in 2005. Of the plastic recovered, 45% is plastic film[4], and 70% of the plastic film recovered is HDPE.[8] That makes 96 thousand tons of plastic film recovered in 2006. Of the 96 thousand tons of plastic recovered, it was assumed that 15% can be recovered for this process, which gives 5,000 tons per year.

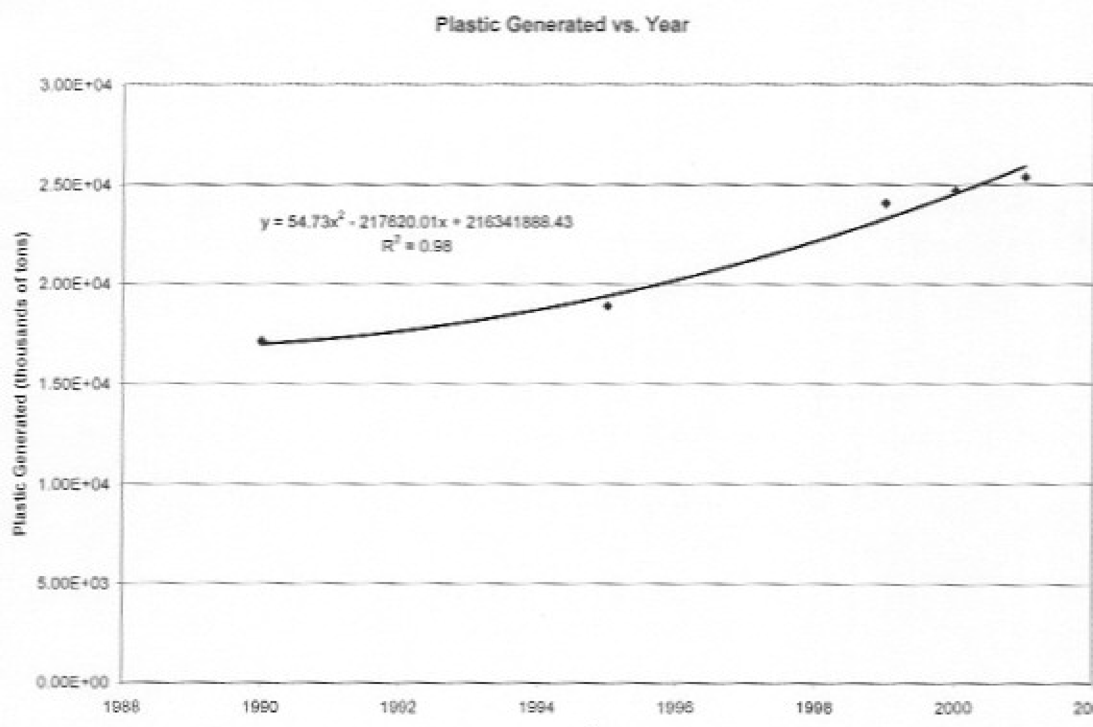


Figure 9: Plastic Generated vs. Year

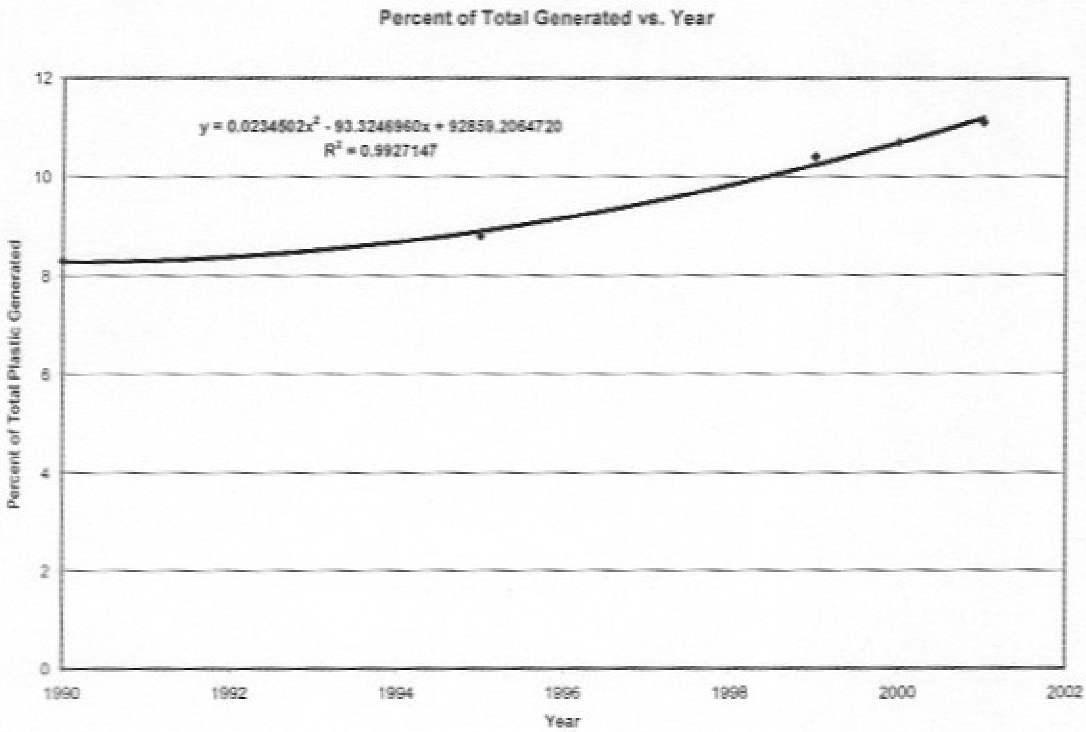


Figure 10: Percent of Total Generated vs. Year

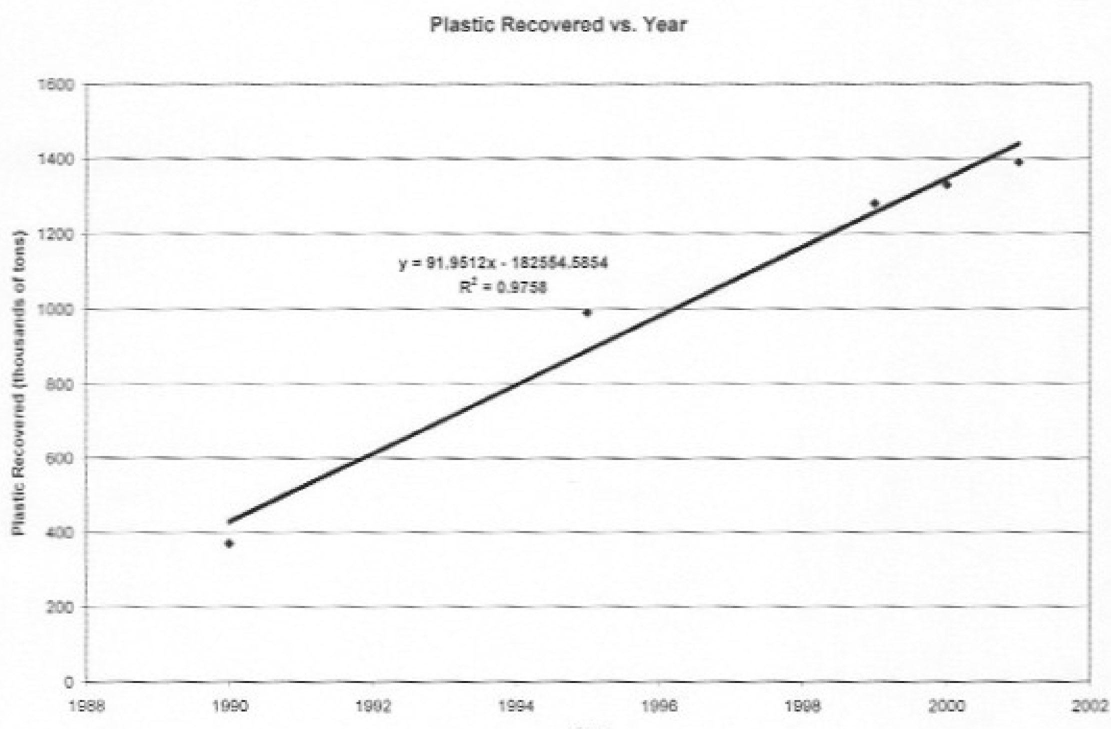


Figure 11: Plastic Recovered vs. Year

4.4 Pricing Equipment

The equipment was priced using Peters and Timmerhaus's *Plant Design and Economics for Chemical Engineers* (PT&W)[9] for generic equipment and company prices for the rest.

The prices are summarized in Table 1. All the prices are within a standard deviation of about 20%. The calculations for each piece of equipment can be found in the appendix.

Table 2: Equipment prices for de-inking process

Equipment Cost Before Installation	Price	Quantity	Total
Rotary Cutter Slicer	$4,305	1	$4,300
Soakers	$5,439	4	$21,800
Rotary Washer/Dryer	$236,021	1	$236,000
Extruder	$488,909	1	$488,900
Pelletizer	$92,917	1	$92,900
Storage Tank	$13,257	1	$13,300
Hydrocyclone	$138,886	1	$138,900
Recycle Tank	$4,958	1	$5,000
Pump	$1,750	1	$1,800
Trucks	$100,000	1	$100,000
Total Equipment Cost			**$1,102,800**

The rotary cutter slicer, soakers, storage tank, recycle tank, and pump were priced using PT&W. Capacity was used for the tanks and pump to determine the prices. Mass flow rate was used to price the slicer. The tanks were made of carbon steel. They are rated for atmospheric pressure, since no pressure is needed for the process. A minimum wall thickness is used. The pump is centrifugal with cast iron material at atmospheric pressure.

The rotary washer dryer was priced from JENFAB.[12] It has a 24'' drum diameter and can clean 6,700 lb/hour. The extruder and pelletizer were priced from The Pelletizer Group, Inc. The extruder 2.5" with an L/D of 24:1. The pelletizer is a strand pelletizer with an 8" diameter. The hydrocyclone produced by Krebs Engineering and is from the gMAX® Series.[13] The truck is a side loader Express from Leach. It is constructed with abrasion resistant steel.[10]

4.5 Operating Costs

The operating costs were calculated considering the cost of water, surfactant, base, ink disposal, and electricity costs. Table 13 shows the daily operating costs. The sample calculations can be found in the appendix.

Table 13: Daily Operating Costs

$0.05	$/d	water
$0.94	$/d	base
$53.68	$/d	surfactant
$192.00	$/d	ink disposal costs
$180	$/d	cost of pump
$196	$/d	cost of electricity for washer, dryer
$0	$/d	cost of separation
$659	$/d	cost of extruder, pelletizer
$41	$/d	cost of slicing
$1,322		**Total Operating Cost per Day**

4.6 Net Present Worth

4.6.1 Total Capital Investment

To determine the Fixed Capital Investment (FCI) and Total Capital Investment (TCI), the sizes and capacities of all pieces of equipment were sized and priced. This includes all equipment needed for the de-inking process, as well as trucks to use for transportation. The cost of land also determines the FCI and TCI costs. The cost of land for the three plant locations can be found in Table 2 in Appendix A. All other costs including direct and indirect costs were determined using percentages based on typical plants for PT&W.[9] The total equipment cost calculated based on a capacity of 5360 tons/year of plastic bags processed is approximately $1.1 million. The FCI found based on this equipment price is $7.1 million and the total capital investment is $8.4 million. Tables 1 and 3 in Appendix A summarize these results.

4.6.2 Total Annual Product Cost

The Total Annual Product Cost was determined considering the cost of raw materials, utilities, labor, and transportation costs. Raw materials in the de-inking process include water, surfactant, and the base sodium hydroxide. Operating labor was calculated by determining the number of workers needed and by determining individual wages for different levels of employment. Tables 4, 5, and 6 in Appendix A summarize these results. The Total Annual Product Cost for the de-inking plant is $6.2 million.

4.6.3 Net Present Worth

The profitability of the company takes into account the incoming volume of plastic bags per year, the revenue generated and the product costs. Depreciation and state and federal tax rates are taken into consideration when determining the net profit and the annual cash flow. For Englewood, New Jersey, the state tax is 9%. The federal tax is 34%, based on the net present worth of the company. Assumptions taken into account while calculating the Net Present Worth (NPW) include that 98% of the incoming bags are processed. The other 2% weight is considered to be ink. A 3% inflation rate is used to determine the product cost over a project life of 10 years, and the product is sold at $0.70 per pound. The Net Present Worth (NPW), Return on Investment (ROI) and Pay Out Time (POT) all depend on the FCI, TCI and total Annual Product Cost. The NPW for DeMark Inc. is $1.75 million. The ROI is 16% and the POT is approximately 4 years. Tables 7 and 8 in Appendix A summarize these results.

5. Conclusion

DeMark Inc., proposes to build a de-inking plant in Englewood, New Jersey. With a NPW of $1.75 million, a Pay Out Time of approximately 4 years, and a return of investment of 16%, DeMark Inc. proves to be a profitable company. The de-inked plastic has comparable quality to that of virgin resin, but is sold for a lower price, making it an ideal choice for plastic producers. With the amount of plastic bags recycled increasing every year, there is a larger demand for recycled plastic than can be met. By de-inking high density polyethylene, the quality of recycled plastic can be improved, allowing recycled plastic to be used for uses usually reserved for virgin resin.

6. Recommendations

In order to more accurately predict the feasibility of the de-inking process, several variables require more extensive analysis. This includes the following items:

1. By considering all states as a possible location, a more profitable scenario can be determined.
2. The current plant capacity is for 2006 plastic film recovery capabilities. However, an analysis for expanding plant capacity to meet an increase in annual plastic recovery should be conducted for optimal NPW
3. The possibility of building onto either an existing plastic recycling plant or a manufacturer who uses plastic film in their products should be evaluated.
4. Investigate the possibilities of de-inking other HDPE objects.
5. A risk analysis for selected variables that may include selling price of de-inked HDPE pellets, plant location, and plant capacity should be conducted.

7. References

1. H.Gecol, et al. *Deinking of Water-Based Ink Printing from Plastic Film Using Nonionic Surfactants*, Journal of Surfactants and Detergents, Vol. 5, No. 4, October (2002) p.363-374.
2. http://www.answers.com/topic/corona-discharge
3. Chotipong et al. *Removal of Solvent-Based Ink From Printed Surface of HDPE Bottles by Alkyltrimethylammonium Bromides: Effects of Surfactant Concentration and Alkyl Chain Length*
4. Gecol et al. *Use of Surfactants to Remove Water-Based Inks from plastic film: Effect of calcium ion concentration and length of surfactant hydrophobe*, Colloid Polymer Science Vol. 283 (2004) p.155 – 163.
5. http://www.dow.com/surfactants/faq/
6. http://www.vortexventures.com/Products/SpintopHydrocyclone/SpintopHydrocyclone.htm
7. *Municipal Solid Waste in the United States: 2001 Facts and Figures*. Office of Solid Waste and Emergency Response. www.epa.gov.
8. *Understanding Plastic Film: Its Uses, Benefits and Waste Management Options*. American Plastics Council, 1996.
9. Peters, Max S., Klaus D.Timmerhaus, and Ronald E.West, *Plant Design and Economics for Chemical Engineers*. 5th ed. New York: McGraw-Hill, 2003.
10. http://www.ccc.govt.nz/Waste/Recycling/Trucks.asp
11. http://www.leachusa.com/product_express.htm
12. JENFAB Aqueous Cleaning Solutions brochure.
13. http://www.krebs.com/products.php/family/1/Solids+Recovery+%26+Classification

Appendix A

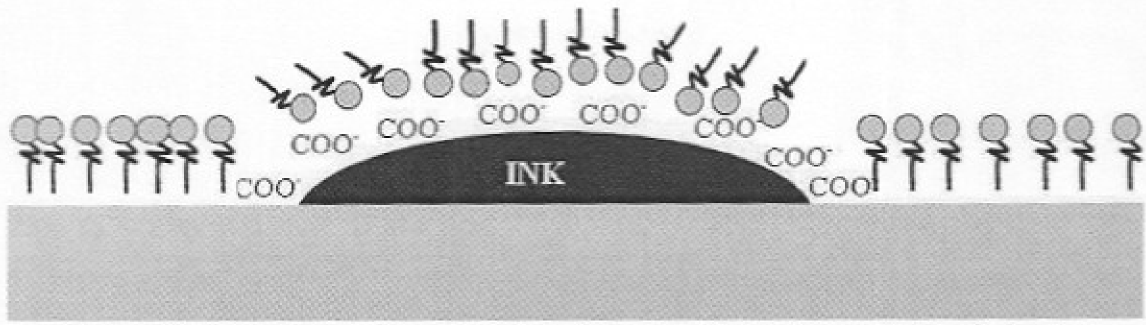


Figure 12: Single layer adsorption of surfactant on the surface on ink and plastic

Table 1: Equipment Pricing

Equipment Cost Before Installation	Price	Quantity	Total
Washer/Dryer	$236,021	1	$236,000
Soaker	$5,439	4	$21,800
Hydrocyclone	$138,886	1	$138,900
Extruder	$488,909	1	$488,900
Pelletizer	$92,917	1	$92,900
Recycle Tank	$4,958	1	$5,000
Slicer	$4,305	1	$4,300
Storage Tank	$13,257	1	$13,300
Pump	$1,750	1	$1,800
Trucks	$100,000	1	$100,000
		Total	**$1,102,900**

Table 2: Cost of land for 2.3 acres

New York	$5,520,000
New Jersey	$183,000
Connecticut	$1,090,000

Table 3: Fixed Capital Investment

Component	Percent of Delivered Equipment Cost	Estimated Cost
Direct Costs		
Purchased Equipment	Based on Equipment Sizes	$1,102,900
Delivery	10% of Purchased Equipment	$110,290
Subtotal: Delivered Equipment	100	$1,213,190
Purchased Equipment Installation	47	$570,200
Instrumentation (Installed)	36	$436,750
Piping (Installed)	68	$824,970
Electrical (Installed)	11	$133,450
Service Facilities Installed	70	$849,230
Land	2.3 acres	$183,000
Total Direct Cost		$5,423,980
Indirect Costs		
Engineering and Supervision	33	$400,350
Construction Expense	41	$497,410
Legal Expense	4	$48,530
Contractor's Fee	22	$266,900
Contingency	44	$533,800
Total Indirect Cost		$1,746,990
Fixed Capital Investment	Direct Cost + Indirect Cost	$7,170,970
Working Capital	15% of TCI	$1,265,460
Total Capital Investment		$8,436,400

Table 4: Labor Costs

	Workers/shift	Number of Shifts	Wages ($/hr)	Total ($/hr)
Bag Sorters	6	3	$8.00	$144
Operation Specialists	1	3	$18.00	$54
Executive Engineers	1	3	$22.50	$68
Janitor	1	2	$15.00	$30
President	1	1	$25.50	$26
Business Consultant	1	1	$15.00	$15
Truck Drivers	1	3	$17.50	$53
				$389

Table 5: Utility Costs

$180	$/d	cost of pump
$196	$/d	cost of electricity for washer, dryer
$0	$/d	cost of separation
$659	$/d	cost of extruder, pelletizer
$41	$/d	cost of slicing
$1,075		**Total Electricity Cost per Day**

Table 6: Total Annual Product Cost

First-Year, Annual Total Product Cost		
Component	Basis for Estimate	Cost
I. Manufacturing Cost		
A. Direct Production Costs		
1. Water	$0.30/day * 330 days/yr	$20
Surfactant	$300/day * 330 days/yr	$17,720
Sodium Hydroxide (NaOH)	$5.24/day * 330 days/yr	$310
2. Operating Labor	Labor Cost * 24 hr/day * 330 days/yr	$3,076,920
3. Utilities		
Electricity	$0.1/kWh	$1,075
4. Maintenance and Repairs	7% of Fixed Capital Investment	$501,970
5. Operating Supplies	15% of Maintenance and Repairs	$75,300
Subtotal		$3,673,320
B. Fixed Charges		
1. Property Taxes	2% of Fixed Capital Investment	$143,420
2. Insurance	1% of Fixed Capital Investment	$71,710
Subtotal (Without Depreciation)		$215,130
C. Overhead costs	10% of Total Product Cost	$619,410
Total Manufacturing Cost		$4,507,860
II. General Expenses		
A. Transportation	$0.16/mi base on distance from Englewood, NJ	$451,418
B. Administrative Costs	20% of Operating Labor	$615,380
C. Distribution and Marketing Costs	10% of Total Product Cost	$619,410
Total General Expenses		$1,686,208
Total Product Cost		$6,194,055

Table 7: Profitability

Year	Product Rate (tons/year)	Sales ($/year)	Product Cost	Gross Earnings	Depreciation	Taxes	Subsidy	Net Profit	Cash Flow
2006	5,520	$7,727,495	$6,194,055	$1,533,440	$843,640	$296,614	$500,000	$893,186	$1,236,826
2007	5,787	$8,101,724	$6,379,876	$1,721,847	$1,518,552	$87,417	$500,000	$615,878	$1,634,430
2008	6,054	$8,475,953	$6,571,273	$1,904,680	$1,214,842	$296,631	$500,000	$893,208	$1,608,050
2009	6,322	$8,850,182	$6,768,411	$2,081,771	$971,873	$477,256	$500,000	$1,132,642	$1,604,515
2010	6,589	$9,224,411	$6,971,463	$2,252,948	$777,836	$634,298	$500,000	$1,340,814	$1,618,650
2011	6,856	$9,598,640	$7,180,607	$2,418,033	$621,763	$772,396	$500,000	$1,523,874	$1,645,637
2012	7,123	$9,972,869	$7,396,025	$2,576,843	$552,584	$870,431	$500,000	$1,653,828	$1,706,412
2013	7,391	$10,347,098	$7,617,906	$2,729,192	$552,584	$935,941	$500,000	$1,740,666	$1,793,250
2014	7,658	$10,721,327	$7,846,443	$2,874,884	$553,428	$998,226	$500,000	$1,823,230	$1,876,658
2015	7,925	$11,095,556	$8,081,836	$3,013,719	$552,584	$1,058,288	$500,000	$1,902,847	$1,955,431

Table 8: Net Present Worth

Pay-Out Time, POT	4.2992
Return on Investment, ROI	16.03%
Net Present Worth with Original Estimated Product Price	$1,749,635

Table 9: Total Bags Available

State	Population	Bags (tons)
New York	19,190,115	17,673
New Jersey	8,638,396	7,955
Pennsylvania	12,365,455	11,388
Connecticut	3,483,372	3,208
Total US	**281,421,906**	**95,695**

Table 10: Location Model, NPW for Greenwich, CT

State	City	Population	Plastic Bags Recovered (Tons)	Distance from Greenwich, CT (Miles)	Revenue	Profit = Revenue - Trans. Cost	Transportation Cost	Actual Amount of Bags Collected (Tons)	Total Transportation Cost
New York	New York City	8,008,278	2723.14	33.62	$3,812,392	3810616.74	1775.14	2723	1775.14
	Buffalo	292,648	99.51	432.32	$139,317	116490.45	22826.50	100	22826.50
	Rochester	219,773	74.73	369.61	$104,624	85108.93	19515.41	75	19515.41
	Yonkers	196,086	66.68	21.06	$93,348	92236.02	1111.97	67	1111.97
	Syracuse	147,306	50.09	288.6	$70,126	54887.88	15238.08	50	15238.08
	Albany	95,658	32.53	148.1	$45,539	37718.92	7819.68	33	7819.68
	New Rochelle	72,182	24.54	12.44	$34,363	33705.87	656.83	25	656.83
	Mount Vernon	68,381	23.25	16	$32,553	31708.41	844.80	23	844.80
	Schenectady	61,821	21.02	162.27	$29,430	20862.43	8567.86	21	8567.86
	Utica	60,651	20.62	238.61	$28,873	16274.69	12598.61	21	12598.61
	White Plains	53,077	18.05	11.93	$25,268	24637.74	629.90	18	629.90
	Niagara Falls	55,593	18.90	446.03	$26,465	2915.02	23550.38	19	23550.38
	Troy	49,170	16.72	155.82	$23,408	15180.40	8227.30	17	8227.30
	Binghamton	47,380	16.11	199.84	$22,556	12004.00	10551.55	16	10551.55
	Long Beach	35,462	12.06	44.12	$16,882	14552.38	2329.54	12	2329.54
	Rome	34,950	11.88	255.71	$16,638	3136.68	13501.49	12	13501.49
	North Tonawanda	33,262	11.31	433.74	$15,835	-7066.88	22901.47	0	0.00
	Jamestown	31,730	10.79	403.72	$15,105	-6211.15	21316.42	0	0.00
	Ithaca	29,287	9.96	246.19	$13,942	943.43	12998.83	10	12998.83
	Elmira	30,940	10.52	254.32	$14,729	1301.09	13428.10	11	13428.10
New Jersey	Newark	273,546	93.02	44.85	$130,223	127855.24	2368.08	93	2368.08
	Jersey City	240,055	81.63	41.83	$114,280	112071.09	2208.62	82	2208.62
	Paterson	149,222	50.74	40.98	$71,038	68874.34	2163.74	51	2163.74
	Elizabeth	120,568	41.00	50.39	$57,397	54736.57	2660.59	41	2660.59
	Edison	97,687	33.22	66.46	$46,505	42995.43	3509.09	33	3509.09
	Woodbridge	97,203	33.05	61.73	$46,274	43014.76	3259.34	33	3259.34
	Dover	89,706	30.50	70.4	$42,705	38987.99	3717.12	31	3717.12
	Hamilton	87,109	29.62	88.51	$41,469	36795.47	4673.33	30	4673.33
	Toms River	86,327	29.35	107.69	$41,097	35410.49	5686.03	29	5686.03
	Trenton	85,403	29.04	97.79	$40,657	35493.33	5163.31	29	5163.31

	Camden	79,904	27.17	129.73	$38,039	31189.07	6849.74	27	6849.74
	Clifton	78,672	26.75	43.75	$37,452	35142.31	2310.00	27	2310.00
	Brick	76,119	25.88	100.11	$36,237	30951.13	5285.81	26	5285.81
	Cherry Hill	69,965	23.79	120.14	$33,307	26963.89	6343.39	24	6343.39
	East Orange	69,824	23.74	47.41	$33,240	30736.91	2503.25	24	2503.25
	Passaic	67,861	23.08	43.36	$32,306	30016.25	2289.41	23	2289.41
	Union City	67,088	22.81	39.14	$31,938	29871.08	2066.59	23	2066.59
	Middletown	66,327	22.55	76.17	$31,575	27553.62	4021.78	23	4021.78
	Gloucester	64,350	21.88	127.81	$30,634	23885.86	6748.37	22	6748.37
	Bayonne	61,842	21.03	49.67	$29,440	26817.70	2622.58	21	2622.58
Connecticut	Bridgeport	139,529	47.45	28.02	$66,424	64944.22	1479.46	47	1479.46
	Hartford	124,121	42.21	84.72	$59,089	54615.38	4473.22	42	4473.22
	New Haven	123,626	42.04	47.44	$58,853	56348.11	2504.83	42	2504.83
	Stamford	117,083	39.81	6.14	$55,738	55413.92	324.19	40	324.19
	Waterbury	107,271	36.48	58	$51,067	48004.64	3062.40	36	3062.40
	Norwalk	82,951	28.21	15.02	$39,489	38696.30	793.06	28	793.06
	Danbury	74,848	25.45	45.01	$35,632	33255.34	2376.53	25	2376.53
	New Britain	71,538	24.33	79.28	$34,056	29870.14	4185.98	24	4185.98
	Greenwich	61,101	20.78	0	$29,088	29087.52	0.00	21	0.00
	West Hartford	61,046	20.76	87.6	$29,061	24436.06	4625.28	21	4625.28
	Bristol	60,062	20.42	73.32	$28,593	24721.60	3871.30	20	3871.30
	Meriden	58,244	19.81	68.27	$27,727	24122.77	3604.66	20	3604.66
	Fairfield	57,340	19.50	22.99	$27,297	26083.20	1213.87	19	1213.87
	Hamden	56,913	19.35	52.1	$27,094	24342.92	2750.88	19	2750.88
	Manchester	54,740	18.61	91.58	$26,059	21223.90	4835.42	19	4835.42
	West Haven	52,360	17.80	43.93	$24,926	22606.81	2319.50	18	2319.50
	Milford	52,305	17.79	36.87	$24,900	22953.39	1946.74	18	1946.74
	Stratford	49,976	16.99	31.5	$23,791	22128.19	1663.20	17	1663.20
	East Hartford	49,575	16.86	86.31	$23,600	19043.33	4557.17	17	4557.17
	Middletown	45,563	15.49	72.54	$21,691	17860.45	3830.11	15	3830.11
Pennsylvania	Philadelphia	1,492,231	507.42	128.11	$710,386	703621.89	6764.21	507	6764.21
	Pittsburgh	327,898	111.50	413.57	$156,098	134261.44	21836.50	111	21836.50
	Allentown	106,105	36.08	130.65	$50,512	43613.64	6898.32	36	6898.32
	Erie	102,122	34.73	465.26	$48,616	24050.10	24565.73	35	24565.73
	Reading	80,494	27.37	165.21	$38,320	29596.59	8723.09	27	8723.09

	Scranton	74,712	25.41	143.94	$35,567	27967.09	7600.03	25	7600.03
	Bethlehem	71,749	24.40	126.27	$34,157	27489.51	6667.06	24	6667.06
	Lancaster	58,802	20.00	196.36	$27,993	17625.26	10367.81	20	10367.81
	Harrisburg	58,639	19.94	119.43	$27,915	21609.57	6305.90	20	6305.90
	Altoona	56,064	19.06	307.04	$26,690	10477.91	16211.71	19	16211.71
	Wilkes-Barre	42,021	14.29	158.25	$20,004	11648.77	8355.60	14	8355.60
	York	40,296	13.70	219.17	$19,183	7610.99	11572.18	14	11572.18
	State College	38,098	12.95	268.56	$18,137	3956.83	14179.97	13	14179.97
	Chester	37,058	12.60	148.13	$17,642	9820.43	7821.26	13	7821.26
	Bethel	33,135	11.27	415.1	$15,774	-6143.15	21917.28	0	0.00
	Norristown	31,311	10.65	134.79	$14,906	7788.89	7116.91	11	7116.91
	Williamsport	30,084	10.23	221.84	$14,322	2608.53	11713.15	10	11713.15
	Monroeville	28,952	9.84	402.04	$13,783	-7444.93	21227.71	0	0.00
	Plum	26,985	9.18	404.57	$12,846	-8514.91	21361.30	0	0.00
	Easton	26,139	8.89	113.75	$12,444	6437.64	6006.00	9	6006.00
								5360	**$489,745 Greenwich, CT**

Table 11: Location Model, NPW for Englewood, NJ

State	City	Population	Plastic Bags Recovered (Tons)	Distance from Englewood, NJ (Miles)	Revenue	Profit = Revenue - Trans. Cost	Transportation Cost	Actual Amount of Bags Collected (Tons)	Total Transportation Cost
New York	New York City	8,008,278	2723.14	16.79	$3,812,392	3811505.37	886.51	2723	886.51
	Buffalo	292,648	99.51	397.04	$139,317	118353.24	20963.71	100	20963.71
	Rochester	219,773	74.73	334.33	$104,624	86971.72	17652.62	75	17652.62
	Yonkers	196,086	66.68	12.76	$93,348	92674.26	673.73	67	673.73
	Syracuse	147,306	50.09	247.96	$70,126	57033.67	13092.29	50	13092.29
	Albany	95,658	32.53	143.23	$45,539	37976.06	7562.54	33	7562.54
	New Rochelle	72,182	24.54	19.49	$34,363	33333.63	1029.07	25	1029.07
	Mount Vernon	68,381	23.25	14.19	$32,553	31803.98	749.23	23	749.23
	Schenectady	61,821	21.02	157.4	$29,430	21119.56	8310.72	21	8310.72
	Utica	60,651	20.62	233.74	$28,873	16531.82	12341.47	21	12341.47
	White Plains	53,077	18.05	27.47	$25,268	23817.23	1450.42	18	1450.42
	Niagara Falls	55,593	18.90	411.11	$26,465	4758.79	21706.61	19	21706.61
	Troy	49,170	16.72	149.75	$23,408	15500.89	7906.80	17	7906.80
	Binghamton	47,380	16.11	178.2	$22,556	13146.59	9408.96	16	9408.96
	Long Beach	35,462	12.06	34.32	$16,882	15069.82	1812.10	12	1812.10
	Rome	34,950	11.88	249.63	$16,638	3457.71	13180.46	12	13180.46
	North Tonawanda	33,262	11.31	398.81	$15,835	-5222.58	21057.17	0	0.00
	Jamestown	31,730	10.79	372.43	$15,105	-4559.03	19664.30	0	0.00
	Ithaca	29,287	9.96	224.55	$13,942	2086.02	11856.24	10	11856.24
	Elmira	30,940	10.52	232.68	$14,729	2443.68	12285.50	11	12285.50
New Jersey	Newark	273,546	93.02	18.06	$130,223	129269.75	953.57	93	953.57
	Jersey City	240,055	81.63	15.04	$114,280	113485.60	794.11	82	794.11
	Paterson	149,222	50.74	14.17	$71,038	70289.91	748.18	51	748.18
	Elizabeth	120,568	41.00	23.6	$57,397	56151.09	1246.08	41	1246.08
	Edison	97,687	33.22	42.92	$46,505	44238.34	2266.18	33	2266.18
	Woodbridge	97,203	33.05	34.73	$46,274	44440.36	1833.74	33	1833.74
	Dover	89,706	30.50	39.25	$42,705	40632.71	2072.40	31	2072.40
	Hamilton	87,109	29.62	61.52	$41,469	38220.54	3248.26	30	3248.26
	Toms River	86,327	29.35	80.69	$41,097	36836.09	4260.43	29	4260.43
	Trenton	85,403	29.04	70.99	$40,657	36908.37	3748.27	29	3748.27

	Camden	79,904	27.17	102.94	$38,039	32603.58	5435.23	27	5435.23
	Clifton	78,672	26.75	15.62	$37,452	36627.57	824.74	27	824.74
	Brick	76,119	25.88	73.11	$36,237	32376.73	3860.21	26	3860.21
	Cherry Hill	69,965	23.79	93.15	$33,307	28388.97	4918.32	24	4918.32
	East Orange	69,824	23.74	20.42	$33,240	32161.99	1078.18	24	1078.18
	Passaic	67,861	23.08	16.36	$32,306	31441.85	863.81	23	863.81
	Union City	67,088	22.81	12.14	$31,938	31296.68	640.99	23	640.99
	Middletown	66,327	22.55	49.18	$31,575	28978.69	2596.70	23	2596.70
	Gloucester	64,350	21.88	100.81	$30,634	25311.46	5322.77	22	5322.77
	Bayonne	61,842	21.03	22.67	$29,440	28243.30	1196.98	21	1196.98
Connecticut	Bridgeport	139,529	47.45	57.9	$66,424	63366.55	3057.12	47	3057.12
	Hartford	124,121	42.21	114.59	$59,089	53038.24	6050.35	42	6050.35
	New Haven	123,626	42.04	77.32	$58,853	54770.45	4082.50	42	4082.50
	Stamford	117,083	39.81	36.01	$55,738	53836.78	1901.33	40	1901.33
	Waterbury	107,271	36.48	87.88	$51,067	46426.98	4640.06	36	4640.06
	Norwalk	82,951	28.21	44.89	$39,489	37119.16	2370.19	28	2370.19
	Danbury	74,848	25.45	62.34	$35,632	32340.32	3291.55	25	3291.55
	New Britain	71,538	24.33	109.15	$34,056	28293.00	5763.12	24	5763.12
	Greenwich	61,101	20.78	31.21	$29,088	27439.63	1647.89	21	1647.89
	West Hartford	61,046	20.76	117.48	$29,061	22858.39	6202.94	21	6202.94
	Bristol	60,062	20.42	102.68	$28,593	23171.39	5421.50	20	5421.50
	Meriden	58,244	19.81	97.63	$27,727	22572.56	5154.86	20	5154.86
	Fairfield	57,340	19.50	52.34	$27,297	24533.52	2763.55	19	2763.55
	Hamden	56,913	19.35	81.46	$27,094	22792.71	4301.09	19	4301.09
	Manchester	54,740	18.61	120.93	$26,059	19674.22	6385.10	19	6385.10
	West Haven	52,360	17.80	73.29	$24,926	21056.60	3869.71	18	3869.71
	Milford	52,305	17.79	66.23	$24,900	21403.19	3496.94	18	3496.94
	Stratford	49,976	16.99	60.86	$23,791	20577.99	3213.41	17	3213.41
	East Hartford	49,575	16.86	115.67	$23,600	17493.12	6107.38	17	6107.38
	Middletown	45,563	15.49	101.9	$21,691	16310.24	5380.32	15	5380.32
Pennsylvania	Philadelphia	1,492,231	507.42	101.11	$710,386	705047.49	5338.61	507	5338.61
	Pittsburgh	327,898	111.50	378.68	$156,098	136103.63	19994.30	111	19994.30
	Allentown	106,105	36.08	95.76	$50,512	45455.83	5056.13	36	5056.13
	Erie	102,122	34.73	433.97	$48,616	25702.21	22913.62	35	22913.62
	Reading	80,494	27.37	130.32	$38,320	31438.79	6880.90	27	6880.90

Scranton	74,712	25.41	122.29	$35,567	29110.21	6456.91	25	6456.91
Bethlehem	71,749	24.40	91.38	$34,157	29331.71	4824.86	24	4824.86
Lancaster	58,802	20.00	169.37	$27,993	19050.33	8942.74	20	8942.74
Harrisburg	58,639	19.94	92.44	$27,915	23034.64	4880.83	20	4880.83
Altoona	56,064	19.06	275.75	$26,690	12130.03	14559.60	19	14559.60
Wilkes-Barre	42,021	14.29	126.95	$20,004	13301.41	6702.96	14	6702.96
York	40,296	13.70	192.18	$19,183	9036.06	10147.10	14	10147.10
State College	38,098	12.95	237.28	$18,137	5608.41	12528.38	13	12528.38
Chester	37,058	12.60	121.14	$17,642	11245.51	6396.19	13	6396.19
Bethel	33,135	11.27	380.21	$15,774	-4300.96	20075.09	0	0.00
Norristown	31,311	10.65	107.79	$14,906	9214.49	5691.31	11	5691.31
Williamsport	30,084	10.23	190.55	$14,322	4260.64	10061.04	10	10061.04
Monroeville	28,952	9.84	367.15	$13,783	-5602.74	19385.52	0	0.00
Plum	26,985	9.18	369.68	$12,846	-6672.72	19519.10	0	0.00
Easton	26,139	8.89	78.86	$12,444	8279.83	4163.81	9	4163.81
							5360	**$451,418**

Englewood, NJ

Table 12: Location Model for New Rochelle, NY

State	City	Population	Plastic Bags Recovered (Tons)	Distance from New Rochelle, NY (Miles)	Revenue	Profit = Revenue - Trans. Cost	Transportation Cost	Actual Amount of Bags Collected (Tons)	Total Transportation Cost
New York	New York City	8,008,278	2723.14	21.74	$3,812,392	3811244.01	1147.87	2723	1147.872
	Buffalo	292,648	99.51	437.46	$139,317	116219.06	23097.89	100	23097.888
	Rochester	219,773	74.73	374.75	$104,624	84837.54	19786.80	75	19786.8
	Yonkers	196,086	66.68	7.97	$93,348	92927.18	420.82	67	420.816
	Syracuse	147,306	50.09	262.88	$70,126	56245.90	13880.06	50	13880.064
	Albany	95,658	32.53	153.24	$45,539	37447.53	8091.07	33	8091.072
	New Rochelle	72,182	24.54	0	$34,363	34362.70	0.00	25	0
	Mount Vernon	68,381	23.25	3.67	$32,553	32359.44	193.78	23	193.776
	Schenectady	61,821	21.02	167.41	$29,430	20591.03	8839.25	21	8839.248
	Utica	60,651	20.62	243.75	$28,873	16003.30	12870.00	21	12870
	White Plains	53,077	18.05	10.27	$25,268	24725.39	542.26	18	542.256
	Niagara Falls	55,593	18.90	447.59	$26,465	2832.65	23632.75	19	23632.752
	Troy	49,170	16.72	157.39	$23,408	15097.50	8310.19	17	8310.192
	Binghamton	47,380	16.11	193.46	$22,556	12340.86	10214.69	16	10214.688
	Long Beach	35,462	12.06	32.42	$16,882	15170.14	1711.78	12	1711.776
	Rome	34,950	11.88	257.27	$16,638	3054.31	13583.86	12	13583.856
	North Tonawanda	33,262	11.31	435.3	$15,835	-7149.25	22983.84	0	0
	Jamestown	31,730	10.79	387.69	$15,105	-5364.76	20470.03	0	0
	Ithaca	29,287	9.96	239.81	$13,942	1280.30	12661.97	10	12661.968
	Elmira	30,940	10.52	247.93	$14,729	1638.48	13090.70	11	13090.704
New Jersey	Newark	273,546	93.02	32.97	$130,223	128482.50	1740.82	93	1740.816
	Jersey City	240,055	81.63	29.94	$114,280	112698.88	1580.83	82	1580.832
	Paterson	149,222	50.74	29.09	$71,038	69502.13	1535.95	51	1535.952
	Elizabeth	120,568	41.00	38.5	$57,397	55364.37	2032.80	41	2032.8
	Edison	97,687	33.22	58.84	$46,505	43397.77	3106.75	33	3106.752
	Woodbridge	97,203	33.05	50.01	$46,274	43633.58	2640.53	33	2640.528

	Dover	89,706	30.50	54.17	$42,705	39844.94	2860.18	31	2860.176
	Hamilton	87,109	29.62	76.81	$41,469	37413.23	4055.57	30	4055.568
	Toms River	86,327	29.35	95.98	$41,097	36028.78	5067.74	29	5067.744
	Trenton	85,403	29.04	85.9	$40,657	36121.12	4535.52	29	4535.52
	Camden	79,904	27.17	117.84	$38,039	31816.86	6221.95	27	6221.952
	Clifton	78,672	26.75	32.04	$37,452	35760.60	1691.71	27	1691.712
	Brick	76,119	25.88	88.4	$36,237	31569.42	4667.52	26	4667.52
	Cherry Hill	69,965	23.79	108.44	$33,307	27581.65	5725.63	24	5725.632
	East Orange	69,824	23.74	35.71	$33,240	31354.67	1885.49	24	1885.488
	Passaic	67,861	23.08	31.65	$32,306	30634.54	1671.12	23	1671.12
	Union City	67,088	22.81	27.43	$31,938	30489.37	1448.30	23	1448.304
	Middletown	66,327	22.55	64.47	$31,575	28171.38	3404.02	23	3404.016
	Gloucester	64,350	21.88	116.1	$30,634	24504.15	6130.08	22	6130.08
	Bayonne	61,842	21.03	37.96	$29,440	27435.99	2004.29	21	2004.288
Connecticut	Bridgeport	139,529	47.45	39.74	$66,424	64325.40	2098.27	47	2098.272
	Hartford	124,121	42.21	96.44	$59,089	53996.56	5092.03	42	5092.032
	New Haven	123,626	42.04	59.15	$58,853	55729.83	3123.12	42	3123.12
	Stamford	117,083	39.81	17.86	$55,738	54795.10	943.01	40	943.008
	Waterbury	107,271	36.48	69.72	$51,067	47385.83	3681.22	36	3681.216
	Norwalk	82,951	28.21	26.74	$39,489	38077.48	1411.87	28	1411.872
	Danbury	74,848	25.45	47.49	$35,632	33124.40	2507.47	25	2507.472
	New Britain	71,538	24.33	90.99	$34,056	29251.85	4804.27	24	4804.272
	Greenwich	61,101	20.78	13.05	$29,088	28398.48	689.04	21	689.04
	West Hartford	61,046	20.76	99.32	$29,061	23817.24	5244.10	21	5244.096
	Bristol	60,062	20.42	84.95	$28,593	24107.54	4485.36	20	4485.36
	Meriden	58,244	19.81	79.9	$27,727	23508.71	4218.72	20	4218.72
	Fairfield	57,340	19.50	34.62	$27,297	25469.14	1827.94	19	1827.936
	Hamden	56,913	19.35	63.74	$27,094	23728.33	3365.47	19	3365.472
	Manchester	54,740	18.61	103.21	$26,059	20609.84	5449.49	19	5449.488
	West Haven	52,360	17.80	55.56	$24,926	21992.74	2933.57	18	2933.568
	Milford	52,305	17.79	48.51	$24,900	22338.80	2561.33	18	2561.328
	Stratford	49,976	16.99	43.13	$23,791	21514.13	2277.26	17	2277.264

	East Hartford	49,575	16.86	97.95	$23,600	18428.74	5171.76	17	5171.76
	Middletown	45,563	15.49	84.17	$21,691	17246.38	4444.18	15	4444.176
Pennsylvania	Philadelphia	1,492,231	507.42	116.41	$710,386	704239.65	6146.45	507	6146.448
	Pittsburgh	327,898	111.50	393.98	$156,098	135295.79	20802.14	111	20802.144
	Allentown	106,105	36.08	111.06	$50,512	44647.99	5863.97	36	5863.968
	Erie	102,122	34.73	449.22	$48,616	24897.01	23718.82	35	23718.816
	Reading	80,494	27.37	145.61	$38,320	30631.47	7688.21	27	7688.208
	Scranton	74,712	25.41	137.55	$35,567	28304.48	7262.64	25	7262.64
	Bethlehem	71,749	24.40	106.67	$34,157	28524.39	5632.18	24	5632.176
	Lancaster	58,802	20.00	184.66	$27,993	18243.02	9750.05	20	9750.048
	Harrisburg	58,639	19.94	107.73	$27,915	22227.33	5688.14	20	5688.144
	Altoona	56,064	19.06	291.01	$26,690	11324.30	15365.33	19	15365.328
	Wilkes-Barre	42,021	14.29	142.21	$20,004	12495.68	7508.69	14	7508.688
	York	40,296	13.70	207.46	$19,183	8229.28	10953.89	14	10953.888
	State College	38,098	12.95	252.53	$18,137	4803.21	13333.58	13	13333.584
	Chester	37,058	12.60	136.43	$17,642	10438.19	7203.50	13	7203.504
	Bethel	33,135	11.27	395.5	$15,774	-5108.27	20882.40	0	0
	Norristown	31,311	10.65	123.08	$14,906	8407.18	6498.62	11	6498.624
	Williamsport	30,084	10.23	205.8	$14,322	3455.44	10866.24	10	10866.24
	Monroeville	28,952	9.84	382.45	$13,783	-6410.58	20193.36	0	0
	Plum	26,985	9.18	384.97	$12,846	-7480.03	20326.42	0	0
	Easton	26,139	8.89	94.15	$12,444	7472.52	4971.12	9	4971.12
								5360	**$471,666 New Rochelle, NY**

Appendix B

Sample Calculations

Initial transportation cost

$$initial\ transportation\ cost = distance\ from\ collection\ site\ (miles) \times \frac{\$0.16}{mile} \times \frac{330\ days}{year}$$

\$0.16 = cost per mile of transportation, and is a function of gasoline prices, maintenance of the vehicle, and load

Revenue generated

$$revenue = plastic\ bags\ recoverd\ (tons) \times \frac{\$0.70}{lb} \times \frac{2000\ lb}{ton}$$

\$0.70 is the price of pellets.

Plastic Bags Recovered

$$Bags\ recovered = \frac{population\ of\ collection\ site}{population\ of\ U.S.} \times total\ amount\ of\ bags\ available\ in\ U.S.$$

Profit of each collection site

$$profit = revenue - transportation\ cost$$

Equipment Pricing

General Equipment Information

All of the equipment cost equations were put in equation form from PT&W using the following equation

$$y = 10^{(m*\log(x)+\log(b))}$$

where m and b are found using equations 25 and 26

$$m = \frac{\log(y_1) - \log(y_2)}{\log(x_2) - \log(x_1)}$$

$$b = -m * \log(x_1) + \log(y_1)$$

and y is the cost and x is the independent variable. The subscripts 1 and 2 represent two points on the line from the equipment pricing charts. Some of the graphs were not linear and the equations were obtained by approximating a linear line, by only using a small range. All of the equations are only good over a certain range of the independent variable.

Since there was such a large amount of variables needed to calculated all the costs a prescript/postscript system has been made to easily name each variable Tables 14 and 15 show these.

Table 14: Postscripts

Post scripts				
i	slicer		w	washer
o	soaker		x	extruder
r	recycle tank		y	dryer
s	seperator		t	storage
k	ink waste tank		p	pump
eq	equipment		l	pelletizer
bag	bags			

Table 15: Prescripts

Prescripts				
b	base		i	ink
w	water		s	surfactant
e	energy		d	disposal
			c	container

Rotary Drum Washer

$$C_{eq,w} = 92150 * LN(M_y) - 576204$$

$$M_y = V\left(\frac{ton}{yr}\right)\left(\frac{lb}{ton}\right)\left(\frac{yr}{hr}\right) + Va\left(\frac{L}{day}\right)\left(\frac{day}{hr}\right)\left(\frac{m^3}{L}\right)(Bat,a)\left(w\rho\frac{g}{cm^3}\right)\left(\frac{lb}{g}\right)\left(\frac{cm^3}{m^3}\right)$$

Where V = tons per year of plastic bags processed
Va = volume of the rotary drum washer
Bat,a = number of batches per day
wρ = density of solution (density of the solution is assumed to be the density of water)

$$Bat,a = \frac{24}{t_a} = 36.00\left(\frac{batch}{day}\right)$$

Where t_a = residence time of agitator

$$V_a = \frac{V\left(\frac{L}{day}\right)}{v_{bag,a} * Bat,a}$$

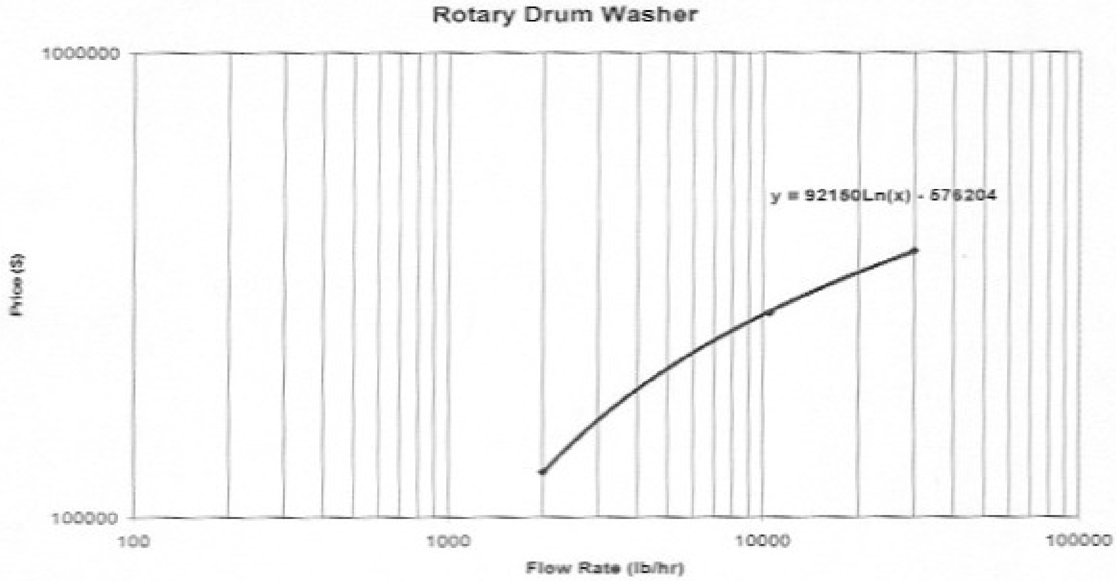
Where $v_{bag,a}$ = fraction of bags to solution in the rotary drum washer

$$V_a = \frac{15540\left(\frac{L}{day}\right)}{0.265 * 36.00\left(\frac{batch}{day}\right)} = 1629 \text{ L/batch}$$

$$M_y = 5360\left(\frac{ton}{yr}\right)\left(\frac{2000lb}{ton}\right)\left(\frac{1yr}{330day}\right)\left(\frac{1day}{24hr}\right) +$$

$$1629\left(\frac{L}{day}\right)\left(\frac{1m^3}{1000dm^3}\right)36.00\left(1\frac{g}{cm^3}\right)\left(\frac{kg}{1000g}\right)\left(\frac{1000000cm^3}{m^3}\right)\left(\frac{2.2lb}{kg}\right)\left(\frac{1day}{24h}\right)$$

M_y = 6949 lb/hr



Soaker

$$C_{eq,o} = Eq_o * \left(10^{0.44*\log(V_o/1000)+\log 4000}\right)$$

Where Eq_o = number of soakers

V_o = volume capacity of the soakers

$$V_o = bV_a + wV_a + v_{bag,o}\left(bV_a + wV_a\right)$$

Where bV_a = volume of base in soaker

wV_a = volume of water in soaker

$v_{bag,o} = v_{bag,a} = 0.265$

$$bV_a = \frac{V_a}{\left[\left(bM - 10^{-2}\right)/0.0099999 + 1 + sv_a\left(1 + \left(bM - 10^{-2}\right)/0.0099999\right)\right]}$$

Where bM = molarity of base

$$bV_a = \frac{1629}{\left[\left(19 - 10^{-2}\right)/0.0099999 + 1 + .025\left(1 + \left(19 - 10^{-2}\right)/0.0099999\right)\right]} = .8364L/day$$

$$wV_a = bV_a\left[\left(bM - 10^{-2}\right)/0.0099999\right]$$

$$wV_a = .8364\left[\left(19 - 10^{-2}\right)/0.0099999\right] = 1588\ L/day$$

$$V_o = .8364\frac{L}{day} + 1588\frac{L}{day} + .265\left(0.8364\frac{L}{day} + 1588\frac{L}{day}\right) = 2010L/day$$

Hydrocyclone

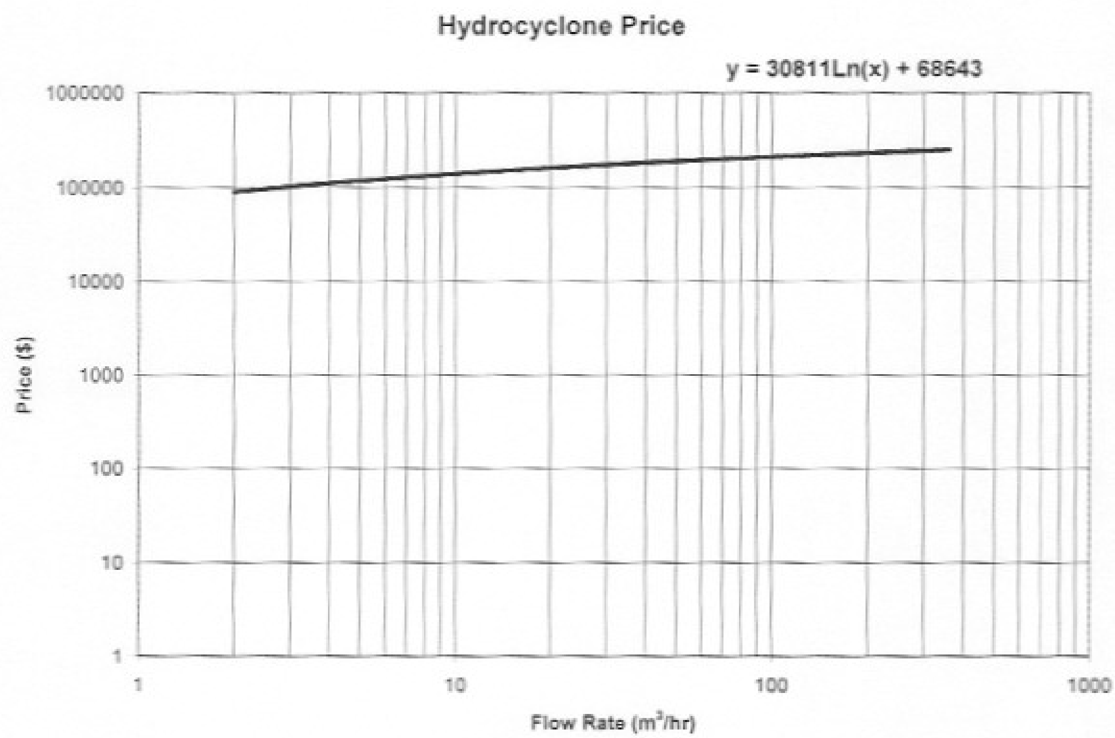
$$C_{eq,s} = 30811 * LN\left(\frac{Q_s\left(\frac{L}{h}\right)}{1000\left(\frac{L}{m^3}\right)}\right) + 68643$$

Q_s = Capacity of the hydrocyclone

$$Q_s = \frac{V_a * Bat, a}{24hr * cycles / batch}$$

$$Q_s = \frac{1629\frac{L}{batch} * 36.00}{24hr * 4\left(\frac{cycles}{batch}\right)} = 9775L/hr$$

$$C_{eq,s} = 30811 * LN\left(\frac{9775\left(\frac{L}{h}\right)}{1000\left(\frac{L}{m^3}\right)}\right) + 68643 = \$138,900$$



Extruder

$$C_{eq,x} = \left[10215 * LN\left(M_x\left(\frac{lb}{h}\right)\right)^{.538}\right]$$

$$M_x = V\left(\frac{ton}{yr}\right)\left(\frac{2000ib}{yr}\right)\left(\frac{yr}{330*24hr}\right)(1-0.02)$$

Where 0.02 is the fraction of ink assumed to be taken off the bag
M_x = is the mass flow rate of plastic into the extruder

$$M_x = 5360\left(\frac{ton}{yr}\right)\left(\frac{2000lb}{yr}\right)\left(\frac{yr}{330*24hr}\right)(1-0.02) = 1326lb/hr$$

$$C_{eq,x} = Eq.,_x * \left[10215 * LN\left(1326\left(\frac{lb}{h}\right)\right)^{.538}\right] = \$488,900$$

Pelletizer

$$C_{eq,l} = 95280 * LN(M_x) - 592164$$

M_x = the same as the mass flow rate to the extruder

$$C_{eq,l} = 95280 * LN\left(1326\left(\frac{lb}{hr}\right)\right) - 592164 = \$92,900$$

Recycle Tank

$$C_{eq,r} = 10^{\left[0.44LOG\left(\frac{Q_r}{1000}\right)+LOG4000\right]}$$

Where Q_r = capacity of the recycle tank in liters

$$Q_r = V_a$$

$$C_{eq,r} = 10^{\left[0.44LOG\left(\frac{1629(L)}{1000}\right)+LOG4000\right]} = \$5,000$$

Sedimentation Tank

$$C_{eq,i} = 10^{[.477*LOG(M_i)+LOG1000]}$$

Where M_i = mass flow rate of ink and surfactant into the sedimentation tank

$$M_i = V\left(\frac{L}{day}\right) * \rho_{plastic} * \left(\frac{1day}{24*3600s}\right)$$

$$M_i = 15540\left(\frac{L}{day}\right) * 0.95\left(\frac{g}{cm^3}\right)\left(\frac{1000cm^3}{dm^3}\right)\left(\frac{1day}{24*3600s}\right)\left(\frac{kg}{1000g}\right) = 0.17\frac{kg}{s}$$

$$C_{eq,i} = 10^{[.477*LOG(0.17)+LOG1000]} = \$4,300$$

Storage Tank

$$C_{Eq,s} = 10^{\left[0.44*LOG\left(\frac{Q_z}{1000}\right)+LOG4000\right]}$$

Q_z = capacity of the storage tank in liters

$$Q_z = 0.02\left[V\left(\frac{L}{day}\right) + sV_a * Bat,_a\right]$$

$$Q_z = 0.02\left[15540\left(\frac{L}{day}\right) + 40*36\right] = 339L$$

$$C_{Eq,s} = 10^{\left[0.44*LOG\left(\frac{339}{1000}\right)+LOG4000\right]} = \$13,300$$

Pumps

The head needed for the pump to work is 30m and the pump was priced in PT&W as $1,750.

The equipment prices obtained are the purchased cost only.

Operating Costs

Agitator (Rotary Drum Washer)

$C_a = wC_a + bC_a + sC_a + eC_y$

$wC_a = [wP*wV_a]*w_l$

$$wC_a = \frac{\$0.00085}{L} * \frac{1588L}{batch} * 0.02 = \$0.027/day$$

$bC_a = [bP*bV_a]*b_l$

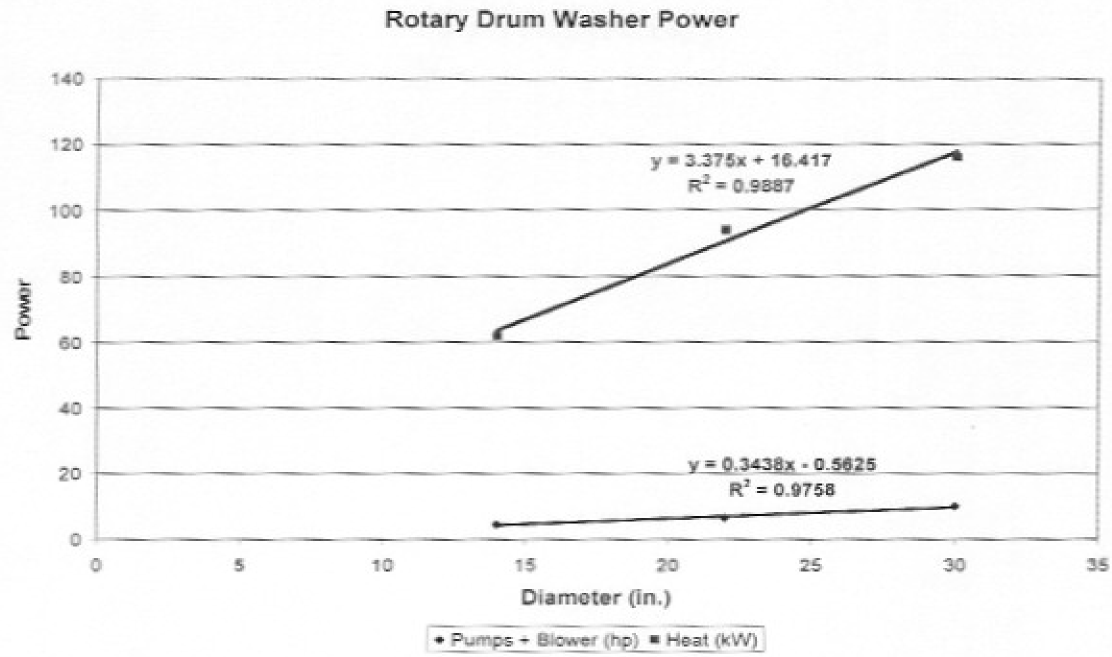
$$bC_a = \frac{\$28}{L} * \frac{0.836L}{batch} * 0.02 = \$0.468/day$$

$$sC_a = sP * sV_a * sl$$

$$sC_a = \frac{\$33.8}{day} * \frac{39.7L}{batch} * 0.04 = \$53.7/day$$

$eC_y = [eP*P_y]$

$$P_y = (0.003438 * M_y + 56.25) * \frac{24h}{d}$$



$$eC_y = \frac{\$0.1}{kWh} * 1957kWh = \$195.7$$

$$C_a = \$0.027 + \$0.468 + \$53.7 + \$195.7 = \$249.90$$

Where bP = price of base per unit volume
wP = price of water per unit volume
eP = price of electricity per unit volume
sP = price of surfactant per unit volume
wl = fraction of water lost per day
bl = fraction of base lost per day
sl = fraction of surfactant lost per day
P_y = power requirement for the dryer

Soaker

$C_o = wC_o + bC_o$

$wC_o = (wP*wV_o)*w_l$

$$wC_o = \frac{\$0.00085}{L} * \frac{1588L}{batch} * 0.02 = \$0.027/day$$

$bC_o = (bP*bV_o)*b_l$

$$bC_o = \frac{\$28}{L} * \frac{0.836L}{batch} * 0.02 = \$0.468/day$$

$wV_o = wV_a$ = 1588L/day
$bV_o = bV_a$ = \$0.836L/day

$$C_o = \frac{\$0.027}{day} + \frac{\$0.468}{day} = \$0.495/day$$

Extruder/Pelletizer

$C_x = eC_x = eP*W_x$

$$W_z = \left[\left(\frac{M_z - 90}{7500 - 90}\right) * (1590 - 11) + 11\right] * 24$$

$$W_z = \left[\left(\frac{1326 - 90}{7500 - 90}\right) * (1590 - 11) + 11\right] * 24 = 6587kWh$$

$$C_z = \frac{\$0.10}{kWh} * 6587kWh = \$658.7$$

Pump

$C_p = eC_p = W_p * eP$

$$C_p = 1800kWh * \frac{\$0.10}{kWh} = \$180$$

Ink Disposal

$C_k = dC_k = Eq_k * cP + dP * Q_z * (1.1 * 10^{-3})$

$$Q_z = 0.02 * V \frac{L}{day} + 0.02(sv_a * Bat_a)$$

$$Q_z = 0.02 * 15540 \frac{L}{day} + 0.02(0.025 * 36) = 339L$$

$$Eq_k = \frac{\frac{Q_z}{1000}}{0.06}$$

$$Eq_k = \frac{\frac{339L}{1000}}{0.06} = 6 / day$$

$$C_k = 6 * \frac{\$3.70}{0.06m^3} + \frac{\$36}{1000kg} * 339L * (1.1 * 10^{-3}) = \$34 / day$$

Where Eq_k = number of ink waste disposal containers

cP = price of containers per unit volume

dP = price of ink disposal