Ethyl Lactate Production

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1. Project Statement

Ethyl lactate is an environmentally benign solvent, whose effectiveness can be compared to other petroleum-based chemicals. The purpose of this project is to determine the economic possibilities of ethyl lactate production using agricultural products as raw materials. A production plant is designed and a planning model is used to determine the plant sizes, locations, and target markets.

1.1 Project Objectives

Three objectives were required to evaluate the varying scenarios for ethyl lactate production. First, an analysis on the validity of ethyl lactate entering the solvent market needed to be established. Next, information regarding process design and economic evaluations had to be performed. Finally, a mathematical model was constructed to determine plant locations, plant sizes, and a strategy to enter into the ethyl lactate wholesale market. This report is structured as follows:

- Solvent Market Analysis
  - Comparison of ethyl lactate properties to the properties of petroleum-based solvents and other degreasing agents
  - Discussion of environmental impact and life cycle analysis of solvents
- Model Considerations
  - Locations for possible raw materials, production plants, and markets
  - Changes in market demands and price fluctuations
  - Fixed capital investment versus capacity data
  - Operating costs
- Mathematical Model Setup
- Results and Conclusions

2.0 Solvent market analysis

The worldwide solvent market is 33 billion lbs/yr, of which approximately 11 billion lbs are used domestically. Almost all manufacturing and processing industries depend on the use of solvents. This large consumption means that eventually some products will leach into the ecosystem, most critically resulting in contamination of large amounts of water.

Many petroleum-based solvents have the drawbacks of high toxicity and cause ozone depletion. Some examples include the dry cleaning industry's use of the toxic solvent perchlorethylene and degreasers such as trichlorethane and acetone. Green solvents, such as ethyl lactate, are those produced from renewable resources and are neither toxic nor ozone depleting. In addition to the environmental benefits of these solvents, the economical savings from cheaper disposal make them an attractive alternative.

Ethyl lactate is produced in three different qualities – higher selling price denoting increased purity. At \$1.60-\$2.10 per pound, ethyl lactate has served as a specialty chemicals and high-end electronics with a market size of 20 million pounds per year. Specialty applications, including those for electronics, semiconductors, water-based coatings, etc., require a lower cost at about \$1.25 per pound, with a market of 120 million pounds per year. At \$0.85-\$1.00 per pound ethyl lactate has begun to be used in general-purpose industrial and household cleaners and degreasers with a market of 5 billion pounds per year worldwide and 1-2 billion pounds in the United States.

2.1 Comparisons between ethyl lactate and petroleum-based solvents

Organic solvents are beneficial in terms of health and safety aspects. Common solvents are both toxic and flammable, while ethyl lactate is not found on Environmental Protection Agency's (EPA) Toxic Release Inventory (TRI) or listed in the Hazardous Air Pollutant (HAP) section. Additionally, ethyl lactate is not an ozone depleter, is biodegradable, and is not a volatile organic compound (VOC). Finally, ethyl lactate has certain solvating properties that are comparable to traditional solvents used. The following table shows solvating properties of ethyl lactate compared to N-methylpyrrolidone, which shares properties with typical solvents used in industry.

	Ethyl Lactate	**N-methylpyrrolidone**
SOLVATING PROPERTIES		
Kauri Butanol(KB) Value	>1000	350
Solubility Parameters		
Hildebrand	21.3	23.1
Hansen		
Disperse	7.8	8.8
Polar	3.7	6.0
Hydrogen	6.1	3.5
Solubility	Miscible in Water and Hydrocarbons	Miscible in Water and Hydrocarbons

Table 1: Solvating properties of ethyl lactate and NMP

3.0 Planning Model

A mathematical model to plan the enterprise was constructed. This plan includes the following information:

- Raw Material Converions and Location
- Market Locations and Demand for Each location
- Plant Location
- Fixed Capital Investment Versus Capacity

3.1 Raw material selection and locations

Six different types of raw materials were considered based on their product conversion comparison including oats, corn, wheat, rice, barley and sugar beets. Ethanol and lactic acid conversion factors were found from USDA website. ProII was then used to calculate how much raw material in mass basis needed to produce a fixed amount of ethyl lactate. Once the amount of raw material was found, the total conversion was calculated for each type of grains as follows:

Material	Ethyl lactate lb/hr	Mass conv lbm/lbm
Corn	7.11E+05	0.241
Wheat	7.37E+05	0.232
Rice	1.98E+06	0.086
Beet	2.64E+06	0.065
Barley	9.18E+05	0.186
Oat	1.01E+06	0.170

Table 2: conversion rates from grains to ethyl lactate.

The raw material chosen for an ethyl lactate production process was corn. Oats was also a viable option due to its low price and availability close to possible plant locations. However, corn contains a higher conversion factor to sugars. Essentially, less corn is required for the same level of ethyl lactate production than oats is required. Current operating costs for corn milling are less than operating costs for oat milling, since corn milling requires less throughput. A table relates the differing annual operating costs (including equipment-dependent costs) based on varying the raw material selection. These costs were calculated using SuperPro simulation at different product capacities:

Product capacity	48.8 million	117 million	175 million	292 million
Corn	$1,909,000	$8,219,000	$12,248,000	$19,828,000
Oats	$5,598,000	$10,172,000	$14,747,000	$24,075,000

Table 3: Annual Operating Cost for Milling Processes based on Raw Material

While the price for oats is $0.055 per kg compared to the price for corn ($0.067 per kg), the break-even point where the price for the raw material would outweigh the price for operation would be 561 million pounds of ethyl lactate production. Thus, since all major processes in the United States operate below 561 million pounds of production, corn as a raw material is a more economic option. Even if a process that required over 561 million pounds of production could be accomplished, the chances for acquiring this amount of oats in a close proximity are unlikely. For all these reasons, corn was selected as the optimum raw material.

The United States Department of Agriculture (USDA) and the National Agricultural Statistics Service (NASS) provided a database of estimated crop yield for the county, state, and national level on a yearly basis for the five types of raw materials. Figure 1 shows the detailed production for Corn.

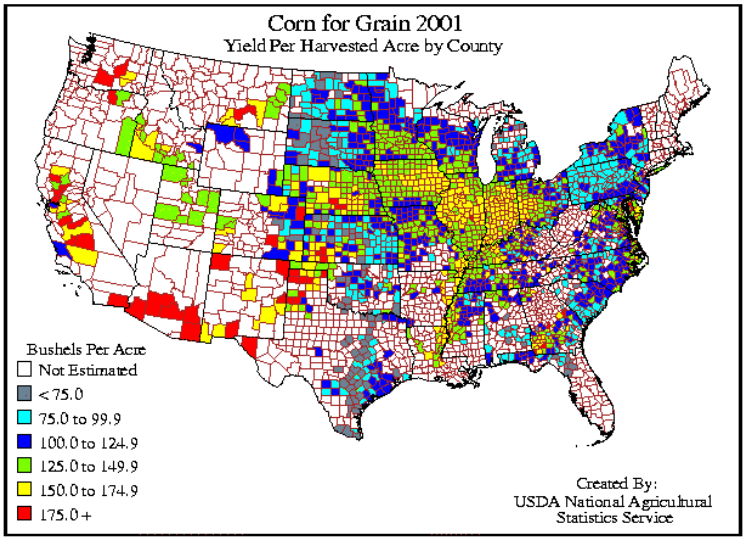

Figure 1: Corn production harvested in the United States in 2001. Source: USDA-NASS.

3.2 Market Locations

Locations for potential wholesale markets were determined by identifying companies that would purchase ethyl lactate as a degreaser. In particular, companies specializing in motor vehicles (and their parts), computer equipment, aircraft (and parts), and electronic equipment were considered for ethyl lactate purchasing. Industry Week and Special Issues listed information pertaining to wholesale markets. The cities where these types of companies were located were chosen for potential ethyl lactate wholesale markets.

City	State	City	State	City	State	City	State	City	State
Los Angeles	CA	Bowling Green	KY	Jackson	MS	Columbus, OH	OH	Ft. Worth	TX
San Jose	CA	Madisonville	KY	Charlotte	NC	Toledo	OH	Austin	TX
Denver	CO	Shreveport	LA	Durham	NC	Oklahoma City	OK	Dallas	TX
Wilmington	DE	Boston	MA	Wilmington	NC	Portland	OR	Houston	TX
Jacksonville	FL	Baltimore	MD	Albuquerque	NM	Pittsburgh	PA	Fredericksburg	VA
Atlanta	GA	Bangor	ME	Reno	NV	Erie	PA	Charlottesville	VA
Chicago	IL	Detroit	MI	Massena	NY	Philadelphia	PA	Rutland	VT
Indianapolis	IN	Lansing	MI	Schenectady	NY	Greenville	SC	Seattle	WA
Fort Wayne	IN	Minneapolis	MN	Cincinatti	OH	Charleston	SC	Spokane	WA
Bedford	IN	St. Louis	MO	Dayton	OH	Memphis	TN	Martinsburg	WV

Table 4: Market locations

The domestic ethyl lactate market was estimated to be between 30 and 40 million pounds per year in 2001. It was estimated that the price would fall to below a dollar per pound once pervaporation processes were more commonplace within ethyl lactate production. Demand projections estimate that at $1.25, the domestic ethyl lactate market will grow to 120 million pounds per year. We use these as initial values and assume that the price will decrease by 0.5%

annually due to continuing research, technological innovation, and emerging large-scale productions.

The change in demand for ethyl lactate was estimated from a report from Fredonia (Industry Study #1418, Solvents: Green & Conventional, May 2001). First the pounds of solvents used per $1000 GDP were projected into the future. The GDP of all the potential markets was then found. We know that solvent usage is distributed as seen below:

Industries	Demand %
Paints and Coatings	22.1
Transportation	27.5
Cleaning Products	9.9
Printing Inks	9.1
Other	31.4

Table 5: Percent of Solvent Usage by Industry

3.3 Plant locations

To determine potential plant locations, the population of different cities, the taxes associated with land and plant holdings, and the amount of growth of new and preexisting companies within those cities was considered. The National Commission on Entrepreneurship (NCOE) provided much of the information regarding high labor market areas. Additionally, information for taxes associated with land and plant holdings was found through Bankrate. Finally, cities that were considered to have high values for growth were chosen for potential plant locations (Table 3). Some of these areas containing high-growth companies are shown in figure 2.

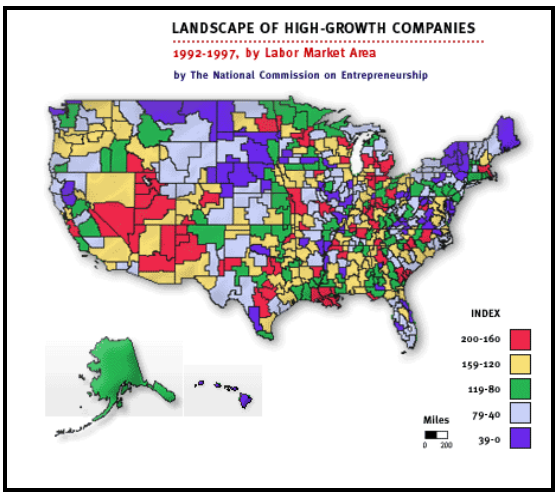

Figure 2: Index values for areas containing high-growth companies. Source: NCOE.

City	State	City	State	City	State	City	State	City	State
Anniston	AL	Columbus	IN	Tupelo	MS	Tulsa	OK	Milwaukee	WI
Tuscaloosa	AL	Monroe	LA	Greensboro	NC	Eugene	OR	Racine	WI
Gadsden	AL	Detroit	MI	Hickory	NC	Medford	OR	Green Bay	WI
Talladega	AL	Grand Rapids	MI	Manchester	NH	Greenville	SC	Appleton	WI
Hot Springs	AR	Kalamazoo	MI	Keene	NH	Dallas	TX	Wasau	WI
Los Angeles	CA	Minneapolis	MN	Cleveland	OH	Fort Worth	TX	Sheboygan	WI
Dubuque	IA	St. Cloud	MN	Dayton	OH	Waco	TX		
Ottumwa	IA	Fergus Falls	MN	Toledo	OH	Longview	TX		
Fort Wayne	IN	Mankato	MN	Youngstown	OH	Lufkin	TX		
South Bend	IN	Joplin	MO	Findlay	OH	Sherman	TX		

Table 6: Cities considered.

3.5 Fixed capital investment versus capacity

Major equipment costs were calculated based on capacities ranging from a completed ethyl lactate production plant of 50 million pounds per year to 250 million pounds per year. Processes required for ethyl lactate production include the following:

- Raw material milling
- Ethanol and lactic acid fermentation
- Ethanol distillation
- Lactic acid purification via electrodialysis
- Ethyl lactate esterification
- Ethyl lactate purification via pervaporation and distillation

The following figure illustrates the proposed process for ethyl lactate production in flow sheet form.

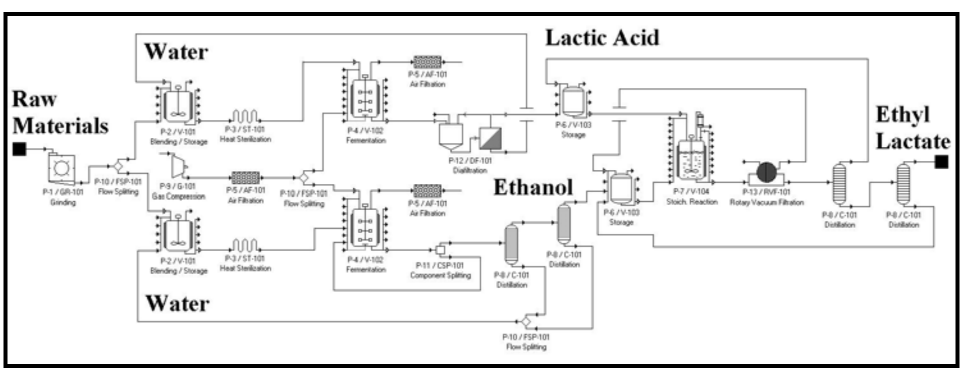

Figure 3: Schematic flow diagram

After evaluating all the major pieces of equipment, total capital investment costs were plotted and a linear relation was determined. Table 4 shows the equipment cost versus capacity for the individual pieces of process equipment.

Capacity (Million lb/yr)	Process Fermentors	Distillation Columns	Pervaporation Units	Electrodialysis Units
400	$209,700,000	$970,000	$842,000	$256,000
160	$83,900,000	$474,000	$421,000	$112,000
80	$41,900,000	$261,000	$421,000	$58,000
53.3	$28,000,000	$207,000	$421,000	$40,000
40	$21,000,000	$174,000	$421,000	$30,000
250	$131,000,000	$659,000	$579,000	$166,000

Table 7: Equipment cost versus capacity for individual components

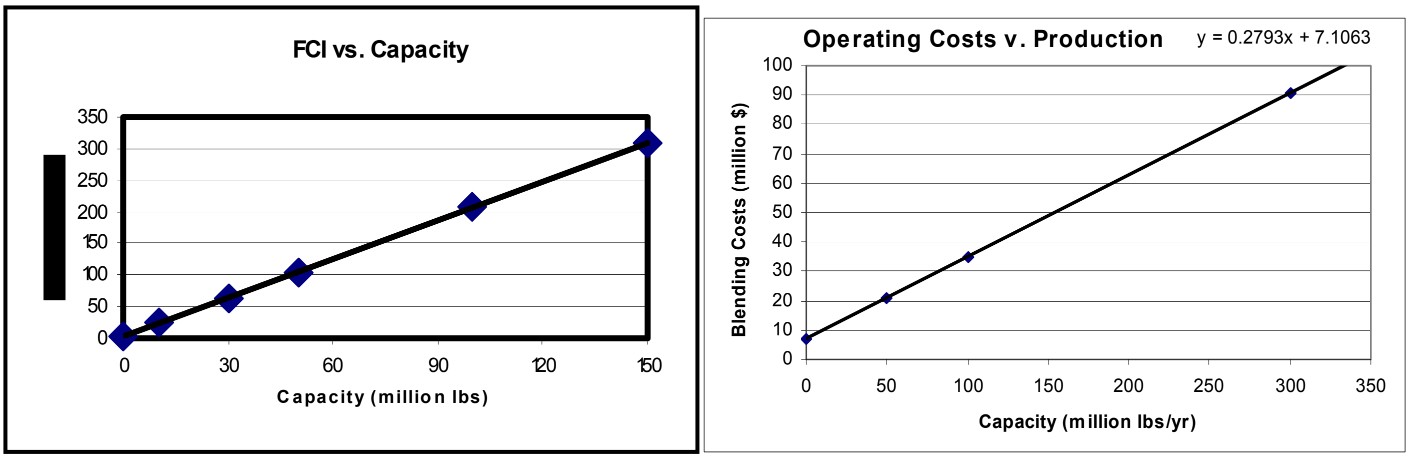

Figure 4: Fixed capital investment versus ethyl lactate capacity

3.5.1 Milling, fermentation, and esterification processes

Another model (SuperPro Designer), coupled with hand calculations and company analysis, led to verifiable equipment costs for the milling, fermentation, and esterification processes. SuperPro Designer, enabled the user to create a specific process with a known amount of raw materials, particular sets of equipment, and expected stoichiometric reactions. In return, the mathematical model would evaluate the specific units of equipment necessary for the desired process, the amount of products, and equipment cost analysis. Additionally, the model allowed a determination of the effective batch time and the number of batches possible for a year. These results were extremely reasonable when compared to other hand calculations and designs of companies using fermentation processes.

Results and Conclusions

The mathematical model determined from the provided information that an ethyl lactate production plant should be placed in Dubuque, Iowa. At this location all raw material needs will be satisfied by local supply and the main markets, Great Lakes industrial areas, will be located nearby as shown in figure 6. The final capacity for the plant should be the production of 198 million pounds of ethyl lactate per year.

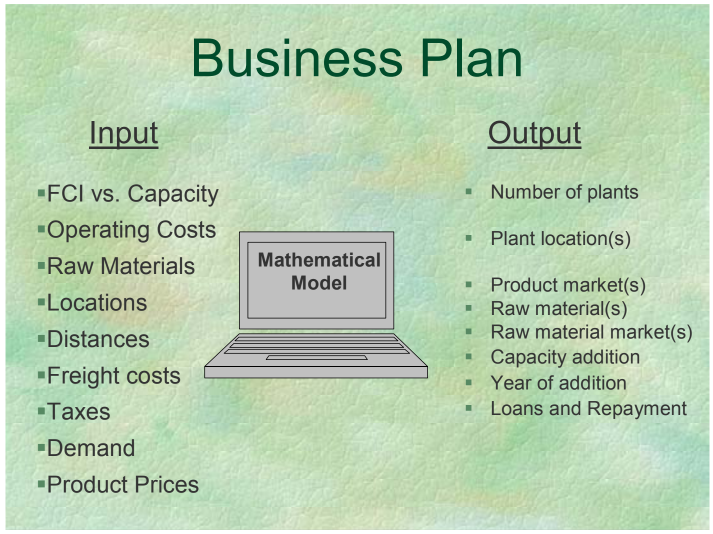

Figure 5: Input and Outputs of Model

The model was run for different levels of complexity. The initial model found the optimum plant location and raw material and product locations. Another model allowed for capital improvements to occur over the twenty year lifetime of the project. Then budgeting was added to the model. This business plan allowed for loans or revenues to fund capital improvements with the constraint that debt would be zero at the end of the twenty year project lifetime.

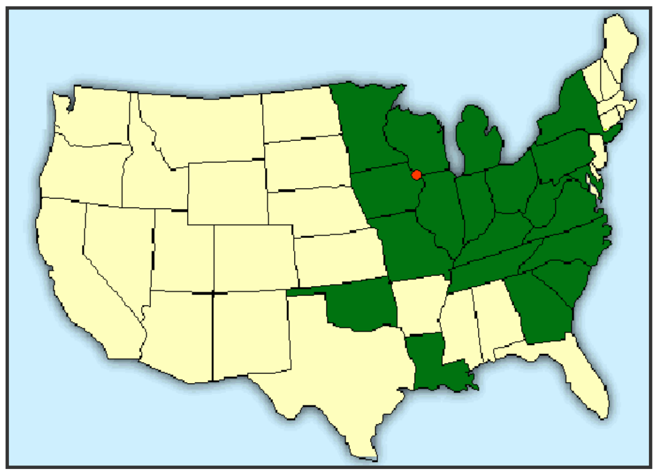

Figure 6: Plant and Market locations

Figure 7 shows the increasing capacity and production over twenty years. Notice that the production is almost at full capacity. Below is the cash flow analysis from that model. It estimated a $41.6 million NPW. The income comes from product sales and loans and the negative side is due to operating costs, capital investments, and repayment of loans.

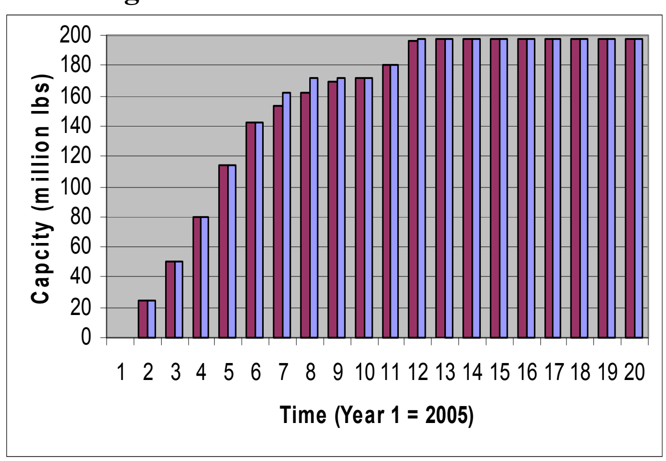

Figure 7: Plant capacity and production

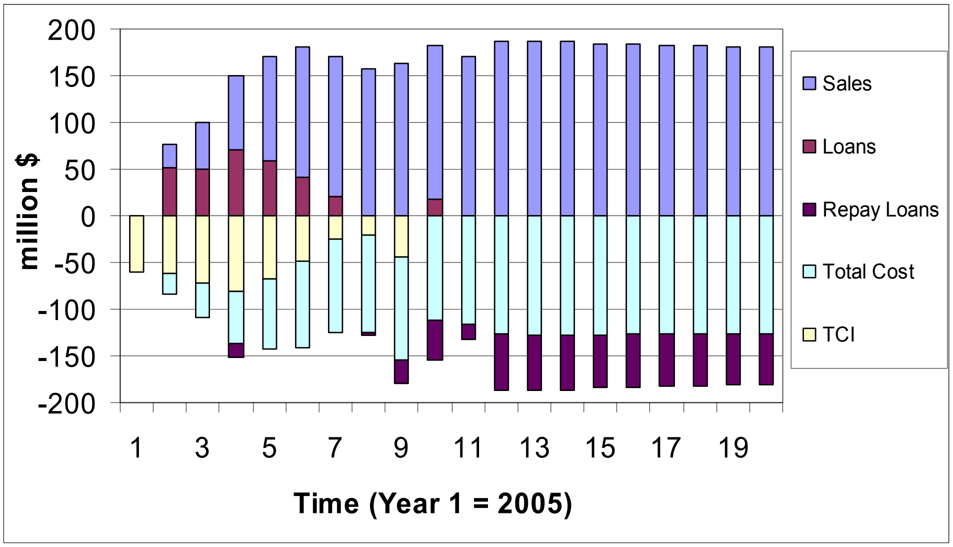

Figure 8: Annual Cash Flow

Various sensitivity analyses were performed with the model. One of the most important is based on the amount of initial capital need to perform the project. The project is feasible with a minimum of $40 million initially. But if more is raised then the plant may be built bigger at the beginning and larger loans taken out allowing for quicker expansion resulting in a higher NPW as shown by table 8. The size of debt was limited by a sum of the fixed capital investment and a percent of the annual cash flow. As expected, the bigger the debt may be the higher the expected NPW.

	NPW (million $, interest used = 15%)	
Initial Capital (million$)	**0%**	**20% CF**
68	42.2	42.7
52	41.6	42.1
40	34.8	35.4

Table 8: Sensitivity Analysis by varying initial capital

Further study would add greater depth to the mathematical model by focusing on the Dubuque area. A detailed study of the potential plant and raw material locations in the local area performed. Also, more risk analysis could focus on variance in raw material prices.