OU Biorefining

Technical Report for Biorefining Plant

OU Biorefining Technical Report for Biomass Production

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Executive Summary

The demand of fermentation chemicals in the United States is steadily growing as many chemical processing industries aim to take advantage of the environmentally friendly profile of biochemicals and products. Therefore, the purpose of this report is to evaluate the most economically favorable fermentation process as well as the raw material choice that will best produce the end products and propose a business plan for a biorefining plant. The chemicals evaluated that can be produced by fermentation are succinic acid, fumaric acid, propionic acid, and ethanol, each with various end uses. Characteristics of good bio based products are those that are biodegradable, non toxic, and generate less volatile organic compounds. By investigating these characteristics, we proved that upstream and downstream chemical production by fermentation is more environmentally sound, can pass environmental regulations, stimulates rural economic growth, and lowers overall economic costs.

Input parameters were provided into a reducible mathematical model to determine which biorefining investments are most profitable, what raw materials should be used, as well as their location and demand. As a result, it was determined that the process should include the milling of corn into sugar, which is fermented to produce chemicals that can be used to develop plastics and solvents. Different potential plant locations and production rates were analyzed to determine the most profitable scenario.

The model considered the variation of the total capital investment to determine the investment that would maximize the net present value. From the total capital investment, the investment opportunities for each process were determined from the mathematical model. This model considered the mass balances, equipment cost, material demands and supplies, and the market prices for each potential process. The material balances and equipment cost pricing was determined based on simulation of the process flow.

The total initial capital investment available at the beginning of the project is \$150 million. With this initial capital, the net present value for this investment is \$321 million. This plant will be built in Dubuque, Iowa with corn as the agricultural source of the biorefining process. The initial annual total capacity for the project should be 180 million pounds, but with expansion opportunities, the final annual total capacity is 550 million pounds. The plant will include the production of succinic acid, ethanol, propionic acid, and fumaric acid.

It is recommended that a more thorough analysis be performed to determine different investment possibilities and future expenditures.

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1. Introduction

In a time marked by increasing crude oil prices, waste management problems, and continued global pollution, a new generation of bio-based products and chemicals has emerged representing an attractive alternative to fossil fuel derived products. Bio-based products are those that use agricultural materials as their main ingredient. These products are made from renewable resources and in most cases do not contain synthetics, toxins, or substances dangerous to the environment. By using fermented bio-based products, reliance on petroleum is avoided and good uses of our natural resources are promoted.

Encouraged by a number of policy initiatives, the chemical industry is shifting from concentration on capital and highly toxic energy intensive processes which use non-renewable feedstocks to more progressive, knowledge-intensive processes using renewable agricultural feedstocks that are more environmentally friendly. This new trend in environmental viability has promoted the recovery of various fermentation products to use in industry. For the most profitable economic considerations, the approach is to combine a designed fermentation process and downstream separation into one integrated unit.

Bio-based products are those that use agricultural materials as their main ingredient. These products are made from renewable resources and in most cases do not contain synthetics, toxins, or substances dangerous to the environment. By using fermented bio-based products, reliance on petroleum is avoided and good uses of our natural resources are promoted.

To help alleviate environmental concerns, there are an increasing number of national and local policies that promote the development of bio based products. As these initiatives continue to be encouraged, the uses of nonrenewable fossil fuel derived products continue to be phased out. These strict environmental regulations increase the cost of extracting, processing, using, as well as the disposal of products made from fossil fuels. So as a better understanding of how solvents and chemicals affect the society, government agencies continue to pass regulations as shown in Figure 1, by the sharp rise in the number of laws and amendments that have been implemented.

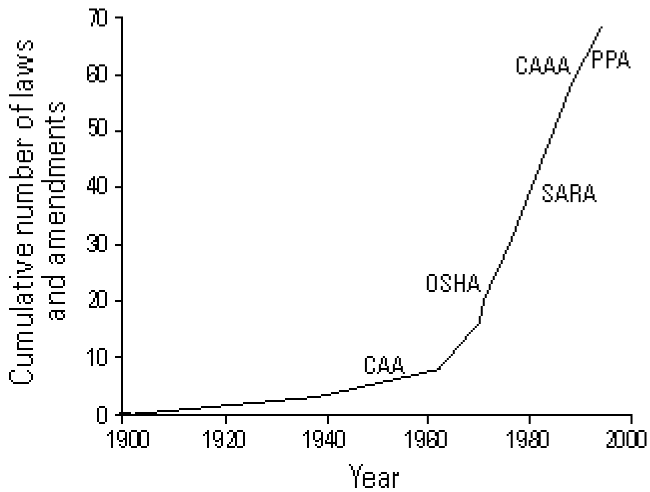

Figure 1: Cumulative federal regulations. CAA-Clean Air Act, OSHA–Occupational Safety and Health Administration, SARA-Superfund Amendments and Reauthorization Act of 1986, CAAA-Clean Air Act Amendment, PPA-Pollution Prevention Act of 1990.[1]

As these regulations continue to mount, much notice is being taken and more products are being produced as the demand for fermentation chemicals steadily increases. Many of the value-added, environmentally friendly products are:

- Food products (oils, starch, sweeteners)
- Industrial products
- Chemical intermediates
- Fuels
- Solvents
- Industrial enzymes
- Biodegradable plastic resins

Other than the fact that they are safer for the environment, also allowing these products grow in popularity are their economic benefits. In addition to lowering capital costs, operating costs are also reduced due to reduced energy consumption, decreased overall steps in the process, and safer hazardous waste removal. Products for downstream use can be disposed of inexpensively.

Furthermore, the use of agricultural feedstocks in chemical processing stimulates rural economic development. Because the feedstocks are bulky and costly to transport, processing and manufacturing facilities are likely to locate near the region in which the raw material is located. These facilities which include waste plants, water treatment plants, and additional warehousing units, provide more income and opportunities to surrounding rural communities.

[1] http://ehp.niehs.nih.gov/members/1998/Suppl-1/253-271sherman/full.html

1.1 Project Purpose

In an effort to capitalize on these economic and environmental benefits of products derived from agricultural resources, the competition to produce fermentation chemicals in the United States is sharply on the rise. Therefore, the purpose of this report is to evaluate the most economically constructive fermentation process, using the most optimal raw material. The second concern for this report is to select the best end product to sell in order to produce a viable business plan for construction of a biorefining plant.

For this study, there were seven different fermentation processes evaluated which include, acetic acid, citric acid, fumaric acid, succinic acid, lactic acid, propionic acid, and ethanol, each with various end product uses. Summarized in the Table 1, is a list of each process and its various end uses.

Table 1: Chemicals Produced by Fermentation[2]

Chemical	End Uses
Acetic Acid	industrial solvent, intermediates for other chemicals, food acidulant
Citric Acid	food, beverages, industry, detergents detergents, cosmetics
Fumaric Acid	dyes, acidulant, antioxidant, intermediate for synthetic resins
Succinic Acid	Pharmaceuticals, toiletries, paper, Beverages, dyes, manufacture of lacquers
Lactic Acid	Pharmaceuticals, personal care, plastics, industrial applications, food, beverages, intermediate for lactates
Propionic Acid	animal feed/grain preservatives calcium & sodium salts
Ethanol	Plastics, herbicides, fuels, solvents, chemicals, beverages

[2] http://www.the-innovation-group.com/ChemProfiles

For the synthesis of the vast array of chemicals and numerous products above, many feedstock elements can be used along with the agricultural resource of choice. The possible fermentation processes evaluated as well as the microorganisms involved are shown in Figure 2.

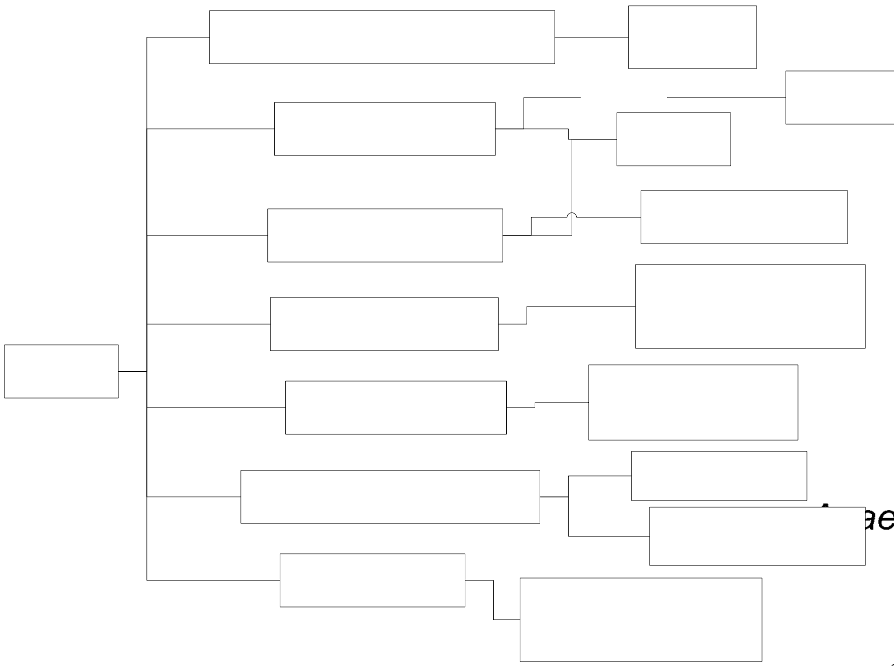

Figure 2: Chemicals, Microorganisms, and End Products of Fermentation Processes[3,4]

Several factors are considered in making the best feedstock selection, some of which are listed below.

- Price; this may have political and economical influences[5]
- Availability; seasonal availability for example means additional requirements for long term storage. This is undesirable unless the feedstock is used for waste and disposal purposes. [5]
- Effect on process productivity; the best feedstocks to use are those that satisfy the nutritional requirements for the microorganism. Additionally, the feedstock should provide good productivity and fermentability.[5]
- Diversification and process flexibility [5]
- Stability and consistency; this should be batch to batch and year to year[5]
- Ease of handling, transport, and storage[5]

[3] http://www.oit.doe.gov/chemicals
[4] http://www.ryanherco.com/Industries/Health/Articles/BiotechnologyBook/Health03_Microorganisms.pdf
[5] http://www.uoguelph.ca/~hlee/426%20feedstocks.htm

Once the best raw material feedstock selection is made, the biorefining process, which includes fermentation and purification, may begin and various platform chemicals can be produced.

1.2 Market Analysis / Demand

In the United States it is forecasted that the demand for fermentation chemicals will exceed $9 billion in 2007 and the volume demanded is expected to exceed 30 billion pounds.[6] Based on the market analysis in Table 2 for all seven chemicals, the major uses for these fermentation chemicals are expected to come from the areas of solvents, plastics and fibers, and fuels.

Table 2: Market Analysis[6,7]

	Demand	Growth Outlook	Price
Acetic Acid	2002: 5.6M lbs	Historical (1997-2002): 1.2% per year	Historical (1997-2002): High $0.27 /lb
	2006: 6.1 M lbs	2% per yr through 2006 in US	Low $0.25 /lb
		3-4% /yr world wide	Current: Low $0.465 /lb , High $0.52 /lb
Citric Acid	2003: 5.35 M lbs	Historical (1996-1995): 5.5% /yr	Historical (1996-1999): prices fell
		3.5% expected over the next 5 yrs	from $0.52 to $0.42 / lb
			Current: $0.65 /lb
Fumaric Acid	2003: 4.34 M lbs	Historical (1994-1999): 1.6% /yr	Historical (1994-1999): High $0.65 /lb
		1.6% /yr through 2005	Low $0.58 /lb
			Currently: $0.65 /lb industrial grade
			$0.85 /lb food grade
Succinic Acid	PVP (polyvinly pyrrolidinone)	6-10% /yr Overall	PVP sells for $3.00-$8.00 /lb
	50M lbs/yr		depending on grade
	Itaconic acid - 20M lb/yr world-wide		Itaconic acid sells for $2.00 /lb
Lactic Acid	50,000 tons/yr total	food/beverage: 3.5 - 4% /yr b/n 2002-2007	Currently-
	50 M lb/yr for food use	pharmaceuticals, personal care: 5.2% /yr	food grade $0.80 /lb
	300 M lb/yr for PLA	b/n 2002-2007	technical grade $0.85 /lb
		Industry: PLA 22% /yr, Ethyl lactate 5% /yr	PLA $1.00-1.50 /lb
		b/n 2002-2007	
Ethanol	Industrial (synthetic and fermentation)-	Historical (1996-2001): 7.8 % /yr	Industrial-
	2001: 269M gal	10.5% yr through 2005 projected	High $2.80 /gal , Low $1.80/gal
	2005: 287M gal projected		Currently $2.65 /gal
			Fuel (grade)-
	Fuel, Food, Beverages (all fermentation)-		High $1.81 /gal , Low $0.99 /gal
	2001: 1.7M gal		Currently $1.55 /gal
	2005: 2.79M gal projected		
Propionic	2002: 204M lbs	Historical (1997-2002): 1.2% /yr	Historical(1997-2002): High $0.49/lb
Acid	2006: 219M lbs projected	1.8% /yr through 2006 expected	Low $0.41/lb
(Sodium Propionate)			Current: $0.51 -$0.54/lb

[6] http://mindbranch.com/listing/product/R154-858.html

Annually, the global consumption of solvents is estimated at 30 billion lb/yr while the United States consumptions are in excess of 8.4 billion lb/yr.[7]

Solvents are widely used in many industries in products such as adhesives, paints, inks, and cleansers. This wide variety of uses is what is expected to drive the demand for fermented solvents.

The world market for plastic related products is a demand of more than 200 billion lb/yr with a United States demand of about 80 billion pounds each year. It is projected that the plastics and fibers market will see the fastest growth through 2007[7] mainly sparked by the 22% growth outlook and demand of polylactic acid.

Due to favorable tax provisions such as the Fuel Ethanol Tax Incentive which runs through 2007, it is projected that fuel will remain the largest market for fermentation products. Fuel is projected to account for 92% of fermentation ethanol use. However, much uncertainty exists in this market, since demand is highly sensitive to politically derived influences. Once an energy bill is decided upon by the House and Senate, major fluctuations in the demand for ethanol is expected to no longer be a problem. [8]

Overall, based on the growth outlook and price from Table 2 for all seven chemicals studied, the market demands and price projections for 2005 to 2025 are graphed below in Figures 3 and 4 to show the expected trends.

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[7] http://pep.sric.sri.com/Public/Reports/Phase_2003/RP206A/RP206A.html
[8] http://www.the-innovation-group.com/ChemProfiles/Ethanol.htm

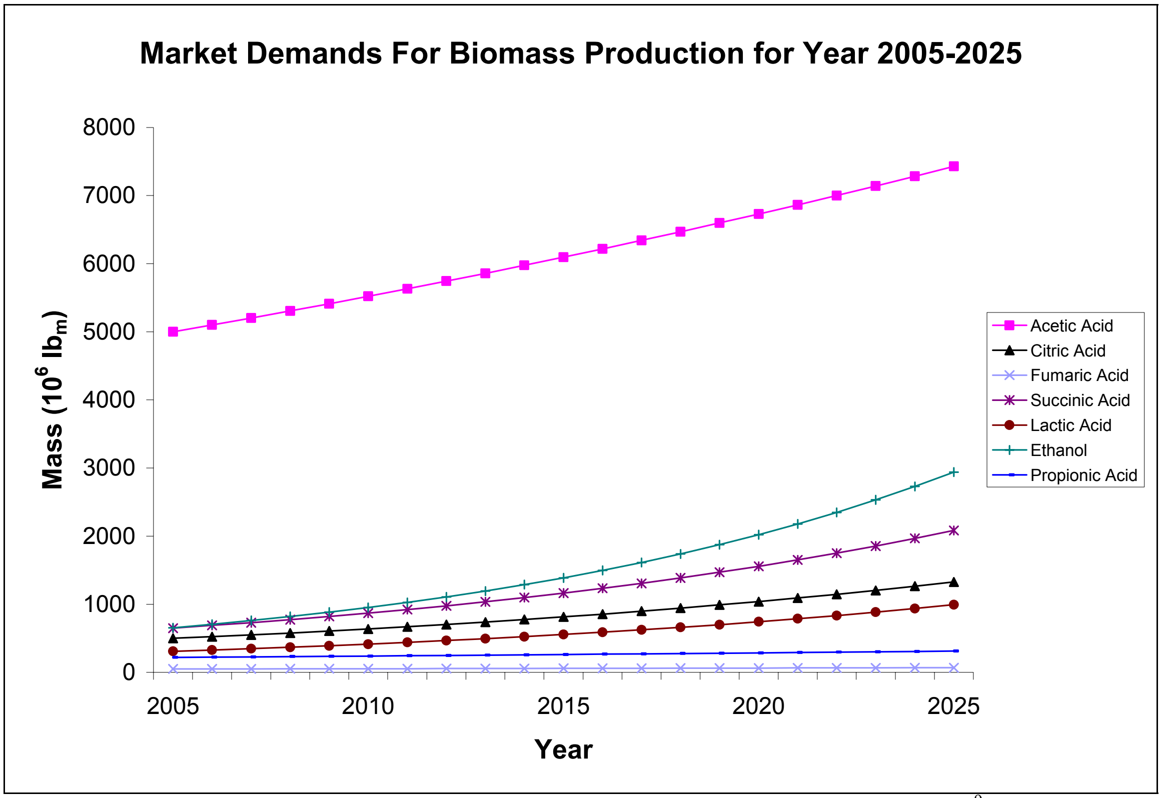

Figure 3: Market Demands of Biomass Production for Year 2005 to 2025[9]

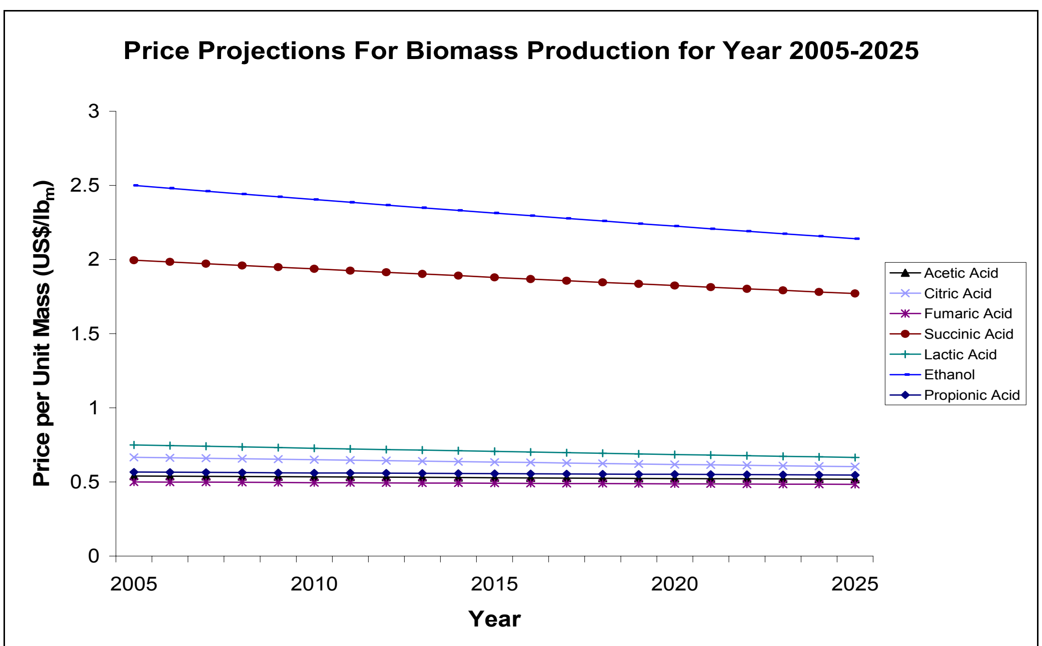

Figure 4: Projected Market Prices of products for Year 2005 to 2025[8]

[9] http://www.the-innovation-group.com/ChemProfiles/

It is expected that the demand for fermentation chemicals will steadily grow due its environmental profile. This positive profile will increase consumer interest and industrial applications of fermentation chemicals. As a result, it is assumed that more competition will arise to take advantage of the demand, and this will result in an over capacity of production. Therefore, because price is a combination of supply and demand, it is projected that prices will drop and remain fairly steady over the lifetime of our project.

2. Plant Design

This section describes the possible design opportunities for glucose fermentation producing seven profitable processes. Each of these processes includes fermentation and purification in order to sell the final, sanitized product. Each acid (citric, acetic, succinic, propionic, fumaric, lactic and ethanol) can be generated from a biomass raw material. A detailed analysis of the processes is performed first by utilizing literature research and then referring to computer simulation models. An overall economic analysis has been performed at an annual capacity of 32 million pounds produced of each acid.

2.1 Fermentation Processes

The production processes of four different acids (acetic, citric, propionic and succinic) were performed. Each of these acids is generated using a nearly identical process using different bacteria used dictating the end result. The software package "SuperPro Designer" was used to simulate the fermentation process of each design.

For each fermentation process, the production of each acid from glucose had to be known. Below are the following equations[10] inputted for each fermentation reaction.

Acetic acid

$$C_6H_{12}O_6 + 7O_2 \rightarrow CH_3COOH + 4CO_2 + 4H_2O$$

Citric acid

$$2C_6H_{12}O_6 + \frac{27}{2}O_2 \rightarrow C_6H_8O_7 + 6CO_2 + 8H_2O$$

Propionic acid

$$C_6H_{12}O_6 + \frac{11}{2}O_2 \rightarrow C_3H_6O_2 + 3CO_2 + 3H_2O$$

Succinic acid

$$C_6H_{12}O_6 + \frac{11}{2}O_2 \rightarrow C_4H_6O_4 + 2CO_2 + 3H_2O$$

In order to obtain the glucose necessary for the reactions, it must be obtained from raw materials. Various raw materials are grinded together with water to form a slurry mixture. Saccarification takes place and glucose is formed.

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[10] http://www.chemindustry.com/chemicals/index.asp?=search

2.2 Bacteria

All the fermentation processes are catalyzed by the appropriate bacteria. They are grown along with inoculum seeds in small laboratory vessels. Once the nutrients and inoculum seeds are grown sufficiently, they form a slurry which is transferred to the fermentors. The cost of using bacteria was found to be $0.80 per ton. The theoretical yields for each of the fermentation processes were found and are shown in the following table. The theoretical yield for each of the processes is the amount of glucose converted into the respective products.

Table 3: Theoretical yields for each fermentation process

Bacteria Name	**Yield**	**Product**
Anaerobiospirillum succiniciproducens	87%	Succinic Acid[11]
Lactobacillus delbrueckii	95%	Lactic Acid[12]
Saccharomyces cerevisiae	67%	Ethanol[13]
Aspergillus niger	66%	Citric Acid[14]
Clostridium thermocellum	100%	Acetic Acid[15]
Propionibacterium acidipropionici	67%	Propionic Acid[16]
Rhizopus	69%	Fumaric Acid[17]

Two other streams are added to this batch reactor. An ammonia stream is charged into this fermentation vessel. The purpose of this stream is to provide an ammonia source as a means of nutrients for the bacteria. Another stream is charged into the reaction vessel containing compressed air. The air is a source of oxygen for the glucose and bacteria. The oxygen creates an aerobic environment for which the reaction can takes place.

Once all three streams have entered the fermentation vessel, a reaction occurs that produces carbon dioxide, water, acid and biomass. This product stream is referred to as the fermentation broth. This broth is next shipped to a nearby storage tank where it is intermittently transported to its designated purification route.

2.3 Process Description

The SuperPro simulation flowsheet is shown in Figure 6. As stated previously, the difference in each acid production exists in the bacteria used, which determines the stoichiometry of the reaction. Once glucose is obtained from the upstream milling of the the chosen raw material, it is combined with a salt solution. This stream is sent to a

[11] "Enhanced Production of Succinic Acid"
[12] "Lactic Acid Production in a Stirred-Tank Fermentor"
[13] www.es.anl.gov
[14] www.fgsc.net/asilomar/citric.html
[15] scifun.chem.wisc.edu/chemweek/AceticAcid
[16] "Propionic Acid Production by batch fermentation"
[17] "Simultaneous Production and Recovery of Fumaric Acid"

mixer where it is combined with a water source. The processed water stream and glucose/nutrient stream must be in a 10:1 mass ratio. The water introduced into this storage ensures that the glucose and nutrients will be in a slush phase as it enters the fermentor. After the two streams are mixed in a storage tank, they are transported to a heat sterilizer which is responsible for decontamination of the glucose stream. The introduction of the bacteria to the glucose requires this heat sterilizer because contaminated conditions may disrupt production. Once this stream has been heat sterilized it is transported into a batch reactor.

2.3.1 Citric acid (Upstream section)

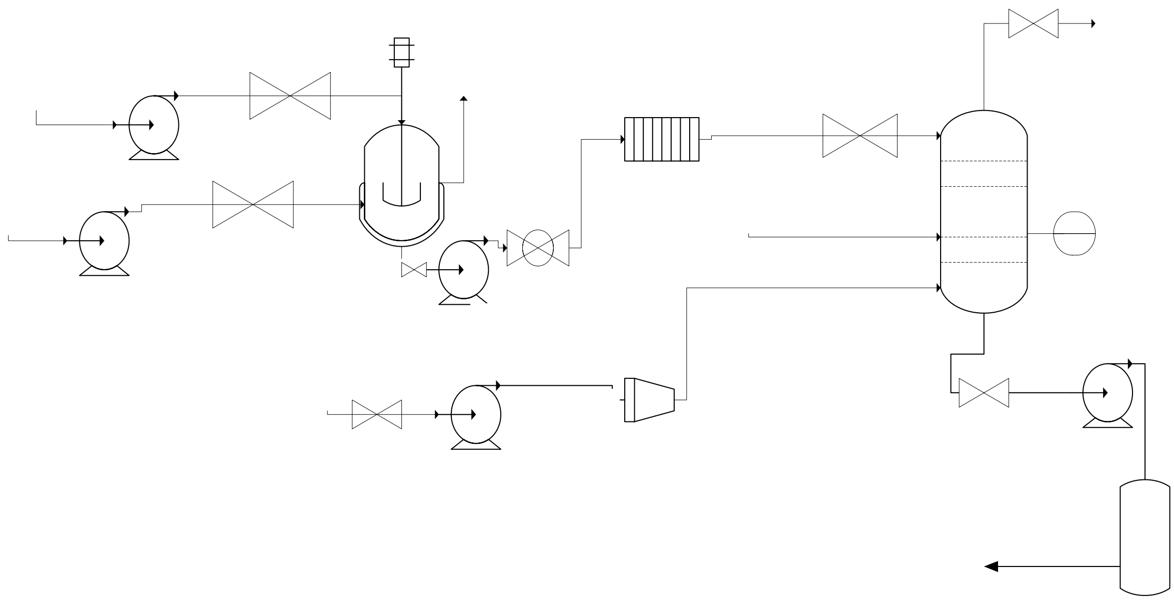

Figure 6: Citric acid fermentation design flowsheet[3]

The above flow sheet is for the citric acid production obtained from the SuperPro Designer simulation. The carbon source of fermentation is diluted from about 90% fermentable sugars content to 10% with salts in a blending tank (V-101). There are three blending tanks operating in parallel. The purified raw material solution is heat-sterilized (ST-101). This is performed in order to ensure that the bacteria and glucose avoid contamination. Nutrients (i.e., sources of ammonium, potassium, phosphorous, magnesium, copper, and zinc) are dissolved in water (V-101) and heat-sterilized (ST-101). The fermentation cycle is 1.2 days, and the production is handled by three fermentors operating in staggered mode. Since the plant operates around the clock, one fermentation cycle is initiated daily and another one is completed eight hours after one. Each fermentor has a vessel volume of 350 m^3 and handles broth of around **207.4 m^3**. A pure culture of the mold *Aspergillus niger* is used to inoculate the all fermentors.

When optimum growth of mycelium is reached, the contents of the seed fermentor are transferred to the next stage fermentor. Similarly, this larger seed fermentor inoculates the production fermentor with about 10% volume of actively growing mycelium broth. Air is supplied by a compressor (G-101) at a rate that gradually increases from 0.15 to 1.0 VVM (volume of air per volume of liquid per minute). Cooling water removes the heat produced by the exothermic process (2,990 kcal/kg of citric acid formed) and maintains the temperature at 28 °C. The fermented broth is discharged into the holding tank (V-103), which acts as a buffer tank between the batch upstream section and the continuous downstream section. After the holding tank, the fermentation broth can be intermittently transferred through ion exchange columns used to begin the purification process.

2.4 Ion Exchange Column

An ion exchange is the reversible exchange of ions between a liquid and a solid. This process is generally used to remove undesirable ions from a liquid and substitute acceptable ions from the solid (resin). Ion exchange chromatography is applicable to the separation of almost any type of charged molecule, from large proteins to small nucleotides and amino acids. This method is an adsorption process in which charged particles bind reversibly to molecules such as proteins. For this process diethyl aminoethyl (DEAE) is used. The ionic properties of DEAE are dependent on pH and have proven to work well within the pH range 4 to 8. Depending on the identity of the ions that a resin releases to the water, the process may result in purification of water or in control of the concentration of a particular ion in a solution.

Each fermentation broth stream is sent through an ion exchange column in order to reduce the broth to simplify the acid and water mixture which reduces the complexity of the separation process. Once the streams are sent through the ion exchange columns, the exiting stream sent for purification is the acid (acetic, lactic, citric, etc.) and water. The other exiting stream is the waste stream that is handled in the proper manner which is discussed in detail later.

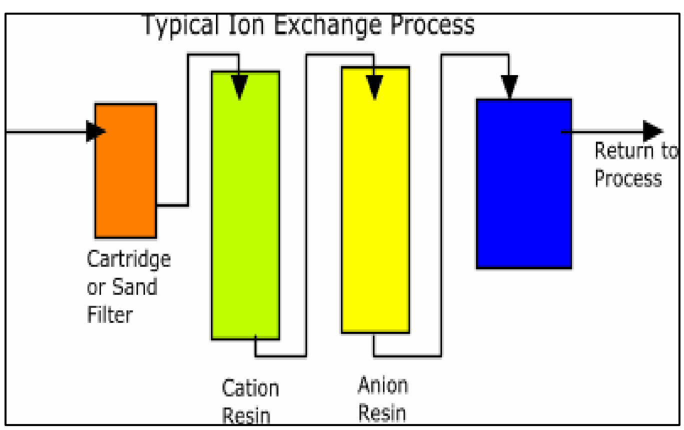

Figure 7: Ion Exchange Column design[18]

[18] ntri.tamuk.edu/fplc/ion.html

2.5 Purification

Purification for each acid varies according to the properties of the acid in the fermentation broth and desired final product. For example, propionic acid is not as marketable as is sodium propionate, the salt; therefore, the purification process involves a step that crystallizes the final product. SuperPro and Pro/II were the simulation software used to create a realistic model. Described below are the simulations for purification of each acid.

2.5.1 Citric Acid (Downstream section)

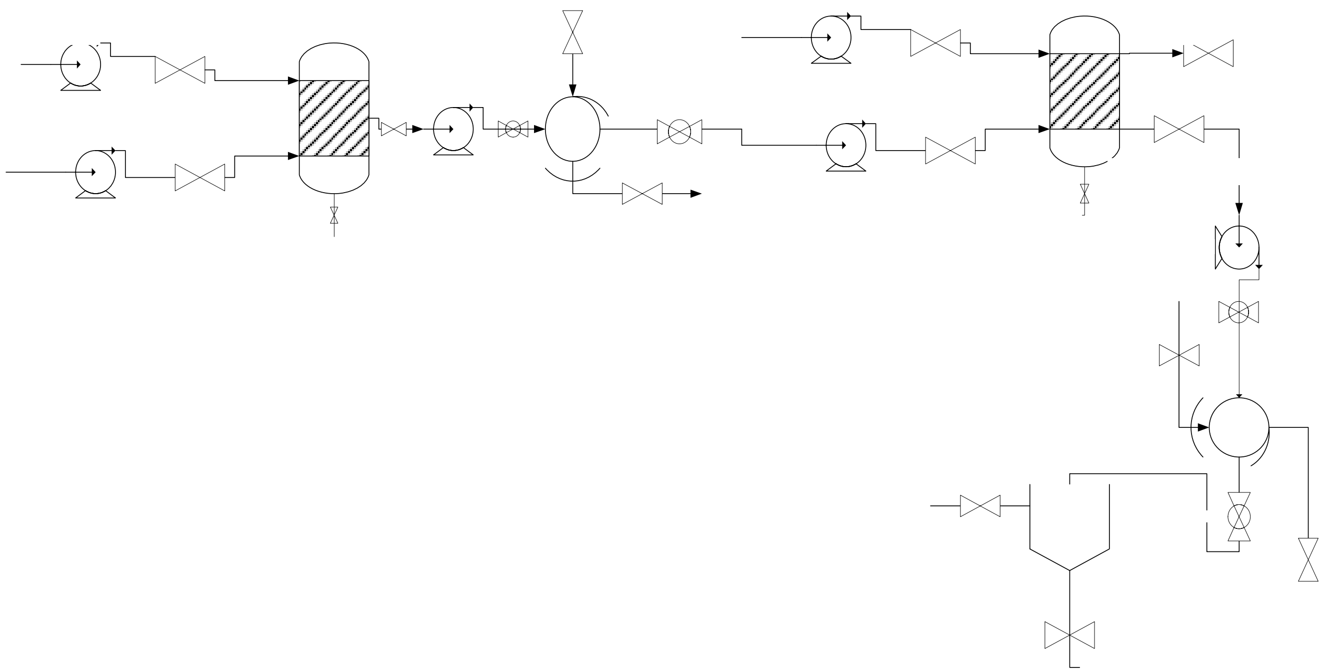

Figure 8: Citric Acid purification flowsheet[3]

Purification starts with the removal of biomass by a rotary vacuum filter (RVF-101). The clarified fermentation liquor flows to an agitated reaction vessel (V-104). Approximately 1 part of hydrated lime, $Ca(OH)_2$, for every 2 parts of liquor is slowly added to precipitate calcium citrate. The lime solution must be very low in magnesium content if losses due to the relatively soluble magnesium citrate are to be avoided. Calcium citrate is separated by a second rotary vacuum filter (RVF-102) and the citrate-free) is disposed of. The calcium citrate cake is sent to another agitated reaction vessel (V-105) where it is acidified with dilute sulfuric acid to form a precipitate of calcium sulfate (gypsum). A third filter (RVF-103) removes the precipitated gypsum and yields an impure citric acid solution. Careful control of pH and temperature of the precipitation steps is important for maximizing the yield of citric acid. The pH is maintained by the ammonia stream introduced into the fermentation vessel. A controller is set in place to inject a necessary amount of ammonia as the pH decreases below desired levels. The resulting solution is concentrated and crystallized using a continuous evaporator/crystallizer (CR-101). The crystals formed are separated by filtration (RVF-104) and dried in a rotary dryer (RDR-101). The overall conversion of glucose obtained from corn milling to citric acid produced and marketed is 66.0% as provided by the simulation in SuperPro. According to literature values, the conversion rate is expected to be 66.7% which very closely correlates with the reported value. If the final product is required in high purity, treatment with activated carbon may precede crystallization to remove colorants. Ion exchange is used to remove metal ions and other ionic species.

2.5.1.1 Citric Acid Equipment Costs

The process flow diagram (PFD) for the purification and fermentation of citric acid is shown in the above sections. In Table 4, the facts of the equipment are described detailing the number of units, size, and purchasing cost.

Table 4: Citric Acid Equipment Details[19, 20]

Equipment	Units	Size per Unit	Cost ($)
Blending/Storage	3	21000 gal	110000
Sterilizer	3	80 m^3/hr	200000
Air Filtration -1	7	4m^3/s	25000
Compressor	2	2350 kW	270000
Air Filtration -2	6	8m^3/s	15000
Fermentor	5	350000 L	1200000
Blending/Storage 2	20	80000 L	110000
Reactor vessel -1	3	27500 L	323000
Rotart vaccum -1	2	65 m^2	115000
Reaction vessel - 2	7	35000 L	364000
Rotary vaccum -2	2	47 m^2	91200
Crystallizer	1	30000 L	35000

2.5.2 Acetic acid (Downstream Section)

Acetic acid is one of the most widely used carboxylic acids. It is used in the synthesis of acetic esters, or as a solvent, in the manufacture of cellulose acetate or pharmaceutical products. In these processes, aqueous solutions of acetic acid are used and economically recovered. The separation of acetic aid acid and water by simple rectification is very difficult because it requires a column with many stages and a high reflux ratio, thus incurring high running costs. The final conversion of glucose to acetic acid as

[19] www.matche.com
[20] www.mcmaster.com

determined by products from SuperPro Designer is 63.3% which deviates largely from the 100% expected yield. The final conversion is ratio of the final product to the amount of glucose is used.

In practice other processes are used depending on the concentration of acetic acid present in the feed. Between 50% and 70% water / acetic acid, extractive distillation is used. By adding a third component, the volatility of water is increased and the separation can be achieved with less energy. Below 40% acetic acid, liquid-liquid extraction is most appropriate. Acetic acid is extracted from water by a suitable solvent in order to obtain substantially pure acetic acid. Liquid-liquid extraction is also useful, independent of concentration, when other contaminants such as salts interfere with direct distillation. QVF is able to offer systems using either technique.

2.5.2.1 Acetic Acid recovery

In order to minimize energy costs in the distillation stage, a lower boiling point solvent is usually chosen. In practice, ethyl acetate or methyl isobutyl ketone are usually preferred.

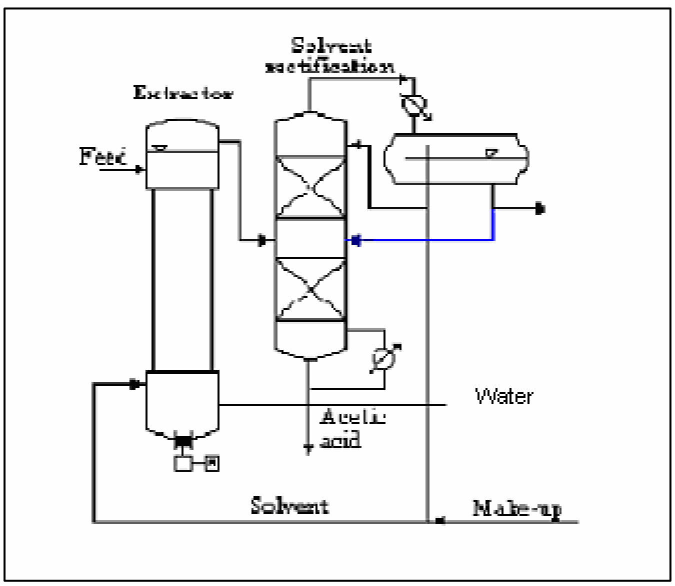

Figure 9: Extraction plant for recovery of acetic acid[21]

The plant displayed above for recovery of acetic acid comprises, essentially, the extraction column, the solvent recovery column and the aqueous phase stripping column. Since the feed mixture has a higher density than the solvent, it is introduced at the top of the extraction column. It flows to the bottom of the column transferring acetic acid to the solvent. The usual concentration in the bottom is 0.1-0.5%, yet it is still possible to improve this if required.

[21] Separation Process Principles, Seader and Henley

In the solvent rectification column, solvent and water leave the column at the top. After condensation the two liquid phases are separated. A part of the solvent phase is refluxed to the column. The remainder is returned to the extraction column.

The aqueous phase is stripped of any solvent in the stripping column. Under certain conditions, it is also important to reflux a part of the aqueous phase to the column. The bottoms product from the solvent recovery column contains acetic acid, where a concentration of between 95% and 100% can be obtained. If there is a possibility that in the extraction process higher boiling components will go into the organic phase, it is recommended that the acetic acid is removed as a vapor stream. Figure 10 depicts the PRO-II simulation for the acetic acid + water mixture from the fermentation broth to obtain the 96.5 % purity of acetic acid.

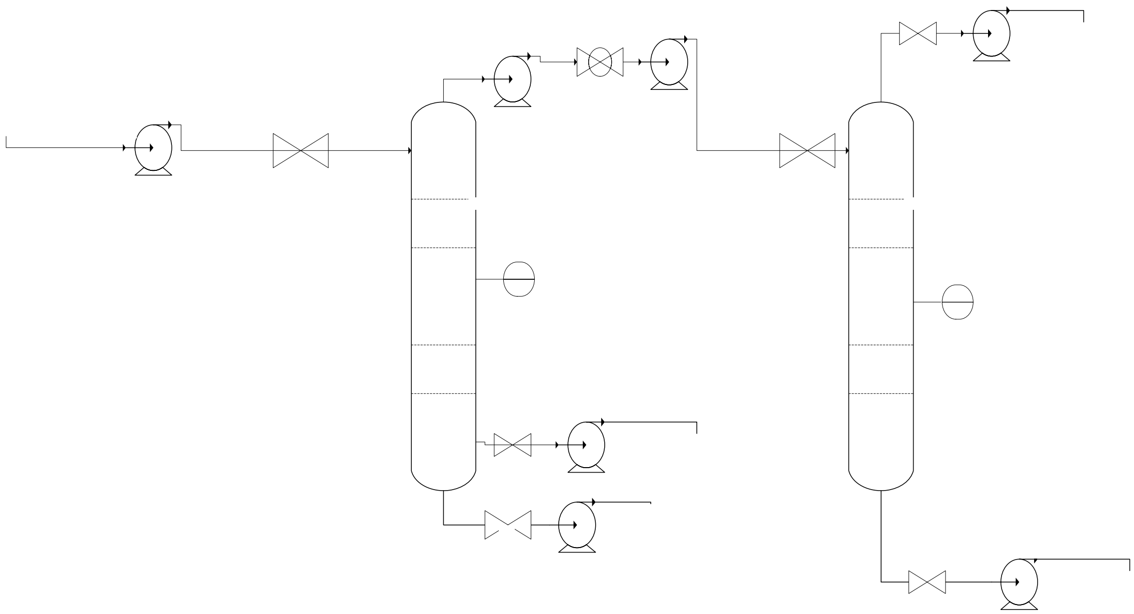

Figure 10: Downstream purification of acetic acid[16]

2.5.2.2 Solvent Rectification

The economics of the entire process is strongly dependent on the costs for the separation of the acetic acid from the solvent by distillation. The scale up and the control of this column should be done very carefully. The actual process design depends on the solvent used.

In the system ethyl acetate/acetic acid/water, a binary azeotrope exists between water and ethyl acetate (Boiling point 70.4 Deg. C). The separation by distillation of water and acetic acid in the ethyl acetate can be done without difficulty. As far as operating costs are concerned, one must ensure that the ration of ethyl acetate/water used in the column corresponds to the maximum volatility for acetic acid. Consequently the feeds to the extraction column must be held within closely controlled limits, necessitating a carefully designed control system.

2.5.2.3 Choice of a Suitable Extraction Column

The control system situation can be solved in general with a pulsed column for which the operation conditions must be determined by pilot plant trials. QVF Process Systems has a suitable pilot unit and is able to carry out pilot plant trials on the customer's behalf.

If corrosive substances are present in the mixture, a column fabricated from corrosion resistant materials must be chosen. Borosilicate glass is an ideal material for extraction columns - allowing the drops and interfaces to be readily observed.

2.5.2.4 Acetic Acid Equipment Costs

The process flow diagram (PFD) for the purification and fermentation of acetic acid is shown in the above sections. In Table 5, the facts of the equipment are described detailing the number of units, size, and purchasing cost.

Table 5: Acetic Acid Equipment Details[14, 15]

Equipment	Units	Size per unit	Cost ($)
Blending/Storage	3	21000 gal	110000
Sterilizer	3	$80m^3$/hr	200000
Air Filtration -1	7	$4m^3$/s	25000
Compressor	2	2350 kW	275125
Air Filtration -2	6	$8m^3$/s	15000
Fermentor	5	350000 L	1200000
Blending/Storage 2	20	80000 L	110000
Ion Exchanger	15	6300 L	75120
Distillation column	1	-	60000
Distillation column	1	(D = 3m)	95000

2.5.3 Purification of Succinic Acid

The purification of succinic acid begins in a reaction vessel, the fermentation broth is introduced to lime. Lime is the common name for calcium hydroxide. In the reaction vessel, succinic acid reacts with this lime forming calcium succinate. Once this reaction has taken place, a rotary vacuum filter removes excess air and dries some of the broth. This calcium succinate cake is sent to another agitated vessel where a dilute solution of sulfuric acid neutralizes the cake. The precipitate formed in this procedure is known as gypsum. A filter is added to the third stream that removes the gypsum, leaving succinic acid with minute impurities. Finally, a crystallizer is used to crystallize the final product, for a high purity is desired. The annual capacity of succinic acid produced in this overall process is 14.77 kg/year. The overall conversion of glucose obtained from corn milling to succinic acid produced and marketed is 59.9% as provided by the simulation in Process simulations. According to literature values, the conversion rate is expected to be 87%.

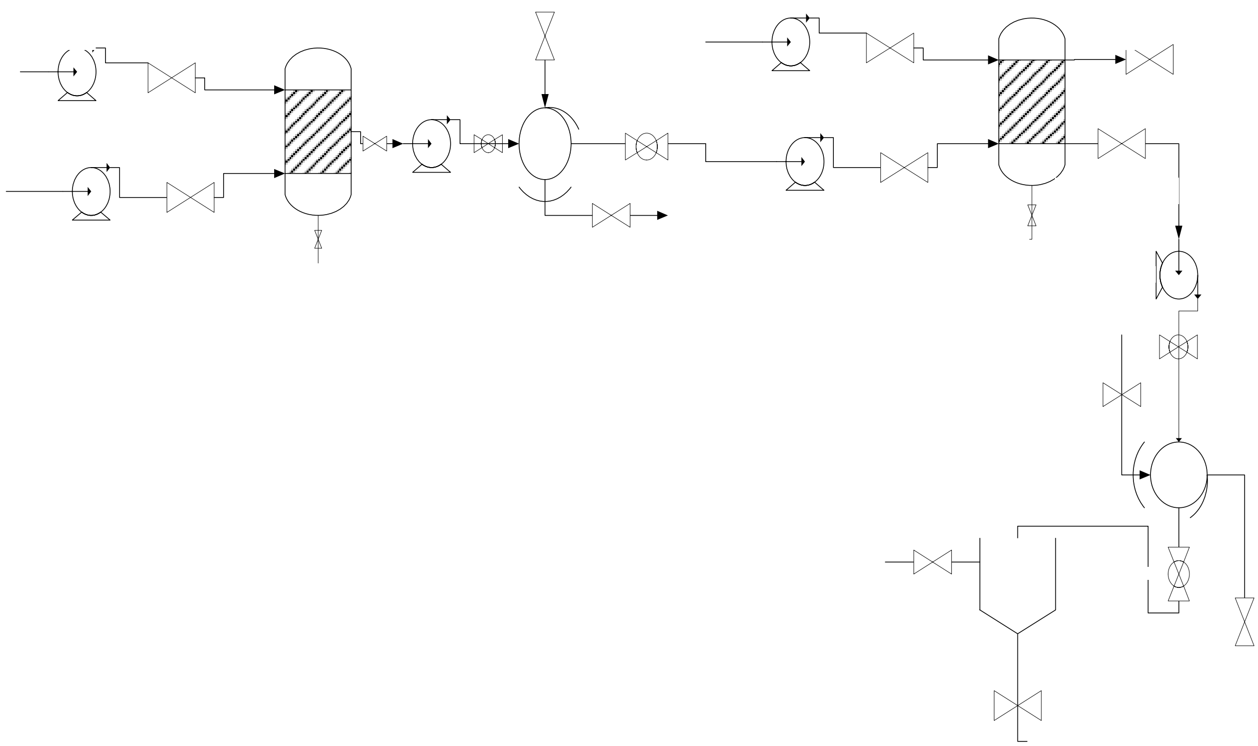

Figure 11: Succinic Acid Simulation[3]

Succinic acid - 70041 kg/batch
water - 7000 kg/batch @ 25 C

Water
10000 kg/batch

Calcium succinate -

2.5.3.1 Succinic Acid Equipment Costs

The process flow diagram (PFD) for the purification and fermentation of succinic acid is shown in the above sections. In Table 6, the details of the equipment are described detailing the number of units, size, and purchasing cost.

Table 6: Succinic Acid Equipment Details[14, 15]

Equipment	Units	Capacity	Cost ($)
Blending/Storage	3	79500 L	110000
Sterilizer	4	$100 m^3/hr$	220000
Air Filtration -1	8	$4 m^3/s$	25000
Compressor	2	2350 kW	275000
Air Filtration -2	6	$8 m^3/s$	15000
Fermentor	5	350000 L	1200000
Blending/Storage 2	20	80000 L	110000
Ion Exchanger	15	6300 L	75000
Reactor vessel -1	3	27000 L	325000
Rotart vaccum -1	2	$45 m^2$	91000
Reaction vessel - 2	8	40000 L	39500
Rotary vaccum -2	2	$37 m^2$	87000
Crystallizer	1	40000 L	410000

2.5.4 Propionic Acid

The purification process of propionic acid results in a sodium propionate salt state because it is more profitable to sell in that form. The market demand for propionic acid is extremely low and not profitable. After this was discovered, *OU Biorefining* decided to forgo the production of propionic acid for that of sodium propionate which has higher demand and higher prices yet remain relatively simple to produce. Once the fermentation broth is transferred to the ion exchange column, the stream is reduced to an acid/water mixture. This stream is then mixed in a reaction vessel with sodium hydroxide. This reaction takes place producing the sodium propionate to be sold off in the market. This stream is then transferred to a crystallizer that solidifies the sodium propionate which will be marketed and sold as one revenue option. The annual capacity produced in the procedure simulated is 15.5 kg/year. The conversion of this procedure from glucose yielded a rate of 48.1%. The literature values for the bacteria used report a theoretical yield of 66.7%; however, this is the yield for the acid. It can be expected that transforming the acid to salt may breed an even lower yield since losses must be accounted for in the conversion. The Process simulations simulation is displayed below.

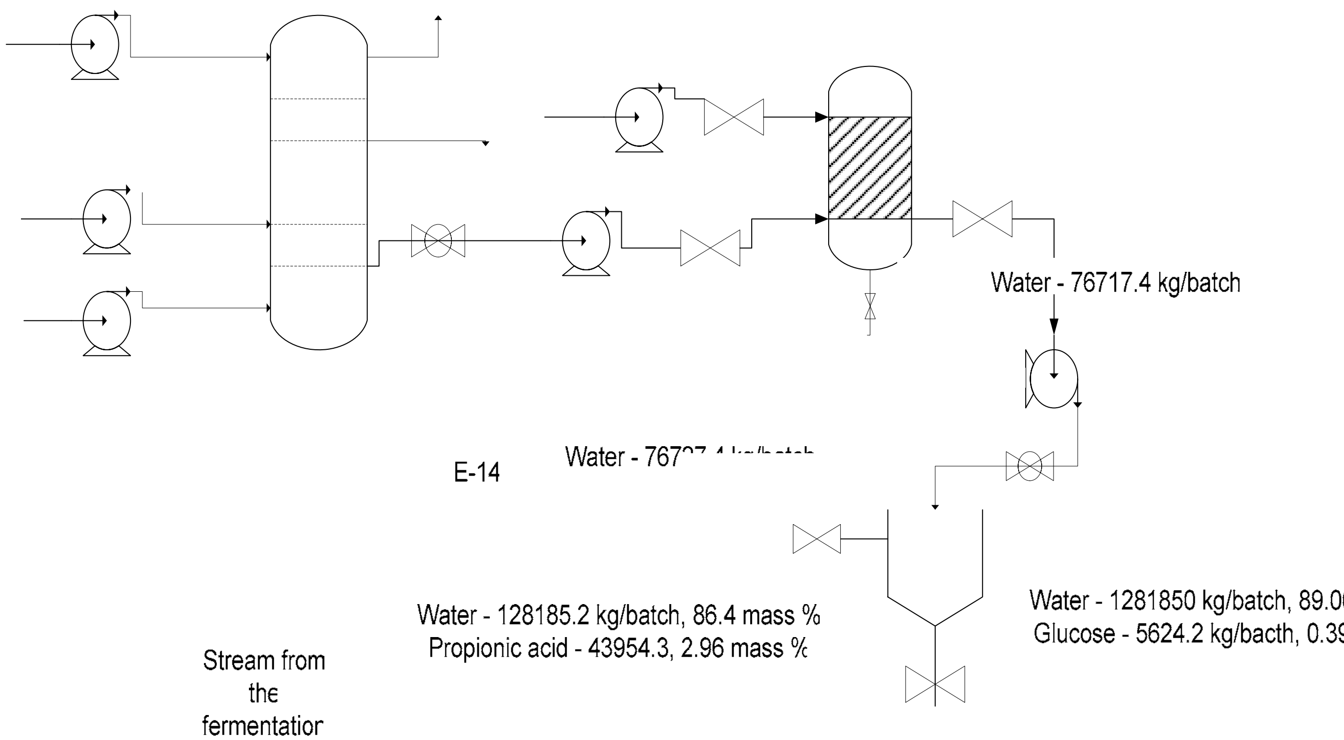

Figure 12: Sodium Propionate purification[3]

2.5.4.1 Propionic Acid Equipment Costs

The process flow diagram (PFD) for the purification and fermentation of propionic acid is shown in the above sections. In Table 7, the details of the equipment are described detailing the number of units, size, and purchasing cost.

Table 7: Propionic Acid Equipment Details[14, 15]

Equipment	Units	Size per unit	Cost ($)
Blending/Storage	3	79500 L	110000
Sterilizer	3	100m^3/hr	220000
Air Filtration -1	9	4m^3/s	25000
Compressor	3	1300 kW	250000
Air Filtration -2	5	8m^3/s	15000
Fermentor	5	350000 L	1200000
Blending/Storage 2	19	80000 L	110000
Ion Exchanger	15	7100 L	85000
Reaction Vessel	3	35500 L	374000
Crystallizer	1	40000 L	410000

2.5.5 Purification Conclusion

	Acetic Acid	Succinic Acid	Citric Acid	Propionic Acid
Fermentation Broth Mass (%)	4.83	4.24	3.79	2.97
Final Conversion to Sell(%)	63.3	59.9	66.0	48.1

The above table shows the final conversion of all the acid. The mass % of the acids in the fermentation broth is between 3 -5 wt %. So it was necessary to purify the acids from the fermentation broth. The final conversion from glucose to acids varied from 50-80 %.

3. Process Economics

The economic evaluation of a project for manufacturing a biological product usually involves the estimation of capital investment, estimation of operating costs, and analysis of profitability.

The capital investment **(Citric acid)** for a new plant includes three main items: 1) direct fixed capital (DFC), 2) working capital, and 3) startup and validation cost. For preliminary design purposes, the various items of DFC are estimated based on the total equipment purchase cost (PC) using several multipliers. Detailed definitions of the various cost items and additional information can be found in traditional process design textbooks and the technical literature (Peters and Timmerhaus, 1991; Ulrich, 1984; Valle-Riestra, 1983; Garrett, 1989; Seider et al., 1999; Douglas 1988).

Table 9: Fixed Capital Cost Estimation

Cost Analysis	Calculated values, million ($)
Direct Costs	
Purchased equipment, E'	**13.9**
Delivery, fraction of E'	1.39
Subtotal: delivered equipment	15.29
Purchased equipment installation	7.186
Instrumentation&Controls(installed)	2.294
Piping (installed)	6.116
Electrical systems (installed)	1.682
Buildings (including services)	2.752
Yard improvements	1.529
Service facilities (installed)	5.352
Total direct costs	**42.2**
Indirect Costs	
Engineering and supervision	3.67
Construction expenses	3.058
Legal expenses	0.612
Contractor's fee	0
Contingency	0.765
Total indirect costs	8.104
Fixed capital investment (FCI)	**50.304**
Working capital (WC)	**13.608**
Total capital investment (TCI)	**63.912**

Based on different capacity and FCI, the FCI vs. the capacity of the citric acid is plotted in Figure 16.

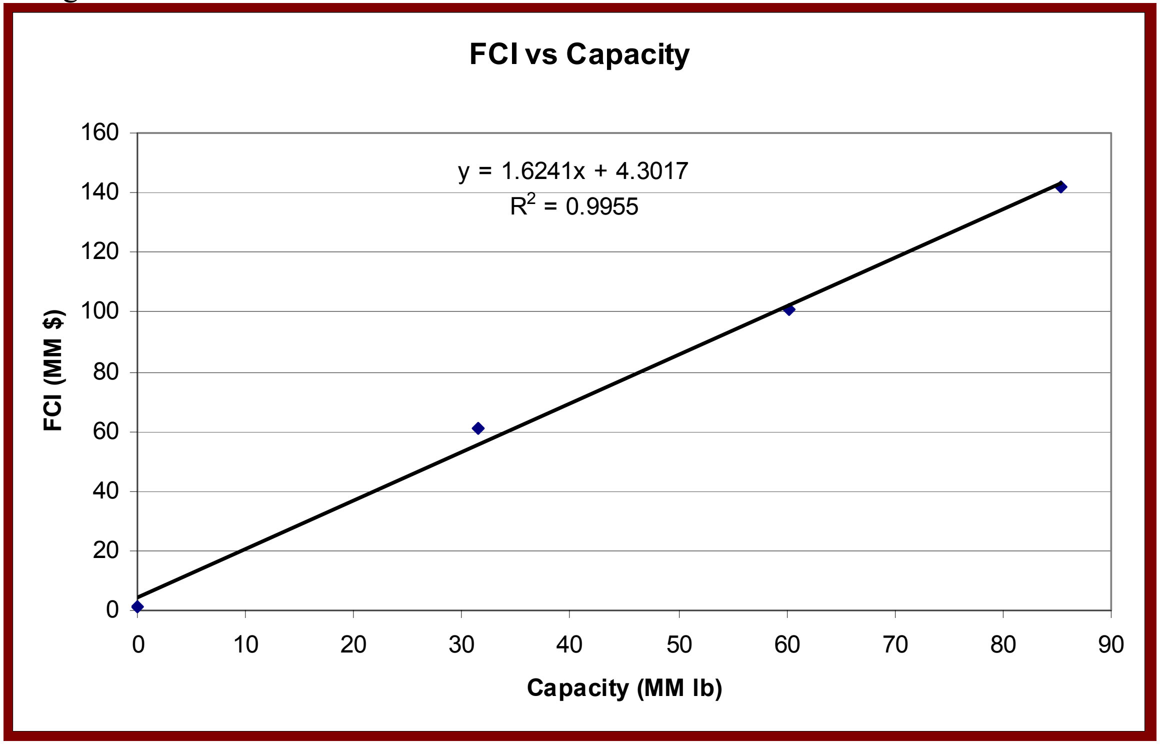

Figure 16: The FCI of the citric acid production

3.1 Operating Cost Estimation

The operating cost to run a biochemical plant is the sum of all expenses associated with raw materials, labor, utilities, waste disposal, overhead, etc. Dividing the annual operating cost by the annual production rate yields the unit production cost (in $/kg). Biotechnology is a unique industry when it comes to the range in unit production cost. Table 10 displays the various types of operating costs, their direct or indirect nature, and ranges for their values relative to the total operating cost. Sometimes cost items are categorized as either fixed or variable. Fixed costs are those that are incurred regardless of volume of product output. The clearest case of a fixed cost is depreciation, which is part of the equipment-dependent cost. The clearest case of a variable cost would be the cost of raw materials. Most other costs have a fixed and a variable component. Based on the process simulations results capacity of the citric acid the following operating costs vs. capacity of the citric acid are obtained.

Table 10: Total operating cost for citric acid production	
Capacity	**35 MM lb**
Raw materials	4.50
Operating labor	1.34
Utility --Electricity	4.46
Maintenance and repairs	3.78
Operating supplies	0.60
Total ($MM)	**14.68**

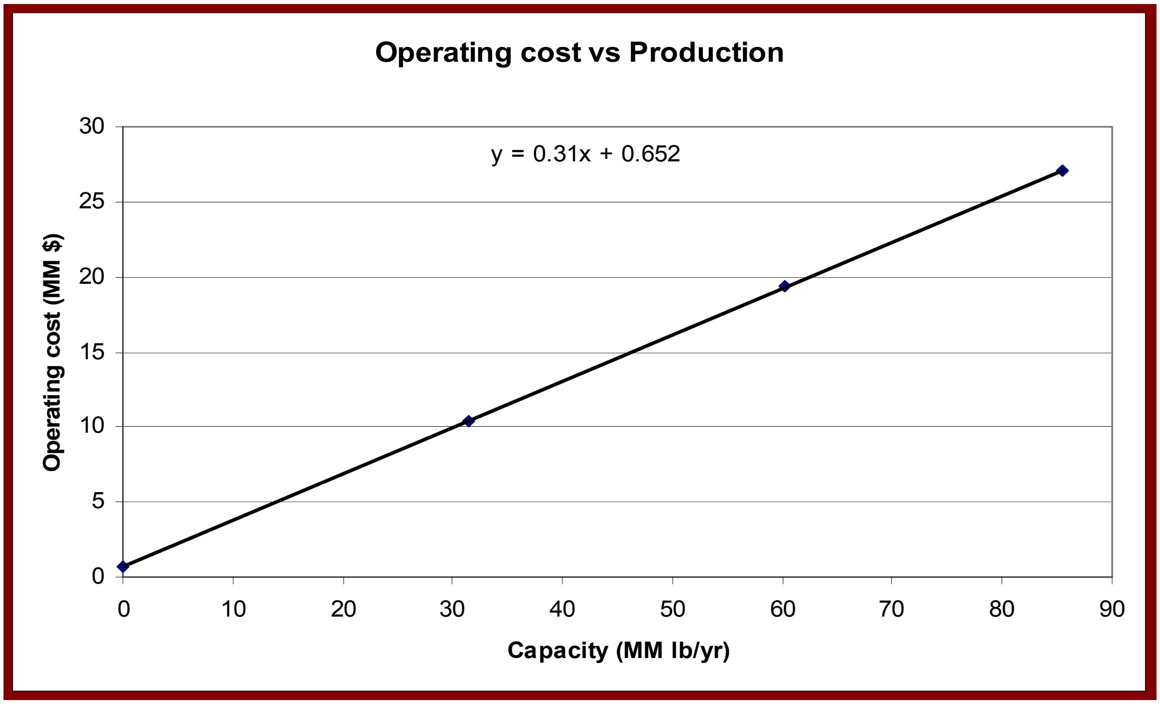

Figure 17: Operating cost for the citric acid production.

3.1.1 Labor

This is estimated based on the total number of operators, which in turn is calculated by summing up the operator requirements of the various operations as a function of time. As will become clear in the examples later in this chapter, the labor requirement in a batch manufacturing facility varies with time. In a single product facility, the number of operators in each shift must be based on maximum demand during that shift. In multi-product facilities, each product line can employ a certain number of dedicated operators and utilize floating operators during periods of peak demand. In general, smaller facilities tend to utilize a larger number of operators per processing step because they are less automated. For instance, a small biotech company may utilize 2-3 operators to set up a fermentor, whereas in a large, highly automated fermentation facility a single operator may remotely handle the setup of six different fermentors from the control room. In general, a typical biotech company that deals with high-value products will allocate at least one operator to each processing step, such as centrifugation, membrane filtration, chromatography, etc. during its operation. The setup of a step may require multiple operators for a short period.

Table 11: Operating Costs			
Operating Labor			
Employees	Shifts per day**	Operator rate, \$/h #	Annual operating labor cost, million \$/y
-	3	-	**1.336**

3.1.2 Waste Treatment / Disposal

In the construction of a biorefining plant, waste treatment and disposal must be considered. It must be determined if the waste produced from the plant can be recycled into products that can be profitable, and if not, it must be disposed of in a regulatory manner. In the construction of a biorefining plant, potential waste that must be considered is carbon dioxide, unused glucose, and wastewater. The diagram below illustrates the phases of the process and the products and waste produced in each phase.

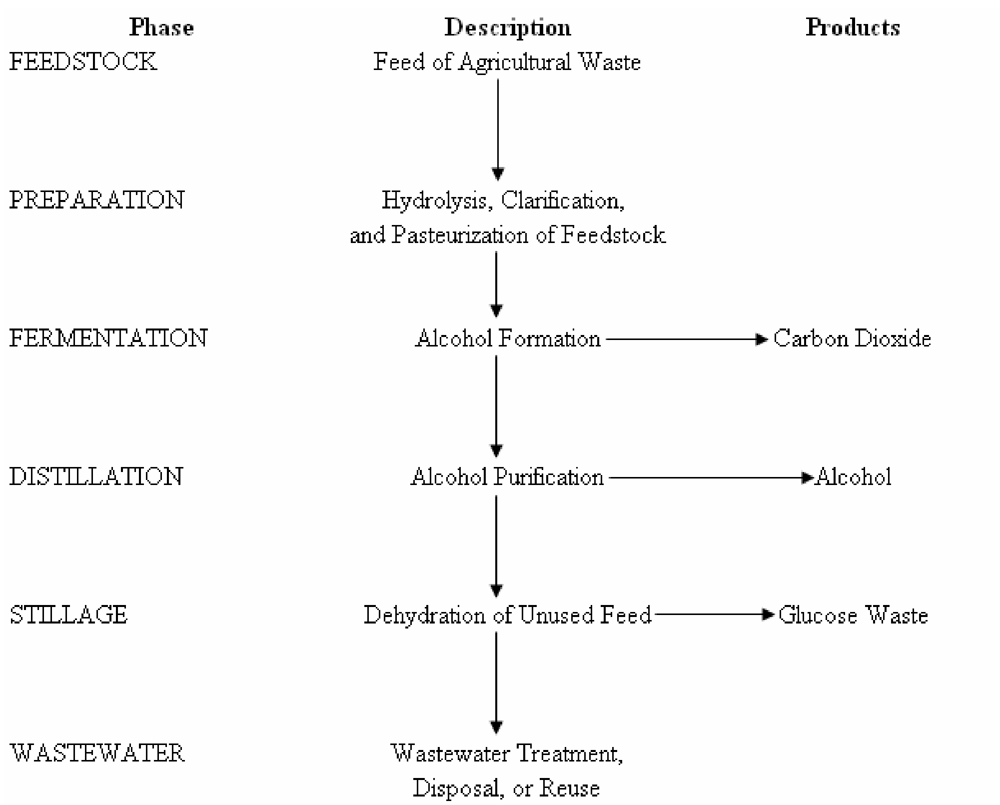

Figure 18: Process Waste of Biorefining Process.

3.1.2.1 Carbon Dioxide Waste

A byproduct of the formation of alcohol during the fermentation process is carbon dioxide. This carbon dioxide is formed from the conversion of the glucose during the fermentation process, which decreases the amount of glucose available for alcohol production. During this fermentation process, large quantities of carbon dioxide are formed and must be disposed of properly. Instead of disposing carbon dioxide, another option would be to sell the carbon dioxide produced as a refrigerant of cooling agent. This can be done by solidifying it by maintaining it under -80˚C.

There are many potential markets available for the selling of carbon dioxide. Below shows the potential markets that can be targeted if it is determined the selling of the carbon dioxide is profitable when considering the installation cost of the recovery equipment.

- Food freezing & refrigeration
- Fire suppression
- Alkali neutralization
- Mould setting
- Inert gas pressurization
- Beverage carbonation
- Tobacco expansion
- Oil well recovery
- Plant growth
- Carrier gas for deodorants
- Breathing stimulant

The existing carbon dioxide production capacity far exceeds the demand in the United States, with the majority of the market being in beverage carbonization and poultry freezing. The estimated total capital investment required for a carbon dioxide production plant is approximately $3MM plus an additional annual cleaning cost of $0.5MM. With a national market price of $75/ton, approximately 20,000 tons must be produced annually for the processes to be considered profitable considering the annual cleaning cost and the capital investment requirement. The projected production of carbon dioxide from a large biorefining plant is estimated to be approximately 10,000 tons. Since this production is less than the profitable production rate, the construction of a carbon dioxide processing plant is not recommended.[22]

Since the selling of the carbon dioxide produced from the fermentation process is not profitable, other options must be considered in its disposal. Currently, carbon dioxide emission is not regulated by the United States government, as stated by the Environmental Protection Agency's Clean Air Act on August 23, 2003. Therefore the release of carbon dioxide in the atmosphere meets all current standards. Furthermore, the

[22] www.qlg.org/pub/act_acp/ethanol/feasibility.htm

emission of carbon dioxide plants from biorefining plants is approximately 99% less than that of petroleum based processes.

To incorporate the cost of carbon dioxide release to the atmosphere, the equipment and installation cost needs to be determined for the discharging process. The cost will be determined based upon the amount of carbon dioxide produced per amount of the main alcohol produced. Then this number can be included into the varying total annualized cost of the deterministic model.

Based on the Process simulations simulations, the total amount of carbon dioxide produced by the process is 70,000 kg per every 6,000 kg of the main chemical produced. Based on this amount, the required cost for equipment and installation are given in the table below:

Equipment	Cost ($)
Compressor	$27,000
Piping	$5,500
Installation Cost	$5,000

Based on these figures, for every 6,000 kg of alcohol produced there is a cost of $37,500. This will be factored into the deterministic model by adding it into the varying annualized cost per mass of main chemical produced.

3.1.2.2 Biomass Waste

Three potential options were considered concerning the proper use of the biomass waste. These options include recycling or selling of the biomass waste. It will be determined if recycling or selling the biomass waste would be profitable, and if not, the waste be disposed of properly. Recycling the biomass will lead to a higher conversion and possibly lessen raw material usages. Selling the biomass could be profitable if the capital investment requirements for a biomass processing plant are less than the revenue expected. Below discuss each potential option in detail.

The first option is to send the waste stream to other separators to separate out the organic compounds which could be sold to independent markets. However, doing this would require more equipment yielding a higher initial capital investment. The addition of more equipment would result in more labor and maintenance needed increasing the cost. All of these increases lead to a higher product cost and less profit. Therefore, this option was not considered because of the amount of possible extraction of organic compounds from the stream.

The second option is to sell the biomass stream to which independent markets could use the biomass to extract the wanted organic compounds. When entering the sale of the biomass into the mathematical model the NPW only increased by 0.1%. It did not affect the plant the plant location or expansion scenarios, it then provides for only a minimal gain in the NPW from the original value. The increase in NPW is only dictated by selling the biomass product and does not include the addition of any equipment, storage vessels, or labor needed for the sale of the stream. Thus, the increase in NPW of 0.1% is arbitrarily insignificant. Therefore, the sale of biomass did not have a significant impact on the economic life of the project.[18]

Lastly, biomass stream could be sent back to the mixer before fermentation as a recycle stream. The objective of this option is to increase the overall conversion of glucose to alcohol. This option has little or no equipment cost (piping and possibly a pump) and can be easily regulated. The addition of labor would not be necessary. This option is the most cost effective of the three options, and was the best option for the biorefining process. Therefore the selling or disposal of the biomass waste is not recommended.

3.1.2.3 Wastewater

The majority of the wastewater used in the process is to be recycled back to the process. In order for the water to be recycled, it has to first be treated. Treatment of low biological oxygen demand (BOD) wastewater (less than 1,000 mg/L) by a municipal wastewater treatment facility usually costs $0.20-0.50 per cubic meter. This is the preferred option because high volumes of water are needed for the process. Considering capital expenses required to handle higher capacities of water, water treatment is a minimal expense for most biotech facilities that deal with high value products. For any solid and liquid waste, the disposal cost is approximately $.05 per kilogram.

The renewal of water is not required in this process because it is just used to aid in the fermentation process. Also, the capital required for the amount initial required is insignificant relative to other capital expenses. Therefore the cost of water is assumed inconsequential to the total capital investment required. The majority of the cost associated with water is the cost of storage and treatment. Based on the biorefining process, possible contaminants introduced to the water includes bacteria, salts, and gypsum. Since the water is going to be recycled back to the fermentation process, the presence of bacteria will not hinder the yield of the alcohol. Therefore it will not be required to remove. On the other hand, all salts and gypsum must be removed from the water before it is recycled.

Based on the data from the Process simulations simulations, the total amounts of salts and gypsum produced is 50,000 kg per 6,000 kg of main chemical produced. Based on the figures presented above, the total cost for the water treatment is $2,500 per 60,000 kg of the main chemical produced**.**

3.1.3 Utilities

This accounts for heating and cooling utilities as well as electricity and employee amenities to the plant. The amounts are calculated as part of the material and energy balances. These utilities are ultimately broken down into 2 distinct subsections discussed below, Electricity and Water.

3.1.3.1 Electricity

The utility cost for each process can be broken down into two categories, these are Fermentation and Separation Processes. Citric Acid can be used to illustrate utility consumption for this venture as all the fermentation processes are similar, the only difference being the final product. A single batch of Citric acid yields 54,268.7kg, and the fermentation takes 32.7 hours while the separation takes 6 hours. The fermentation process uses up a total of about 240,000kW-h of electricity whilst the separation uses about 50kW-hr. This totals about 250,000kW-h of electricity used over a 48 hr period in order to manufacture one batch of citric acid..

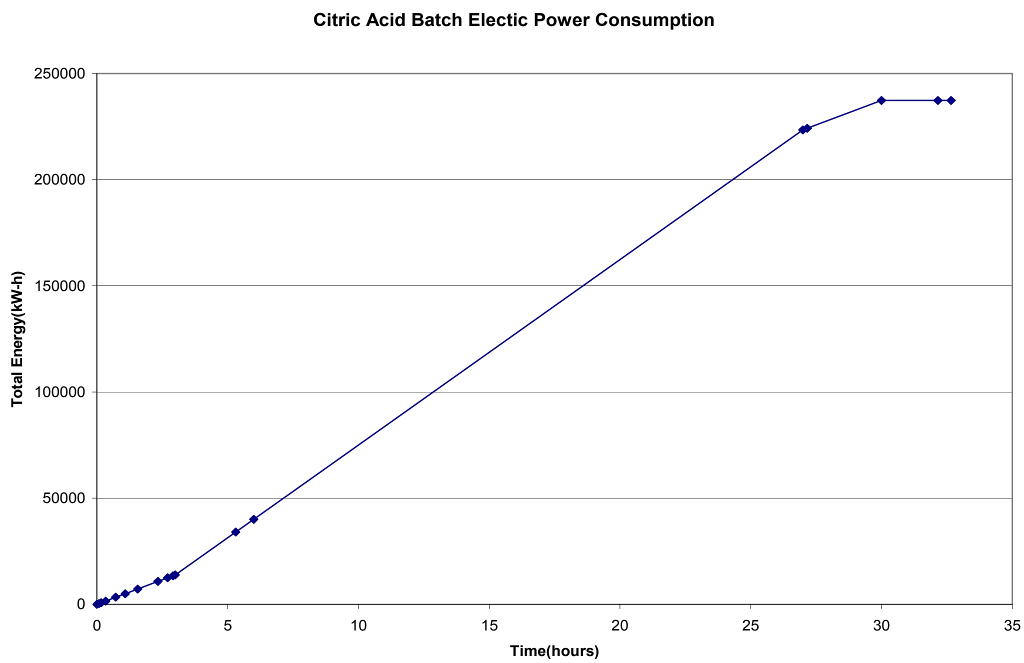

Figure 19: Citric Acid Power Consumption/Batch time[23].

The equipment utilized for fermentation is identical for all four processes that are planned for production, as such, Figure 19. will be almost identical for all processes and will be used as a benchmark for the determination of electricity consumption.

For our plant located in Hot-Springs, Arkansas, we would be using about $15,000 of electricity over a 2 day period for 1 batch of citric acid. Electricity is calculated from Figure 20. at a cost of about $0.06/kW-h, therefore for a plant of capacity 35MM lb, a total of $4,395,000 will be spent over the entire year. The unit cost per lb of product comes to $0.13/lb of product for electricity cost

[23] Process simulations Simulation: See Appendix

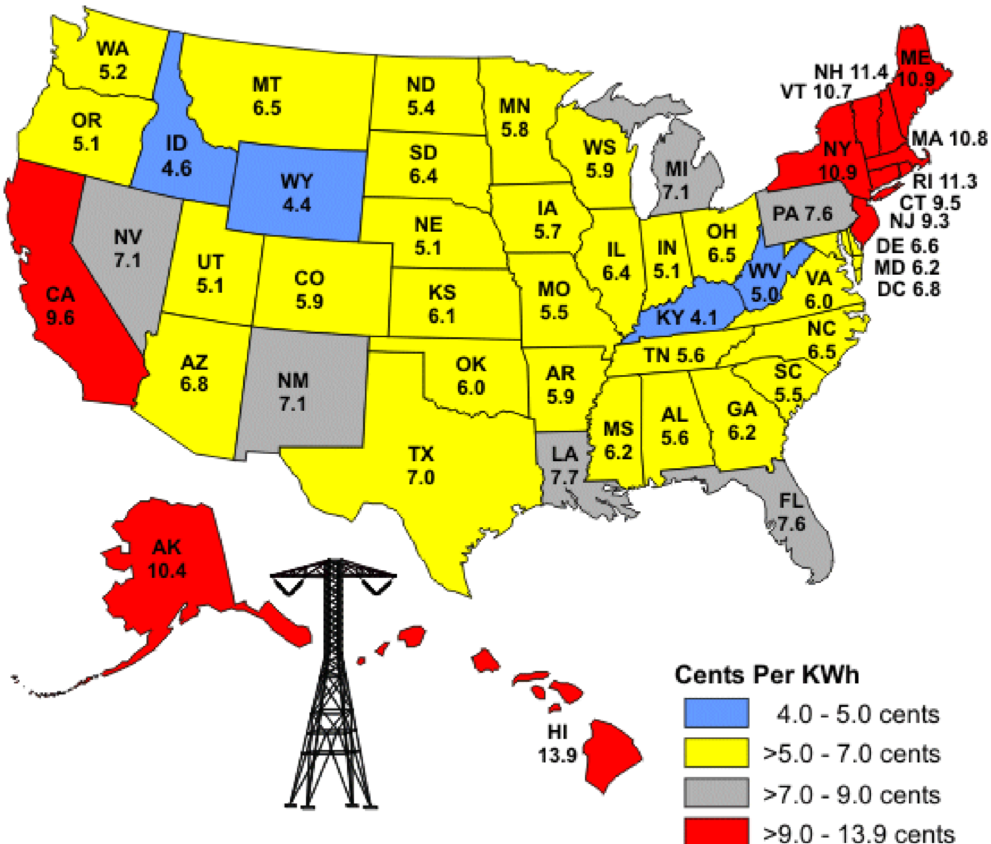

Figure 20: Electricity Cost by Region.[24]

3.1.3.2 Water

Water is a major utility for all our processes, it is used at a minimum ratio of 10:1 for all our fermentation processes and its also utilized for cleaning of equipment after each batch is completed, A lot of water is utilized for all processes and this water will be recycled, however a significant amount is still needed to flow in the system and this amount can then be recycled and changed as necessary. The figure below shows the process water consumption for a batch of citric acid in the fermentation process, this figure amounts to about 1600 tons each month for each process or 6400tons/12,800,000lbs total water use in a month. This value after dividing by the density of water comes to about 1.5 million gallons/month. The cost of water is calculated at an average rate of $1.60/1000 gallons. Possible discounts exist for conservation, i.e recycling water which would be applicable in our case.

The total cost of the water utilized by our processes this cost comes to about $625/batch/process or a total of $2500 for all processes, if the water is recycled and changed a maximum of twice a month we have a maximum cost of $5000/month for our water utility cost. The total comes to $60,000 a year for water utility cost. The figure below illustrates the consumption of water by one of our fermentation processes.

[24] Source: U.S. DOE - Energy Information Administration, Electric Power Monthly Annual, August, 2001.

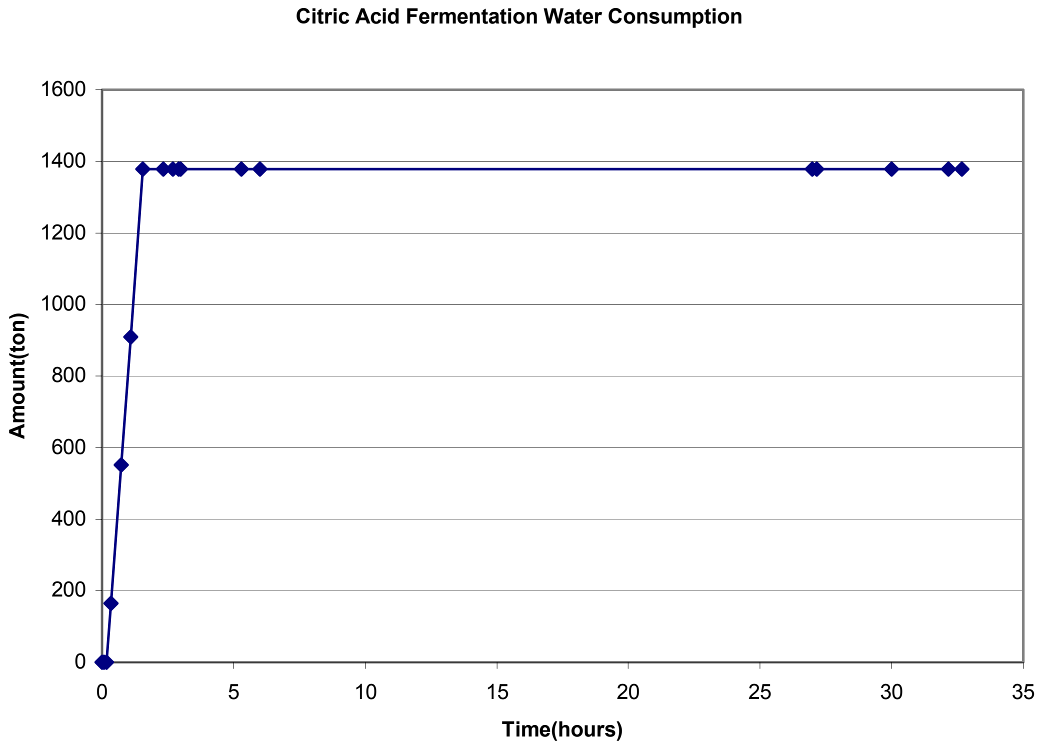

Figure 21: Water Consumption for Citric Acid Fermentation

Table 11 shows the total annual product cost for citric acid production, the breakdown shows how utilities make up about 30% or 4.46 million dollars

Table 11: Total operating cost for citric acid production	
Capacity	**35 MM lb**
Raw materials	4.50
Operating labor	1.34
Utility --Electricity Utility --Water	4.40 0.06
Maintenance and repairs	3.78
Operating supplies	0.60
Total	**14.68**

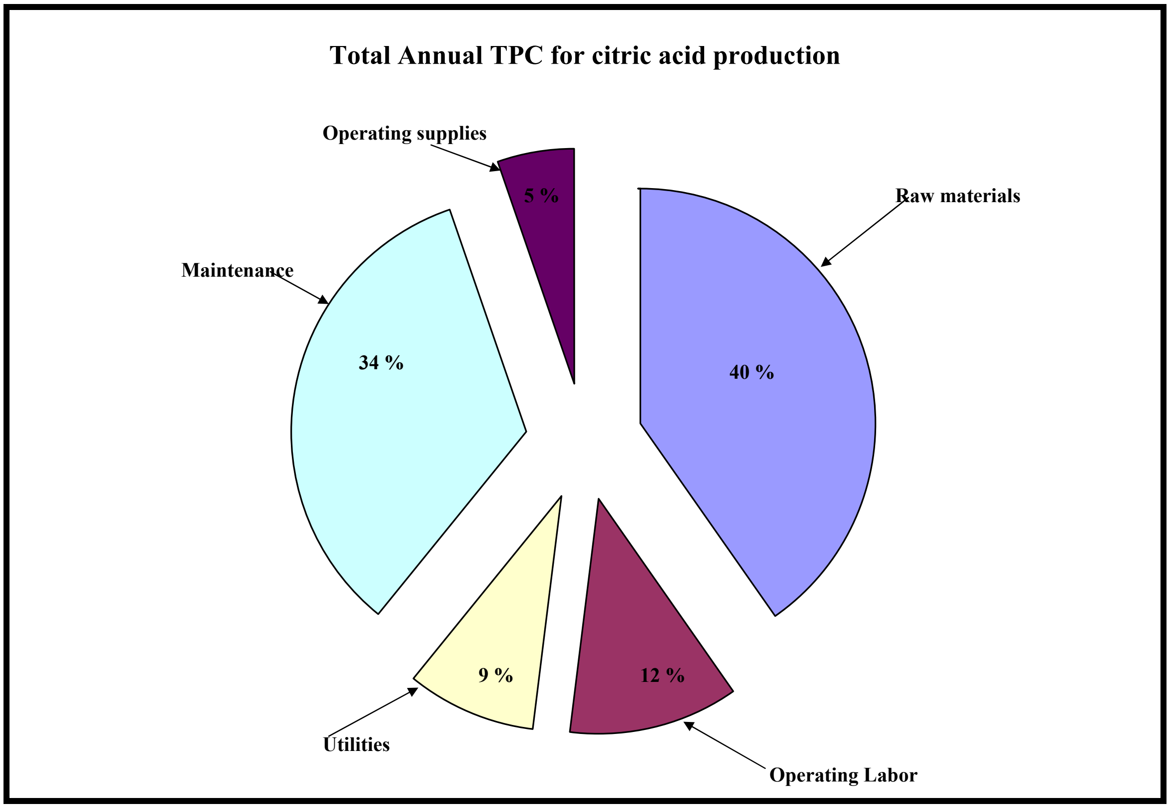

Figure 22: The distribution of the TPC for citric acid production.

The raw materials and maintenance expense is the biggest cost of the total annual cost for the production.

Table 12 shows the summary of the operating cost and FCI for different processes. (See Appendix for all the results and figures for these processes.)

Table 12: Summary of Operating and FCI

Acids	Capacity (MM lb)	FCI ($ /MM/yr)	Operating cost ($ MM/ yr)
Succinic Acid	34.9	71.9	20.5
Acetic Acid	37.9	49.8	14.4
Propionic Acid	34.1	56.9	15.8

These results are obtained by using the modified Peters & Timmerhaus spreadsheets based upon the capacity and necessary equipment requirements. The mathematical model will give the optimal capacity of each process.

3. Mathematical Model

A Mathematical model was developed utilizing the GAMS program. The purpose of this program is to simulate the Biorefining venture over a predetermined life cycle and generate the most profitable result. The purpose of this model is to provide us with our initial business plan, it also dictates all initial business decisions that will produce our most profitable outcome.

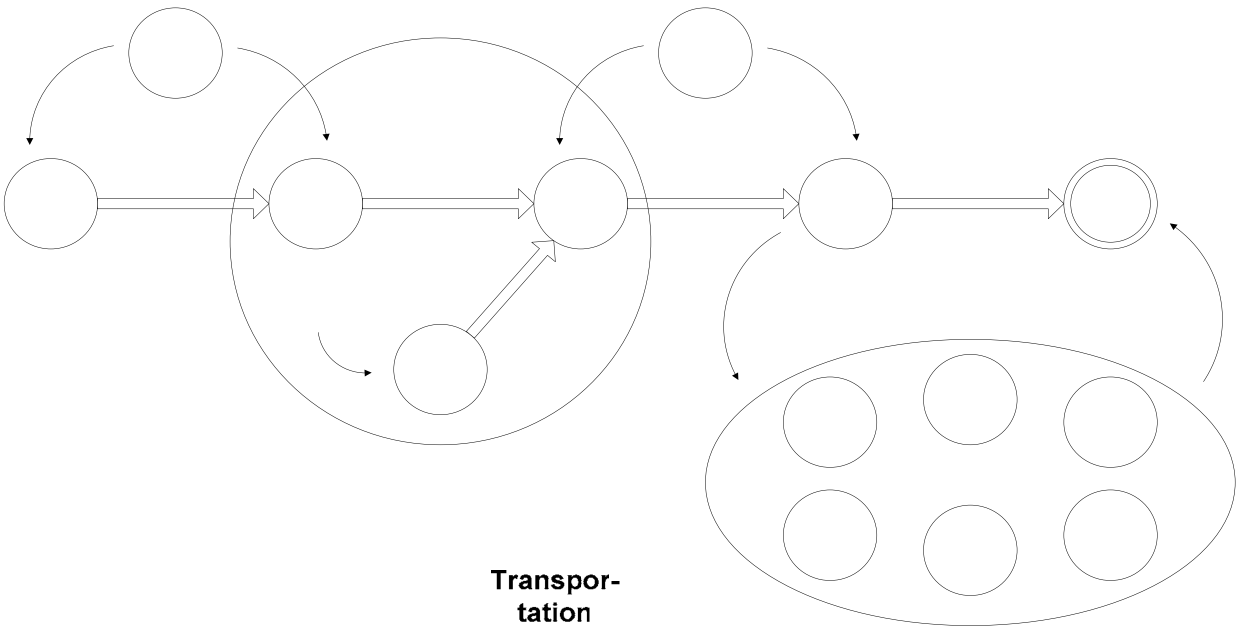

Figure 19: Mathematical Model

The model is constructed using the flow diagram illustrated above, once the simulation is run, the conclusions can be implemented. The mathematical model also delivers the advantage of customizability, in that one can always return and adjust any input variables that may change as the project advances. The mathematical model is an essential tool for business venture planning as it can significantly reduce risk by considering a plethora of variables that would be impossible without a model. Coupling this with the fact we can customize variables such as prices, and other costs as time passes, the mathematical model becomes a crucial and even indispensable factor for this or any other Capital venture.

4.1 Model Input

The mathematical model was designed with the expectation that some inputs will be entered into the model to generate our desired results, these are:

- Fixed Capital Investment (FCI)
- Operating Costs as a function of plant production
- Mass balances obtained from process simulations[25]
- raw materials and their conversion rates to final product
- raw material market, plant, and product market locations
- Distances between raw material markets and plant location
- Distances between plant location and final product markets
- Freight costs for raw materials and product
- Cost of raw materials from different location including state sales tax
- State property taxes for plant locations
- Demand at different product markets over the life cycle of the venture
- Product prices at product markets over the life cycle of the venture
- Salvage value and working capital as a percentage of FCI
- Depreciation and lifespan of project

4.1.1 FCI and operating costs versus production

The net present value of our venture changes with our initial capital investment, the mathematical model predicts the optimal Total Capital investment that gives our maximum NPV. The aim of this input is to determine the optimal initial investment that will return the most profitable decision. It is obvious that the larger the FCI, the greater the capacity of the plant, however, this also leads to as higher operating cost and the possibility of overproducing product that exceeds demand, or not utilizing all available equipment. The model therefore has to find a value that meets a set demand over a given period of time, and maximizes the profit.

[25] An addition/improvement on Ethyl Lactate GAMS model.

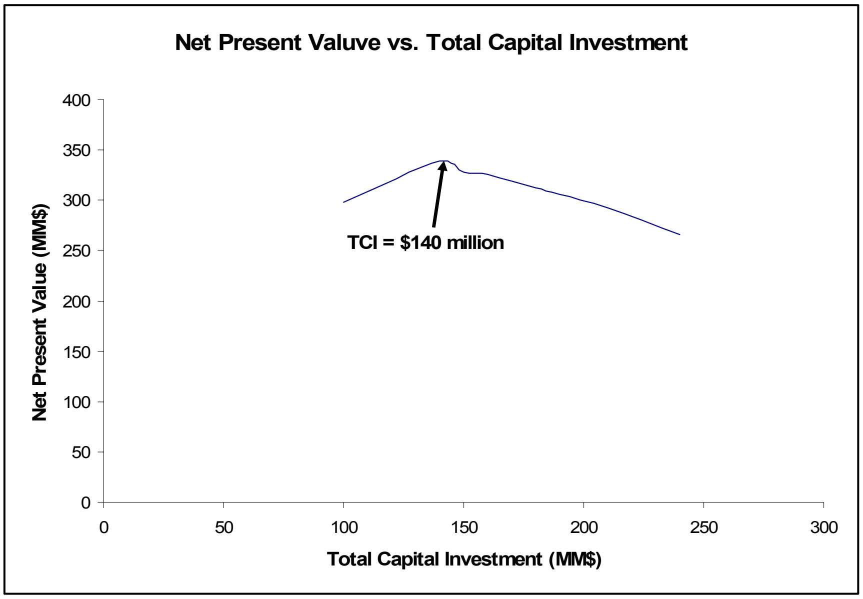

Figure 13: Total capital investment versus Net Present value

The operating costs for the venture also vary with overall production. These costs change linearly with the intercept at a fixed cost at no production. These operating costs are composed of various different costs such as labor and utilities; they are tabulated below at a capacity of 35 million pounds per year. The figure below displays the Fixed Capital investment vs Capacity for our Succinic Acid Production, this plot determined from Superpro Simulation allows us to determine what FCI is required to meet a certain demand and is an input for the final mathematical model.

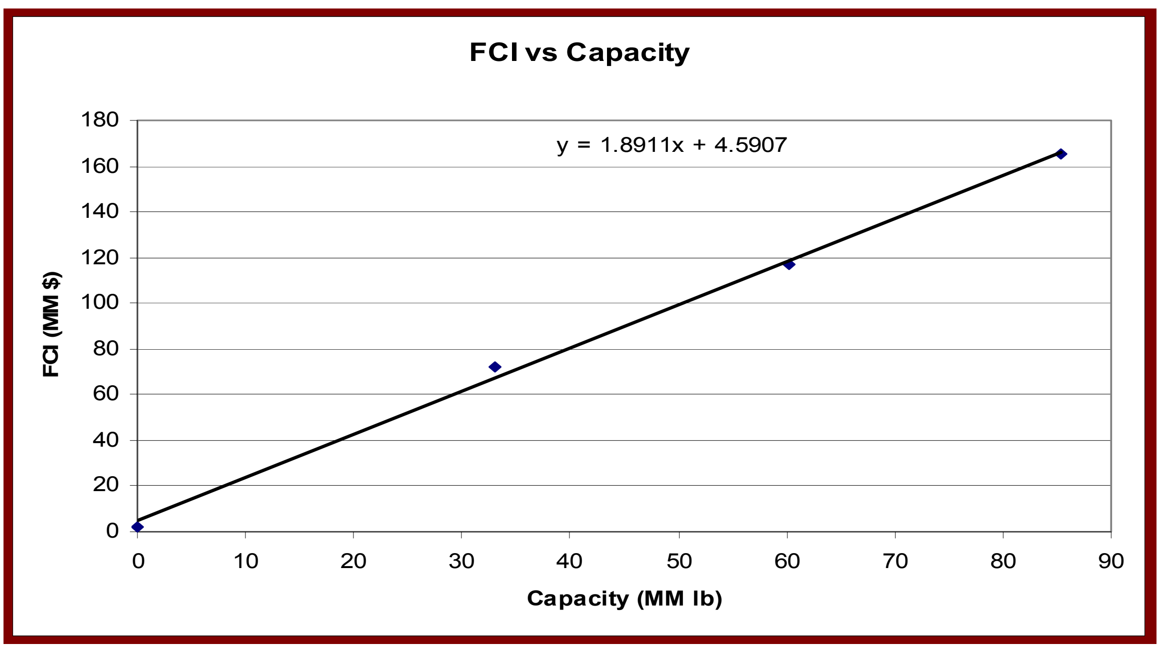

Figure 14: FCI of Succinic Acid vs Capacity

The total operating costs based on production is calculated by summing the separate costs associated with the process. These costs are tabulated below and then the operating cost is plotted as a function of capacity.

Table 8: Annual Operating Cost in Million Dollars	
Capacity	**35 MM lb**
Raw materials	12.68
Operating labor	1.34
Utilities	0.99
Maintenance and repairs	4.43
Operating supplies	1.01
Total	**20.45**

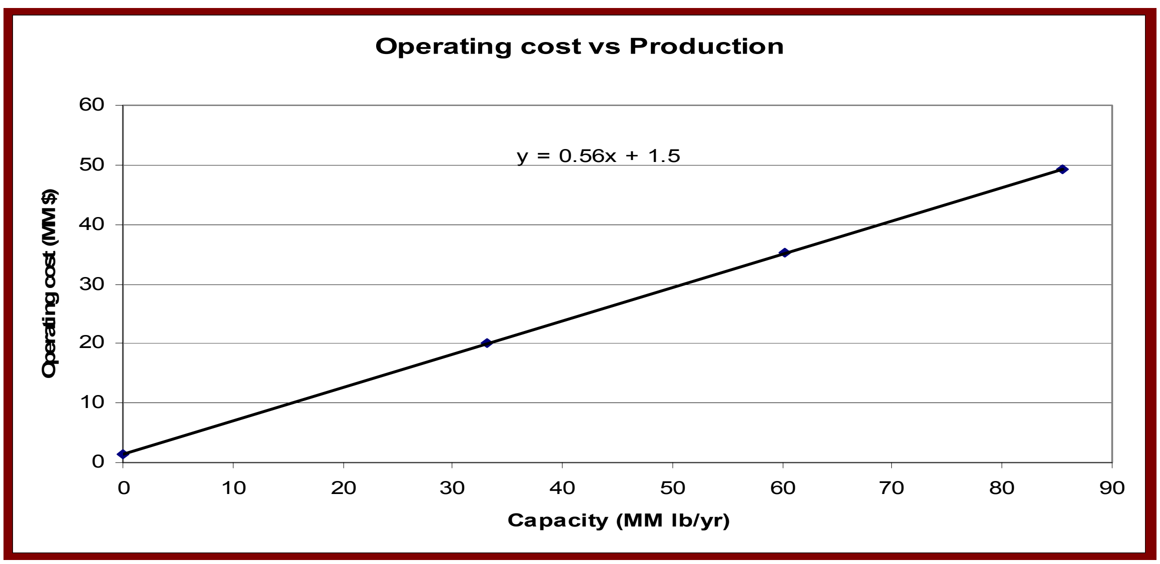

Figure 15: Operating cost versus Succinic Acid production

4.1.2 Freight costs/transportation issues

Freight costs may only be found by getting quotes from transportation companies. In order to generalize for the entire United States, median values of \$0.04 per pound per thousand miles were used for the raw materials and \$0.02 for the final product. A company fleet was considered however this option was decided against after consideration. A fleet would require the employment of professional drivers, possible union involvement, Unnecessary expansion of plant to include a transportation department as opposed to a basic shipping and receiving, as well as various equipment operating costs involved with the trucks and government regulations.

Contracting through transportation companies would create competition and allow Biorefining to obtain the best possible price.

4.2 Model Equations and Constraints[17]

This section includes the necessary equations the mathematical model used to determine how profitable biorefining is over a 20 year period. Additionally, some constraints were necessary in making the mathematical model more realistic. The model maximized the net present worth, determined the plant location, and a constraints maintained that production of any product does not exceed market demand. This last feature is more of a safety 'valve', as the project aims to capture only 1 percent of the market. Constants such as fixed costs and operating cost per pound of product were different for the different products, and a second model was used to determine how much of each product should be manufactured given limited capital. The equations below were obtained from a previous biorefining project that focused on the production of Ethyl Lactate alone.

Below is a summary of the equations utilized in the mathematical model.

$$RawMatCosts_{i,j} = frm * \sum_{rm} \sum_{i,j} ((drm_{i,rm} + \cos trm_{rm}) * yrm_{i,j,tp}) \quad \text{.............(4)}$$

where: frm = freight costs for raw materials (\$/lb)
drm = distance from raw material market to plant (miles)
yrm = weight of raw material shipped (lb)
costrm = cost of raw material (\$/lb)

$$OperatingCosts_{i,j} = Op_{fix} + x_{i,j} * O_{OP} \quad \text{...(5)}$$

where: Opfix = \$3,000,000
x = weight of final product shipped per year(lbs/year)
Oop = \$0.331/lb product

$$TotalCosts_{i,tp} = RawMatCosts_{i,tp} + OperatingCosts_{i,tp} + ffp * \sum tp(dpm_{i,j} * x_{i,j,tp}) \quad (6)$$

where: ffp = freight costs for final product ($/lb)
dpm = distance plant to market (miles)
$TotalCosts_{i,j} = RawMatCosts_{i,j} + OperatingCosts_{i,j}$

$$Revenue_{i,tp} = \sum_j (prodprice_{j,tp} * x_{i,j,tp}) - TotalCosts_{i,j} \quad \text{.....(7)}$$

where: prodprice = price of final product ($/lb)

$$FCI_i = A + B * Capacity_i + C * MaxCap_{i,year=20} \quad \text{.....(8)}$$

where : FCI = fixed capital investment
A = fixed cost for pervaporation units, piping, columns, and electrodialysis units
B = cost to expand capacity for fermentation units reactors
C = linear cost for size of columns sized for max production

$$CF_{i,tp} = Revenue_{i,tp} - (Revenue_{i,tp} - Dep * FCI_i) * tax_i \quad \text{.....(9)}$$

where: CF = cash flow ($)
Dep = depreciation
tax = property tax in specified state

$$TCI_i = (1 + I_W) * FCI_i \quad \text{.....(10)}$$

where Iw = working capital as a percentage of FCI (15%)

$$NPW = \sum_i (\sum_{tp} \frac{CF_{i,tp}}{(1+i)^{tp}} + \frac{(Vs_i + Iw_i) * FCI}{(1+i)^{tp}} - TCI_i) \quad \text{.....(11)}$$

where: NPW = net present worth ($)
i = nominal interest rate
Vs = salvage value as a percentage of FCI
Iw = working capital as a percentage of FCI

4.2.1 Constraints

The constraints served the purpose of making the model realistic. For example, it limited the supply by demand and mass flow of raw material.

$$NumPlants = \sum_i bi_i \quad \ldots\ldots(12)$$

where: bi = binary variable, bi = 1 if plant is built, else bi = 0

$$\Sigma_j yrm_{i,k,tp} \leq yrm\max_{k,tp} \quad \ldots\ldots(13)$$

where: yrm = lbs of raw materials from market j to plant i at time period tp
yrmmax = max pounds possible at raw material market k

$$Cap_i * bi_i \geq \sum_j x_{i,j,tp} \quad \ldots\ldots(14)$$

where: Cap = capacity of plant i (pounds product/year)

$$Demand_{j,tp} * PM \geq \sum_i x_{i,j,tp} \quad \ldots\ldots(15)$$

where: Demand = Demand in pounds product/year
PM = percent of market occupied

$$\sum_j x_{i,j,tp} = \sum_{rm} (yrm_{i,krm} * conv_{rm}) \quad \ldots\ldots(16)$$

where: conv = conversion of raw material to final product (lb product/lb raw material)

$$Capacity_i \geq \sum_j x_{i,j,tp} \quad \ldots\ldots(17)$$

where: capacity = maximum production of plant
hrsoper = hours in operation per year (~8000)

5. Mathematical Model Results

After inputting all model specifications, the output reported the most feasible plant location, the portion of the total capital investment allocated for each potential markets, the capacity of each potential markets for the plant throughout the lifetime of the project, and the expansion of the potential markets throughout the life of the project to maximize the net present value of the project. Based on the market analysis of possible sources of agriculture, corn was determined to be the source of all glucose milling. Also, a single production plant should be constructed located in Dubuque, Iowa. The following reports the design specification of the plant for the total life of the project, 20 years. This life cycle is broken down into ten intervals of two years. This breakdown is done to accommodate for expansion opportunities based on the increase of market demands of the chemicals produced. The model calculates expansion under the assumption it can occur in 1 operational year.

5.1 Initial Plant Specification

The total initial capacity for the first time period of the plant is $179\,\frac{MM\ lb_m}{year}$, with an initial capital investment requirement of \$150,000,000. It is assumed that the revenue generated from the sale of the biomass products is used to invest towards additional capital requirements. The following table shows the allocation of the investment opportunities with the flow rates of each product for the first time period.

Table 14: FCI Allocation and Mass Flow Rate of Main Product for Time Period 2005-2007

Chemical	FCI (MM \$)	Mass Flow Rate (MM lbm/2 year)
Succinic Acid	41.3	74
Ethanol	32.6	78
Propionic Acid	7.2	22
Fumaric Acid	2.0	5

The following block diagram shows the chemicals produced, amount of biomass used in the reaction, and main product flow rate for the plant for the initial time period.

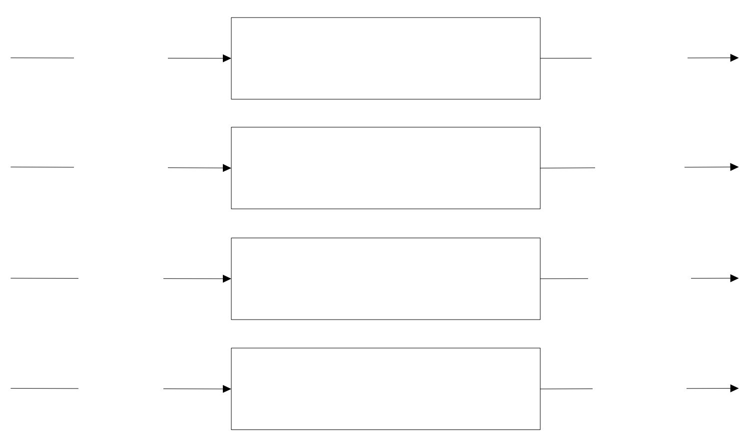

Figure 23: Block Diagram for Biomass Production for Time Period 2005-2007

As illustrated in the flow diagram above, the majority of the capital will be invested in the production of succinic acid and ethanol for the initial time period. In addition to the production of these chemicals, the plant will also produce propionic acid and fumaric acid, but in smaller quantities. This is because the demand and market price are less for these chemicals compared to that of succinic acid and ethanol.

5.2 Expansion Opportunities

Throughout the lifetime of the process, expansion opportunities that would increase the net present value of the plant were considered. The evaluation for expansion was considered for each two year interval, with the production increase occurring in the first year of the period. The expansion can either include the addition to the existing processes of the plant or the construction of a new biorefining process. Below states the expansion requirements for each period that increases the net present value.

5.2.1 Expansion Opportunity 1 (2007-2009)

Based on the initial design parameters, the plant was evaluated for expansions opportunities for each time interval of 2 years. For this evaluation, it was determined if an increase in plant capacity would increase the net present value of the project by capitalizing on the increase of market demands. In addition to the increase of market demands, more capital is available from the revenue generated from the sales of the chemicals produced. The following table shows the allocation of the investment opportunities with the flow rates of each product for the time period.

Table 15: FCI Allocation and Mass Flow Rate of Main Product for Time Period 2007-2009

Chemical	FCI (MM $)	Increase of Mass Flow Rate (MM lbm/2 year)
Succinic Acid	5.1	9.2
Ethanol	5.3	12.6
Propionic Acid	0.3	0.9
Fumaric Acid	0.05	0.1

The flow diagram of the main reactant and product for time period 2007-2009 are given in the figure below:

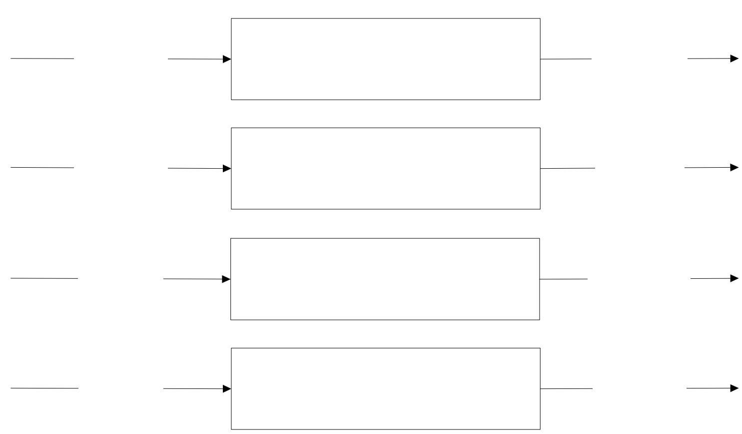

Figure 24: Block Diagram for Biomass Production for Time Period 2007-2009

For the first expansion period, all capital investment will be used to expand on the current processes. Based on the figures above, the majority of this capital will be used to expand on the production of ethanol and succinic acid.

5.2.2 Expansion Opportunity 2 (2009-2011)

For the second expansion period, there was not an increase in the capacity of the plant. Therefore there was no additional fixed capital investment required for the addition of capacity increases.

5.2.3 Expansion Opportunity 3 (2011-2013)

For the third expansion period, revenue generated was used to increase the capacity of the plant. For this time period, more equipment was added to the existing process to increase the product flow rates for all of the current chemicals being produced. The following table shows the fixed capital investment requirements and the increase in the product flow rate.

Table 16: FCI Allocation and Mass Flow Rate of Main Product for Time Period 2011-2013

Chemical	FCI (MM $)	Increase of Mass Flow Rate (MM lbm/2 year)
Succinic Acid	5.7	10.2
Ethanol	6.1	14.5
Propionic Acid	0.3	0.7
Fumaric Acid	0.05	0.1

The flow diagram of the main reactant and product for time period 2011-2013 are given in the figure below:

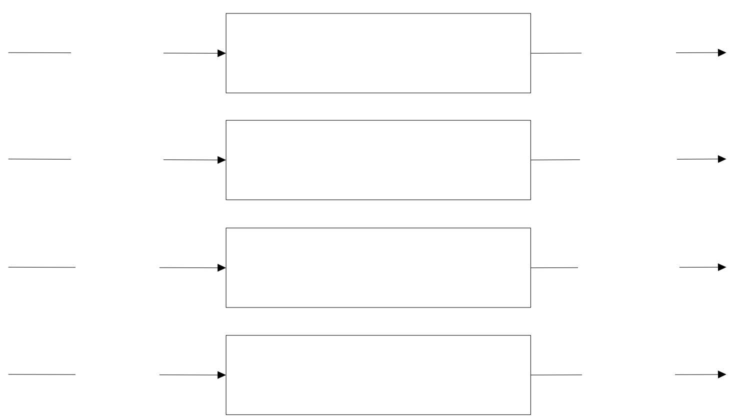

Figure 25: Block Diagram for Biomass Production for Time Period 2011-2013

For the third expansion period, all capital investment will be used to expand on all of the current processes. Based on the figures above, the majority of this capital will be used to expand on the production of ethanol and succinic acid.

5.2.4 Expansion Opportunity 4 (2013-2015)

In the fourth expansion period, additions to the plant increased the mass flow rate of all produced currently produced by the plant. This increase in production required a fixed capital investment, which was supplied by the revenue generated from plant production. The following table shows the fixed capital investment requirements and the increase in the product flow rate for the time period.

Table 17: FCI Allocation and Mass Flow Rate of Main Product for Time Period 2013-2015

Chemical	FCI (MM $)	Increase of Mass Flow Rate (MM lbm/2 year)
Succinic Acid	6.5	11.6
Ethanol	7.2	17.0
Propionic Acid	0.2	0.9
Fumaric Acid	0.09	0.3

The flow diagram of the main reactant and product for time period 2013-2015 are given in the figure below:

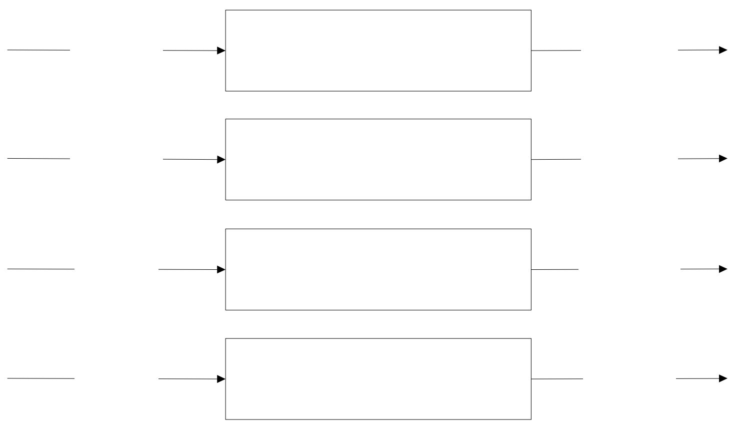

Figure 26: Block Diagram for Biomass Production for Time Period 2013-2015

For the fourth expansion period, all capital investment will be used to expand on all of the current processes. Based on the figures above, the majority of this capital will be used to expand on the production of ethanol and succinic acid.

5.2.5 Expansion Opportunity 5 (2015-2017)

In the fifth expansion period, the expansion of the production of fumaric acid halted. This in returned allowed for the increase of production of the remaining chemicals. The following table shows the fixed capital investment requirements and the increase in the product flow rate for the time period.

Table 18: FCI Allocation and Mass Flow Rate of Main Product for Time Period 2015-2017

Chemical	FCI (MM $)	Increase of Mass Flow Rate (MM lbm/2 year)
Succinic Acid	7.2	12.8
Ethanol	8.2	19.6
Propionic Acid	0.3	1.0
Fumaric Acid	0.0	0.0

The flow diagram of the main reactant and product for time period 2015-2017 are given in the figure below:

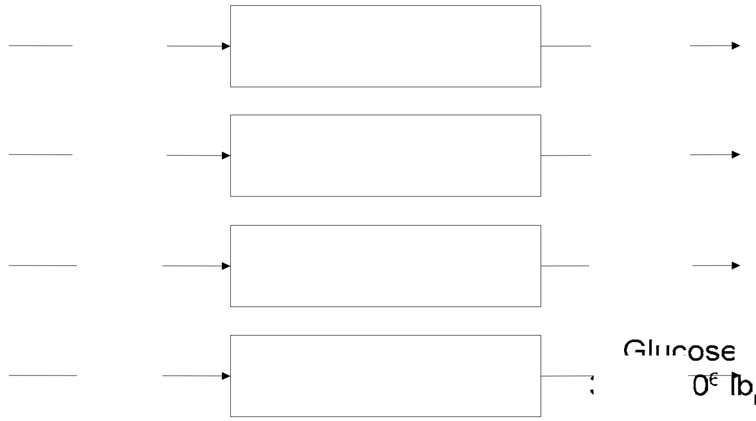

Figure 27: Block Diagram for Biomass Production for Time Period 2015-2017

For the fifth expansion period, all capital investment will be used to expand on current processes. Based on the figures above, the majority of this capital will be used to expand on the production of ethanol and succinic acid, while the production of fumaric acid halted.

5.2.6 Expansion Opportunity 6 (2017-2019)

In the sixth expansion period, the production of all chemicals beside fumaric acid increased. The capital requirements for this expansion were funded from revenue generated. The following table shows the fixed capital investment requirements and the increase in the product flow rate for the time period.

Table 19: FCI Allocation and Mass Flow Rate of Main Product for Time Period 2017-2019

Chemical	FCI (MM $)	Increase of Mass Flow Rate (MM lbm/2 year)
Succinic Acid	8.1	14.5
Ethanol	9.7	23.1
Propionic Acid	0.3	1.0
Fumaric Acid	0.0	0.0

The flow diagram of the main reactant and product for time period 2017-2019 are given in the figure below:

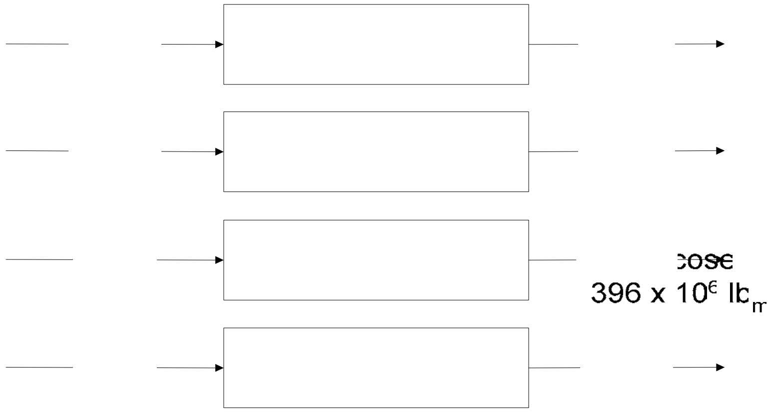

Figure 28: Block Diagram for Biomass Production for Time Period 2017-2019

For the sixth expansion period, all capital investment will be used to expand on current processes. Based on the figures above, the majority of this capital will be used to expand on the production of ethanol and succinic acid, while the production of fumaric acid did not increase.

5.2.7 Expansion Opportunity 7 (2019-2021)

In the seventh expansion period, the production of fumaric acid stilled remained constant, while the production of all other chemicals increased. The capital requirements for this expansion were funded from revenue generated. The following table shows the fixed capital investment requirements and the increase in the product flow rate for the time period.

Table 20: FCI Allocation and Mass Flow Rate of Main Product for Time Period 2019-2021

Chemical	FCI (MM $)	Increase of Mass Flow Rate (MM lbm/2 year)
Succinic Acid	9.2	16.4
Ethanol	11.1	26.5
Propionic Acid	0.3	1.0
Fumaric Acid	0.0	0.0

The flow diagram of the main reactant and product for time period 2019-2021 are given in the figure below:

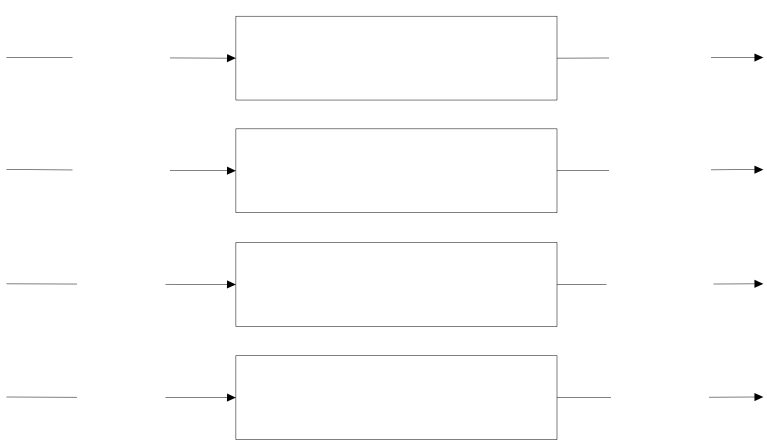

Figure 29: Block Diagram for Biomass Production for Time Period 2019-2021

For the sixth expansion period, all capital investment will be used to expand on current processes. Based on the figures above, the majority of this capital will be used to expand on the production of ethanol and succinic acid, while the production of fumaric acid did not increase.

5.2.8 Expansion Opportunity 8 (2021-2023)

In the eighth expansion period, the production of fumaric acid stilled remained constant, while the production of all other chemicals increased. The capital requirements for this expansion were funded from revenue generated from prior sales. The following table shows the fixed capital investment requirements and the increase in the product flow rate for the time period.

Table 21: FCI Allocation and Mass Flow Rate of Main Product for Time Period 2021-2023

Chemical	FCI (MM $)	Increase of Mass Flow Rate (MM lbm/2 year)
Succinic Acid	10.3	18.4
Ethanol	13.0	31.0
Propionic Acid	0.3	1.0
Fumaric Acid	0.0	0.0

The flow diagram of the main reactant and product for time period 2021-2023 are given in the figure below:

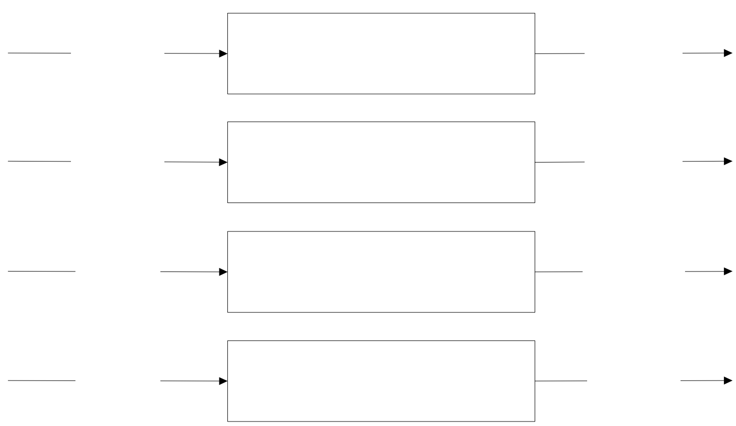

Figure 30: Block Diagram for Biomass Production for Time Period 2021-2023

For the eighth expansion period, all capital investment will be used to expand on all current processes besides fumaric acid. Based on the figures above, the majority of this capital will be used to expand on the production of ethanol and succinic acid.

5.2.9 Expansion Opportunity 9 (2023-2025)

In the ninth and final expansion period, the production of fumaric acid stilled remained constant, while the production of all other chemicals increased. The capital requirements for this expansion were funded from revenue generated from prior sales. The following table shows the fixed capital investment requirements and the increase in the product flow rate for the time period.

Table 22: FCI Allocation and Mass Flow Rate of Main Product for Time Period 2023-2025

Chemical	FCI (MM $)	Increase of Mass Flow Rate (MM lbm/2 year)
Succinic Acid	11.5	20.6
Ethanol	15.1	36.0
Propionic Acid	0.4	1.2
Fumaric Acid	0.0	0.0

The flow diagram of the main reactant and product for time period 2023-2025 are given in the figure below:

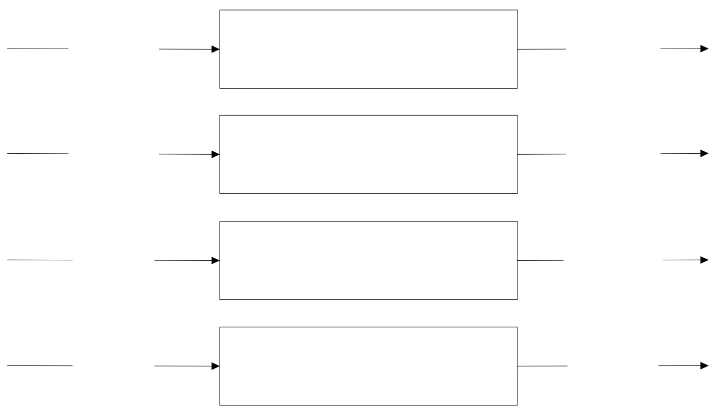

Figure 31: Block Diagram for Biomass Production for Time Period 2023-2025

For the eighth expansion period, all capital investment will be used to expand on all current processes besides fumaric acid. Based on the figures above, the majority of this capital will be used to expand on the production of ethanol and succinic acid.

5.3 Deterministic Mathematical Model Overview

Based on the initial capital investment of $150,000,000, the net present value of the biorefining plant is projected to be $280,000,000. It was determined that the optimal location for this plant would be in Dubuque, Iowa. This biorefinig plant is designed to produce four of the possible seven potential fermentation products, succinic acid, ethanol, propionic acid, and fumaric acid. The product flow rate of each process based on the total capacity of the plant is illustrated in the figure below:

Glucose
501 x 10^6 lb$_m$
Succi
Prod
Glucose
666 x 10^6 lb$_m$
Ethanol
Glucose
86 x 10^6 lb$_m$
Propio
Prod
Glucose
17 x 10^6 lb$_m$
Fuma
Prod

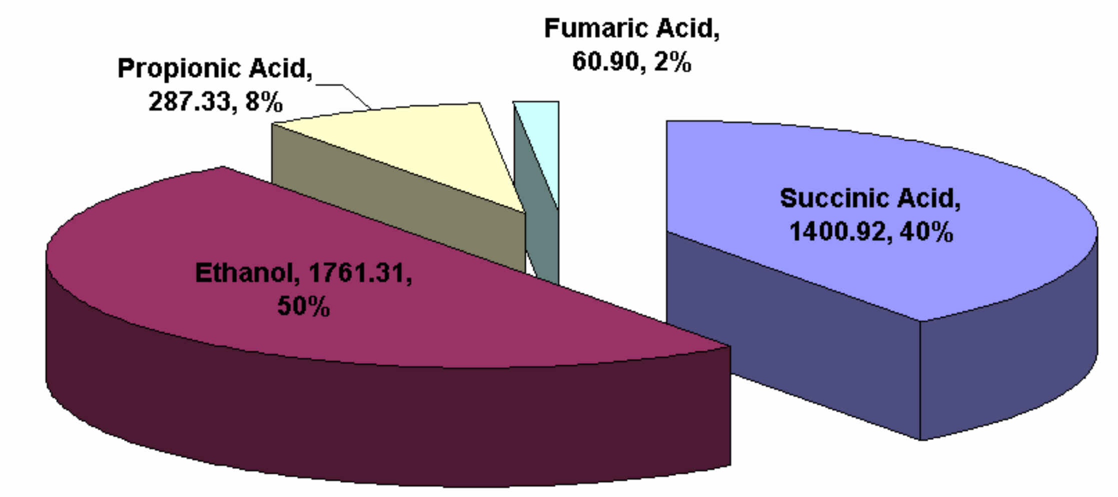

Figure 32: Product Flow Rate (MM lb_m) Distribution for Lifespan of Project

To achieve the above flow rates, there was a fixed capital investment associated with it. The total initial capital available was only $150,000,000, but once revenue was generated, this monetary sum was used to invest in expansion opportunities for the plant. The total fixed capital requirements for the production of each chemical is given in the figure below, as well as the percent distribution for each process.

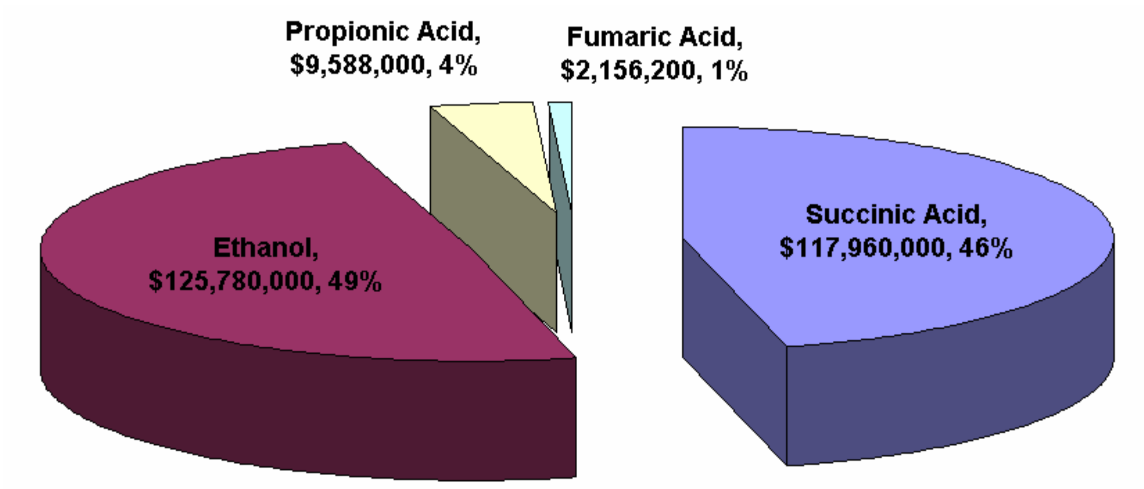

Figure 33: Fixed Capital Distribution for Lifespan of Project

Based on the figures above, the majority of product produced from the biorefining plant will be ethanol and succinic acid. They were produced in the greatest quantity, as well as having the greatest allocation of the fixed capital investment. This was because the market prices for these chemicals are greater than that of fumaric and propionic acid. Even though the capital investment for fumaric and propionic acid seem relatively insignificant, there was excess capital available to make the investment profitable.

In addition to the consideration of different possible fermentation products, different markets throughout the United States were considered. These markets were broken down by three regions: West, Central, and East. Because the demand and the market prices for the chemicals produced varied between the regions, each region varied in the amount of the product transported to their region. The figure below illustrated the distribution of the amount of the products sold by region.

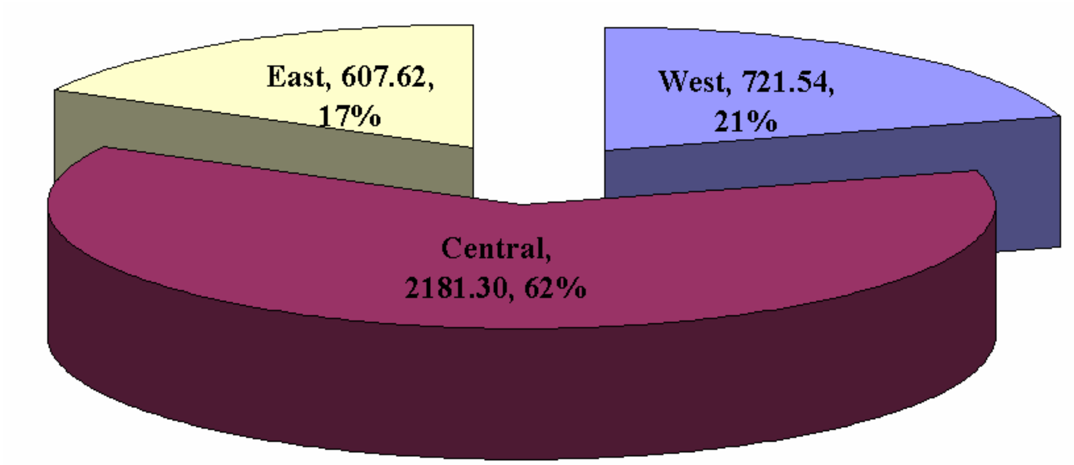

Figure 34: Market Region Distribution of Sold Chemicals (MM lb_m) for Lifespan of Project

As revenue was being generated, this inflow of cash was used to invest in expansion opportunities for the biorefining plant. The following figure illustrates the increases in production due to these expansion opportunities.

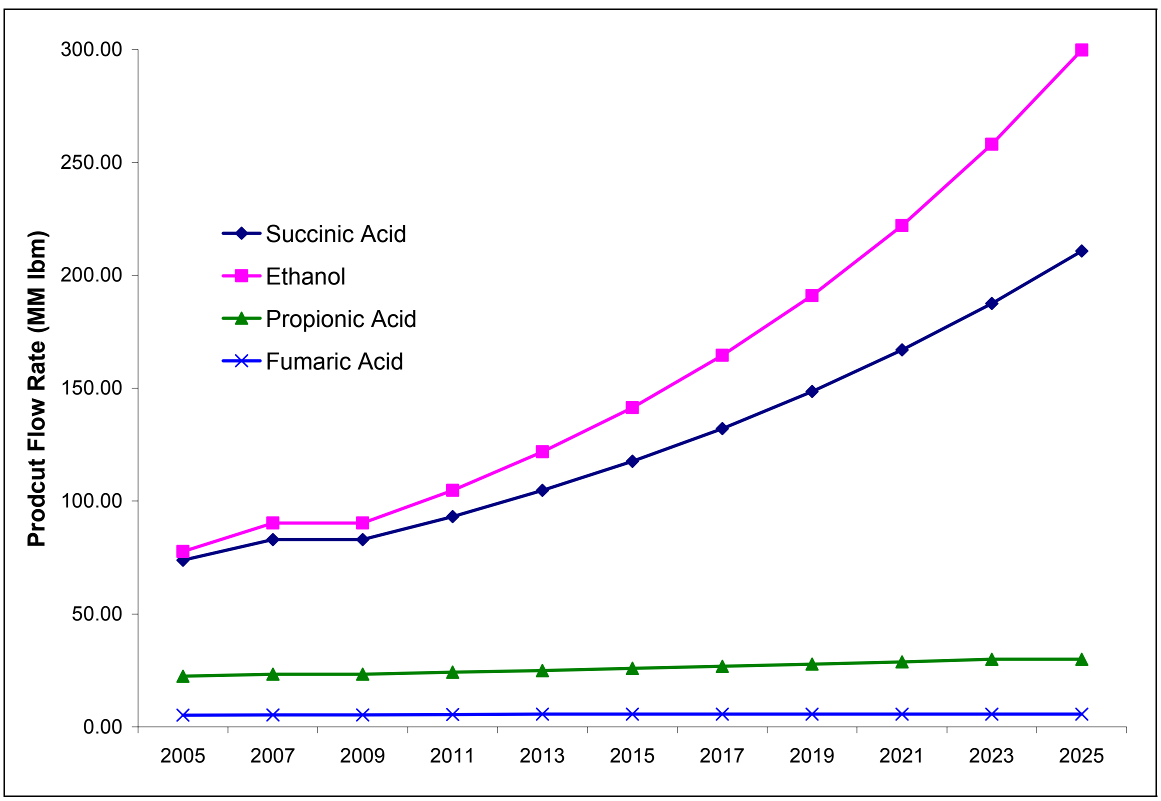

Figure 35: Biomass Production Increase for Lifespan of Project

5.4 Stochastic Model Results

From the deterministic model, a stochastic model was developed which took into account the variation in the market prices for all raw materials and products sold. This model more accurately depicts the fluctuations of market prices, which will give a more realistic net present value. The scenarios for the two independent variables were generated in excel using a standard deviation of 10% of the mean price at the beginning of plant production and increased linearly to 40% at the end of the project life span. This is because prices in the distant future are much harder to predict than prices in the near future. All scenarios were generated around a mean value projected over the economic life span of the project.

The stochastic model determined that Dubuque, Iowa as the optimal plant location, which was the same as the deterministic model. With an initial capital investment of $150,000,000, the net present value is expected to be $321,000,000 with a return on investment of 10.5%. This is an increase of $27,000,000 over the deterministic model.

5.4.1 Uncertainty Model

The stochastic model was developed based upon 20 different scenarios. When entering the scenarios into the mathematical model, the scenarios are paired so that all possible scenarios would be covered. For example, one year the raw material price might be high when the selling price of the chemical is very low and vise versa. These scenarios were used to determine the probability and the distribution of the net present value considering the different possibilities. The first chart developed was the uncertainty curve, as shown below.

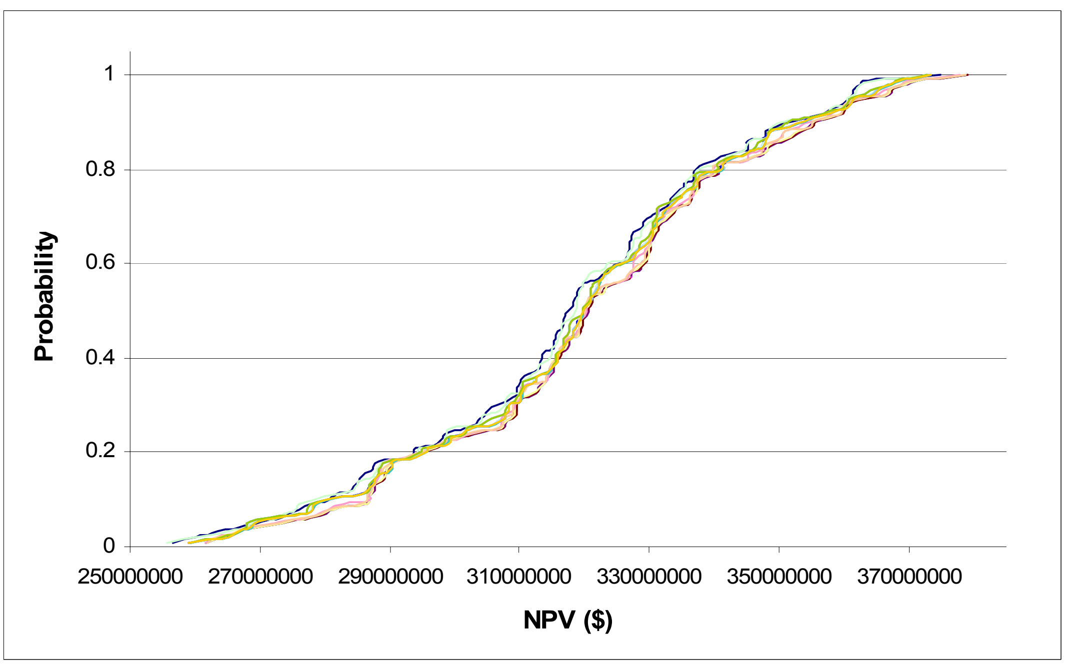

Figure 36: Uncertainty Curves of Net Present Values for Different Scenarios

From these results the best scenario is chosen, which is called the upper bound. The upper bound represents the best case scenario in order to maximize the NPV of the project. The above figures illustrates that the plant will be profitable based on the positive net present value at all probabilities. The range of the net present value is from $260,000,000 to $380,000,000. The expected net present value using the uncertainty curve is determined using the mean curve considering all scenarios. This mean curve is given in the figure below, with the distribution of each given in the risk histogram.

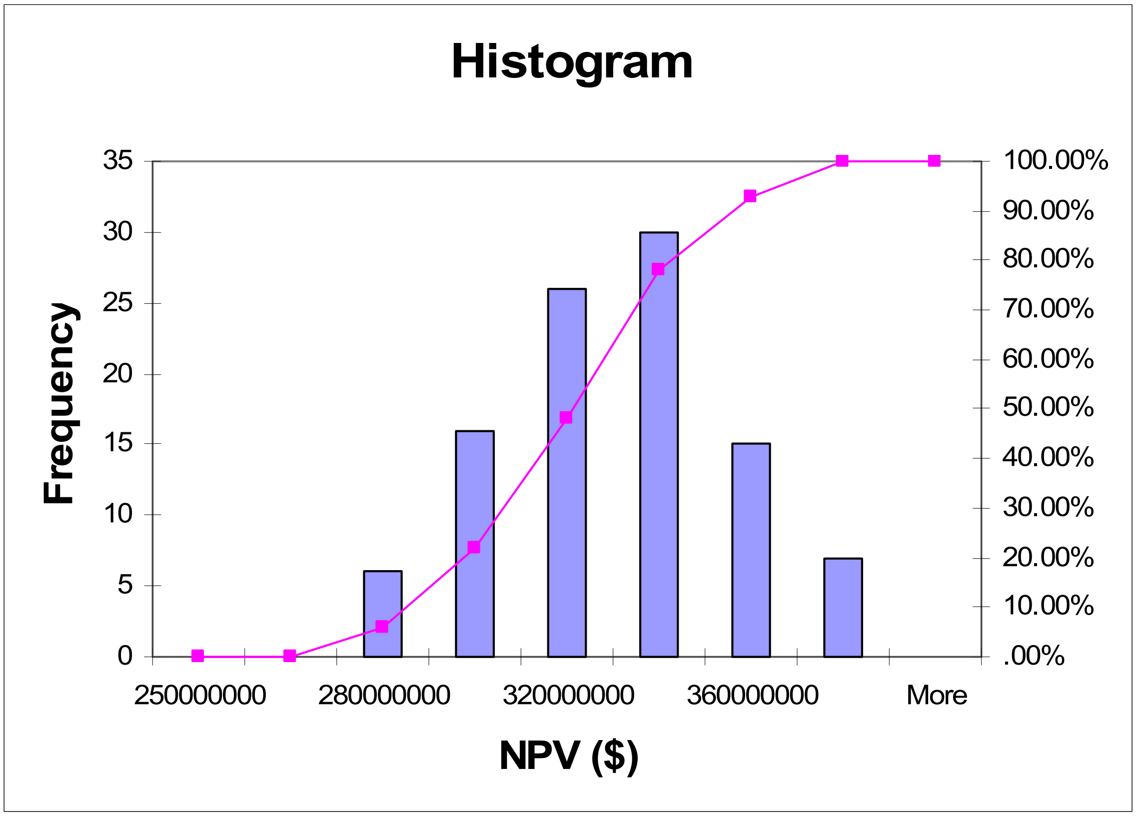

Figure 37: Risk Histogram for Stochastic Model

Using the risk histogram from above, the highest area of distribution is the most probable net present value, which is about $321,000,000.

6. Conclusion

The construction of the biorefining plant is expected to be profitable with a return on investment of 10.5%. With the initial capital investment of $150,000,000, the net present value is expected to be $321,000,000. Since the project is expected to be profitable, it is recommended that the plant start its initial construction in 2005 at Dubuque, Iowa. The agricultural source for the biorefining process is corn, which is abundant in the region of the plant. The chemicals produced at this plant will be succinic acid, ethanol, propionic acid, and fumaric acid. The main chemicals produced will be succinic acid and ethanol, which will contribute to 95% of the total 260 million pounds produced throughout the 20 year life cycle of the plant. By implementing this plant, with expansion throughout the life of the project, it will be one of the largest contributors in the biorefining industry.

7.0 Reference:

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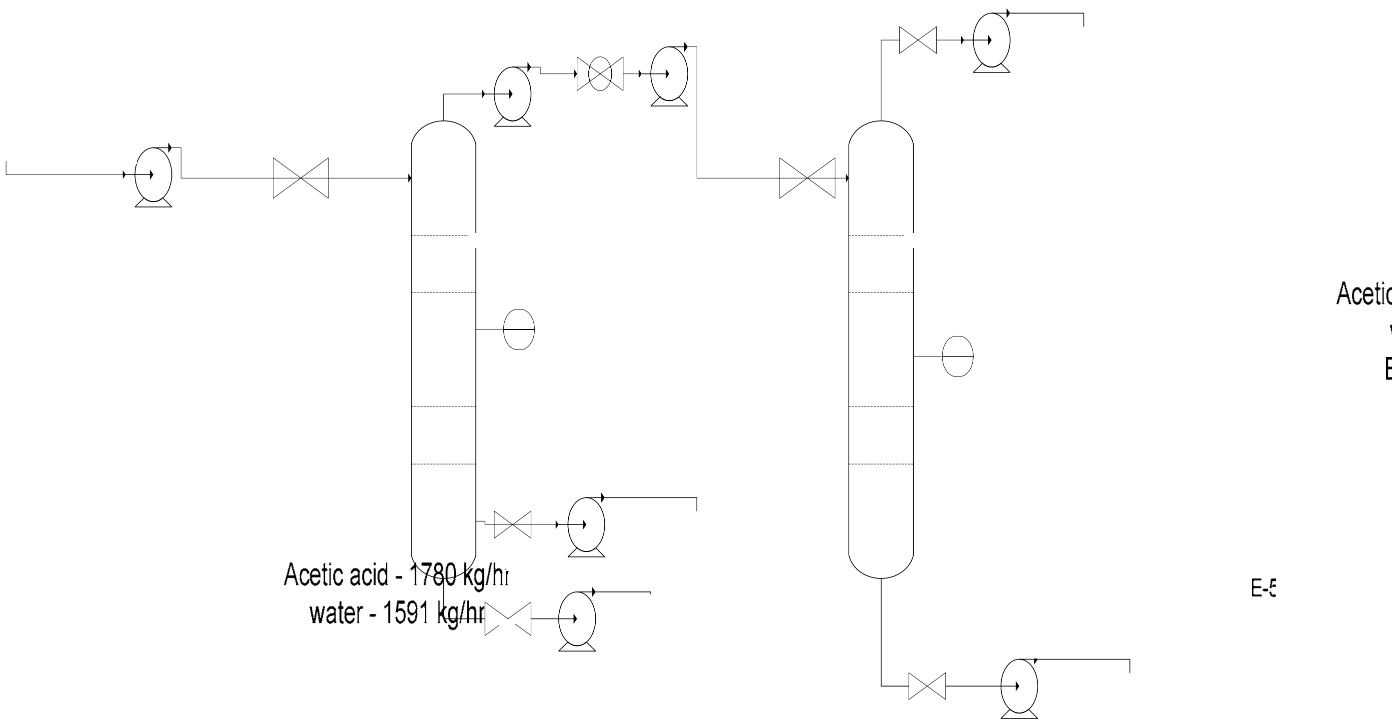
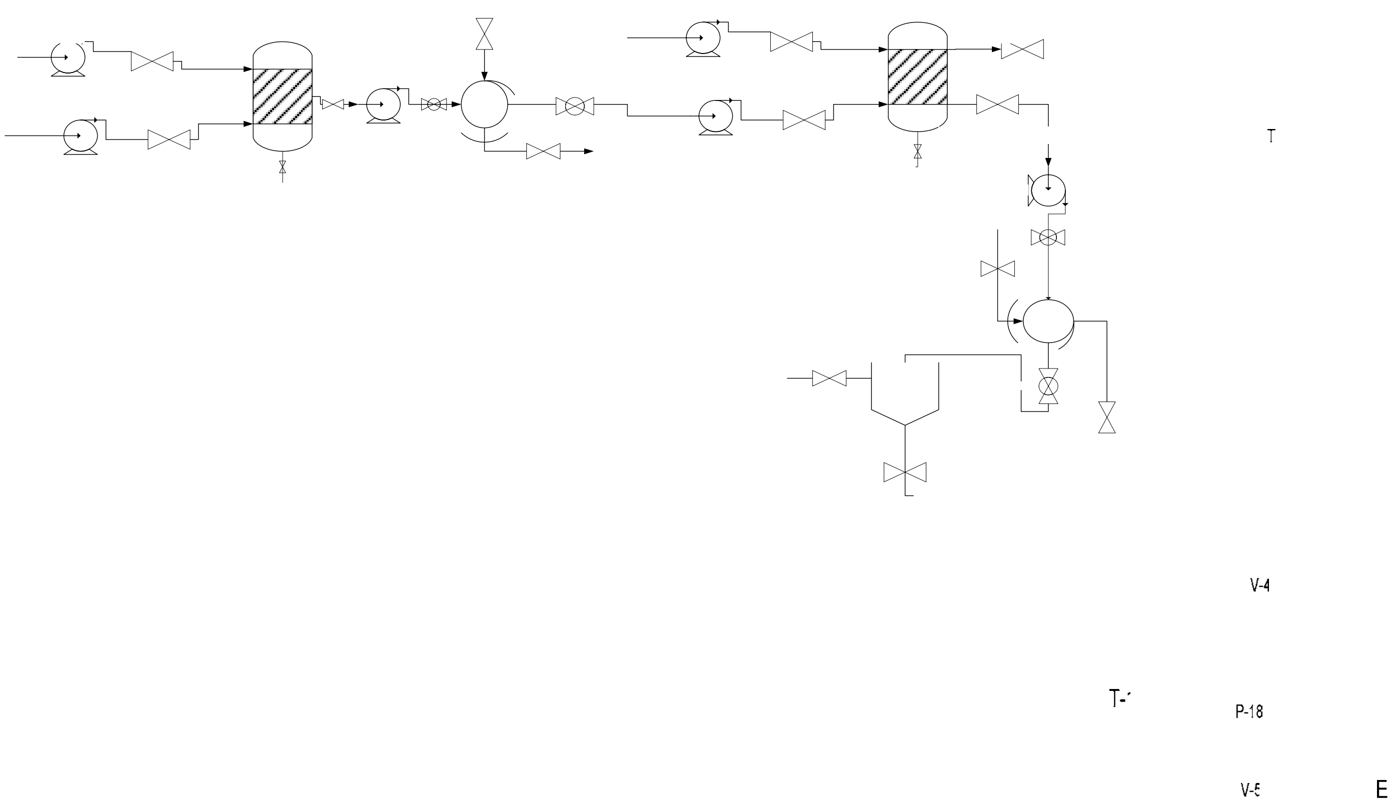
Appendix

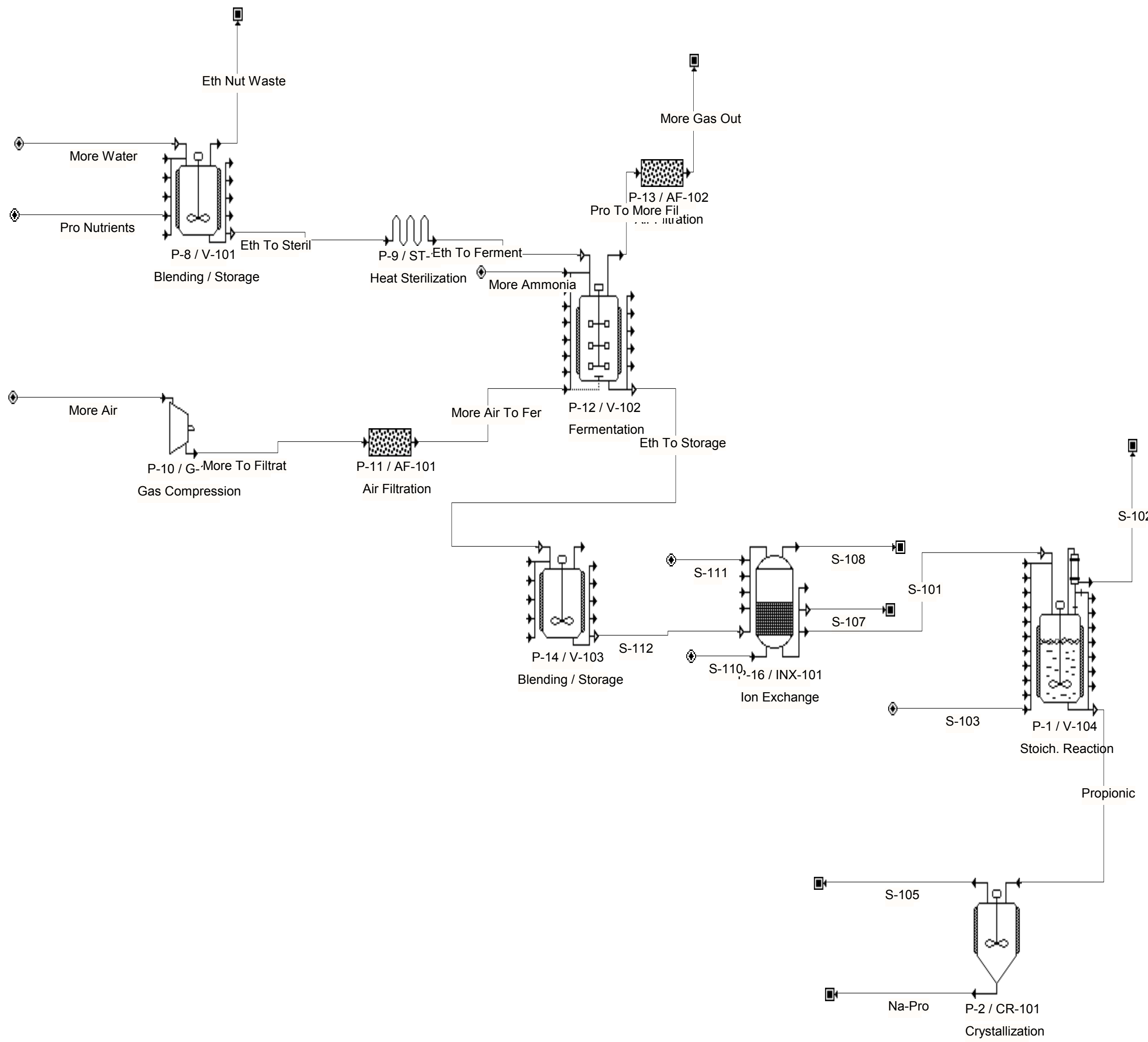
Appendix A – All the fermentation and process economics
Acetic acid process simulations simulation



Succinic acid process simulations simulation –



Propionic acid process simulations simumation



Process Economics for each processes

Acetic acid –

ANNUAL RAW MATERIAL COSTS AND PRODUCTS VALUES

Process Identifier: Illustration 101

Required user input | Notes & comments

Default, may be changed

RESULT

Products, Coproducts and Byproducts

Name of Material	Price, $/kg	Annual Amount, million kg/y	Annual value of product, million $/y
Main	1.19	17.100	20.35
byproduct	0.00	12.000	0.00
			0.00
			0.00
			0.00
			0.00
Total annual value of products =			20.35

Sent to **'Evaluation'** and **'Year-0 $'**

Raw Materials

Name of Material	Price, $/kg	Annual Amount, million kg/y	Annual raw materials cost, million $/y
water	0.00	325.000	0.16
salt	0.13	3.000	0.39
ammonia	0.09	1.500	0.14
ethyl lactate	0.54	0.120	0.06
resin(L)	2.00	0.050	0.10
			0.00
Total annual cost of raw materials =			0.85

Sent to sheet **'Annual TPC'**

ANNUAL OPERATING LABOR COSTS

Process Identifier: Illustration 101

Required user input | Notes & comments

Default, may be changed

RESULT

Operating Labor

Number of operators per shift*	Shifts per day**	Operator rate, $/h #	Annual operating labor cost,
5	3	30.5	1.336

*See Tables 6-13 and Fig. 6-9.

**Default = 3 for continuous process.

Enter appropriate value for batch operation.

#To obtain current, local value, enter (latest local

ENR skilled labor index)/6067 = 1

TCI for the acetic acid – It is obatained by the Peters and Timmerhaus spreadsheet

Project Identifier: Illustration 101	Calculated values, million $
Direct Costs	
Purchased equipment, E'	**11.300**
Delivery, fraction of E'	1.130
Subtotal: delivered equipment	12.430
Purchased equipment installation	5.842
Instrumentation&Controls(installed)	1.865
Piping (installed)	4.972
Electrical systems (installed)	0.525
Buildings (including services)	1.380
Yard improvements	0.125
Service facilities (installed)	4.351
Total direct costs	31.489
Indirect Costs	
Engineering and supervision	2.921
Construction expenses	2.486
Legal expenses	0.497
Contractor's fee	0.012
Contingency	0.622
Total indirect costs	6.538
Fixed capital investment (FCI)	**38.027**
Working capital (WC)	**11.063**
Total capital investment (TCI)	**49.090**

Annual product cost for the acetic acid –

Item	Default factor, user may change	Basis	Basis cost, million $/y	Cost, million $/y
Capacity	30	10^6 kg per year		
Fixed Capital Investment, FCI	51.200	million $		
Raw materials				0.852
Operating labor				1.336
Operating supervision	0.05	of operating labor	1.336	0.067
Utilities				0.990
Maintenance and repairs	0.06	of FCI	51.200	3.072
Operating supplies	0.15	of maintenance &	3.072	0.461
Laboratory charges	0.03	of operating labor	1.336	0.040
Royalties (if not on lump-sum basis)	0.01	of c_o	13.260	0.133
Catalysts and solvents	0	--		0.000
Variable cost =				**6.950**
Taxes (property)	0.02	of FCI	51.200	1.024
Financing (interest)	0	of FCI	51.200	0.000
Insurance	0.01	of FCI	51.200	0.512
Rent	0	of FCI	51.200	0.000
Depreciation	Calculated separately			
Fixed Charges =				**1.536**
Plant overhead, general	0.6	of labor, supervisi	4.475	2.685
Plant Overhead =				**2.685**
Manufacturing cost =				**11.171**
Administration	0.2	of labor, supervisi	4.475	0.895
Distribution & selling	0.05	of c_o	13.260	0.663
Research & Development	0.04	of c_o	13.260	0.530
General Expense =				**2.088**
TOTAL PRODUCT COST WITHOUT DEPRECIATION = c_o =				**13.260**

Succinic acid raw materials –

ANNUAL RAW MATERIAL COSTS AND PRODUCTS VALUES					
Process Identifier: Illustration 101					
Required user input		Notes & comments			
Default, may be changed					
RESULT					
Products, Coproducts and Byproducts					
Name of Material	Price, $/kg	Annual Amount, million kg/y	Annual value of product, million $/y		
Main	4.40	14.770	64.99		
byproduct	0.00	12.000	0.00		
			0.00		
			0.00		
			0.00		
			0.00		
Total annual value of products =			64.99	Sent to 'Evaluation' and 'Year-0 $'	
Raw Materials					
Name of Material	Price, $/kg	Annual Amount, million kg/y	Annual raw materials cost, million $/y		
water	0.00	361.000	0.18		
salt	0.13	2.780	0.36		
ammonia	0.09	14.000	1.26		
H2SO4	0.01	158.000	1.58		
resin(L)	2.00	0.050	0.10		
CaOH	0.05	184.000	9.20		
Total annual cost of raw materials =			12.68	Sent to sheet 'Annual TPC'	

ANNUAL OPERATING LABOR COSTS			
Process Identifier: Illustration 101			
Required user input		Notes & comments	
Default, may be changed			
RESULT			
Operating Labor			
Number of operators per shift*	Shifts per day**	Operator rate, $/h #	Annual operating labor cost,
5	3	30.5	1.336
*See Tables 6-13 and Fig. 6-9.			
**Default = 3 for continuous process.			
Enter appropriate value for batch operation.			
#To obtain current, local value, enter (latest local			
ENR skilled labor index)/6067 =			1

TCI for succinic acid –

ESTIMATION OF CAPITAL INVESTMENT BY PERCENTAGE OF DELIVERED EQUIPMENT METHOD

(See Table 6-9)

The fractions in the cells below are approximations applicable to typical chemical processing
plants. These values may differ depending on many factors such as location, process type, etc.

Required user input		**Result**
Required, from a linked sheet or entered manually		
Project Identifier: Illustration 101		Calculated values, million $
Direct Costs		
Purchased equipment, E'		**16.300**
Delivery, fraction of E'		1.630

Subtotal: delivered equipment	17.930
Purchased equipment installation	8.427
Instrumentation&Controls(installed)	2.690
Piping (installed)	7.172
Electrical systems (installed)	1.972
Buildings (including services)	3.227
Yard improvements	1.793
Service facilities (installed)	6.276
Total direct costs	49.487
Indirect Costs	
Engineering and supervision	5.917
Construction expenses	5.379
Legal expenses	0.717
Contractor's fee	3.227
Contingency	3.586
Total indirect costs	18.827
Fixed capital investment (FCI)	**68.313**
Working capital (WC)	**15.958**
Total capital investment (TCI)	**84.271**

Annual Product cost for succinic acid –

Item	Default factor, user may change	Basis	Basis cost, million $/y	Cost, million $/y
Capacity	30	10^6 kg per year		
Fixed Capital Investment, FCI	73.855	million $		
Raw materials				12.682
Operating labor				1.336
Operating supervision	0.05	of operating labor	1.336	0.067
Utilities				0.990
Maintenance and repairs	0.06	of FCI	73.855	4.431
Operating supplies	0.15	of maintenance &	4.431	0.665
Laboratory charges	0.03	of operating labor	1.336	0.040
Royalties (if not on lump-sum basis)	0.01	of c_o	30.104	0.301
Catalysts and solvents	0	--		0.000
Variable cost =				**20.512**
Taxes (property)	0.02	of FCI	73.855	1.477
Financing (interest)	0	of FCI	73.855	0.000
Insurance	0.01	of FCI	73.855	0.739
Rent	0	of FCI	73.855	0.000
Depreciation	Calculated separately			
Fixed Charges =				**2.216**
Plant overhead, general	0.6	of labor, supervisi	5.834	3.500
Plant Overhead =				**3.500**
Manufacturing cost =				**26.228**
Administration	0.2	of labor, supervisi	5.834	1.167
Distribution & selling	0.05	of c_o	30.104	1.505
Research & Development	0.04	of c_o	30.104	1.204
General Expense =				**3.876**
TOTAL PRODUCT COST WITHOUT DEPRECIATION = c_o =				**30.104**

Propionic acid –

ANNUAL RAW MATERIAL COSTS AND PRODUCTS VALUES			
Process Identifier: Illustration 101			
Required user input		Notes & comments	
Default, may be changed			
RESULT			
Products, Coproducts and Byproducts			
Name of Material	Price, $/kg	Annual Amount, million kg/y	Annual value of product, million $/y
Main	1.25	15.500	19.38
byproduct	0.00	12.000	0.00
			0.00
			0.00
			0.00
			0.00
Total annual value of products =			**19.38**

Sent to 'Evaluation' and 'Year-0 $'

Raw Materials			
Name of Material	Price, $/kg	Annual Amount, million kg/y	Annual raw materials cost, million $/y
water	0.00	280.000	0.14
salt	0.13	2.900	0.38
ammonia	0.09	14.700	1.32
sodium hydroxide	0.04	5.800	0.23
			0.00
			0.00
Total annual cost of raw materials =			**2.07**

Sent to sheet 'Annual TPC'

ANNUAL OPERATING LABOR COSTS			
Process Identifier: Illustration 101			
Required user input		Notes & comments	
Default, may be changed			
RESULT			
Operating Labor			
Number of operators per shift*	Shifts per day**	Operator rate, $/h #	Annual operating labor cost,
5	3	30.5	**1.336**

*See Tables 6-13 and Fig. 6-9.

**Default = 3 for continuous process.

Enter appropriate value for batch operation.

#To obtain current, local value, enter (latest local ENR skilled labor index)/6067 = 1

TCI for propionic acid –

plants. These values may differ depending on many factors such as location, process type, etc.

Required user input		**Result**
Required, from a linked sheet or entered manually		
Project Identifier: Illustration 101		Calculated values, million $
Direct Costs		
Purchased equipment, E'		**12.900**
Delivery, fraction of E'		1.290
Subtotal: delivered equipment		14.190
Purchased equipment installation		6.669
Instrumentation&Controls(installed)		2.129
Piping (installed)		5.676
Electrical systems (installed)		1.561
Buildings (including services)		2.554

Yard improvements	1.419
Service facilities (installed)	4.967
Total direct costs	39.164
Indirect Costs	
Engineering and supervision	4.683
Construction expenses	4.257
Legal expenses	0.568
Contractor's fee	2.554
Contingency	2.838
Total indirect costs	14.900
Fixed capital investment (FCI)	**54.064**
Working capital (WC)	**12.629**
Total capital investment (TCI)	**66.693**

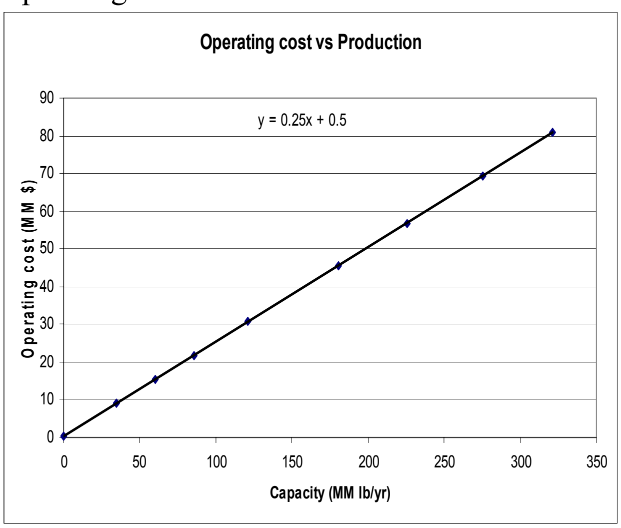
Annual Product cost for propionic acid –

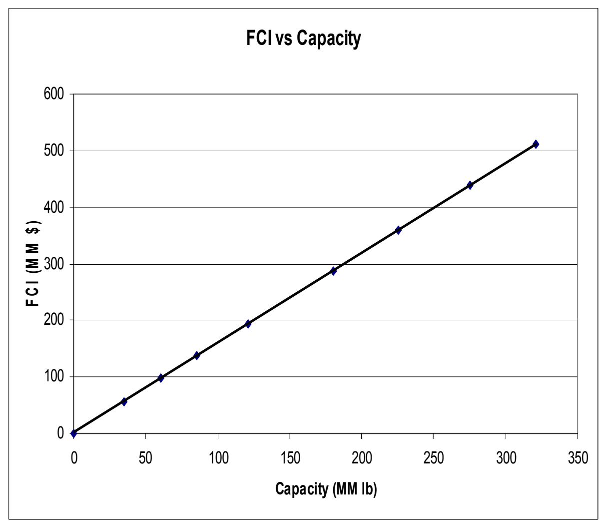
Capacity	30	10^6 kg per year		
Fixed Capital Investment, FCI	58.450	million $		
Item	Default factor, user may change	Basis	Basis cost, million $/y	Cost, million $/y
Raw materials				2.072
Operating labor				1.336
Operating supervision	0.05	of operating labor	1.336	0.067
Utilities				0.990
Maintenance and repairs	0.06	of FCI	58.450	3.507
Operating supplies	0.15	of maintenance &	3.507	0.526
Laboratory charges	0.03	of operating labor	1.336	0.040
Royalties (if not on lump-sum basis)	0.01	of c_o	15.799	0.158
Catalysts and solvents	0	--		0.000
Variable cost =				**8.696**
Taxes (property)	0.02	of FCI	58.450	1.169
Financing (interest)	0	of FCI	58.450	0.000
Insurance	0.01	of FCI	58.450	0.584
Rent	0	of FCI	58.450	0.000
Depreciation	Calculated separately			
Fixed Charges =				**1.753**
Plant overhead, general	0.6	of labor, supervisi	4.910	2.946
Plant Overhead =				**2.946**
Manufacturing cost =				**13.395**
Administration	0.2	of labor, supervisi	4.910	0.982
Distribution & selling	0.05	of c_o	15.799	0.790
Research & Development	0.04	of c_o	15.799	0.632
General Expense =				**2.404**
TOTAL PRODUCT COST WITHOUT DEPRECIATION = c_o =				**15.799**

Appendix B – Equiment costs and operating cost for each process
Propionic acid –

Propionic acid			
	Units	Size per unit	Cost ($)
Blending/Storage	3	21000 gal	110000
Sterilizer	3	100m3/hr	220000
Air Filtration -1	9	4m3/s	25000
Compressor	3	1300 kW	250000
Air Filtration -2	5	8m3/s	15000
Fermentor	5	350000 L	1200000
Blending/Storage 2	19	80000 L	110000
Ion Exchanger	15	7100 L	85125
Reaction Vessel	3	35500 L	374000
Crystallizer	1	40000 L	410000

Operating cost –

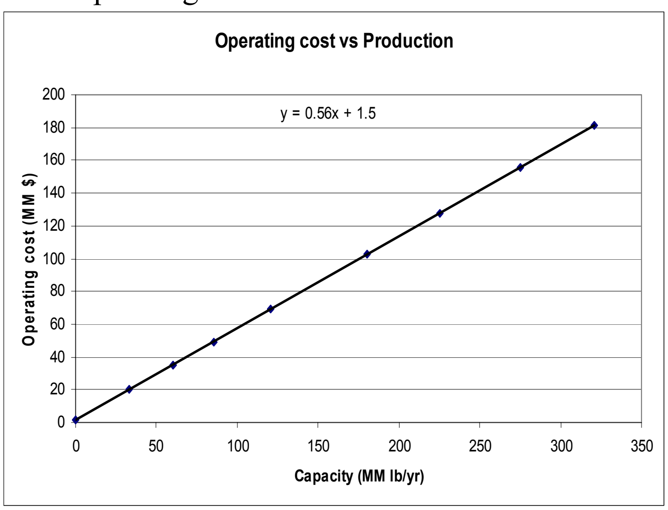


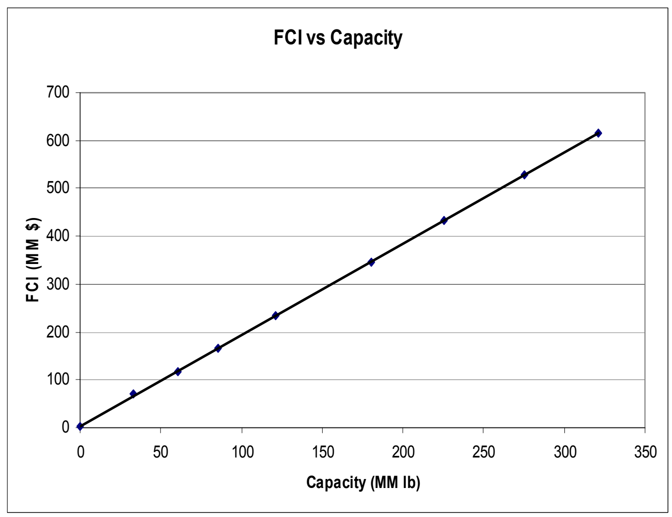


Succinic acid –
Equiment cost –

Succinic Acid			
Costs of Equipment	Units	Size per Unit	Cost
Blending/Storage	3	21000 gal	110000
Sterilizer	4	100m3/hr	220000
Air Filtration -1	8	4m3/s	25000
Compressor	2	2350 kW	275125
Air Filtration -2	6	8m3/s	15000
Fermentor	5	350000 L	1200000
Blending/Storage 2	20	80000 L	110000
Ion Exchanger	15	6300 L	75120
Reactor vessel -1	3	27000 L	325000
Rotart vaccum -1	2	45 m2	91200
Reaction vessel - 2	8	40000 L	395120
Rotary vaccum -2	2	37 m2	87000
Crystallizer	1	40000 L	410000

Operating and FCI for succnic acid –



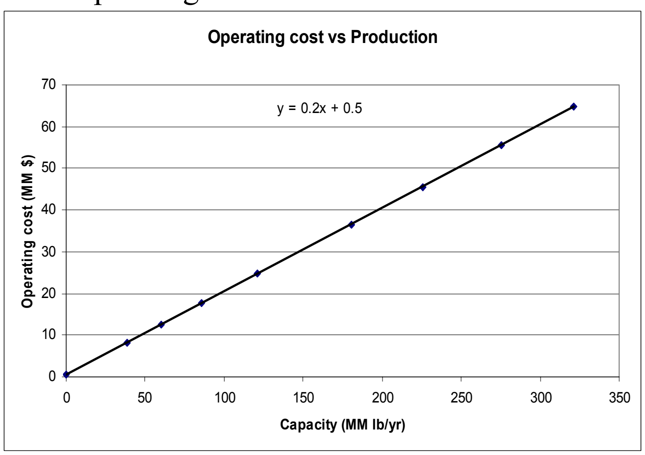


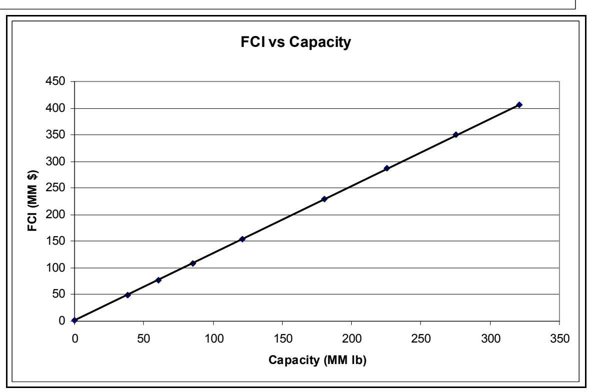
Acetic acid –

Equipment cost –

Acetic Acid			
Costs of Equipment	Units	Size per unit	Cost
Blending/Storage	3	21000 gal	110000
Sterilizer	3	80m3/hr	200000
Air Filtration -1	7	4m3/s	25000
Compressor	2	2350 kW	275125
Air Filtration -2	6	8m3/s	15000
Fermentor	5	350000 L	1200000
Blending/Storage 2	20	80000 L	110000
Ion Exchanger	15	6300 L	75120
Distillation column	1	-	60000
Distillation column	1	(D = 3m)	95000

Operating cost and FCI for acetic acid –





Appendix – C market demands for each acids

Demand Projections (lbm)

YEAR	Acetic Acid	Citric Acid	Fumaric Acid	Succinic Acid	Lactic Acid	Ethanol	Propionic Acid
2005	5000.0000	500.0000	50.0000	650.0000	310.0000	655.0000	219.0000
2006	5100.0000	525.0000	50.8000	689.0000	328.6000	706.0900	222.9420
2007	5202.0000	551.2500	51.6128	730.3400	348.3160	761.1650	226.9550
2008	5306.0400	578.8125	52.4386	774.1604	369.2150	820.5359	231.0401
2009	5412.1608	607.7531	53.2776	820.6100	391.3679	884.5377	235.1989
2010	5520.4040	638.1408	54.1301	869.8466	414.8499	953.5316	239.4324
2011	5630.8121	670.0478	54.9961	922.0374	439.7409	1027.9071	243.7422
2012	5743.4283	703.5502	55.8761	977.3597	466.1254	1108.0839	248.1296
2013	5858.2969	738.7277	56.7701	1036.0012	494.0929	1194.5144	252.5959
2014	5975.4628	775.6641	57.6784	1098.1613	523.7385	1287.6865	257.1427
2015	6094.9721	814.4473	58.6013	1164.0510	555.1628	1388.1261	261.7712
2016	6216.8715	855.1697	59.5389	1233.8941	588.4726	1496.3999	266.4831
2017	6341.2090	897.9282	60.4915	1307.9277	623.7809	1613.1191	271.2798
2018	6468.0332	942.8246	61.4594	1386.4034	661.2078	1738.9424	276.1628
2019	6597.3938	989.9658	62.4427	1469.5876	700.8802	1874.5799	281.1338
2020	6729.3417	1039.4641	63.4418	1557.7628	742.9330	2020.7971	286.1942
2021	6863.9285	1091.4373	64.4569	1651.2286	787.5090	2178.4193	291.3457
2022	7001.2071	1146.0092	65.4882	1750.3023	834.7596	2348.3360	296.5899
2023	7141.2312	1203.3096	66.5360	1855.3204	884.8451	2531.5062	301.9285
2024	7284.0559	1263.4751	67.6006	1966.6397	937.9358	2728.9637	307.3632
2025	7429.7370	1326.6489	68.6822	2084.6381	994.2120	2941.8229	312.8958

Price Projections ($/lbm)

YEAR	Acetic Acid	Citric Acid	Fumaric Acid	Succinic Acid	Lactic Acid	Ethanol	Propionic Acid
2005	0.5398	0.6668	0.5000	1.9958	0.7500	2.5000	0.5670
2006	0.5387	0.6635	0.4992	1.9839	0.7455	2.4807	0.5660
2007	0.5376	0.6602	0.4984	1.9721	0.7411	2.4615	0.5650
2008	0.5366	0.6569	0.4976	1.9603	0.7367	2.4424	0.5639
2009	0.5355	0.6536	0.4968	1.9486	0.7323	2.4235	0.5629
2010	0.5344	0.6504	0.4960	1.9370	0.7279	2.4047	0.5619
2011	0.5334	0.6471	0.4952	1.9254	0.7236	2.3861	0.5609
2012	0.5323	0.6439	0.4944	1.9140	0.7192	2.3677	0.5599
2013	0.5312	0.6407	0.4936	1.9025	0.7150	2.3493	0.5589
2014	0.5302	0.6375	0.4929	1.8912	0.7107	2.3312	0.5579
2015	0.5291	0.6344	0.4921	1.8799	0.7065	2.3131	0.5569
2016	0.5281	0.6312	0.4913	1.8687	0.7022	2.2952	0.5559
2017	0.5270	0.6281	0.4905	1.8576	0.6980	2.2774	0.5549
2018	0.5260	0.6249	0.4897	1.8465	0.6939	2.2598	0.5539
2019	0.5249	0.6218	0.4889	1.8355	0.6897	2.2423	0.5529
2020	0.5239	0.6187	0.4882	1.8245	0.6856	2.2250	0.5519
2021	0.5228	0.6157	0.4874	1.8136	0.6815	2.2078	0.5509
2022	0.5218	0.6126	0.4866	1.8028	0.6775	2.1907	0.5499
2023	0.5207	0.6095	0.4858	1.7921	0.6734	2.1737	0.5489
2024	0.5197	0.6065	0.4850	1.7814	0.6694	2.1569	0.5480
2025	0.5187	0.6035	0.4843	1.7708	0.6654	2.1402	0.5470

Appendix D – Production rate, capacity, and expansion opportunities from mathematical model

GAMS Simulation

```
$TITLE GLUC biorefining

$ontext

The price of chemical are scaled to year 2001 dollar. The net present value is
calculated using this dollar value too.

$offtext

SETS

*All the major chemicals and byproducts used in the analysis.

     c      Chemicals      /GLU, SUC, LAC, ETH, CIT, ACE, PRO, FUM, WAT,
                           SAL, AMM, SOD, AIR, CAR, CAL, SUL, GYP, CAC/

*     GLU     Glucose
*     SUC     Succinic Acid
*     LAC     Lactic Acid
*     ETH     Ethanol
*     CIT     Citric Acid
*     ACE     Acetic Acid
*     PRO     Propionic Acid
*     FUM     Fumaric Acid
*     WAT     Water
*     SAL     Salt
*     AMM     Ammonia
*     SOD     Sodium Hydoxide
*     AIR     Air
*     CAR     Carbon Dioxide
*     CAL     Calcium Hydroxide
*     SUL     Sulfuric Acid
*     GYP     Gypsum
*     CAC     Calcium Citrate

*The only market being considered is the North American Market
*because of the biomass feed and plant location originates here.

     m      Markets     /CA1, OH1, VA1 /

*Unit production.
```

p Processes /SUCPUR, LACPUR, ETHPUR, CITPUR, ACEPUR, PROPUR, FUMPUR/

* SUCPUR Succinic Acid Seperation and Purification
* LACPUR Lactic Acid Seperation and Purification
* ETHPUR Ethanol Seperation and Purification
* CITPUR Citric Acid Seperation and Purification
* ACEPUR Acetic Acid Seperation and Purification
* PROPUR Propionic Acid Seperation and Purification
* FUMPUR Fumaric Acid Seperation and Purification

*The project will begin on year 2005. The project is split into 11 period
*(2 years each): year 2003 - 2005, 2005 - 2007, 2007 - 2009, 2009 - 2011,
*2011 - 2013, 2013 - 2015, 2015 - 2017, 2017 - 2019, 2019 - 2021, 2021 - 2023, 2023 - 2025.
*The starting year for each period is use in the analysis.

t Periods /2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019, 2021, 2023, 2025/

*For each processes, there is one main chemical (product) and excess glucose. Other products
*or reactants in the process will be reference to main chemical.

main(p,c) Main chemicals for each process (process node)

/SUCPUR.SUC, LACPUR.LAC, ETHPUR.ETH, CITPUR.CIT, ACEPUR.ACE, PROPUR.PRO, FUMPUR.FUM/

i plants /Anniston, Tuscaloosa, Gadsden, Talladega, Hot-Springs, Los-Angeles,
Dubuque, Ottumwa, Fort-Wayne, South-Bend, Columbus, Monroe, Detroit,
Grand-Rapids, Kalamazoo, Minneapolis, St-Cloud, Fergus-Falls, Mankato,
Joplin, Tupelo, Greensboro, Hickory, Manchester, Keene, Cleveland,
Dayton, Toledo, Youngstown, Findlay, Tulsa, Eugene, Medford,
Greenville, Dallas, Ft-Worth, Waco, Longview, Lufkin, Sherman, Milwaukee,
Racine, Green-Bay, Appleton, Wasau, Sheboygan/
*,dummy /

kc corn markets /Pheonix, Yuma, Bakersfield, Fresno, Napa, Greeley, Pueblo, Louisville,
Cedar-Rapids, Dubuque, Mountain-Home, Danville, Peoria, Quincy, Evansville,

```
                  Fort-Wayne, Meade, Bastrop, Denton, Billings, Lexington, Clovis, Las-
Cruces,
                  Roswell, Cincinatti, Dayton, Heppner, Dumas, El-Paso, Yakima /

      taxprop(i)  property taxes on plant locations

         /  Anniston     30
            Tuscaloosa   30
            Gadsden      30
            Talladega    30
            Hot-Springs  20
            Los-Angeles  30
            Dubuque      23
            Ottumwa      23
            Fort-Wayne   33
            South-Bend   33
            Columbus     33
            Monroe       25
            Detroit      34
            Grand-Rapids 34
            Kalamazoo    34
            Minneapolis  34
            St-Cloud     34
            Fergus-Falls 34
            Mankato      34
            Joplin       25
            Tupelo       34
            Greensboro   34
            Hickory      34
            Manchester   58
            Keene        58
            Cleveland    25
            Dayton       25
            Toledo       25
            Youngstown   25
            Findlay      25
            Tulsa        34
            Eugene       34
            Medford      34
            Greenville   34
            Dallas       34
            Ft-Worth     34
            Waco         34
            Longview     34
            Lufkin       34
            Sherman      34
```

```
              Milwaukee    34
              Racine       34
              Green-Bay    34
              Appleton     34
              Wasau        34
              Sheboygan    34    /
*               dummy       0   /

ALIAS (p,pp),(c,cc),(t,tt)     ;

PARAMETERS

       int /0.535/

      maxinvest /150000000/

      corn(p) Percent of the reactants that are corn

              /SUCPUR      0.194
              LACPUR       0.220
              ETHPUR       0.217
              CITPUR      0.142
              ACEPUR       0.280
              PROPUR       0.277
              FUMPUR       0.237/

      alpha(p) Variable investment cost based on capacity (MM$ per MM lbm)

              /SUCPUR            .56
               LACPUR            .28
               ETHPUR            .42
               CITPUR           .40
               ACEPUR            .24
               PROPUR            .32
               FUMPUR             .38/

       beta(p) Fixed investment cost (MM$)

              /SUCPUR            71.8
               LACPUR            55.5
               ETHPUR            62.1
               CITPUR           61.3
               ACEPUR            46.8
               PROPUR            56.9
               FUMPUR             41.1/
```

delta(p) Unit operation cost based on main chemicals ($ per MM lbm)

/SUCPUR 630886
LACPUR 535465
ETHPUR 521032
CITPUR 327922
ACEPUR 411590
PROPUR 255132
FUMPUR 200050/ ;
;

TABLE
price1(c,t) Average purchase price of chemicals in the time period ($per lbm)

*Price is determined from the market analysis done, adjusted to year 2001 value.
*The price of the chemical used is an average price over the 5 year period.
*The purchase price is approximately 1% - 2% higher than sales price to account
*for the transportation cost as well as other transection costs.

	2003	2005	2007	2009	2011	2013	2015	2017	2019	2021	2023	2025
SUC	2.020	1.996	1.972	1.949	1.925	1.903	1.879	1.858	1.835	1.814	1.792	1.771
LAC	0.759	0.750	0.741	0.732	0.724	0.715	0.707	0.698	0.690	0.682	0.673	0.665
ETH	2.539	2.500	2.461	2.423	2.386	2.349	2.313	2.277	2.242	2.208	2.174	2.140
CIT	0.675	0.667	0.659	0.650	0.647	0.641	0.634	0.627	0.619	0.616	0.610	0.603
ACE	0.543	0.540	0.537	0.534	0.533	0.531	0.529	0.526	0.524	0.523	0.521	0.519
PRO	0.567	0.567	0.567	0.567	0.566	0.566	0.566	0.566	0.566	0.565	0.565	0.565
FUM	0.502	0.500	0.498	0.496	0.494	0.493	0.492	0.490	0.488	0.486	0.484	0.482
GLU	0.070	0.070	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.068	0.068
WAT	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
SAL	0.060	0.059	0.058	0.057	0.057	0.057	0.057	0.056	0.056	0.056	0.055	0.055
AMM	0.041	0.041	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.039	0.039	0.039
SOD	0.018	0.018	0.018	0.018	0.018	0.017	0.017	0.017	0.017	0.016	0.016	0.015

AIR 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000
CAR 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000
CAL 0.023 0.023 0.023 0.022 0.022 0.022 0.022
0.022 0.022 0.021 0.021 0.021
SUL 0.005 0.005 0.004 0.004 0.004 0.004 0.004
0.004 0.004 0.004 0.004 0.004
GYP 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000
CAC 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000 0.000

TABLE
price2(c,t) Sales price of chemicals per lbm

*Price is determined from the market analysis done, adjusted to year 2001 value.
*The price of the chemical used is an average price over the 5 year period.

2003 2005 2007 2009 2011 2013 2015 2017
2019 2021 2023 2025
SUC 2.010 1.986 1.962 1.939 1.915 1.893 1.869
1.848 1.825 1.804 1.782 1.761
LAC 0.749 0.740 0.731 0.722 0.714 0.705 0.697
0.688 0.680 0.672 0.663 0.655
ETH 2.529 2.490 2.451 2.413 2.376 2.339 2.303
2.267 2.232 2.198 2.164 2.130
CIT 0.665 0.657 0.649 0.640 0.637 0.631 0.624
0.617 0.609 0.606 0.600 0.593
ACE 0.533 0.530 0.527 0.524 0.523 0.521 0.519
0.516 0.514 0.513 0.511 0.509
PRO 0.557 0.557 0.557 0.557 0.556 0.556 0.556
0.556 0.556 0.555 0.555 0.555
FUM 0.492 0.490 0.488 0.486 0.484 0.483 0.482
0.480 0.478 0.476 0.474 0.472
GLU 0.040 0.040 0.039 0.039 0.039 0.039 0.039
0.039 0.039 0.039 0.038 0.038
WAT 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001
0.0001 0.0001 0.0001 0.0001 0.0001
SAL 0.059 0.058 0.057 0.057 0.056 0.056 0.056
0.055 0.055 0.055 0.055 0.054
AMM 0.040 0.040 0.039 0.039 0.039 0.039 0.039
0.039 0.039 0.038 0.038 0.038
SOD 0.017 0.017 0.017 0.017 0.017 0.016 0.016
0.016 0.016 0.015 0.015 0.014

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 AIR       0.000     0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000
 CAR       0.000     0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000
 CAL       0.022     0.022     0.022     0.022     0.022     0.022     0.022
0.021     0.021     0.021     0.021     0.020
 SUL       0.004     0.004     0.004     0.004     0.004     0.004     0.004
0.004     0.004     0.004     0.003     0.003
 GYP       0.000     0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000
 CAC       0.000     0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000   ;

TABLE
      mu1(p,c) Positive constant charateristic of process (product)

*Relationship between the main chemical and other products in the reaction.
*This relationship is based on the reaction coefficient of each material
*compare to the main chemical and the conversion data for the reaction.
*The relationship is based on mass balance rather than mole balance.
*All the main chemical will have mu value of 1.

             SUC   LAC   ETH   CIT   ACE   PRO   FUM    WAT    GLU
SAL   AMM   SOD   AIR   CAR   CAL   SUL   GYP   CAC
     SUCPUR    1    0    0    0    0    0    0     0     0    0    0    0    0
0.6667  0    0    0.6297   0
     LACPUR    0    1    0    0    0    0    0     0     0    0    0    0    0
1.0101  0    0    0     0
     ETHPUR    0    0    1    0    0    0    0     0     0    0    0    0    0
1.0101  0    0    0     0
     CITPUR    0    0    0    1    0    0    0     0     0    0    0    0    0
1.4137  0    0    0.7371   0.0888
     ACEPUR    0    0    0    0    1    0    0     0     0    0    0    0    0
0.6905  0    0    0     0
     PROPUR    0    0    0    0    0    1    0     0     0    0    0    0    0
1.3444  0    0    0     0
     FUMPUR    0    0    0    0    0    0    1     0     0    0    0    0    0
1.0126  0    0    0     0     ;

TABLE
      mu2(p,c) Positive constant charateristic of process (reactant)

*Relationship between the main chemical and other reactants in the reaction.
*This relationship is based on the reaction coefficient of each material
*compare to the main chemical and the conversion data for the reaction.
*The relationship is based on mass balance rather than mole balance.
```

```
              SUC   LAC   ETH   CIT   ACE   PRO   FUM     WAT     GLU
SAL    AMM    SOD    AIR    CAR    CAL    SUL    GYP    CAC
     SUCPUR     0     0     0     0     0     0     0     2.3     3     0.36   0     0
4.220  0     1.65   3.931  0     0
     LACPUR     0     0     0     0     0     0     0     2.1     3     3.1    0     0
5.41   0     0     0     0     0
     ETHPUR     0     0     0     0     0     0     0     2.3     3     3.1    0     0
5.41   0     0     0     0     0
     CITPUR     0     0     0     0     0     0     0     2.2     3     3.14   0     0
6.143  0     2.930  3.685  0     0
     ACEPUR     0     0     0     0     0     0     0     2.3     3     2.05   0     0
3.371  0     0     0     0     0
     PROPUR     0     0     0     0     0     0     0     2.4     3     1.30   0     0
4.129  0     0     0     0     0
     FUMPUR     0     0     0     0     0     0     0     2.1     3     2.36   0     0
5.177  0     0     0     0     0   ;

TABLE
     usupply(c,m,t) Upper supply of chemicals (MM lbm per time period)

*The supply of glucose stream is at 1.88 MM lbm per day for 330 days per year
*and for 2 years per time period. Assume constant supply of glucose stream for
*the whole time period.

            2003      2005      2007      2009      2011      2013      2015
2017      2019      2021      2023      2025
 GLU.CA1     5465501     5465416     5465331     5465246     5465161
5465293     5465426     5465558     5466552     5467546     546853     546953
 SUC.CA1     546546     546546     546546     546546     546546     546546
546546     546546     546546     546546     546546     546546
 LAC.CA1     546546     546546     546546     546546     546546     546546
546546     546546     546546     546546     546546     546546
 ETH.CA1     546546     546546     546546     546546     546546     546546
546546     546546     546546     546546     546546     546546
 CIT.CA1     546546     546546     546546     546546     546546     546546
546546     546546     546546     546546     546546     546546
 ACE.CA1     546546     546546     546546     546546     546546     546546
546546     546546     546546     546546     546546     546546
 PRO.CA1     546546     546546     546546     546546     546546     546546
546546     546546     546546     546546     546546     546546
 FUM.CA1     546546     546546     546546     546546     546546     546546
546546     546546     546546     546546     546546     546546
 WAT.CA1     546546     546546     546546     546546     546546     546546
546546     546546     546546     546546     546546     546546
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SAL.CA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
AMM.CA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
SOD.CA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
AIR.CA1 4546565 4546565 4546565 4546565 4546565
4546565 4546565 4546565 4546565 4546565 4546565 4546565
CAR.CA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
CAL.CA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
SUL.CA1 4546565 4546565 4546565 4546565 4546565
4546565 4546565 4546565 4546565 4546565 4546565 4546565
GYP.CA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
CAC.CA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546

GLU.OH1 5465501 5465416 5465331 5465246 5465161
5465293 5465426 5465558 5466552 5467546 546853 546953
SUC.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
LAC.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
ETH.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
CIT.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
ACE.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
PRO.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
FUM.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
WAT.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
SAL.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
AMM.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
SOD.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
AIR.OH1 4546565 4546565 4546565 4546565 4546565
4546565 4546565 4546565 4546565 4546565 4546565 4546565

CAR.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
CAL.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
SUL.OH1 4546565 4546565 4546565 4546565 4546565
4546565 4546565 4546565 4546565 4546565 4546565 4546565
GYP.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
CAC.OH1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546

GLU.VA1 5465501 5465416 5465331 5465246 5465161
5465293 5465426 5465558 5466552 5467546 546853 546953
SUC.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
LAC.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
ETH.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
CIT.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
ACE.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
PRO.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
FUM.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
WAT.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
SAL.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
AMM.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
SOD.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
AIR.VA1 4546565 4546565 4546565 4546565 4546565
4546565 4546565 4546565 4546565 4546565 4546565 4546565
CAR.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
CAL.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546
SUL.VA1 4546565 4546565 4546565 4546565 4546565
4546565 4546565 4546565 4546565 4546565 4546565 4546565
GYP.VA1 546546 546546 546546 546546 546546 546546
546546 546546 546546 546546 546546 546546

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 CAC.VA1      546546      546546      546546      546546      546546      546546
546546      546546      546546      546546      546546      546546
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TABLE

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      udemand(c,m,t) Upper demand of chemicals (MM lbm per time period)

*Assume no sale of the glucose stream for time period.

          2003      2005      2007      2009      2011      2013      2015
2017      2019      2021      2023      2025
GLU.CA1      0.0000      0.0000      0.0000      0.0000      0.0000      0.0000
0.0000      0.0000      0.0000      0.0000      0.0000      0.0000
ACE.CA1      102.0      106.1      110.4      110.4      114.9      119.5      124.3
129.4      134.6      140.0      145.7      151.6
CIT.CA1      10.4      11.4      12.6      12.6      13.9      15.3      16.9
18.6      20.5      22.6      24.9      27.5
FUM.CA1      1.0      1.1      1.1      1.1      1.1      1.2      1.2      1.2
1.3      1.3      1.4      1.4
SUC.CA1      13.5      15.2      17.1      17.1      19.2      21.6      24.2
27.2      30.6      34.4      38.6      43.4
LAC.CA1      6.4      7.2      8.1      8.1      9.1      10.3      11.6
13.0      14.6      16.4      18.4      20.7
ETH.CA1      13.7      16.0      18.6      18.6      21.6      25.1      29.1
33.9      39.3      45.7      53.1      61.7
PRO.CA1      4.5      4.6      4.8      4.8      5.0      5.1      5.3      5.5
5.7      5.9      6.2      6.4
WAT.CA1      121333      121333      121333      121333      121333      121333
121333      121333      121333      121333      121333      121333
SAL.CA1      121333      121333      121333      121333      121333      121333
121333      121333      121333      121333      121333      121333
AMM.CA1      121333      121333      121333      121333      121333      121333
121333      121333      121333      121333      121333      121333
SOD.CA1      121333      121333      121333      121333      121333      121333
121333      121333      121333      121333      121333      121333
AIR.CA1      121333      121333      121333      121333      121333      121333
121333      121333      121333      121333      121333      121333
CAR.CA1      121333      121333      121333      121333      121333      121333
121333      121333      121333      121333      121333      121333
CAL.CA1      121333      121333      121333      121333      121333      121333
121333      121333      121333      121333      121333      121333
SUL.CA1      121333      121333      121333      121333      121333      121333
121333      121333      121333      121333      121333      121333
GYP.CA1      121333      121333      121333      121333      121333      121333
121333      121333      121333      121333      121333      121333
```

CAC.CA1 121333 121333 121333 121333 121333 121333
121333 121333 121333 121333 121333 121333

GLU.OH1 0 0 0 0 0 0 0 0
0 0 0 0
ACE.OH1 307.5 320.0 332.9 332.9 346.3 360.3 374.9
390.0 405.8 422.2 439.2 457.0
CIT.OH1 31.2 34.4 37.9 37.9 41.8 46.1 50.8
56.1 61.8 68.1 75.1 82.8
FUM.OH1 3.1 3.2 3.3 3.3 3.4 3.5 3.6 3.7
3.8 4.0 4.1 4.2
SUC.OH1 40.8 45.8 51.5 51.5 57.8 65.0 73.0
82.0 92.2 103.6 116.4 130.8
LAC.OH1 19.4 21.8 24.5 24.5 27.6 31.0 34.8
39.1 44.0 49.4 55.5 62.4
ETH.OH1 41.4 48.2 56.0 56.0 65.0 75.6 87.8
102.1 118.6 137.8 160.2 186.1
PRO.OH1 13.5 13.9 14.5 14.5 15.0 15.5 16.1
16.7 17.3 17.9 18.6 19.2
WAT.OH1 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514
SAL.OH1 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514
AMM.OH1 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514
SOD.OH1 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514
AIR.OH1 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514
CAR.OH1 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514
CAL.OH1 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514
SUL.OH1 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514
GYP.OH1 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514

CAC.OH1 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514 332846.514 332846.514 332846.514 332846.514 332846.514
332846.514

GLU.VA1 0 0 0 0 0 0 0 0
0 0 0 0
ACE.VA1 85.85 89.32 92.93 92.93 96.68 100.59
104.65 108.88 113.28 117.85 122.61 127.57
CIT.VA1 8.71 9.61 10.59 10.59 11.68 12.87 14.19
15.65 17.25 19.02 20.97 23.12
FUM.VA1 0.86 0.88 0.91 0.91 0.94 0.97 1.00
1.04 1.07 1.10 1.14 1.18
SUC.VA1 11.38 12.79 14.37 14.37 16.14 18.14 20.38
22.90 25.73 28.91 32.49 36.50
LAC.VA1 5.43 6.10 6.85 6.85 7.70 8.65 9.72
10.92 12.27 13.79 15.49 17.41
ETH.VA1 11.57 13.44 15.62 15.62 18.16 21.10 24.52
28.49 33.11 38.48 44.71 51.96
PRO.VA1 3.76 3.89 4.03 4.03 4.18 4.33 4.49
4.65 4.82 5.00 5.18 5.37
WAT.VA1 92912.82 92912.82 92912.82 92912.82 92912.82
92912.82 92912.82 92912.82 92912.82 92912.82 92912.82 92912.82
SAL.VA1 92912.82 92912.82 92912.82 92912.82 92912.82
92912.82 92912.82 92912.82 92912.82 92912.82 92912.82 92912.82
AMM.VA1 92912.82 92912.82 92912.82 92912.82 92912.82
92912.82 92912.82 92912.82 92912.82 92912.82 92912.82 92912.82
SOD.VA1 92912.82 92912.82 92912.82 92912.82 92912.82
92912.82 92912.82 92912.82 92912.82 92912.82 92912.82 92912.82
AIR.VA1 92912.82 92912.82 92912.82 92912.82 92912.82
92912.82 92912.82 92912.82 92912.82 92912.82 92912.82 92912.82
CAR.VA1 92912.82 92912.82 92912.82 92912.82 92912.82
92912.82 92912.82 92912.82 92912.82 92912.82 92912.82 92912.82
CAL.VA1 92912.82 92912.82 92912.82 92912.82 92912.82
92912.82 92912.82 92912.82 92912.82 92912.82 92912.82 92912.82
SUL.VA1 92912.82 92912.82 92912.82 92912.82 92912.82
92912.82 92912.82 92912.82 92912.82 92912.82 92912.82 92912.82
GYP.VA1 92912.82 92912.82 92912.82 92912.82 92912.82
92912.82 92912.82 92912.82 92912.82 92912.82 92912.82 92912.82
CAC.VA1 92912.82 92912.82 92912.82 92912.82 92912.82
92912.82 92912.82 92912.82 92912.82 92912.82 92912.82 92912.82

Table dcorn(i,kc) distance from corn markets to plant (miles)

Pheonix Yuma Bakersfield Fresno Napa Greeley Pueblo
Louisville Cedar-Rapids Dubuque Mountain-Home Danville Peoria Quincy

Evansville Fort-Wayne Meade Bastrop Denton Billings Lexington Clovis
Las-Cruces Roswell Cincinatti Dayton Heppner Dumas El-Paso Yakima
Anniston 1505 1662 1888 1917 2053 1137 1091
203 657 664 1745 468 533 531 323 514 855
355 670 1465 911 1344 1224 1077 392 446 1950
928 1201 2022
Tuscaloosa 1407 1564 1795 1827 1966 1064 1008
303 640 657 1672 483 528 506 334 555 771
250 768 1408 848 1247 1123 977 445 499 1881
837 1099 1956
Gadsden 1493 1651 1873 1901 2035 1115 1072
219 626 633 1723 437 502 501 292 485 836
351 660 1439 887 1331 1215 1067 364 419 1926
913 1192 1997
Talladega 1492 1649 1876 1906 2042 1130 1081
216 659 668 1738 474 537 531 328 525 845
339 687 1461 906 1331 1210 1063 404 458 1944
917 1186 2016
Hot-Springs 1086 1244 1468 1500 1639 754 686
624 517 563 1359 498 467 392 396 624 449
137 1006 1127 567 924 811 661 574 616 1575
510 792 1654
Los-Angeles 360 230 105 206 366 868 821
2057 1537 1595 634 1733 1627 1541 1731 1863 1028
1519 2364 960 1114 510 666 790 1894 1911 779
929 704 874
Dubuque 1313 1468 1592 1587 1681 735 779
792 63 0 1277 222 131 171 344 300 624
670 820 914 481 1148 1129 981 394 379 1440
754 1131 1491
Ottumwa 1197 1353 1491 1491 1593 639 668
787 67 127 1208 262 148 103 336 378 500
577 896 869 382 1030 1005 855 441 441 1385
630 1006 1443
Fort-Wayne 1560 1718 1868 1869 1971 1017 1042
574 342 300 1575 138 236 324 239 0 852
679 521 1214 760 1392 1342 1188 133 92 1740
974 1336 1790
South-Bend 1513 1671 1811 1810 1908 957 989
639 278 230 1507 124 189 283 261 76 809
690 590 1142 701 1346 1306 1153 200 166 1669
934 1302 1718
Columbus 1504 1664 1832 1840 1951 996 1002
475 354 332 1575 111 223 286 122 125 796
561 545 1234 740 1336 1270 1115 75 100 1753
911 1260 1809

Monroe 1159 1314 1558 1597 1743 888 807
561 648 687 1486 586 579 516 459 698 574
19 1012 1271 713 1005 869 727 623 671 1707
613 842 1789

Detroit 1690 1847 1983 1979 2072 1126 1163
652 447 392 1661 283 366 459 385 149 985
825 453 1283 872 1522 1481 1328 239 185 1813
1110 1477 1855

Grand-Rapids 1574 1730 1858 1852 1943 1000 1043
704 323 266 1530 215 264 358 351 131 875
781 580 1152 747 1408 1376 1225 263 217 1682
1003 1375 1725

Kalamazoo 1559 1716 1850 1847 1942 994 1031
665 314 261 1534 178 239 333 310 91 856
743 568 1162 739 1392 1355 1203 224 180 1691
983 1352 1736

Minneapolis 1277 1424 1506 1488 1564 656 738
1005 221 213 1133 432 342 356 557 486 645
841 988 746 437 1120 1140 1003 597 574 1276
776 1150 1318

St-Cloud 1264 1408 1476 1454 1524 637 730
1072 284 280 1086 500 409 418 623 552 659
895 1048 693 435 1112 1143 1012 664 640 1222
786 1156 1260

Fergus-Falls 1222 1360 1410 1382 1445 590 699
1168 373 377 998 598 502 501 716 654 661
959 1149 599 423 1076 1125 1002 765 742 1126
783 1142 1162

Mankato 1218 1366 1455 1440 1521 602 679
991 195 205 1097 426 326 324 539 497 582
795 1009 720 376 1060 1077 940 599 581 1249
712 1087 1295

Joplin 1246 1406 1578 1590 1707 756 750
604 231 259 1351 194 148 95 173 331 538
413 801 1038 506 1078 1015 860 331 354 1542
653 1007 1606

Tupelo 1334 1492 1714 1743 1879 969 918
377 550 572 1577 415 446 415 271 505 682
208 788 1310 751 1172 1057 908 412 463 1786
755 1035 1859

Greensboro 1823 1983 2180 2198 2318 1369 1356
255 747 722 1960 504 615 668 440 443 1132
719 300 1626 1118 1657 1560 1407 328 352 2143
1230 1541 2201

Hickory 1745 1904 2106 2125 2248 1302 1284
199 698 679 1898 458 564 609 375 418 1058

635 377 1572 1054 1579 1479 1327 291 326 2085
1153 1460 2146
Manchester 2278 2436 2570 2563 2651 1712 1753
909 1035 978 2223 856 952 1043 910 720 1571
1315 361 1829 1460 2110 2060 1906 730 695
2355 1693 2052 2386
Keene 2235 2393 2527 2521 2608 1670 1710
879 992 936 2182 813 909 1000 868 677 1528
1276 334 1788 1417 2067 2017 1863 689 653
2315 1651 2010 2347
Cleveland 1736 1895 2042 2042 2140 1189 1217
582 510 461 1736 312 412 500 381 177 1028
814 366 1364 933 1568 1516 1362 210 162 1893
1150 1509 1938
Dayton 1599 1758 1920 1926 2032 1077 1091
488 414 379 1646 180 293 370 219 92 890
653 457 1293 820 1430 1368 1214 54 0 1817
1007 1359 1869
Toledo 1639 1797 1941 1940 2038 1088 1117
600 408 359 1635 221 313 404 316 84 932
756 464 1265 831 1471 1424 1271 174 120 1794
1055 1419 1840
Youngstown 1796 1955 2104 2104 2202 1251 1278
580 572 523 1798 371 473 560 428 237 1088
853 308 1424 995 1628 1573 1418 251 209 1954
1208 1565 1998
Findlay 1639 1797 1948 1949 2050 1097 1122
559 421 375 1652 214 316 403 291 80 931
729 444 1287 840 1471 1418 1264 137 82 1814
1051 1411 1862
Tulsa 934 1094 1297 1322 1455 557 494
799 453 511 1162 529 457 364 479 666 257
329 1117 934 378 767 685 530 655 685 1377
340 674 1457
Eugene 952 919 641 541 411 982 1052
2310 1592 1632 374 1832 1717 1659 1891 1931 1285
1855 2451 727 1216 1001 1201 1251 2011 2006
202 1258 1247 214
Medford 854 809 523 422 289 954 1007
2284 1590 1633 357 1826 1712 1648 1876 1932 1243
1811 2453 749 1198 917 1117 1178 2004 2003 263
1205 1162 312
Greenville 1702 1861 2071 2093 2221 1282 1255
132 705 691 1882 470 570 604 367 452 1025
575 450 1568 1038 1538 1431 1280 320 363 2075
1114 1410 2139

Dallas 879 1032 1281 1323 1474 679 571
838 686 741 1251 722 670 583 636 855 363
288 1250 1090 571 725 588 446 815 855 1479
358 563 1567

Ft-Worth 867 1021 1270 1313 1463 673 563
850 691 747 1242 731 678 590 646 864 358
299 1261 1085 569 714 576 435 825 864 1471
350 551 1560

Waco 871 1021 1283 1332 1488 737 619
871 773 828 1291 801 754 668 707 931 429
321 1307 1153 648 727 571 442 884 926 1522
400 540 1613

Longview 1004 1158 1407 1448 1598 778 681
718 672 722 1363 666 632 554 560 791 459
166 1151 1179 638 851 711 572 735 779 1588
475 685 1675

Lufkin 1014 1163 1423 1470 1623 831 726
733 744 793 1406 729 701 624 617 851 513
194 1190 1237 703 867 714 583 788 834 1634
514 684 1722

Sherman 884 1040 1278 1316 1462 639 540
825 626 682 1222 672 615 527 593 806 321
283 1215 1045 516 726 602 454 773 810 1447
335 581 1534

Milwaukee 1460 1615 1738 1731 1822 880 926
750 208 147 1410 191 183 269 339 194 766
737 693 1036 628 1294 1271 1121 317 285 1565
896 1271 1610

Racine 1457 1613 1739 1733 1825 881 925
735 205 147 1415 175 170 259 323 181 762
723 686 1043 628 1291 1265 1115 302 271 1572
891 1265 1618

Green-Bay 1486 1639 1742 1729 1811 886 948
852 254 193 1384 298 276 351 446 283 810
835 747 997 644 1324 1316 1170 413 375 1526
942 1320 1566

Appleton 1469 1622 1727 1715 1798 870 930
842 234 173 1373 283 257 331 431 277 791
817 750 988 627 1306 1297 1150 405 369 1518
922 1301 1558

Wasau 1432 1583 1677 1661 1740 823 893
910 234 182 1309 342 294 353 487 351 770
849 825 919 588 1272 1274 1131 477 443 1449
902 1280 1487

Sheboygan 1487 1641 1755 1745 1831 896 950
797 240 177 1411 246 236 318 394 230 801

793 706 1029 649 1323 1307 1158 359 322 1559
932 1309 1601
;

Parameter

rmcostcorn(kc) cost of raw materials from corn markets ($ per pound)

/ Pheonix 0.06085
Yuma 0.06085
Bakersfield 0.05357
Fresno 0.05357
Napa 0.05357
Greeley 0.04525
Pueblo 0.04577
Louisville 0.04993
Cedar-Rapids 0.04005
Dubuque 0.03953
Mountain-Home 0.05617
Danville 0.04317
Peoria 0.04317
Quincy 0.04317
Evansville 0.04213
Fort-Wayne 0.04213
Meade 0.043688
Bastrop 0.04889
Denton 0.04473
Billings 0.03849
Lexington 0.04213
Clovis 0.05357
Las-Cruces 0.05357
Roswell 0.05357
Cincinatti 0.04213
Dayton 0.04213
Heppner 0.05045
Dumas 0.04941
El-Paso 0.04941
Yakima 0.05617 /

Table

cornmax(kc,t) maximum initial amount of corn from any corn market location 30% of production and 30% rate of growth

2003 2005 2007 2009 2011
2013 2015 2017 2019 2021 2023
2025

Pheonix 24753178.3 25990837.21 28654898.02 30087642.93
33171626.33 36571718.02 40320319.12 44453151.83 49009599.89
54033083.88 59571474.98 62550048.73
Yuma 24753178.3 25990837.21 28654898.02 30087642.93
33171626.33 36571718.02 40320319.12 44453151.83 49009599.89
54033083.88 59571474.98 62550048.73
Bakersfield 88914477.8 93360201.69 102929622.4 108076103.5
119153904.1 131367179.3 144832315.1 159677627.4 176044584.2
194089154.1 213983292.4 224682457
Fresno 88914477.8 93360201.69 102929622.4 108076103.5
119153904.1 131367179.3 144832315.1 159677627.4 176044584.2
194089154.1 213983292.4 224682457
Napa 88914477.8 93360201.69 102929622.4 108076103.5
119153904.1 131367179.3 144832315.1 159677627.4 176044584.2
194089154.1 213983292.4 224682457
Greeley 554535487.8 582262262.2 641944144.1 674041351.3
743130589.8 819301475.2 903279876.4 995866063.8 1097942335
1210481425 1334555771 1401283559
Pueblo 554535487.8 582262262.2 641944144.1 674041351.3
743130589.8 819301475.2 903279876.4 995866063.8 1097942335
1210481425 1334555771 1401283559
Louisville 196555849.9 206383642.4 227537965.8 238914864.1
263403637.6 290402510.5 320168767.8 352986066.5 389167138.3
429056770 473035088.9 496686843.4
Cedar-Rapids 6613094016 6943748717 7655482960 8038257108
8862178462 9770551754 10772033309 11876166723 13093473812
14435554878 15915199253 16710959216
Dubuque 6613094016 6943748717 7655482960 8038257108
8862178462 9770551754 10772033309 11876166723 13093473812
14435554878 15915199253 16710959216
Mountain-Home 69804881.28 73295125.34 80807875.69
84848269.48 93545217.1 103133601.9 113704796 125359537.6
138208890.2 152375301.5 167993769.9 176393458.4
Danville 4257051705 4469904291 4928069480 5174472954
5704856432 6289604217 6934288649 7645053235 8428671192
9292609989 10245102513 10757357639
Peoria 4257051705 4469904291 4928069480 5174472954
5704856432 6289604217 6934288649 7645053235 8428671192
9292609989 10245102513 10757357639
Quincy 4257051705 4469904291 4928069480 5174472954
5704856432 6289604217 6934288649 7645053235 8428671192
9292609989 10245102513 10757357639
Evansville 3101035927 3256087723 3589836715 3769328550
4155684727 4581642411 5051260758 5569014986 6139839022
6769172522 7463012705 7836163341

Fort-Wayne 3101035927 3256087723 3589836715 3769328550
4155684727 4581642411 5051260758 5569014986 6139839022
6769172522 7463012705 7836163341
Meade 3154231532 3311943109 3651417278 3833988142
4226971926 4660236549 5137910795 5664546651 6245162683
6885291858 7591034273 7970585987
Bastrop 328511568.5 344937146.9 380293204.5 399307864.7
440236920.8 485361205.2 535110728.7 589959578.4 650430435.2
717099554.8 790602259.2 830132372.2
Denton 480482612.1 504506742.7 556218683.8 584029618
643892653.9 709891650.9 782655545.1 862877738.5 951322706.7
1048833284 1156338696 1214155631
Billings 17145058.56 18002311.49 19847548.42 20839925.84
22976018.23 25331060.1 27927493.76 30790061.87 33946043.22
37425512.65 41261627.69 43324709.08
Lexington 7763496829 8151671671 8987218017 9436578918
10403828257 11470220653 12645918270 13942124893 15371192694
16946739945 18683780790 19617969829
Clovis 26942234.88 28289346.62 31189004.65 32748454.89
36105171.51 39805951.59 43886061.63 48384382.95 53343782.2
58811519.87 64839700.66 68081685.69
Las-Cruces 26942234.88 28289346.62 31189004.65 32748454.89
36105171.51 39805951.59 43886061.63 48384382.95 53343782.2
58811519.87 64839700.66 68081685.69
Roswell 26942234.88 28289346.62 31189004.65 32748454.89
36105171.51 39805951.59 43886061.63 48384382.95 53343782.2
58811519.87 64839700.66 68081685.69
Cincinatti 1856488372 1949312791 2149117352 2256573219
2487871974 2742878852 3024023934 3333986387 3675719992
4052481291 4467860624 4691253655
Dayton 1856488372 1949312791 2149117352 2256573219
2487871974 2742878852 3024023934 3333986387 3675719992
4052481291 4467860624 4691253655
Heppner 37198653.84 39058586.53 43062091.65 45215196.23
49849753.85 54959353.62 60592687.36 66803437.82 73650790.19
81199996.19 89522995.8 93999145.59
Dumas 901646383.2 946728702.4 1043768394 1095956814
1208292388 1332142357 1468686949 1619227361 1785198166
1968180978 2169919528 2278415504
El-Paso 901646383.2 946728702.4 1043768394 1095956814
1208292388 1332142357 1468686949 1619227361 1785198166
1968180978 2169919528 2278415504
Yakima 141599814 148679804.7 163919484.7 172115458.9
189757293.5 209207416 230651176.2 254292921.7 280357946.2
309094635.7 340776835.9 357815677.7 ;

Table

transcorn(i,kc) transportation costs from corn market to plant ($ per lb)

Pheonix Yuma Bakersfield Fresno Napa Greeley
Pueblo Louisville Cedar-Rapids Dubuque Mountain-Home Danville
Peoria Quincy Evansville Fort-Wayne Meade Bastrop Denton
Billings Lexington Clovis Las-Cruces Roswell Cincinatti Dayton
Heppner Dumas El-Paso Yakima
Anniston 0.02717 0.03001 0.03408 0.03461 0.03510
0.02053 0.01969 0.00387 0.01248 0.01262 0.03150 0.00889
0.01014 0.01008 0.00614 0.00977 0.01624 0.00674 0.01273
0.02645 0.01732 0.02426 0.02209 0.01944 0.00745 0.00848
0.03520 0.01764 0.02167 0.03457
Tuscaloosa 0.02540 0.02822 0.03239 0.03297 0.03548
0.01920 0.01820 0.00575 0.01215 0.01248 0.03017 0.00918
0.01003 0.00962 0.00635 0.01054 0.01464 0.00476 0.01460
0.02541 0.01612 0.02252 0.02027 0.01857 0.00846 0.00949
0.03396 0.01590 0.01983 0.03531
Gadsden 0.02695 0.02980 0.03380 0.03431 0.03480
0.02013 0.01935 0.00416 0.01190 0.01203 0.03109 0.00830
0.00955 0.00951 0.00555 0.00922 0.01589 0.00668 0.01254
0.02597 0.01685 0.02403 0.02193 0.01925 0.00693 0.00795
0.03477 0.01735 0.02152 0.03605
Talladega 0.02693 0.02976 0.03386 0.03441 0.03493
0.02039 0.01952 0.00411 0.01251 0.01269 0.03137 0.00901
0.01020 0.01009 0.00624 0.00997 0.01605 0.00645 0.01306
0.02637 0.01720 0.02403 0.02184 0.01919 0.00768 0.00871
0.03509 0.01742 0.02141 0.03447
Hot-Springs 0.01960 0.02246 0.02650 0.02707 0.02959
0.01433 0.01303 0.01185 0.00983 0.01069 0.02452 0.00945
0.00887 0.00745 0.00753 0.01185 0.00853 0.00261 0.01817
0.02034 0.01077 0.01756 0.01542 0.01256 0.01091 0.01170
0.02843 0.00969 0.01504 0.02986
Los-Angeles 0.00684 0.00438 0.00100 0.00195 0.00348
0.01649 0.01560 0.03517 0.02775 0.02879 0.01205 0.03128
0.02936 0.02782 0.03124 0.03362 0.01855 0.02742 0.04043
0.01824 0.02010 0.00970 0.01265 0.01500 0.03419 0.03449
0.01479 0.01766 0.01338 0.01661
Dubuque 0.02370 0.02650 0.02873 0.02864 0.03034
0.01396 0.01480 0.01505 0.00059 0.00000 0.02304 0.00421
0.00249 0.00326 0.00654 0.00570 0.01185 0.01272 0.01558
0.01737 0.00915 0.02072 0.02038 0.01864 0.00749 0.00721
0.02600 0.01433 0.02042 0.02691
Ottumwa 0.02160 0.02443 0.02691 0.02691 0.02876
0.01215 0.01270 0.01496 0.00063 0.00121 0.02180 0.00498

0.00281 0.00196 0.00639 0.00718 0.00950 0.01097 0.01703
0.01650 0.00726 0.01860 0.01814 0.01625 0.00837 0.00837
0.02500 0.01197 0.01815 0.02604
Fort-Wayne 0.02815 0.03101 0.03371 0.03373 0.03557
0.01836 0.01880 0.01091 0.00651 0.00570 0.02843 0.00262
0.00448 0.00615 0.00227 0.00000 0.01619 0.01290 0.00990
0.02191 0.01444 0.02512 0.02422 0.02144 0.00253 0.00175
0.03141 0.01850 0.02411 0.03231
South-Bend 0.02732 0.03016 0.03269 0.03267 0.03444
0.01819 0.01879 0.01214 0.00528 0.00437 0.02720 0.00235
0.00360 0.00537 0.00248 0.00072 0.01537 0.01311 0.01120
0.02061 0.01332 0.02430 0.02357 0.02081 0.00380 0.00316
0.03013 0.01775 0.02350 0.03100
Columbus 0.02715 0.03003 0.03307 0.03321 0.03521
0.01893 0.01809 0.00903 0.00673 0.00630 0.02844 0.00211
0.00423 0.00544 0.00116 0.00119 0.01513 0.01065 0.01035
0.02227 0.01406 0.02411 0.02292 0.02013 0.00142 0.00190
0.03164 0.01730 0.02275 0.03266
Monroe 0.02093 0.02371 0.02812 0.02882 0.03146
0.01687 0.01533 0.01066 0.01231 0.01306 0.02683 0.01113
0.01099 0.00981 0.00873 0.01326 0.01091 0.00018 0.01826
0.02294 0.01354 0.01813 0.01650 0.01382 0.01183 0.01275
0.03081 0.01165 0.01600 0.03229
Detroit 0.03050 0.03334 0.03579 0.03572 0.03544
0.02033 0.02100 0.01239 0.00849 0.00745 0.02997 0.00538
0.00695 0.00871 0.00731 0.00284 0.01872 0.01568 0.00860
0.02316 0.01656 0.02748 0.02674 0.02397 0.00454 0.00351
0.03272 0.02004 0.02666 0.03349
Grand-Rapids 0.02841 0.03123 0.03353 0.03342 0.03508
0.01805 0.01882 0.01338 0.00614 0.00505 0.02761 0.00408
0.00502 0.00680 0.00666 0.00249 0.01662 0.01484 0.01102
0.02080 0.01420 0.02541 0.02484 0.02211 0.00501 0.00412
0.03036 0.01810 0.02481 0.03114
Kalamazoo 0.02814 0.03097 0.03340 0.03333 0.03505
0.01889 0.01861 0.01264 0.00597 0.00496 0.02768 0.00338
0.00455 0.00633 0.00589 0.00173 0.01627 0.01412 0.01078
0.02097 0.01405 0.02513 0.02447 0.02171 0.00426 0.00342
0.03051 0.01867 0.02441 0.03134
Minneapolis 0.02305 0.02570 0.02718 0.02686 0.02823
0.01247 0.01403 0.01814 0.00420 0.00405 0.02045 0.00821
0.00650 0.00677 0.01058 0.00924 0.01226 0.01598 0.01877
0.01418 0.00830 0.02022 0.02057 0.01811 0.01134 0.01091
0.02303 0.01474 0.02076 0.02378
St-Cloud 0.02282 0.02541 0.02665 0.02625 0.02751
0.01209 0.01387 0.01936 0.00540 0.00532 0.01960 0.00949
0.00777 0.00794 0.01184 0.01048 0.01252 0.01700 0.01892

0.01316 0.00827 0.02006 0.02063 0.01826 0.01262 0.01216
0.02205 0.01494 0.02087 0.02275
Fergus-Falls 0.02206 0.02456 0.02544 0.02495 0.02608
0.01120 0.01327 0.02108 0.00708 0.00716 0.01897 0.01136
0.00954 0.00952 0.01361 0.01242 0.01257 0.01823 0.02075
0.01138 0.00803 0.01942 0.02030 0.01809 0.01453 0.01410
0.02033 0.01487 0.02061 0.02098
Mankato 0.02198 0.02466 0.02627 0.02599 0.02745
0.01144 0.01290 0.01884 0.00370 0.00389 0.01981 0.00809
0.00619 0.00615 0.01024 0.00945 0.01106 0.01511 0.01822
0.01368 0.00714 0.01914 0.01944 0.01786 0.01137 0.01104
0.02255 0.01353 0.01963 0.02337
Joplin 0.02249 0.02537 0.02849 0.02870 0.03080
0.01436 0.01424 0.01148 0.00438 0.00493 0.02438 0.00369
0.00282 0.00180 0.00329 0.00629 0.01023 0.00785 0.01522
0.01874 0.00962 0.01945 0.01832 0.01635 0.00629 0.00673
0.02783 0.01240 0.01818 0.02899
Tupelo 0.02408 0.02693 0.03094 0.03147 0.03392
0.01841 0.01745 0.00716 0.01046 0.01087 0.02847 0.00789
0.00846 0.00789 0.00514 0.00959 0.01295 0.00396 0.01498
0.02365 0.01427 0.02115 0.01908 0.01725 0.00782 0.00880
0.03223 0.01434 0.01869 0.03356
Greensboro 0.03291 0.03579 0.03728 0.03758 0.03964
0.02471 0.02448 0.00484 0.01420 0.01372 0.03538 0.00957
0.01169 0.01270 0.00836 0.00841 0.02044 0.01366 0.00569
0.02935 0.02018 0.02991 0.02815 0.02540 0.00623 0.00668
0.03665 0.02220 0.02782 0.03764
Hickory 0.03149 0.03437 0.03601 0.03633 0.03844
0.02351 0.02318 0.00378 0.01327 0.01290 0.03426 0.00869
0.01073 0.01158 0.00713 0.00794 0.01909 0.01207 0.00716
0.02838 0.01902 0.02850 0.02669 0.02395 0.00554 0.00620
0.03566 0.02080 0.02635 0.03669
Manchester 0.03895 0.04165 0.04395 0.04383 0.04532
0.03091 0.03164 0.01728 0.01868 0.01859 0.03801 0.01627
0.01809 0.01882 0.01729 0.01367 0.02836 0.02374 0.00686
0.03300 0.02635 0.03608 0.03523 0.03440 0.01387 0.01320
0.04027 0.03057 0.03510 0.04080
Keene 0.03821 0.04092 0.04322 0.04311 0.04460
0.03014 0.03086 0.01670 0.01885 0.01778 0.03731 0.01546
0.01727 0.01900 0.01650 0.01286 0.02759 0.02303 0.00635
0.03228 0.02557 0.03535 0.03450 0.03363 0.01308 0.01240
0.03959 0.02979 0.03437 0.04013
Cleveland 0.03134 0.03420 0.03492 0.03491 0.03660
0.02147 0.02197 0.01105 0.00969 0.00875 0.03133 0.00593
0.00782 0.00951 0.00723 0.00335 0.01856 0.01546 0.00696

0.02462 0.01772 0.02830 0.02737 0.02458 0.00199 0.00154
0.03417 0.02075 0.02724 0.03498
Dayton 0.02885 0.03173 0.03466 0.03476 0.03475
0.01945 0.01969 0.00927 0.00787 0.00721 0.02972 0.00343
0.00557 0.00704 0.00417 0.00175 0.01691 0.01240 0.00869
0.02334 0.01558 0.02582 0.02470 0.02190 0.00052 0.00000
0.03280 0.01817 0.02453 0.03374
Toledo 0.02958 0.03244 0.03503 0.03502 0.03485
0.01963 0.02017 0.01140 0.00775 0.00682 0.02951 0.00420
0.00595 0.00767 0.00600 0.00159 0.01771 0.01436 0.00882
0.02283 0.01579 0.02655 0.02571 0.02293 0.00165 0.00114
0.03237 0.01905 0.02561 0.03321
Youngstown 0.03241 0.03528 0.03597 0.03597 0.03766
0.02259 0.02307 0.01101 0.01087 0.00993 0.03245 0.00704
0.00898 0.01064 0.00813 0.00450 0.01963 0.01621 0.00585
0.02571 0.01890 0.02938 0.02839 0.02560 0.00238 0.00199
0.03526 0.02180 0.02825 0.03606
Findlay 0.02958 0.03244 0.03515 0.03518 0.03505
0.01980 0.02024 0.01062 0.00799 0.00713 0.02982 0.00407
0.00600 0.00766 0.00553 0.00152 0.01768 0.01386 0.00844
0.02323 0.01596 0.02654 0.02560 0.02281 0.00130 0.00078
0.03275 0.01898 0.02547 0.03362
Tulsa 0.01774 0.01974 0.02340 0.02386 0.02627
0.01058 0.00939 0.01518 0.00861 0.00971 0.02097 0.01005
0.00868 0.00692 0.00909 0.01266 0.00489 0.00625 0.02017
0.01774 0.00719 0.01458 0.01301 0.01007 0.01245 0.01302
0.02486 0.00646 0.01281 0.02630
Eugene 0.01810 0.01746 0.01218 0.01027 0.00781
0.01866 0.01898 0.03951 0.02873 0.02945 0.00711 0.03306
0.03100 0.02995 0.03414 0.03486 0.02319 0.03347 0.04191
0.01381 0.02194 0.01807 0.02168 0.02258 0.03439 0.03431
0.00191 0.02271 0.02251 0.00406
Medford 0.01623 0.01538 0.00993 0.00802 0.00549
0.01812 0.01818 0.03906 0.02870 0.02948 0.00678 0.03296
0.03090 0.02975 0.03387 0.03487 0.02244 0.03268 0.04195
0.01424 0.02162 0.01743 0.02016 0.02126 0.03428 0.03426
0.00250 0.02175 0.02098 0.00594
Greenville 0.03072 0.03359 0.03541 0.03580 0.03797
0.02313 0.02266 0.00250 0.01339 0.01314 0.03398 0.00894
0.01084 0.01148 0.00698 0.00859 0.01850 0.01093 0.00855
0.02831 0.01873 0.02776 0.02582 0.02311 0.00608 0.00689
0.03548 0.02011 0.02545 0.03657
Dallas 0.01669 0.01863 0.02311 0.02388 0.02660
0.01290 0.01085 0.01593 0.01303 0.01408 0.02257 0.01372
0.01274 0.01107 0.01208 0.01624 0.00690 0.00547 0.02255

0.01967 0.01084 0.01378 0.01117 0.00848 0.01549 0.01624
0.02669 0.00340 0.00535 0.02828
Ft-Worth 0.01648 0.01843 0.02292 0.02369 0.02641
0.01278 0.01071 0.01615 0.01313 0.01419 0.02243 0.01389
0.01288 0.01121 0.01227 0.01641 0.00680 0.00569 0.02275
0.01958 0.01080 0.01357 0.01095 0.00826 0.01568 0.01643
0.02655 0.00332 0.00523 0.02815
Waco 0.01656 0.01842 0.02316 0.02404 0.02685
0.01400 0.01176 0.01654 0.01468 0.01572 0.02330 0.01521
0.01432 0.01268 0.01342 0.01769 0.00814 0.00610 0.02360
0.02081 0.01232 0.01381 0.01085 0.00841 0.01680 0.01759
0.02746 0.00380 0.00513 0.02911
Longview 0.01813 0.02089 0.02539 0.02615 0.02884
0.01478 0.01295 0.01364 0.01277 0.01371 0.02460 0.01265
0.01202 0.01052 0.01065 0.01503 0.00873 0.00316 0.02078
0.02128 0.01212 0.01618 0.01352 0.01087 0.01397 0.01481
0.02867 0.00452 0.00650 0.03022
Lufkin 0.01830 0.02100 0.02569 0.02653 0.02930
0.01579 0.01380 0.01394 0.01414 0.01506 0.02538 0.01385
0.01331 0.01185 0.01172 0.01617 0.00974 0.00368 0.02149
0.02234 0.01336 0.01647 0.01357 0.01108 0.01498 0.01585
0.02949 0.00488 0.00649 0.03108
Sherman 0.01680 0.01878 0.02306 0.02375 0.02640
0.01214 0.01026 0.01568 0.01190 0.01297 0.02205 0.01276
0.01169 0.01000 0.01126 0.01531 0.00609 0.00539 0.02194
0.01886 0.00981 0.01379 0.01144 0.00864 0.01468 0.01539
0.02612 0.00318 0.00552 0.02768
Milwaukee 0.02635 0.02915 0.03137 0.03125 0.03290
0.01672 0.01760 0.01426 0.00394 0.00280 0.02545 0.00363
0.00347 0.00511 0.00645 0.00368 0.01456 0.01401 0.01318
0.01870 0.01194 0.02336 0.02294 0.02024 0.00601 0.00541
0.02825 0.01703 0.02295 0.02907
Racine 0.02630 0.02911 0.03138 0.03128 0.03295
0.01674 0.01757 0.01396 0.00390 0.00279 0.02555 0.00332
0.00324 0.00491 0.00614 0.00344 0.01447 0.01373 0.01303
0.01883 0.01194 0.02331 0.02284 0.02013 0.00574 0.00515
0.02838 0.01693 0.02284 0.02921
Green-Bay 0.02683 0.02958 0.03145 0.03122 0.03269
0.01682 0.01801 0.01618 0.00483 0.00367 0.02498 0.00565
0.00523 0.00666 0.00848 0.00538 0.01539 0.01587 0.01418
0.01894 0.01223 0.02390 0.02376 0.02111 0.00785 0.00713
0.02755 0.01789 0.02383 0.02826
Appleton 0.02651 0.02927 0.03118 0.03096 0.03246
0.01653 0.01768 0.01600 0.00445 0.00329 0.02479 0.00538
0.00487 0.00628 0.00819 0.00526 0.01503 0.01551 0.01426

0.01878 0.01191 0.02357 0.02341 0.02076 0.00770 0.00701
0.02740 0.01753 0.02347 0.02813
Wasau 0.02585 0.02857 0.03027 0.02999 0.03140
0.01563 0.01696 0.01729 0.00445 0.00346 0.02363 0.00650
0.00559 0.00670 0.00925 0.00667 0.01462 0.01614 0.01568
0.01747 0.01117 0.02296 0.02299 0.02041 0.00906 0.00842
0.02615 0.01713 0.02311 0.02684
Sheboygan 0.02684 0.02962 0.03167 0.03149 0.03305
0.01703 0.01806 0.01514 0.00456 0.00337 0.02546 0.00467
0.00448 0.00605 0.00749 0.00436 0.01522 0.01506 0.01341
0.01857 0.01233 0.02388 0.02359 0.02091 0.00682 0.00611
0.02813 0.01770 0.02362 0.02889

;
Table
marktranscorn(i,m) transportation costs from plant to sales market ($ per pound)

	CA1	OH1	VA1
Anniston	0.016727	0.003725	0.005427
Tuscaloosa	0.015862	0.00423	0.006354
Gadsden	0.016604	0.003463	0.005327
Talladega	0.016613	0.003838	0.005589
Hot-Springs	0.012935	0.005454	0.008629
Los-Angeles	0	0.017093	0.019465
Dubuque	0.014394	0.003744	0.007144
Ottumwa	0.013434	0.004185	0.007784
Fort-Wayne	0.01681	0.001263	0.004294
South-Bend	0.016329	0.001902	0.00498
Columbus	0.016424	0.000708	0.004364
Monroe	0.013668	0.005914	0.008664
Detroit	0.017896	0.002272	0.003876
Grand-Rapids	0.01679	0.002503	0.005017
Kalamazoo	0.016702	0.002128	0.004841
Minneapolis	0.013741	0.005671	0.008845
St-Cloud	0.013513	0.006308	0.009441
Fergus-Falls	0.012964	0.007265	0.00989
Mankato	0.013261	0.005686	0.009001
Joplin	0.014114	0.003145	0.006771
Tupelo	0.015168	0.003911	0.00654
Greensboro	0.01845	0.003115	0.001952
Hickory	0.017796	0.002768	0.002651
Manchester	0.021993	0.006935	0.004279
Keene	0.021625	0.006541	0.003984
Cleveland	0.017427	0.000997	0.003006
Dayton	0.017243	0.000258	0.003598
Toledo	0.017492	0.000825	0.003856

Youngstown	0.017949	0.00119	0.002532
Findlay	0.017531	0.000649	0.003607
Tulsa	0.011456	0.006224	0.009237
Eugene	0.007083	0.017193	0.020375
Medford	0.005963	0.017138	0.020363
Greenville	0.017471	0.003042	0.003356
Dallas	0.011142	0.007743	0.010389
Ft-Worth	0.011041	0.007839	0.010489
Waco	0.011108	0.0084	0.010903
Longview	0.01228	0.006987	0.009493
Lufkin	0.012387	0.00749	0.009842
Sherman	0.011158	0.007339	0.010087
Milwaukee	0.015721	0.003007	0.006028
Racine	0.015718	0.002868	0.005938
Green-Bay	0.015821	0.003926	0.006636
Appleton	0.015678	0.00385	0.00665
Wasau	0.015256	0.004531	0.007372
Sheboygan	0.0159	0.003408	0.006209

Table

dpm(i,m) distance from plant to market in miles

	CA1	OH1	VA1
Anniston	1853	392	571
Tuscaloosa	1758	445	669
Gadsden	1840	364	561
Talladega	1841	404	588
Hot-Springs	1433	574	908
Los-Angeles	0	1894	2277
Dubuque	1595	394	752
Ottumwa	1489	441	819
Fort-Wayne	1863	133	452
South-Bend	1809	200	524
Columbus	1820	75	459
Monroe	1515	623	912
Detroit	1983	239	408
Grand-Rapids	1860	263	528
Kalamazoo	1851	224	510
Minneapolis	1523	597	931
St-Cloud	1497	664	994
Fergus-Falls	1437	765	1096
Mankato	1469	599	947
Joplin	1564	331	713
Tupelo	1681	412	688
Greensboro	2158	328	205

Hickory	2081	291	279
Manchester	2572	730	450
Keene	2529	689	419
Cleveland	2038	210	316
Dayton	1911	54	379
Toledo	1938	174	406
Youngstown	2099	251	266
Findlay	1943	137	380
Tulsa	1269	655	1023
Eugene	746	2011	2383
Medford	628	2004	2382
Greenville	2043	320	353
Dallas	1235	815	1151
Ft-Worth	1223	825	1162
Waco	1231	884	1208
Longview	1361	735	1052
Lufkin	1372	788	1091
Sherman	1236	773	1118
Milwaukee	1742	317	634
Racine	1742	302	625
Green-Bay	1753	413	698
Appleton	1737	405	700
Wasau	1690	477	776
Sheboygan	1762	359	654

;

VARIABLES

Q(p,t) Capacity of the process
QE(p,t) Expansion in capacity of the process
W(p,c,t) Mass flow rate of the product
R(p,c,t) Mass flow rate of reactant
F(p,pp,c,t) Mass flow rate of chemicals from one process to another
PURCH(m,p,c,t) Mass flow rate of purchased chemicals
SALES(m,p,c,t) Mass flow rate of sold chemicals
CAPITAL(p,t) Capital cost for each process
OPCOST(p,t) Operating cost for each process
Y(p,t) Binary variable for fixed investment cost
INVEST(t) Total invenst
NPV Net present value
trans(i,t) Transportation Costs
yc(i,kc,t)
TOTALOPCOST(t)

```
        CORNpurchased(p,kc,t)
        TRANS(i,t)
        AUX11(i,t)
                    ;

POSITIVE VARIABLES

        Q(p,t)
        QE(p,t)
        W(p,c,t)
        R(p,c,t)
        F(p,pp,c,t)
        PURCH(m,p,c,t)
        SALES(m,p,c,t)
        CAPITAL(p,t)
        OPCOST(p,t)
        INVEST(t)
        TRANS(i,t)
        yc(i,kc,t)
        CORNpurchased(p,kc,t)
        FLOCORN(p,t)
        rev(t)
                ;

BINARY VARIABLE

        Y(p,t)
        z(i)
;
Q.fx(p,'2003')=0;
                                                ;
EQUATIONS

        Capacity(p,t,c)       Constrain on capacity
        Expansion(p,t)        Expension in process
        Decision(p,t)         Decision making equation
        Material1(p,c,cc,t)   Material balances in each plant
        Material2(p,c,cc,t)   Material balances in each plant
        Material3(p,c,t)      Material balances in each plant
        Material4(p,c,t)      Material balances in each plant
        Supply(c,m,t)         Upper supply of chemicals
        Demand(c,m,t)         Upper demand of Chemicals
        CapitalInv(p,t)       Capital investment cost of each plant
        TotalInv(t)           Total investment at each time period
        LIMTotalInv(t)        Limit on total investment
        Opercost(p,t,c)       Operation cost of each plant
```

```
        Net                 Net present value of the project
        PlantOpercost(t)
        Cornbalance(p,t)
        Flowofcorn(p,t,c)
         TRcosts1(i,t)            Transportation costs
         TRcosts2(i,t)            Transportation costs
        location1
        Reveq(t)

;

Capacity(p,t,c)$main(p,c)..          Q(p,t) =g= W(p,c,t)                  ;

Expansion(p,t)$(ord(t) gt 1)..       Q(p,t) =e= Q(p,t-1)+ QE(p,t)          ;

Decision(p,t)..                    QE(p,t) - Y(p,t)*10000 =l= 0          ;

Material1(p,c,cc,t)$main(p,cc)..      W(p,c,t) =e= mu1(p,c)*W(p,cc,t)        ;

Material2(p,c,cc,t)$main(p,cc)..      R(p,c,t) =e= mu2(p,c)*W(p,cc,t)        ;

Material3(p,c,t)..    W(p,c,t) =e= SUM(pp,F(p,pp,c,t))+SUM(m,SALES(m,p,c,t)) ;

Material4(p,c,t)$(ord(c) gt 1)..     R(p,c,t) =e=
SUM(pp,F(pp,p,c,t))+SUM(m,PURCH(m,p,c,t)) ;

Supply(c,m,t)..       Usupply(c,m,t) =g= SUM(p,PURCH(m,p,c,t))             ;

Demand(c,m,t)..        Udemand(c,m,t) =g= SUM(p,SALES(m,p,c,t))             ;

CapitalInv(p,t)..     CAPITAL(p,t) =e= 1e6*(alpha(p)*QE(p,t))+(beta(p)*Y(p,t));

TotalInv(t)..        INVEST(t) =e= SUM(p,CAPITAL(p,t))                    ;
LIMTotalInv(t)..         INVEST(t) =l= maxinvest                          ;

Opercost(p,t,c)$main(p,c)..  OPCOST(p,t) =e= delta(p)*W(p,c,t)+(beta(p)*Y(p,t)) +
SUM(i,TRANS(i,t));

PlantOpercost(t)..  TOTALOPCOST(t) =e= sum(p,OPCOST(p,t));

Net..       NPV =e= -SUM(t$(ord(t) gt 1),INVEST(t)/(1+int)**ord(t))-
SUM((t),TOTALOPCOST(t)/(1+int)**ord(t))
              -10000000000* SUM((i,t), TRANS(i,t)/(1+int)**ord(t))
     - SUM((t,cc,m),price1(cc,t)*1e6*SUM(p,PURCH(m,p,cc,t)/(1+int)**ord(t)))
         + sum(t,Rev(t)/(1+int)**ord(t));
Reveq(t)..       Rev(t) =e= SUM((cc,m),price2(cc,t)*1e6*SUM(p,SALES(m,p,cc,t)))   ;
```

```
Flowofcorn(p,t,c)$main(p,c)..       FLOCORN(p,t) =e= W(p,c,t)*corn(p)  ;

Cornbalance(p,t)..     FLOCORN(p,t) =e= sum(kc,CORNpurchased(p,kc,t))     ;

TRcosts1(i,t)..    TRANS(i,t)-1000*z(i) =L= 0;
TRcosts2(i,t)..    TRANS(i,t)+1000*(1-z(i)) =g=
sum(kc,transcorn(i,kc)*sum(p,CORNpurchased(p,kc,t)));

location1   ..   sum(i, z(i))=e= 1;


MODEL

        GLUC    GLUC Model    /all/                              ;

SOLVE

        GLUC using mip MAXIMIZING NPV                               ;

  OPTION LIMCOL =0;
  OPTION LIMROW =0;
  option optcr=0. ;

DISPLAY

 Q.l, R.l, F.l, SALES.l,  CAPITAL.l, INVEST.l, Y.l, QE.l,
  OPCOST.l, CORNpurchased.L, flocorn.l, z.l, Rev.l, W.l, NPV.l ;
```

Appendix F:

Transportation Costs: Farm to Plants and Plants to Markets

(Corn Only)

Farm to Plant Costs per Pound (Corn Only)

City	Pheonix	Yuma	Bakersfield	Fresno	Napa	Greeley	Pueblo
Anniston	0.02717	0.03001	0.03408	0.03461	0.03510	0.02053	0.01969
Tuscaloosa	0.02540	0.02822	0.03239	0.03297	0.03548	0.01920	0.01820
Gadsden	0.02695	0.02980	0.03380	0.03431	0.03480	0.02013	0.01935
Talladega	0.02693	0.02976	0.03386	0.03441	0.03493	0.02039	0.01952
Hot Springs	0.01960	0.02246	0.02650	0.02707	0.02959	0.01433	0.01303
Los Angeles	0.00684	0.00438	0.00100	0.00195	0.00348	0.01649	0.01560
Dubuque	0.02370	0.02650	0.02873	0.02864	0.03034	0.01396	0.01480
Ottumwa	0.02160	0.02443	0.02691	0.02691	0.02876	0.01215	0.01270
Fort Wayne	0.02815	0.03101	0.03371	0.03373	0.03557	0.01836	0.01880
South Bend	0.02732	0.03016	0.03269	0.03267	0.03444	0.01819	0.01879
Columbus	0.02715	0.03003	0.03307	0.03321	0.03521	0.01893	0.01809
Monroe	0.02093	0.02371	0.02812	0.02882	0.03146	0.01687	0.01533
Detroit	0.03050	0.03334	0.03579	0.03572	0.03544	0.02033	0.02100
Grand Rapids	0.02841	0.03123	0.03353	0.03342	0.03508	0.01805	0.01882
Kalamazoo	0.02814	0.03097	0.03340	0.03333	0.03505	0.01889	0.01861
Minneapolis	0.02305	0.02570	0.02718	0.02686	0.02823	0.01247	0.01403
St. Cloud	0.02282	0.02541	0.02665	0.02625	0.02751	0.01209	0.01387
Fergus Falls	0.02206	0.02456	0.02544	0.02495	0.02608	0.01120	0.01327
Mankato	0.02198	0.02466	0.02627	0.02599	0.02745	0.01144	0.01290
Joplin	0.02249	0.02537	0.02849	0.02870	0.03080	0.01436	0.01424
Tupelo	0.02408	0.02693	0.03094	0.03147	0.03392	0.01841	0.01745
Greensboro	0.03291	0.03579	0.03728	0.03758	0.03964	0.02471	0.02448
Hickory	0.03149	0.03437	0.03601	0.03633	0.03844	0.02351	0.02318
Manchester	0.03895	0.04165	0.04395	0.04383	0.04532	0.03091	0.03164
Keene	0.03821	0.04092	0.04322	0.04311	0.04460	0.03014	0.03086
Cleveland	0.03134	0.03420	0.03492	0.03491	0.03660	0.02147	0.02197
Dayton	0.02885	0.03173	0.03466	0.03476	0.03475	0.01945	0.01969
Toledo	0.02958	0.03244	0.03503	0.03502	0.03485	0.01963	0.02017
Youngstown	0.03241	0.03528	0.03597	0.03597	0.03766	0.02259	0.02307
Findlay	0.02958	0.03244	0.03515	0.03518	0.03505	0.01980	0.02024
Tulsa	0.01774	0.01974	0.02340	0.02386	0.02627	0.01058	0.00939
Eugene	0.01810	0.01746	0.01218	0.01027	0.00781	0.01866	0.01898
Medford	0.01623	0.01538	0.00993	0.00802	0.00549	0.01812	0.01818
Greenville	0.03072	0.03359	0.03541	0.03580	0.03797	0.02313	0.02266
Dallas	0.01669	0.01863	0.02311	0.02388	0.02660	0.01290	0.01085
Fort Worth	0.01648	0.01843	0.02292	0.02369	0.02641	0.01278	0.01071
Waco	0.01656	0.01842	0.02316	0.02404	0.02685	0.01400	0.01176
Longview	0.01813	0.02089	0.02539	0.02615	0.02884	0.01478	0.01295
Lufkin	0.01830	0.02100	0.02569	0.02653	0.02930	0.01579	0.01380
Sherman	0.01680	0.01878	0.02306	0.02375	0.02640	0.01214	0.01026
Milwaukee	0.02635	0.02915	0.03137	0.03125	0.03290	0.01672	0.01760
Racine	0.02630	0.02911	0.03138	0.03128	0.03295	0.01674	0.01757
Green Bay	0.02683	0.02958	0.03145	0.03122	0.03269	0.01682	0.01801
Appleton	0.02651	0.02927	0.03118	0.03096	0.03246	0.01653	0.01768
Wasau	0.02585	0.02857	0.03027	0.02999	0.03140	0.01563	0.01696
Sheboygan	0.02684	0.02962	0.03167	0.03149	0.03305	0.01703	0.01806

Louisville	Cedar Rapids	Dubuque	Mountain Home	Danville	Peoria	Quincy
0.00387	0.01248	0.01262	0.03150	0.00889	0.01014	0.01008
0.00575	0.01215	0.01248	0.03017	0.00918	0.01003	0.00962
0.00416	0.01190	0.01203	0.03109	0.00830	0.00955	0.00951
0.00411	0.01251	0.01269	0.03137	0.00901	0.01020	0.01009
0.01185	0.00983	0.01069	0.02452	0.00945	0.00887	0.00745
0.03517	0.02775	0.02879	0.01205	0.03128	0.02936	0.02782
0.01505	0.00059	0.00000	0.02304	0.00421	0.00249	0.00326
0.01496	0.00063	0.00121	0.02180	0.00498	0.00281	0.00196
0.01091	0.00651	0.00570	0.02843	0.00262	0.00448	0.00615
0.01214	0.00528	0.00437	0.02720	0.00235	0.00360	0.00537
0.00903	0.00673	0.00630	0.02844	0.00211	0.00423	0.00544
0.01066	0.01231	0.01306	0.02683	0.01113	0.01099	0.00981
0.01239	0.00849	0.00745	0.02997	0.00538	0.00695	0.00871
0.01338	0.00614	0.00505	0.02761	0.00408	0.00502	0.00680
0.01264	0.00597	0.00496	0.02768	0.00338	0.00455	0.00633
0.01814	0.00420	0.00405	0.02045	0.00821	0.00650	0.00677
0.01936	0.00540	0.00532	0.01960	0.00949	0.00777	0.00794
0.02108	0.00708	0.00716	0.01897	0.01136	0.00954	0.00952
0.01884	0.00370	0.00389	0.01981	0.00809	0.00619	0.00615
0.01148	0.00438	0.00493	0.02438	0.00369	0.00282	0.00180
0.00716	0.01046	0.01087	0.02847	0.00789	0.00846	0.00789
0.00484	0.01420	0.01372	0.03538	0.00957	0.01169	0.01270
0.00378	0.01327	0.01290	0.03426	0.00869	0.01073	0.01158
0.01728	0.01868	0.01859	0.03801	0.01627	0.01809	0.01882
0.01670	0.01885	0.01778	0.03731	0.01546	0.01727	0.01900
0.01105	0.00969	0.00875	0.03133	0.00593	0.00782	0.00951
0.00927	0.00787	0.00721	0.02972	0.00343	0.00557	0.00704
0.01140	0.00775	0.00682	0.02951	0.00420	0.00595	0.00767
0.01101	0.01087	0.00993	0.03245	0.00704	0.00898	0.01064
0.01062	0.00799	0.00713	0.02982	0.00407	0.00600	0.00766
0.01518	0.00861	0.00971	0.02097	0.01005	0.00868	0.00692
0.03951	0.02873	0.02945	0.00711	0.03306	0.03100	0.02995
0.03906	0.02870	0.02948	0.00678	0.03296	0.03090	0.02975
0.00250	0.01339	0.01314	0.03398	0.00894	0.01084	0.01148
0.01593	0.01303	0.01408	0.02257	0.01372	0.01274	0.01107
0.01615	0.01313	0.01419	0.02243	0.01389	0.01288	0.01121
0.01654	0.01468	0.01572	0.02330	0.01521	0.01432	0.01268
0.01364	0.01277	0.01371	0.02460	0.01265	0.01202	0.01052
0.01394	0.01414	0.01506	0.02538	0.01385	0.01331	0.01185
0.01568	0.01190	0.01297	0.02205	0.01276	0.01169	0.01000
0.01426	0.00394	0.00280	0.02545	0.00363	0.00347	0.00511
0.01396	0.00390	0.00279	0.02555	0.00332	0.00324	0.00491
0.01618	0.00483	0.00367	0.02498	0.00565	0.00523	0.00666
0.01600	0.00445	0.00329	0.02479	0.00538	0.00487	0.00628
0.01729	0.00445	0.00346	0.02363	0.00650	0.00559	0.00670
0.01514	0.00456	0.00337	0.02546	0.00467	0.00448	0.00605

Evansville	Fort Wayne	Meade	Bastrop	Denton	Billings	Lexington	Clovis	Las Cruces
0.00614	0.00977	0.01624	0.00674	0.01273	0.02645	0.01732	0.02426	0.02209
0.00635	0.01054	0.01464	0.00476	0.01460	0.02541	0.01612	0.02252	0.02027
0.00555	0.00922	0.01589	0.00668	0.01254	0.02597	0.01685	0.02403	0.02193
0.00624	0.00997	0.01605	0.00645	0.01306	0.02637	0.01720	0.02403	0.02184
0.00753	0.01185	0.00853	0.00261	0.01817	0.02034	0.01077	0.01756	0.01542
0.03124	0.03362	0.01855	0.02742	0.04043	0.01824	0.02010	0.00970	0.01265
0.00654	0.00570	0.01185	0.01272	0.01558	0.01737	0.00915	0.02072	0.02038
0.00639	0.00718	0.00950	0.01097	0.01703	0.01650	0.00726	0.01860	0.01814
0.00227	0.00000	0.01619	0.01290	0.00990	0.02191	0.01444	0.02512	0.02422
0.00248	0.00072	0.01537	0.01311	0.01120	0.02061	0.01332	0.02430	0.02357
0.00116	0.00119	0.01513	0.01065	0.01035	0.02227	0.01406	0.02411	0.02292
0.00873	0.01326	0.01091	0.00018	0.01826	0.02294	0.01354	0.01813	0.01650
0.00731	0.00284	0.01872	0.01568	0.00860	0.02316	0.01656	0.02748	0.02674
0.00666	0.00249	0.01662	0.01484	0.01102	0.02080	0.01420	0.02541	0.02484
0.00589	0.00173	0.01627	0.01412	0.01078	0.02097	0.01405	0.02513	0.02447
0.01058	0.00924	0.01226	0.01598	0.01877	0.01418	0.00830	0.02022	0.02057
0.01184	0.01048	0.01252	0.01700	0.01892	0.01316	0.00827	0.02006	0.02063
0.01361	0.01242	0.01257	0.01823	0.02075	0.01138	0.00803	0.01942	0.02030
0.01024	0.00945	0.01106	0.01511	0.01822	0.01368	0.00714	0.01914	0.01944
0.00329	0.00629	0.01023	0.00785	0.01522	0.01874	0.00962	0.01945	0.01832
0.00514	0.00959	0.01295	0.00396	0.01498	0.02365	0.01427	0.02115	0.01908
0.00836	0.00841	0.02044	0.01366	0.00569	0.02935	0.02018	0.02991	0.02815
0.00713	0.00794	0.01909	0.01207	0.00716	0.02838	0.01902	0.02850	0.02669
0.01729	0.01367	0.02836	0.02374	0.00686	0.03300	0.02635	0.03608	0.03523
0.01650	0.01286	0.02759	0.02303	0.00635	0.03228	0.02557	0.03535	0.03450
0.00723	0.00335	0.01856	0.01546	0.00696	0.02462	0.01772	0.02830	0.02737
0.00417	0.00175	0.01691	0.01240	0.00869	0.02334	0.01558	0.02582	0.02470
0.00600	0.00159	0.01771	0.01436	0.00882	0.02283	0.01579	0.02655	0.02571
0.00813	0.00450	0.01963	0.01621	0.00585	0.02571	0.01890	0.02938	0.02839
0.00553	0.00152	0.01768	0.01386	0.00844	0.02323	0.01596	0.02654	0.02560
0.00909	0.01266	0.00489	0.00625	0.02017	0.01774	0.00719	0.01458	0.01301
0.03414	0.03486	0.02319	0.03347	0.04191	0.01381	0.02194	0.01807	0.02168
0.03387	0.03487	0.02244	0.03268	0.04195	0.01424	0.02162	0.01743	0.02016
0.00698	0.00859	0.01850	0.01093	0.00855	0.02831	0.01873	0.02776	0.02582
0.01208	0.01624	0.00690	0.00547	0.02255	0.01967	0.01084	0.01378	0.01117
0.01227	0.01641	0.00680	0.00569	0.02275	0.01958	0.01080	0.01357	0.01095
0.01342	0.01769	0.00814	0.00610	0.02360	0.02081	0.01232	0.01381	0.01085
0.01065	0.01503	0.00873	0.00316	0.02078	0.02128	0.01212	0.01618	0.01352
0.01172	0.01617	0.00974	0.00368	0.02149	0.02234	0.01336	0.01647	0.01357
0.01126	0.01531	0.00609	0.00539	0.02194	0.01886	0.00981	0.01379	0.01144
0.00645	0.00368	0.01456	0.01401	0.01318	0.01870	0.01194	0.02336	0.02294
0.00614	0.00344	0.01447	0.01373	0.01303	0.01883	0.01194	0.02331	0.02284
0.00848	0.00538	0.01539	0.01587	0.01418	0.01894	0.01223	0.02390	0.02376
0.00819	0.00526	0.01503	0.01551	0.01426	0.01878	0.01191	0.02357	0.02341
0.00925	0.00667	0.01462	0.01614	0.01568	0.01747	0.01117	0.02296	0.02299
0.00749	0.00436	0.01522	0.01506	0.01341	0.01857	0.01233	0.02388	0.02359

Roswell	Cincinatti	Dayton	Heppner	Dumas	El Paso	Yakima	City
0.01944	0.00745	0.00848	0.03520	0.01764	0.02167	0.03457	Anniston
0.01857	0.00846	0.00949	0.03396	0.01590	0.01983	0.03531	Tuscaloosa
0.01925	0.00693	0.00795	0.03477	0.01735	0.02152	0.03605	Gadsden
0.01919	0.00768	0.00871	0.03509	0.01742	0.02141	0.03447	Talladega
0.01256	0.01091	0.01170	0.02843	0.00969	0.01504	0.02986	Hot Springs
0.01500	0.03419	0.03449	0.01479	0.01766	0.01338	0.01661	Los Angeles
0.01864	0.00749	0.00721	0.02600	0.01433	0.02042	0.02691	Dubuque
0.01625	0.00837	0.00837	0.02500	0.01197	0.01815	0.02604	Ottumwa
0.02144	0.00253	0.00175	0.03141	0.01850	0.02411	0.03231	Fort Wayne
0.02081	0.00380	0.00316	0.03013	0.01775	0.02350	0.03100	South Bend
0.02013	0.00142	0.00190	0.03164	0.01730	0.02275	0.03266	Columbus
0.01382	0.01183	0.01275	0.03081	0.01165	0.01600	0.03229	Monroe
0.02397	0.00454	0.00351	0.03272	0.02004	0.02666	0.03349	Detroit
0.02211	0.00501	0.00412	0.03036	0.01810	0.02481	0.03114	Grand Rapids
0.02171	0.00426	0.00342	0.03051	0.01867	0.02441	0.03134	Kalamazoo
0.01811	0.01134	0.01091	0.02303	0.01474	0.02076	0.02378	Minneapolis
0.01826	0.01262	0.01216	0.02205	0.01494	0.02087	0.02275	St. Cloud
0.01809	0.01453	0.01410	0.02033	0.01487	0.02061	0.02098	Fergus Falls
0.01786	0.01137	0.01104	0.02255	0.01353	0.01963	0.02337	Mankato
0.01635	0.00629	0.00673	0.02783	0.01240	0.01818	0.02899	Joplin
0.01725	0.00782	0.00880	0.03223	0.01434	0.01869	0.03356	Tupelo
0.02540	0.00623	0.00668	0.03665	0.02220	0.02782	0.03764	Greensboro
0.02395	0.00554	0.00620	0.03566	0.02080	0.02635	0.03669	Hickory
0.03440	0.01387	0.01320	0.04027	0.03057	0.03510	0.04080	Manchester
0.03363	0.01308	0.01240	0.03959	0.02979	0.03437	0.04013	Keene
0.02458	0.00199	0.00154	0.03417	0.02075	0.02724	0.03498	Cleveland
0.02190	0.00052	0.00000	0.03280	0.01817	0.02453	0.03374	Dayton
0.02293	0.00165	0.00114	0.03237	0.01905	0.02561	0.03321	Toledo
0.02560	0.00238	0.00199	0.03526	0.02180	0.02825	0.03606	Youngstown
0.02281	0.00130	0.00078	0.03275	0.01898	0.02547	0.03362	Findlay
0.01007	0.01245	0.01302	0.02486	0.00646	0.01281	0.02630	Tulsa
0.02258	0.03439	0.03431	0.00191	0.02271	0.02251	0.00406	Eugene
0.02126	0.03428	0.03426	0.00250	0.02175	0.02098	0.00594	Medford
0.02311	0.00608	0.00689	0.03548	0.02011	0.02545	0.03657	Greenville
0.00848	0.01549	0.01624	0.02669	0.00340	0.00535	0.02828	Dallas
0.00826	0.01568	0.01643	0.02655	0.00332	0.00523	0.02815	Fort Worth
0.00841	0.01680	0.01759	0.02746	0.00380	0.00513	0.02911	Waco
0.01087	0.01397	0.01481	0.02867	0.00452	0.00650	0.03022	Longview
0.01108	0.01498	0.01585	0.02949	0.00488	0.00649	0.03108	Lufkin
0.00864	0.01468	0.01539	0.02612	0.00318	0.00552	0.02768	Sherman
0.02024	0.00601	0.00541	0.02825	0.01703	0.02295	0.02907	Milwaukee
0.02013	0.00574	0.00515	0.02838	0.01693	0.02284	0.02921	Racine
0.02111	0.00785	0.00713	0.02755	0.01789	0.02383	0.02826	Green Bay
0.02076	0.00770	0.00701	0.02740	0.01753	0.02347	0.02813	Appleton
0.02041	0.00906	0.00842	0.02615	0.01713	0.02311	0.02684	Wasau
0.02091	0.00682	0.00611	0.02813	0.01770	0.02362	0.02889	Sheboygan

Plant to Market Costs per Pound

Cities	Los Angeles	San Jose	Denver	Wilmington	Jacksonville	Atlanta	Chicago
Anniston	0.016727	0.017415	0.010245	0.006715	0.003073	0.000776	0.005388
Tuscaloosa	0.015862	0.017578	0.009549	0.007625	0.003753	0.001769	0.005712
Gadsden	0.016604	0.017268	0.010053	0.006603	0.003323	0.000888	0.005105
Talladega	0.016613	0.017322	0.010168	0.006877	0.003125	0.000922	0.005479
Hot Springs	0.012935	0.014629	0.007062	0.009278	0.006834	0.004748	0.006114
Los Angeles	0.000000	0.001470	0.007948	0.020252	0.018291	0.017444	0.016597
Dubuque	0.014394	0.015197	0.007221	0.007686	0.009140	0.006597	0.002447
Ottumwa	0.013434	0.014374	0.006268	0.008473	0.009004	0.006435	0.003330
Fort Wayne	0.016810	0.017786	0.009365	0.004885	0.007146	0.004846	0.000582
South Bend	0.016329	0.017234	0.009307	0.005500	0.007754	0.005379	0.000283
Columbus	0.016424	0.017572	0.009123	0.005229	0.006187	0.003771	0.001655
Monroe	0.013668	0.015529	0.008291	0.009394	0.005936	0.004249	0.006916
Detroit	0.017896	0.017750	0.010385	0.004094	0.007861	0.005807	0.001396
Grand Rapids	0.016790	0.017578	0.009258	0.005329	0.008379	0.006093	0.000732
Kalamazoo	0.016702	0.017550	0.009191	0.005247	0.008010	0.005705	0.000337
Minneapolis	0.013741	0.014206	0.006580	0.009202	0.010605	0.008616	0.004107
St. Cloud	0.013513	0.013868	0.006420	0.009272	0.011209	0.009249	0.004718
Fergus Falls	0.012964	0.013175	0.006011	0.010178	0.012053	0.009622	0.005689
Mankato	0.013261	0.013800	0.006047	0.009436	0.010452	0.008440	0.004251
Joplin	0.014114	0.015341	0.007276	0.007680	0.007206	0.004647	0.003199
Tupelo	0.015168	0.016813	0.009167	0.007759	0.004635	0.002396	0.005179
Greensboro	0.018450	0.019749	0.012440	0.003260	0.003792	0.002898	0.004774
Hickory	0.017796	0.019138	0.011820	0.003956	0.003454	0.002149	0.004551
Manchester	0.021993	0.022718	0.015690	0.002972	0.009291	0.009044	0.006984
Keene	0.021625	0.022356	0.015303	0.002691	0.009057	0.008720	0.006575
Cleveland	0.017427	0.018312	0.010929	0.003322	0.007163	0.005267	0.001933
Dayton	0.017243	0.017359	0.009878	0.004352	0.006322	0.004108	0.001453
Toledo	0.017492	0.017441	0.010015	0.004280	0.007378	0.005234	0.000964
Youngstown	0.017949	0.018843	0.011487	0.002742	0.007096	0.005375	0.002523
Findlay	0.017531	0.017530	0.010087	0.004135	0.006989	0.004857	0.001144
Tulsa	0.011456	0.012995	0.005194	0.010203	0.008635	0.006396	0.006344
Eugene	0.007083	0.004481	0.009394	0.020833	0.020856	0.018696	0.017032
Medford	0.005963	0.003319	0.009065	0.020879	0.020574	0.018463	0.017064
Greenville	0.017471	0.018886	0.011609	0.004664	0.002905	0.001457	0.004875
Dallas	0.011142	0.013074	0.006206	0.011476	0.008604	0.006839	0.008239
Fort Worth	0.011041	0.012979	0.006143	0.011574	0.008712	0.006950	0.008320
Waco	0.011108	0.013170	0.006720	0.012021	0.008758	0.007194	0.008990
Longview	0.012280	0.014202	0.007191	0.010620	0.007412	0.005723	0.007712
Lufkin	0.012387	0.014406	0.007666	0.010996	0.007402	0.005924	0.008307
Sherman	0.011158	0.012994	0.005857	0.011148	0.008585	0.006685	0.007751
Milwaukee	0.015721	0.016488	0.008613	0.006436	0.008802	0.006365	0.001295
Racine	0.015718	0.016510	0.008616	0.006373	0.008652	0.006212	0.001191
Green Bay	0.015821	0.016420	0.008709	0.006873	0.009285	0.007362	0.002110
Appleton	0.015678	0.016299	0.008557	0.006924	0.009193	0.007249	0.002056
Wasau	0.015256	0.015787	0.008132	0.007622	0.009800	0.007854	0.002766
Sheboygan	0.015900	0.016583	0.008790	0.006513	0.009253	0.006845	0.001603

Indianapolis	Fort Wayne	Bedford	Bowling Green	Madisonville	Shreveport	Boston
0.004048	0.004885	0.003478	0.001601	0.002604	0.004449	0.009821
0.004339	0.005268	0.003749	0.001911	0.002695	0.003458	0.010619
0.003759	0.004608	0.003187	0.001306	0.002308	0.004414	0.009676
0.004130	0.004983	0.003555	0.001665	0.002647	0.004302	0.009970
0.004963	0.005927	0.004507	0.003691	0.003521	0.001382	0.012242
0.016249	0.016810	0.016129	0.016215	0.015655	0.012753	0.022143
0.002803	0.002850	0.003134	0.004744	0.003713	0.006725	0.009457
0.003212	0.003592	0.003340	0.004562	0.003545	0.005718	0.009999
0.000497	0.000000	0.000779	0.003371	0.002685	0.007205	0.007181
0.000646	0.000359	0.000937	0.003768	0.002940	0.007223	0.007535
0.000182	0.000596	0.000205	0.002188	0.001519	0.006138	0.007999
0.005636	0.006629	0.005101	0.003778	0.003994	0.000494	0.012593
0.002393	0.001419	0.002917	0.004587	0.004037	0.008616	0.005858
0.002104	0.001247	0.002695	0.004570	0.003789	0.008083	0.006948
0.001709	0.000866	0.002300	0.004174	0.003399	0.007738	0.007086
0.004772	0.004621	0.005146	0.006756	0.005722	0.008165	0.009830
0.005412	0.005242	0.005787	0.007386	0.006350	0.008621	0.010215
0.006358	0.006211	0.006713	0.008256	0.007220	0.009139	0.011006
0.004749	0.004724	0.005065	0.006567	0.005531	0.007677	0.010228
0.002327	0.003146	0.002122	0.002801	0.001852	0.004404	0.009802
0.003821	0.004797	0.003240	0.001666	0.002118	0.003013	0.010597
0.004064	0.004207	0.003868	0.003463	0.004050	0.007887	0.007036
0.003650	0.003970	0.003361	0.002711	0.003380	0.007094	0.007679
0.007611	0.006837	0.007937	0.008876	0.008849	0.012782	0.000961
0.007208	0.006429	0.007539	0.008506	0.008461	0.012422	0.001123
0.002469	0.001677	0.002874	0.004283	0.003921	0.008585	0.005556
0.001049	0.000874	0.001349	0.002835	0.002386	0.007047	0.007052
0.001742	0.000796	0.002258	0.003945	0.003378	0.007965	0.006393
0.002981	0.002250	0.003335	0.004580	0.004328	0.008994	0.005066
0.001558	0.000760	0.002016	0.003617	0.003112	0.007743	0.006478
0.005492	0.006329	0.005196	0.005010	0.004490	0.002701	0.012827
0.017222	0.017432	0.017333	0.017164	0.017285	0.016017	0.021723
0.017167	0.017437	0.017241	0.017919	0.017122	0.015574	0.021939
0.003820	0.004295	0.003435	0.002381	0.003215	0.006537	0.008394
0.007187	0.008119	0.006770	0.005986	0.005825	0.001697	0.014410
0.007276	0.008205	0.006863	0.006092	0.005924	0.001805	0.014500
0.007895	0.008844	0.007452	0.006524	0.006462	0.001974	0.015041
0.006545	0.007517	0.006071	0.005044	0.005039	0.000508	0.013689
0.007105	0.008086	0.006608	0.005446	0.005544	0.000881	0.014143
0.006740	0.007655	0.006348	0.005693	0.005448	0.001771	0.014011
0.002259	0.001839	0.002782	0.004646	0.003708	0.007539	0.008057
0.002108	0.001719	0.002628	0.004491	0.003553	0.007412	0.008068
0.003249	0.002691	0.003787	0.005658	0.004720	0.008414	0.008010
0.003140	0.002632	0.003667	0.005527	0.004578	0.008228	0.008143
0.003770	0.003336	0.004267	0.006087	0.005104	0.008456	0.008677
0.002731	0.002181	0.003275	0.005153	0.004229	0.008051	0.007875

Baltimore	Bangor	Detroit	Lansing	Minneapolis	St. Louis	Jackson	Charlotte
0.006249	0.010768	0.005986	0.006079	0.008309	0.004186	0.002478	0.002873
0.007157	0.011583	0.006497	0.006476	0.008176	0.003914	0.001486	0.003861
0.006135	0.010632	0.005729	0.005805	0.008016	0.003908	0.002508	0.002851
0.006411	0.010919	0.006104	0.006181	0.008334	0.004179	0.002321	0.003034
0.009310	0.013251	0.007345	0.006976	0.006834	0.003031	0.002183	0.006574
0.019895	0.023064	0.017896	0.017197	0.013741	0.014114	0.014700	0.018056
0.007368	0.009967	0.003726	0.002961	0.002023	0.002464	0.006633	0.006868
0.008116	0.010993	0.004701	0.003991	0.002513	0.001852	0.005904	0.007086
0.004542	0.008247	0.001419	0.001208	0.004621	0.003146	0.006257	0.004393
0.005181	0.008593	0.001677	0.001097	0.003905	0.002951	0.006473	0.005079
0.004820	0.009066	0.002517	0.002399	0.005130	0.002452	0.005080	0.003718
0.009421	0.013585	0.008016	0.007768	0.008148	0.004099	0.001090	0.006307
0.003853	0.006918	0.000000	0.000401	0.005109	0.004535	0.007587	0.004849
0.005070	0.007992	0.000623	0.000223	0.003874	0.003770	0.007336	0.005552
0.004958	0.008140	0.000629	0.000293	0.004006	0.003467	0.006953	0.005221
0.008943	0.010752	0.005109	0.004309	0.000000	0.004286	0.008411	0.008842
0.009038	0.011116	0.005667	0.004872	0.000321	0.004872	0.008962	0.009481
0.009950	0.011885	0.006624	0.005832	0.000798	0.005652	0.009168	0.009908
0.009154	0.011165	0.005364	0.004561	0.000301	0.003972	0.008029	0.008812
0.007267	0.010817	0.004535	0.004048	0.004286	0.000000	0.004172	0.005568
0.007292	0.011583	0.006117	0.005990	0.007328	0.003044	0.000736	0.004274
0.002816	0.007968	0.004444	0.004993	0.008777	0.005824	0.006034	0.000387
0.003498	0.008638	0.004459	0.004902	0.008419	0.005200	0.005244	0.000213
0.003416	0.001738	0.005602	0.006336	0.009842	0.009436	0.011313	0.007005
0.003118	0.002050	0.005193	0.005929	0.009469	0.009052	0.010973	0.006706
0.003040	0.006624	0.000878	0.001620	0.005904	0.004772	0.007365	0.004090
0.003964	0.008118	0.001757	0.001904	0.005453	0.003365	0.005873	0.003520
0.003978	0.007459	0.000659	0.000870	0.004993	0.003941	0.006930	0.004446
0.002479	0.006132	0.001376	0.002163	0.006467	0.005302	0.007680	0.003978
0.003803	0.007546	0.000974	0.001247	0.005244	0.003842	0.006637	0.004064
0.009791	0.013842	0.007707	0.007169	0.005860	0.003184	0.004059	0.008004
0.020568	0.022518	0.017168	0.017359	0.013289	0.015530	0.017686	0.019721
0.020597	0.022761	0.017242	0.017439	0.013414	0.015379	0.017306	0.019579
0.004208	0.009352	0.004956	0.005321	0.008574	0.005066	0.004626	0.000721
0.011042	0.015422	0.009058	0.009094	0.008120	0.005049	0.003762	0.008796
0.011140	0.015512	0.009139	0.009174	0.008155	0.005127	0.003872	0.008905
0.011583	0.016049	0.009749	0.009357	0.008955	0.005816	0.004002	0.009227
0.010180	0.014694	0.008933	0.008575	0.008195	0.004615	0.002582	0.007738
0.010553	0.015142	0.009497	0.009169	0.008886	0.005253	0.002698	0.008005
0.010718	0.015024	0.009065	0.008601	0.007542	0.004553	0.003741	0.008571
0.006153	0.009091	0.002384	0.001593	0.002818	0.003135	0.007078	0.006196
0.006082	0.009107	0.002347	0.001569	0.002915	0.003010	0.006931	0.006059
0.006645	0.009005	0.002792	0.002018	0.002389	0.004025	0.008057	0.007083
0.006684	0.009144	0.002833	0.002044	0.002300	0.003843	0.007890	0.007022
0.007392	0.009171	0.003540	0.002759	0.001676	0.004148	0.008283	0.007716
0.006262	0.008891	0.002419	0.001621	0.002690	0.003648	0.007611	0.006573

Durham	Wilmington	Albuquerque	Reno	Massena	Schenectady	Cincinatti	Dayton
0.006016	0.004348	0.010726	0.017307	0.009306	0.008633	0.003725	0.004239
0.006715	0.005343	0.009869	0.016545	0.009556	0.009470	0.004230	0.004743
0.006015	0.004398	0.010603	0.017134	0.009116	0.008478	0.003463	0.003977
0.006121	0.004496	0.010615	0.017218	0.009455	0.008790	0.003838	0.004353
0.008932	0.008228	0.007300	0.013614	0.010883	0.010659	0.005454	0.005851
0.019456	0.019597	0.006318	0.003673	0.020544	0.020904	0.017093	0.017243
0.008882	0.008467	0.009459	0.013763	0.007702	0.008090	0.003744	0.003603
0.009177	0.008774	0.008322	0.012998	0.008802	0.009091	0.004185	0.004187
0.006729	0.005821	0.011132	0.016396	0.005602	0.005628	0.001263	0.000874
0.007273	0.006534	0.010733	0.015821	0.005873	0.006054	0.001902	0.001578
0.006396	0.005330	0.010611	0.016251	0.006540	0.006365	0.000708	0.000949
0.008691	0.007823	0.008129	0.014608	0.011362	0.010980	0.005914	0.006375
0.006843	0.005963	0.012326	0.017292	0.004216	0.004390	0.002272	0.001757
0.007537	0.006871	0.011306	0.016122	0.005222	0.005566	0.002503	0.002062
0.007311	0.006586	0.011156	0.016115	0.005398	0.005646	0.002128	0.001709
0.010045	0.009875	0.009320	0.012675	0.008529	0.009202	0.005671	0.005453
0.010590	0.010477	0.009290	0.012310	0.008931	0.009186	0.006308	0.006082
0.011430	0.011390	0.009037	0.011587	0.009276	0.010031	0.007265	0.007048
0.010068	0.009892	0.008737	0.012292	0.008955	0.009085	0.005686	0.005520
0.007977	0.007303	0.008718	0.014075	0.008744	0.008734	0.003145	0.003365
0.007048	0.005889	0.009166	0.015745	0.009416	0.009451	0.003911	0.004402
0.002292	0.000809	0.013514	0.018573	0.006346	0.005385	0.003115	0.003341
0.002365	0.001052	0.012812	0.017986	0.006859	0.005999	0.002768	0.003098
0.007704	0.006592	0.017623	0.021307	0.002083	0.001213	0.006935	0.006599
0.007498	0.006374	0.017234	0.020948	0.001797	0.000804	0.006541	0.006200
0.006235	0.005111	0.012724	0.017914	0.004077	0.003965	0.000997	0.000769
0.006118	0.004958	0.011468	0.016970	0.005614	0.005416	0.000258	0.000000
0.006639	0.005699	0.011855	0.016994	0.004806	0.004860	0.000825	0.000568
0.006053	0.004816	0.013258	0.017503	0.003685	0.003437	0.001190	0.000993
0.006385	0.005347	0.011842	0.017108	0.004955	0.004897	0.000649	0.000392
0.009661	0.009235	0.005771	0.011915	0.011325	0.011314	0.006224	0.006510
0.020959	0.021275	0.009758	0.003468	0.020090	0.020833	0.017193	0.017155
0.020848	0.021143	0.009116	0.002427	0.020301	0.020986	0.017138	0.017129
0.004879	0.002363	0.012450	0.017773	0.007559	0.006714	0.003042	0.003447
0.010357	0.009874	0.005514	0.012237	0.013013	0.012838	0.007743	0.008119
0.010452	0.009979	0.005412	0.012148	0.013098	0.012930	0.007839	0.008213
0.010724	0.010229	0.005629	0.012428	0.013678	0.013455	0.008400	0.008797
0.009449	0.009293	0.006705	0.013341	0.012367	0.012094	0.006987	0.007404
0.009664	0.009495	0.006914	0.013612	0.012860	0.012538	0.007490	0.007926
0.010165	0.009697	0.005464	0.012094	0.012586	0.012451	0.007339	0.007697
0.008182	0.007659	0.010300	0.015032	0.006303	0.006707	0.003007	0.002703
0.008079	0.007534	0.010267	0.015062	0.006325	0.006696	0.002868	0.002577
0.008867	0.008471	0.010607	0.014912	0.006203	0.006818	0.003926	0.003564
0.008836	0.008435	0.010441	0.014798	0.006341	0.006926	0.003850	0.003506
0.009456	0.009149	0.010166	0.014263	0.006861	0.007531	0.004531	0.004209
0.008449	0.007980	0.010575	0.015099	0.006090	0.006602	0.003408	0.003055

Columbus	Toledo	Oklahoma City	Portland	Pittsburgh	Erie	Philadelphia	Greenville
0.004495	0.005374	0.006470	0.018016	0.005454	0.006308	0.006941	0.002155
0.005107	0.005856	0.005602	0.017422	0.006211	0.006986	0.007850	0.003140
0.004257	0.005112	0.006328	0.017812	0.005262	0.006092	0.006828	0.002130
0.004624	0.005487	0.006359	0.017959	0.005602	0.006448	0.007103	0.002316
0.006451	0.006703	0.002497	0.015609	0.007865	0.008311	0.009475	0.005883
0.017882	0.017492	0.010600	0.007867	0.018243	0.018179	0.020401	0.017471
0.004172	0.003409	0.005793	0.014398	0.005421	0.005117	0.007810	0.006569
0.004828	0.004278	0.004590	0.013913	0.006205	0.006057	0.008618	0.006676
0.001331	0.000796	0.007375	0.017104	0.002614	0.002567	0.005027	0.004295
0.002039	0.001237	0.007115	0.016457	0.003234	0.003010	0.005629	0.004942
0.001601	0.001858	0.006613	0.017233	0.003075	0.003396	0.005406	0.003458
0.006898	0.007358	0.003576	0.016786	0.008208	0.008808	0.009601	0.005587
0.001589	0.000659	0.008748	0.017735	0.001969	0.001395	0.004186	0.004956
0.002296	0.001187	0.007867	0.016556	0.003144	0.002637	0.005427	0.005509
0.002014	0.000988	0.007615	0.016643	0.003012	0.002640	0.005359	0.005152
0.005943	0.004993	0.006606	0.012885	0.007008	0.006472	0.009294	0.008574
0.006559	0.005586	0.006904	0.012383	0.007589	0.007012	0.009353	0.009215
0.007529	0.006555	0.007181	0.011510	0.008553	0.007957	0.010255	0.009639
0.006055	0.005178	0.006031	0.012657	0.007207	0.006748	0.009064	0.008499
0.004037	0.003941	0.004231	0.015334	0.005512	0.005692	0.007858	0.005066
0.004865	0.005461	0.004820	0.017526	0.006116	0.006778	0.007978	0.003567
0.002987	0.004125	0.009411	0.019666	0.002869	0.003944	0.003486	0.001440
0.002899	0.004038	0.008660	0.019171	0.003170	0.004206	0.004183	0.000715
0.005952	0.006071	0.013442	0.021392	0.004506	0.004273	0.002748	0.007621
0.005556	0.005663	0.013060	0.021055	0.004117	0.003865	0.002472	0.007307
0.000527	0.000484	0.009000	0.017497	0.001110	0.000932	0.003437	0.004275
0.000337	0.000568	0.007555	0.017804	0.002147	0.002461	0.004519	0.003447
0.000573	0.000000	0.008168	0.017575	0.002029	0.001799	0.004401	0.004477
0.000692	0.000779	0.009044	0.018013	0.000631	0.000587	0.002852	0.004259
0.000387	0.000194	0.008072	0.017769	0.001863	0.001851	0.004272	0.004089
0.007171	0.007123	0.000524	0.013828	0.008644	0.008875	0.010384	0.007359
0.017696	0.017932	0.013371	0.000483	0.018814	0.018408	0.020929	0.019266
0.017686	0.017973	0.012967	0.001041	0.018845	0.018492	0.020984	0.019099
0.003369	0.004477	0.008263	0.019086	0.003824	0.004834	0.004891	0.000000
0.008736	0.008908	0.001725	0.014687	0.009657	0.010041	0.011674	0.008088
0.008832	0.008996	0.001713	0.014614	0.009750	0.010128	0.011771	0.008198
0.009397	0.009146	0.002495	0.015051	0.010264	0.010693	0.012223	0.008510
0.007985	0.008287	0.002481	0.015695	0.009369	0.009372	0.010823	0.007023
0.008485	0.008846	0.003034	0.016092	0.009346	0.009862	0.011202	0.007284
0.008326	0.008448	0.001216	0.014418	0.009282	0.009628	0.011342	0.007875
0.003139	0.002182	0.006993	0.015509	0.004207	0.003779	0.006543	0.006031
0.003030	0.002105	0.006909	0.015576	0.004134	0.003742	0.006485	0.005887
0.003897	0.002814	0.007629	0.015137	0.004747	0.004115	0.006953	0.006967
0.003869	0.002809	0.007436	0.015067	0.004772	0.004178	0.007009	0.006887
0.004590	0.003534	0.007420	0.014433	0.005489	0.004863	0.007701	0.007557
0.003414	0.002361	0.007416	0.015440	0.004340	0.003785	0.006604	0.006449

Charleston	Memphis	Ft. Worth	Austin	Dallas	Houston	Fredericksburg
0.003264	0.002450	0.006174	0.006946	0.006063	0.005815	0.005427
0.004217	0.001770	0.005201	0.005948	0.005090	0.004828	0.006354
0.003387	0.002269	0.006107	0.006946	0.005996	0.005850	0.005327
0.003392	0.002365	0.006035	0.006791	0.005925	0.005655	0.005589
0.007250	0.001714	0.002417	0.003750	0.002314	0.003214	0.008629
0.018778	0.014481	0.011041	0.011078	0.011142	0.012339	0.019465
0.008362	0.004843	0.007097	0.008763	0.007039	0.008522	0.007144
0.008467	0.004172	0.005942	0.007626	0.005890	0.007468	0.007784
0.005987	0.004631	0.008205	0.009190	0.008119	0.009040	0.004294
0.006663	0.004763	0.008077	0.009131	0.007997	0.009071	0.004980
0.005234	0.003504	0.007268	0.008661	0.007175	0.007953	0.004364
0.006673	0.002001	0.002782	0.003495	0.002673	0.002505	0.008664
0.006450	0.006015	0.009139	0.010538	0.009058	0.009924	0.003876
0.007159	0.005632	0.008894	0.009927	0.008817	0.009435	0.005017
0.006824	0.005260	0.008594	0.009624	0.008515	0.009107	0.004841
0.009843	0.006660	0.008155	0.009366	0.008120	0.009361	0.008845
0.010452	0.007229	0.008503	0.009694	0.008475	0.009755	0.009441
0.011341	0.007961	0.008841	0.009998	0.008825	0.010170	0.009890
0.009780	0.006308	0.007600	0.009303	0.007569	0.009337	0.009001
0.006820	0.002389	0.005127	0.006685	0.005049	0.006245	0.006771
0.004899	0.000842	0.004631	0.005602	0.004522	0.004625	0.006540
0.002092	0.005412	0.009494	0.009932	0.009385	0.009376	0.001952
0.002024	0.004637	0.008708	0.009178	0.008599	0.008586	0.002651
0.007930	0.010232	0.014031	0.015246	0.013938	0.014400	0.004279
0.007685	0.009871	0.013659	0.014884	0.013567	0.014049	0.003984
0.005671	0.005920	0.009243	0.010567	0.009156	0.009863	0.003006
0.005118	0.004386	0.008213	0.009110	0.008119	0.008847	0.003598
0.006056	0.005357	0.008996	0.009930	0.008908	0.009303	0.003856
0.005510	0.006313	0.009687	0.010977	0.009598	0.010231	0.002532
0.005675	0.005107	0.008833	0.009744	0.008743	0.009081	0.003607
0.008880	0.003240	0.002298	0.004001	0.002260	0.004095	0.009237
0.020815	0.016818	0.014508	0.015238	0.014586	0.016319	0.020375
0.020621	0.016534	0.014013	0.014643	0.014096	0.015764	0.020363
0.000899	0.004191	0.008198	0.009076	0.008088	0.007967	0.003356
0.009307	0.004003	0.000055	0.000871	0.000000	0.001030	0.010389
0.009418	0.004109	0.000000	0.000852	0.000055	0.001049	0.010489
0.009131	0.004557	0.000402	0.000454	0.000418	0.000749	0.010903
0.008165	0.003093	0.000652	0.001095	0.000599	0.000835	0.009493
0.008302	0.003557	0.000780	0.000896	0.000740	0.000497	0.009842
0.009176	0.003719	0.000309	0.001159	0.000289	0.001279	0.010087
0.007771	0.005300	0.008156	0.009283	0.008087	0.009380	0.006028
0.007631	0.005156	0.008052	0.009178	0.007982	0.009255	0.005938
0.008677	0.006269	0.008905	0.010028	0.008844	0.009729	0.006636
0.008610	0.006100	0.008713	0.009846	0.008651	0.009551	0.006650
0.009296	0.006486	0.008794	0.009949	0.008741	0.009741	0.007372
0.008163	0.005832	0.008626	0.009742	0.008560	0.009394	0.006209

Charlottesville	Rutland	Seattle	Spokane	Martinsburg	
0.004878	0.009312	0.018131	0.017206	0.005642	Anniston
0.005796	0.009636	0.017587	0.016659	0.006515	Tuscaloosa
0.004770	0.009155	0.017915	0.016973	0.005505	Gadsden
0.005040	0.009468	0.018083	0.017160	0.005801	Talladega
0.008061	0.011255	0.015871	0.014025	0.008557	Hot Springs
0.018993	0.021324	0.009159	0.008932	0.019178	Los Angeles
0.006744	0.008542	0.014216	0.012208	0.006609	Dubuque
0.007331	0.009101	0.013834	0.011843	0.007332	Ottumwa
0.003907	0.006179	0.016905	0.014895	0.003770	Fort Wayne
0.004610	0.006564	0.016243	0.014232	0.004424	South Bend
0.003873	0.006969	0.017124	0.015124	0.004023	Columbus
0.008095	0.011602	0.017098	0.015281	0.008720	Monroe
0.003658	0.004888	0.017441	0.015431	0.003189	Detroit
0.004730	0.006020	0.016273	0.014263	0.004372	Grand Rapids
0.004520	0.006132	0.016390	0.014379	0.004232	Kalamazoo
0.008505	0.009068	0.012593	0.010582	0.008233	Minneapolis
0.009112	0.009484	0.012057	0.010049	0.008816	St. Cloud
0.009579	0.010305	0.011157	0.009151	0.009292	Fergus Falls
0.008630	0.009438	0.012422	0.010410	0.008421	Mankato
0.006253	0.009307	0.015346	0.013378	0.006471	Joplin
0.005971	0.009606	0.017688	0.015778	0.006592	Tupelo
0.001485	0.006062	0.019581	0.017687	0.002407	Greensboro
0.002126	0.006680	0.019123	0.017237	0.002981	Hickory
0.004782	0.000854	0.020961	0.019088	0.003984	Manchester
0.004470	0.000555	0.020633	0.018758	0.003644	Keene
0.002780	0.004537	0.017244	0.016191	0.002339	Cleveland
0.003159	0.006021	0.017638	0.015630	0.003170	Dayton
0.003549	0.005398	0.017328	0.015316	0.003245	Toledo
0.002387	0.004035	0.017750	0.016726	0.001819	Youngstown
0.003263	0.005465	0.017545	0.015534	0.003043	Findlay
0.009174	0.011865	0.014090	0.012251	0.009044	Tulsa
0.019998	0.021088	0.002359	0.003482	0.019895	Eugene
0.019967	0.021270	0.003482	0.004259	0.019911	Medford
0.002839	0.007395	0.019082	0.017208	0.003695	Greenville
0.009849	0.013427	0.015125	0.013416	0.010328	Dallas
0.009949	0.013517	0.015059	0.013356	0.010425	Fort Worth
0.010362	0.014053	0.015547	0.013889	0.010883	Waco
0.009423	0.012700	0.016085	0.014330	0.009487	Longview
0.009301	0.013152	0.016523	0.014800	0.009877	Lufkin
0.009550	0.013031	0.014815	0.013073	0.009994	Sherman
0.005689	0.007147	0.015256	0.013244	0.005426	Milwaukee
0.005589	0.007148	0.015334	0.013323	0.005348	Racine
0.006358	0.007177	0.014807	0.012800	0.005974	Green Bay
0.006358	0.007298	0.014752	0.012744	0.006000	Appleton
0.007082	0.007869	0.014096	0.012090	0.006717	Wasau
0.005909	0.007001	0.015143	0.013133	0.005568	Sheboygan

Appendix G:

Taxes by Location

Cities	States	State sale	Property
Anniston	Alabama	4	**30**
Tuscaloosa	Alabama	4	**30**
Gadsden	Alabama	4	**30**
Talladega	Alabama	4	**30**
	Alaska	None	
	Arizona	5.6	
Hot Springs	Arkansas	5.125	**20**
Los Angeles	California	7.25	**30**
	Colorado	2.9	
	Conneticut	6	
	Deleware	None	
	Florida	6	
	Georgia	4	
	Haiwai	4	
	Idaho	5	
	Illinois	6.25	
Fort Wayne	Indiana	6	**33**
South Bend	Indiana	6	**33**
Columbus	Indiana	6	**33**
Ottumwa	Iowa	5	**23**
Dubuque	Iowa	5	**23**
	Kansas	5.3	
	Kentucky	6	
Monroe	Louisiana	4	**25**
	Maine	5	
	Maryland	5	
	Massachusetts	5	
Detroit	Michigan	6	**34**
Grand Rapids	Michigan	6	**34**
Kalamazoo	Michigan	6	**34**
Minneapolis	Minnesota	6.5	**34**
St. Cloud	Minnesota	6.5	**34**
Fergus Falls	Minnesota	6.5	**34**
Mankato	Minnesota	6.5	**34**
Tupelo	Mississippi	7	**34**
Joplin	Missouri	4.225	**25**
	Montana	0	
	Nebraska	5.5	
	Nevada	6.5	
Manchester	New Hampshire	0	**58**
Keene	New Hampshire	0	**58**
	New Jersey	6	
	New Mexico	5	
	New York	4	
Greensboro	North Carolina	4.5	**34**
Hickory	North Carolina	4.5	**34**

	North Dakota	5	
Cleveland	Ohio	5	**25**
Dayton	Ohio	5	**25**
Toledo	Ohio	5	**25**
Youngstown	Ohio	5	**25**
Findlay	Ohio	5	**25**
Tulsa	Oklahoma	4.5	**34**
Eugene	Oregon	0	**34**
Medford	Oregon	0	**34**
	Pennsylvania	6	
	Rhode Island	7	
Greenville	South Carolina	5	**34**
	South Dakota	4	
	Tennessee	7	
Dallas	Texas	6.25	**34**
Fort Worth	Texas	6.25	**34**
Waco	Texas	6.25	**34**
Longview	Texas	6.25	**34**
Lufkin	Texas	6.25	**34**
Sherman	Texas	6.25	**34**
	Utah	4.75	
	Vermont	5	
	Virginia	3.5	
	Washington	6.5	
	West Virginia	6	
Milwaukee	Wisconsin	5	**34**
Racine	Wisconsin	5	**34**
Green Bay	Wisconsin	5	**34**
Appleton	Wisconsin	5	**34**
Wasau	Wisconsin	5	**34**
Sheboygan	Wisconsin	5	**34**
	Wyoming	4	
	Washington DC	5.75	