Biorefining

Chemical Engineering Team

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Presentation Outline

- Purpose
  - What is biorefining
- Plant Design
  - Fermentation processes
  - Purification processes
  - Utilities
  - Waste
  - Economics of each process
- Business Plan Proposal – Mathematical Model
  - Model Description
  - Inputs into the Model
  - Results of Model
  - Sensitivity and Risk of Model

Overview of Biorefining

- What is a bio based product?
  - Made from renewable resources
  - Plant material as main ingredient
  - Biodegradable
- Why bio-refining?
  - National and local policies promote bio-refining
  - Strict environmental regulations
    - Increased cost of products made from fossil fuels
      - Extraction, processing, disposal
  - Advantages
    - Rural economic development, lower economic costs, environmentally safe

http://www.pnl.gov/biobased/docs/prodplas.pdf

Scope of Project

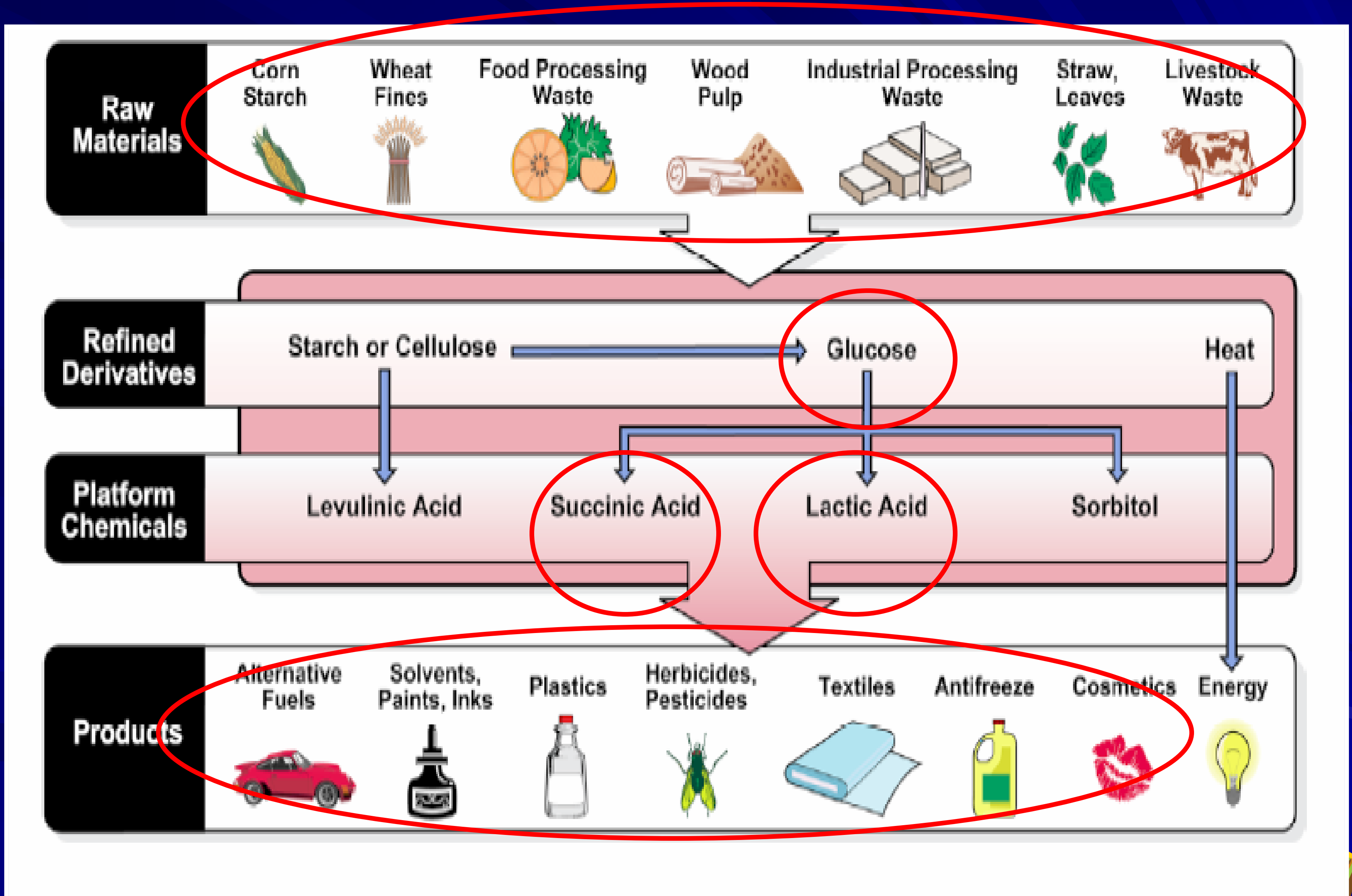
Figure 1: Chemicals, Microorgansims, and End Products of Fermentation Processes

Ethanol
Saccharomyces ce

Each of these acids are generated using nearly identical fermentation processes with different bacteria which dictate the end result

Citric Acid
Aspergillus nig

Scope of Process



http://www.pnl.gov/biobased/docs/prodplas.pdf

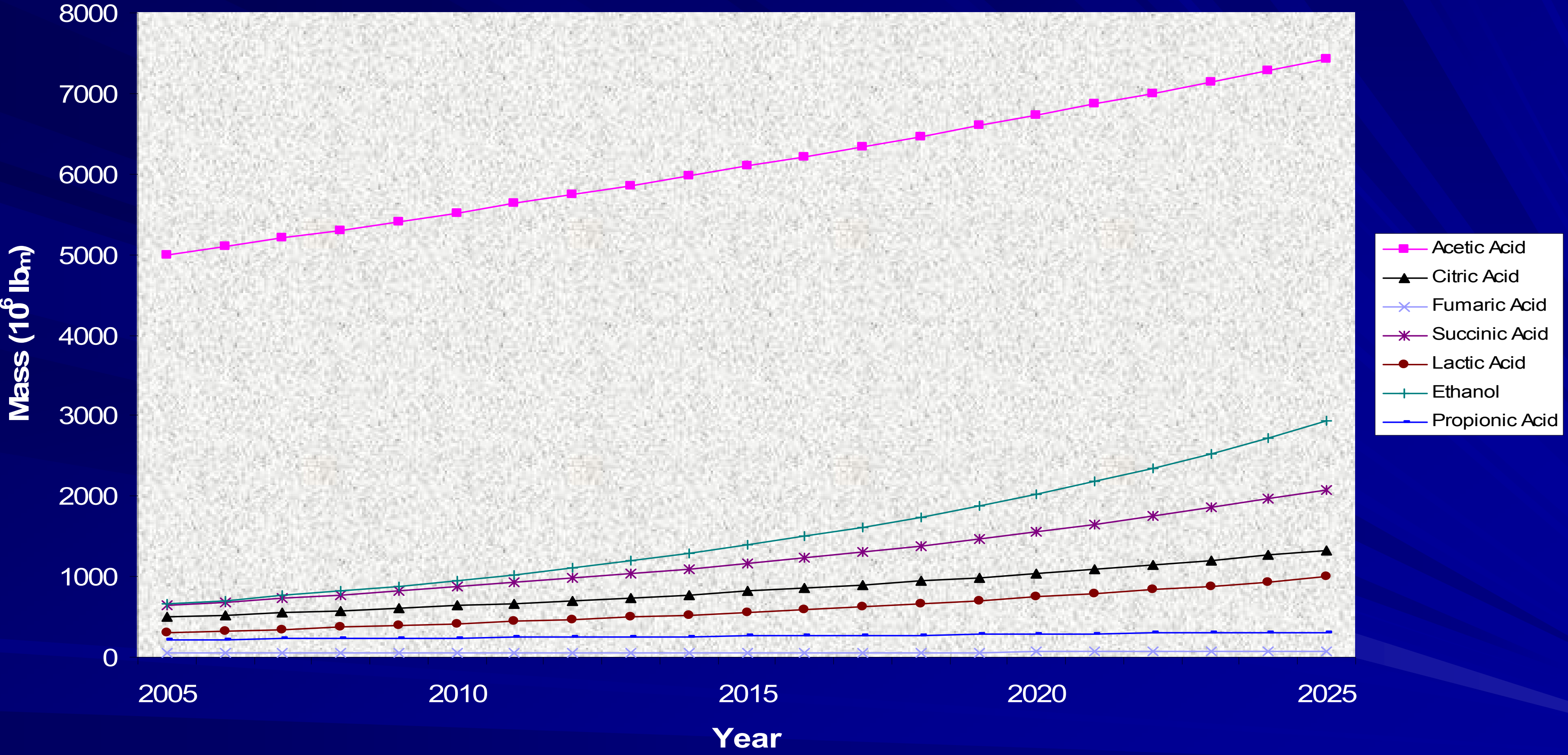
Market Analysis / Demand

Table 1: Market Analysis

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

www.the-innovation-group.com/ChemProfiles.htm

Market Demands for Products Years 2005-2025

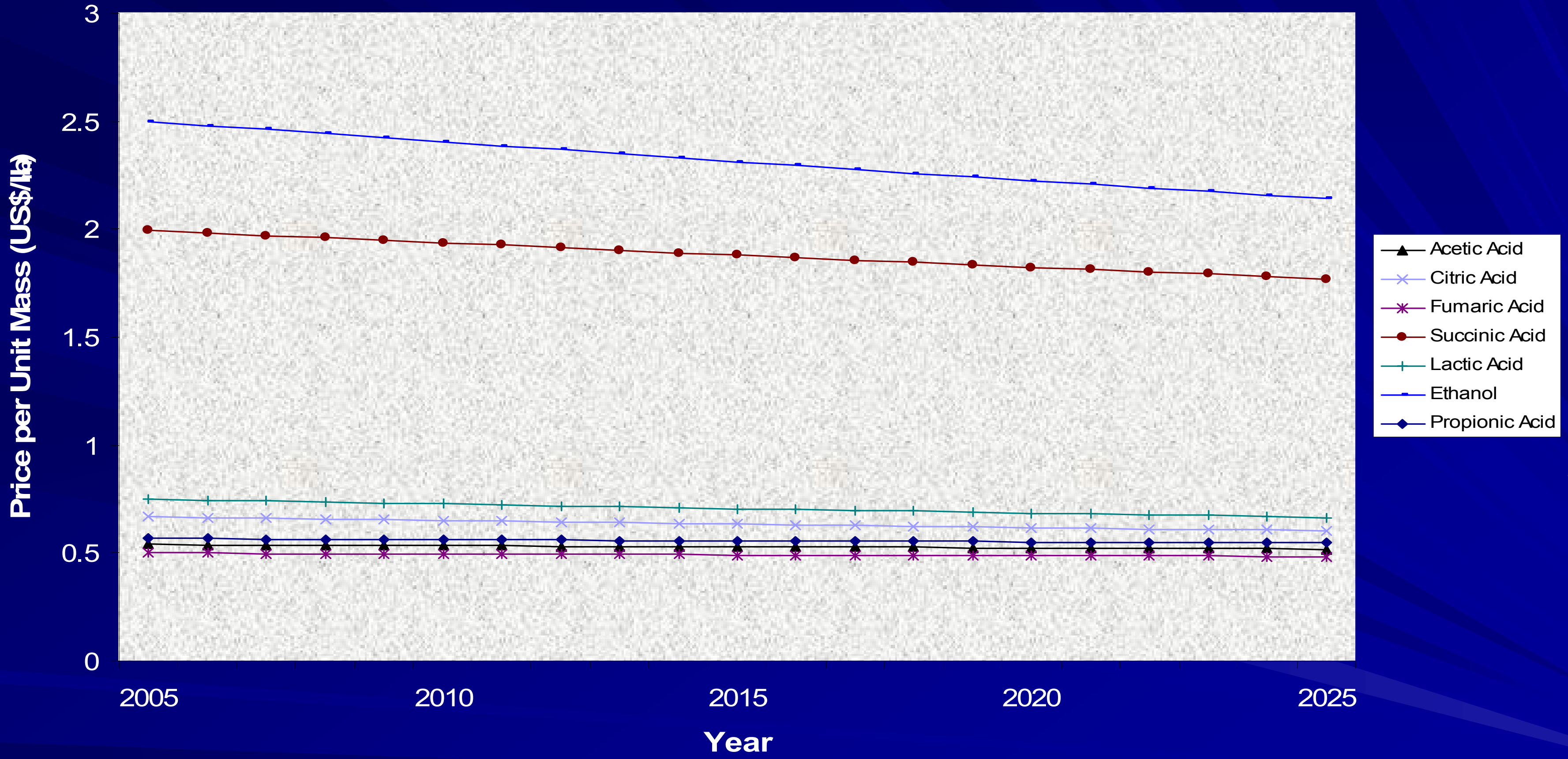


Assumptions:

-growth due to environmental profile

-industrial applications increase due to biodegradable advantages

Price Projections for Products Years 2005-2025



Assumptions:

-an increase in demand will result in over capacity and competition among suppliers

-as a result, a reduction of prices with a corresponding increase in the amount of sales is expected

-more competition will drive prices down and supply up

Process Description

- Simulations for Fermentation/Purification
  - Model Descriptions
- Fermentation
  - Formation of each acid
  - Bacteria Considerations
    - Conversions
- Simulations
  - Outline of Fermentation
  - Outline of Purification Processes

Models

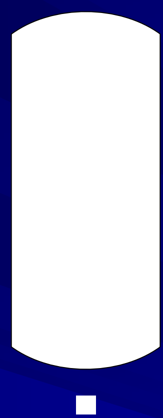
- Citric Acid
- Succinic Acid
- Propionic Acid
- Fumaric Acid
- Acetic Acid

Fermentation

Glucose + Water

Bacteria

Clostridium thermocellum / *Aspergillus niger* / *Rhizopus* / *Propionibacterium acidipropionici* / *Anaerobiospirillum succiniciproducens*



Acid

Fumaric Acid / Propionic Acid / Acetic Acid / Citric Acid / Succinic Acid

Our Scope

- Similar processes
- Formation
  - 10:1 mass ratio of water to glucose
  - Heat sterilization
  - Compressed Air
  - Ammonia
  - Batch Reaction

Fermentation Tank

Bacteria Name	Yield	Product
Clostridium thermocellum	100%	Acetic Acid
Aspergillus niger	66.7%	Citric Acid
Anaerobiospirillum succiniciproducens	87%	Succinic Acid
Propionibacterium acidipropionici	66.7%	Propionic Acid
Rhizopus	69%	Fumaric Acid
Saccharomyces cerevisiae	**66.7%**	**Ethanol**
Lactobacillus delbrueckii	**95%**	**Lactic Acid**

Ethyl Lactate Subgroup

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
- Cost of using bacteria was found to be $0.80 per ton

Process Description
Citric Acid

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

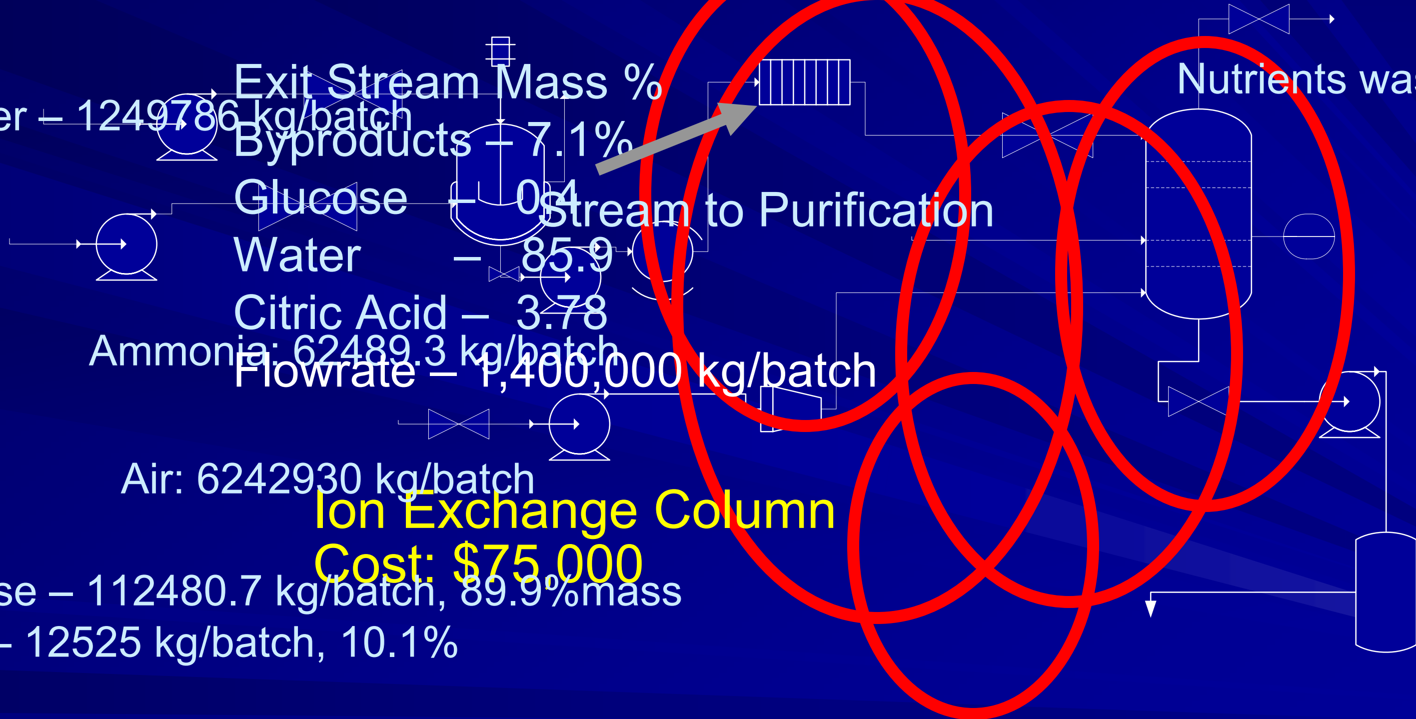
Fermentor
Capacity: 350,000L
Units: 5
Cost: $1.2 Million

Blending/Storage
Capacity: 21,000 gal
Units: 3
Cost: $110,000

Sterilizer
Capacity: 250 m3
Throughput: 80m^3/hr

Rotating Drum
Capacity: 250 m3
Cost: $ 850,000
Units: 2
Cost : $ 115,250

Ion Exchange Column
Cost: $75,000

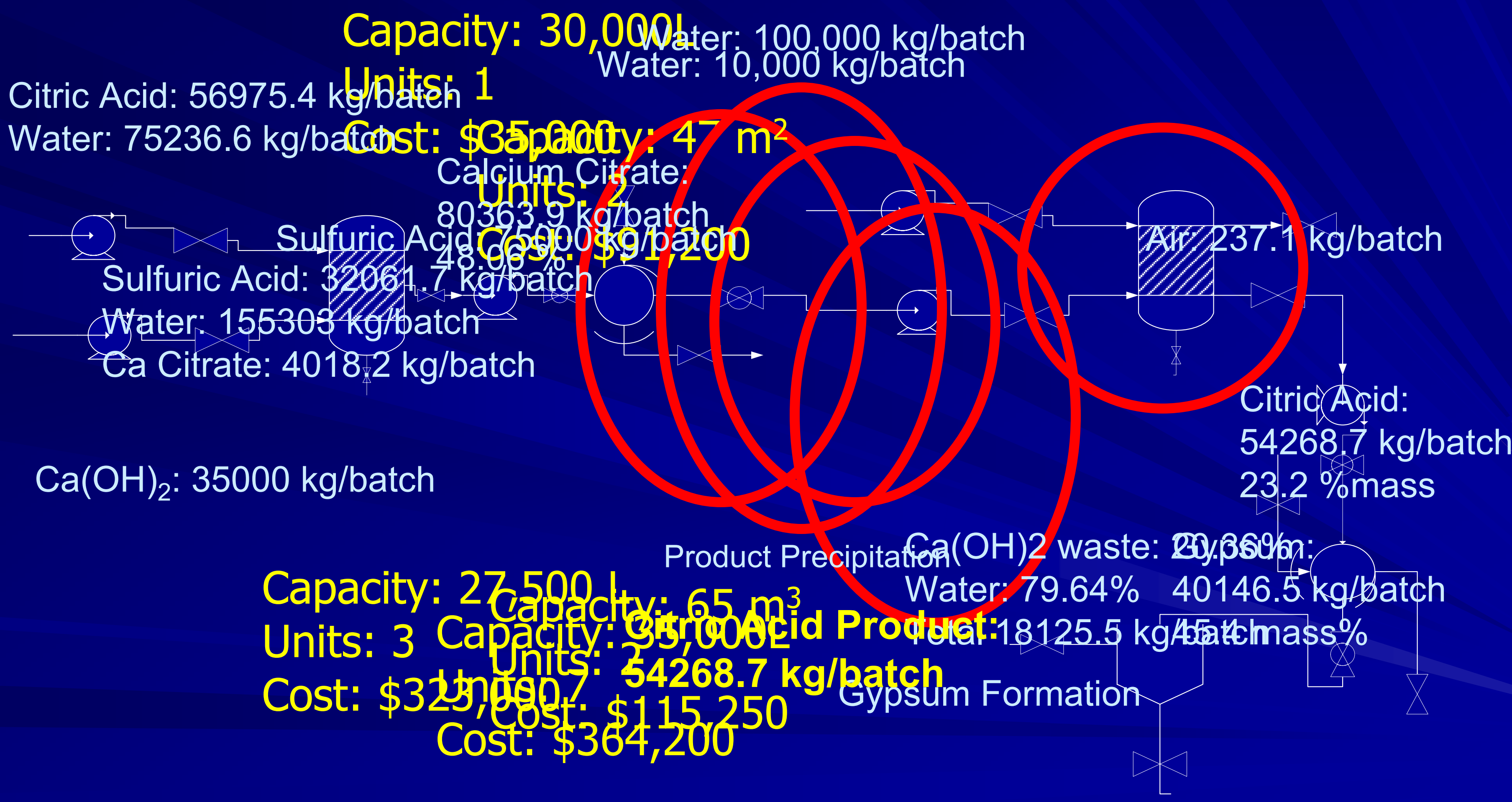


Glucose – 112480.7 kg/batch, 89.9%mass
Salts – 12525 kg/batch, 10.1%

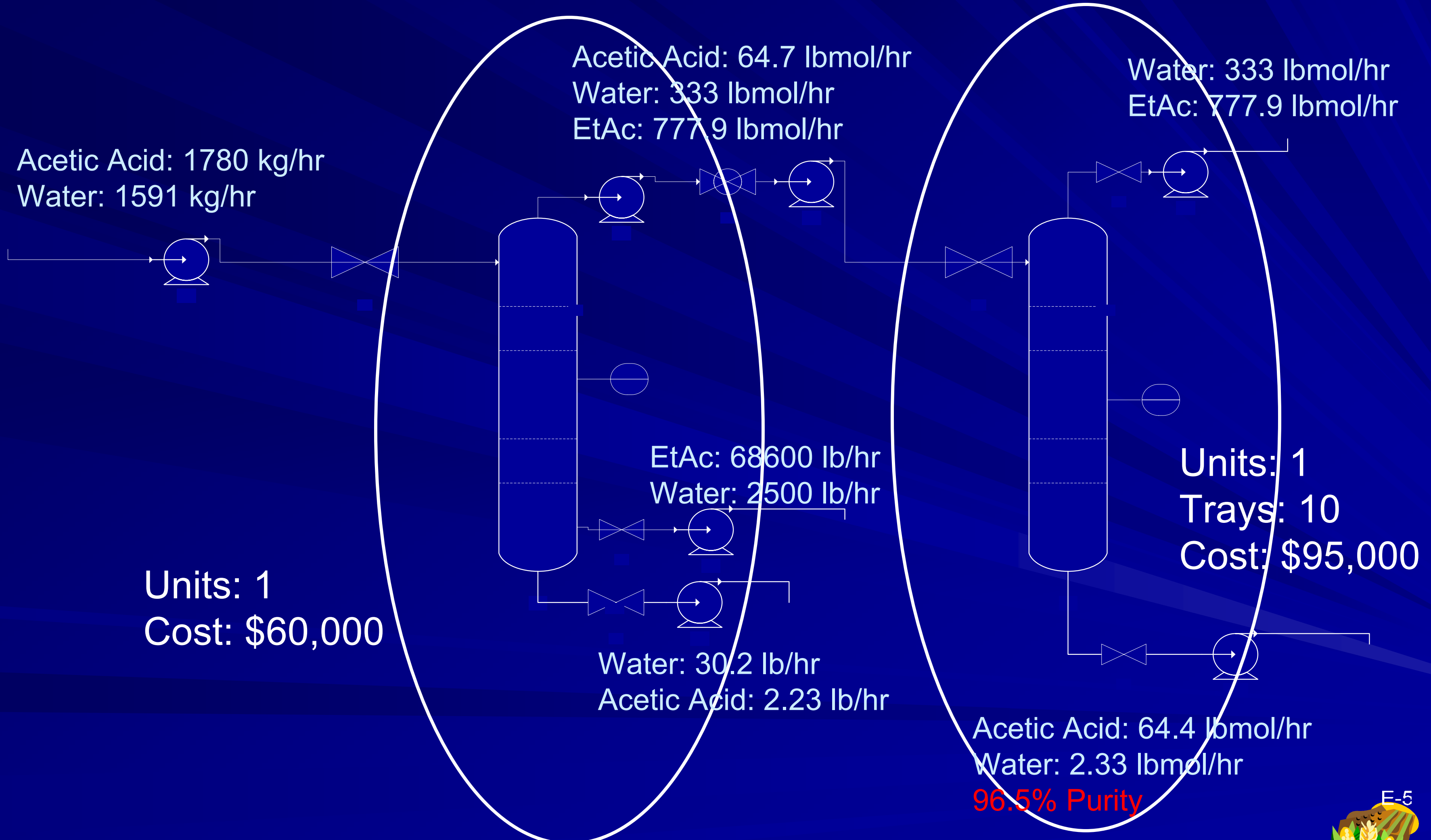
Purification Processes

- Citric Acid
- Succinic Acid
- Propionic Acid (Sodium Propionate)
- Fumaric Acid
- Acetic Acid

Citric Acid

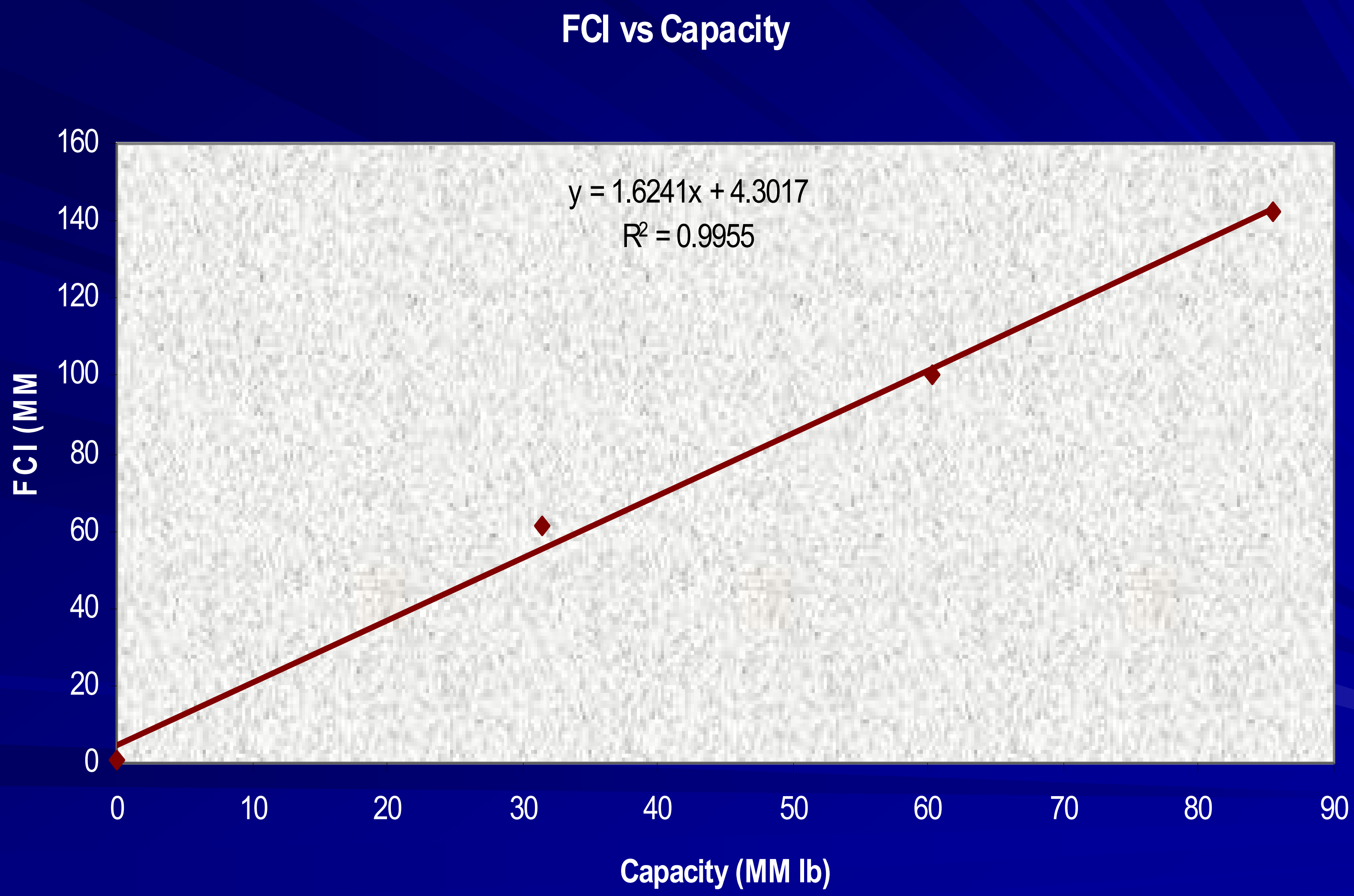

Capacity: 30,000L
Units: 1
Cost: \$35,000
Water: 100,000 kg/batch
Water: 10,000 kg/batch
Citric Acid: 56975.4 kg/batch
Water: 75236.6 kg/batch
Capacity: 47 m^2
Units: 2
Cost: \$91,200
Calcium Citrate:
80363.9 kg/batch
48.06 %
Sulfuric Acid: 75000 kg/batch
Sulfuric Acid: 32061.7 kg/batch
Water: 155303 kg/batch
Ca Citrate: 4018.2 kg/batch
Air: 237.1 kg/batch
Citric Acid:
54268.7 kg/batch
23.2 %mass
$Ca(OH)_2$: 35000 kg/batch
Product Precipitation
Ca(OH)2 waste: 20.36%
Water: 79.64%
Total: 18125.5 kg/batch
Gypsum:
40146.5 kg/batch
45.4 mass%
Capacity: 27,500 L
Units: 3
Cost: \$325,000
Capacity: 35,000L
Units: 7
Cost: \$364,200
Capacity: 65 m^3
Units: 2
Cost: \$115,250
Citric Acid Product:
54268.7 kg/batch
Gypsum Formation

Acetic Acid



E-5

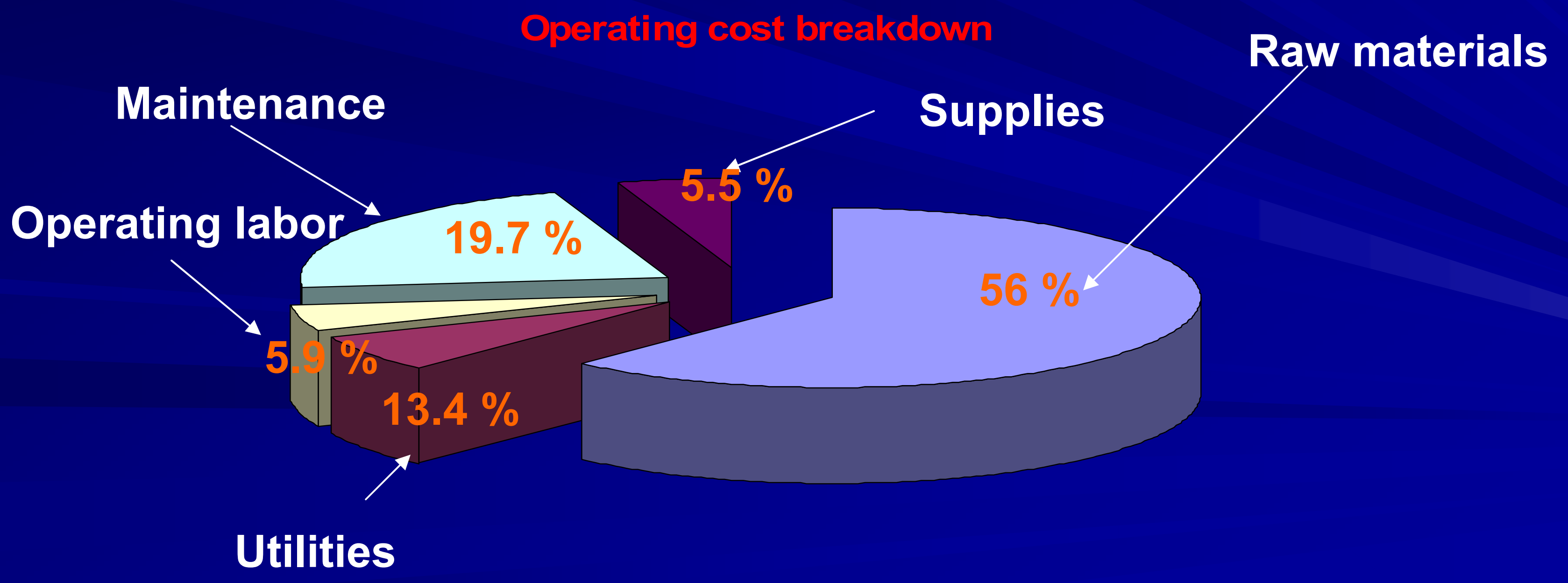
Citric Acid



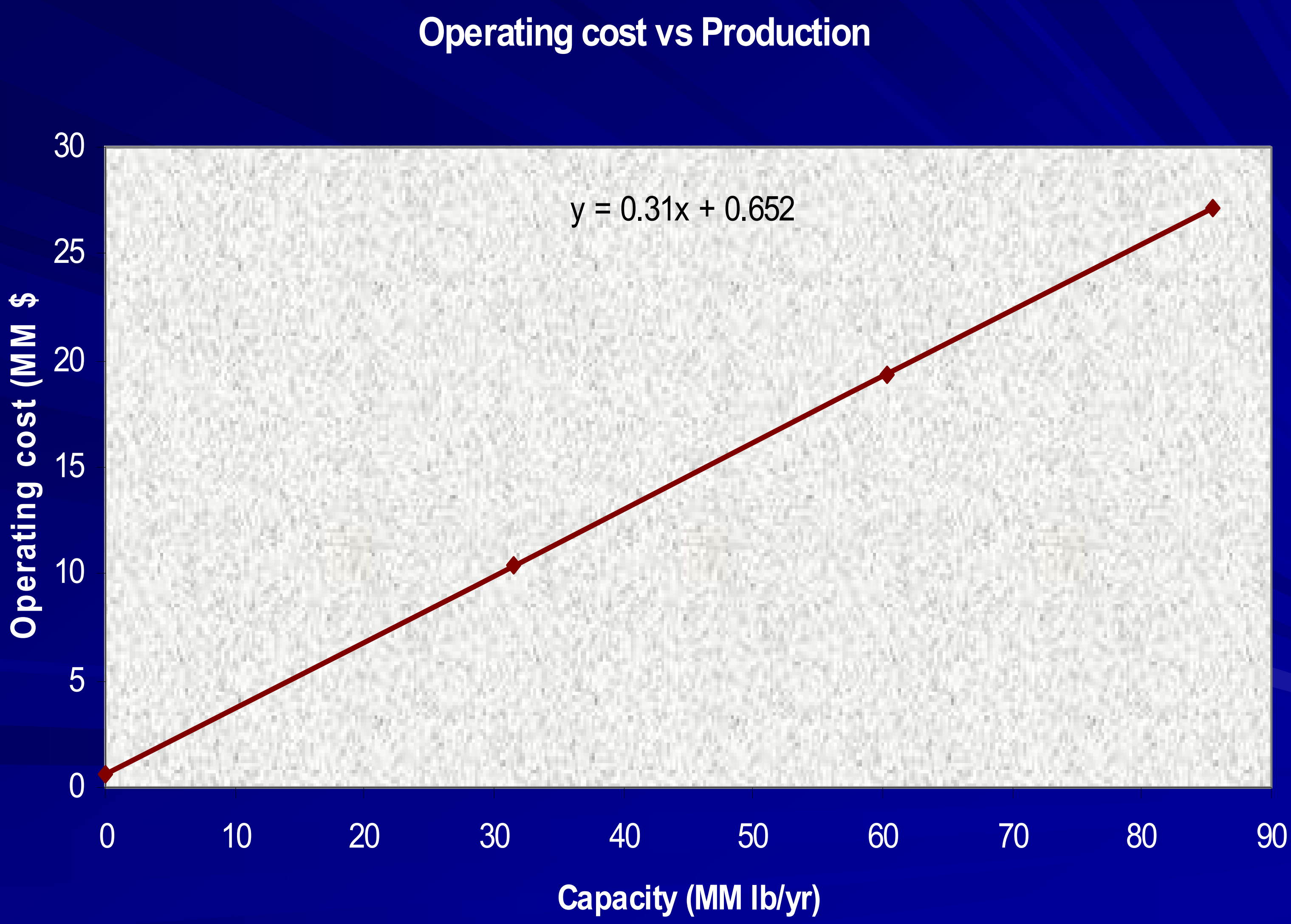
FCI vs Capacity
y = 1.6241x + 4.3017
R2 = 0.9955
160
140
120
100
80
60
40
20
0
FCI (MM
0
10
20
30
40
50
60
70
80
90
Capacity (MM lb)

Annual Operating Cost
Citric Acid

Capacity	35 MM lb
Raw materials	12.68
Operating labor	1.34
Utilities	3.01
Maintenance and repairs	4.43
Operating supplies	1.01
Total ($ MM)	**22.50**



Citric Acid



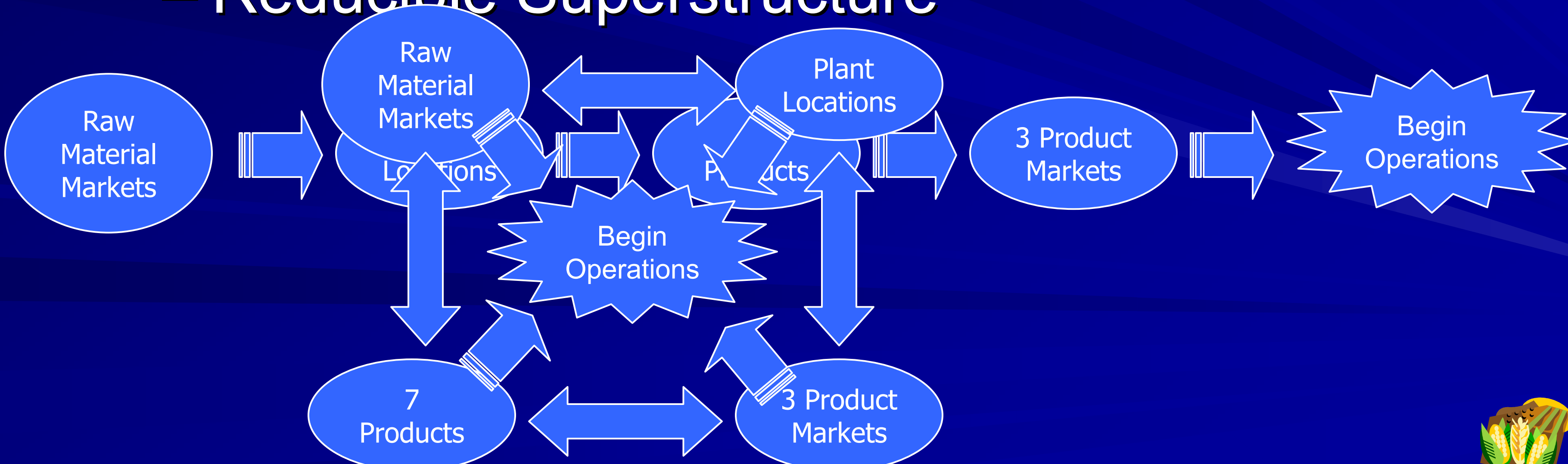
Operating cost vs Production
y = 0.31x + 0.652
Operating cost (MM $)
Capacity (MM lb/yr)
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80
90

Model Considerations

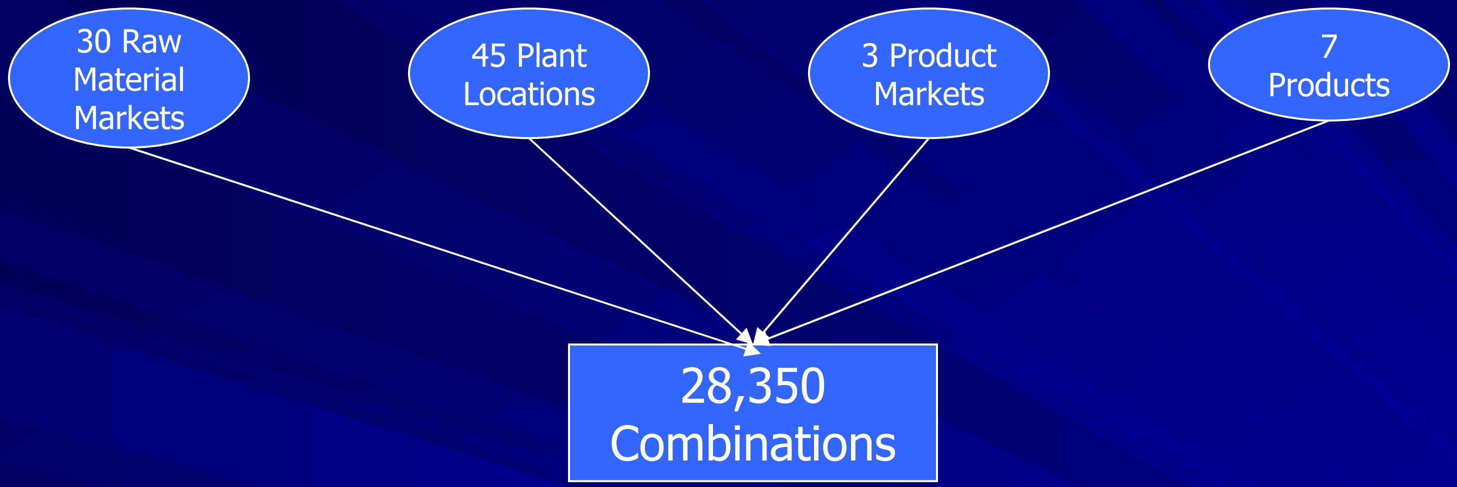
	Acetic Acid	Succinic Acid	Citric Acid	Propionic Acid
Fermentation Broth Mass (%)	4.83	4.24	3.79	2.97
Final Conversion to Sell(%)	63.3	59.9	66.0	48.1

Mathematical Model?

- Venture Design Options
  - – Irreducible Structure
  - – Reducible Superstructure



Mathematical Model?



- Minimize Operating Cost
- Maximize Net Present Value
- GAMS Optimization Software

Business Plan (Mathematical Model)

Input

- FCI based on Capacity
- Operating Costs based on Capacity
- Raw Materials & Chemicals
- Locations & Distances
- Demand
- Material & Mass Balances
- Product Prices

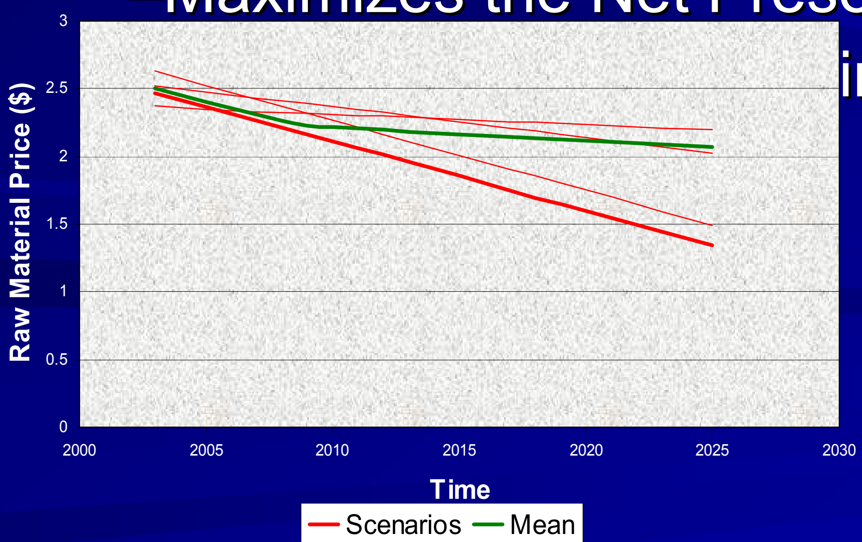
Output

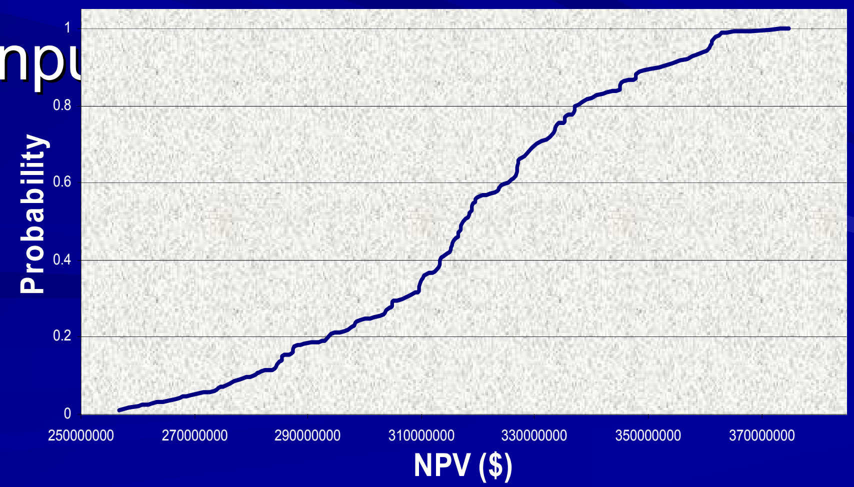
- Plant location
- Plant capacity
- Plant expansion (2 year intervals)
- Product markets
- Raw materials
- NPW

Mathematical Model

- Deterministic
  - –Maximizes the Net Present Value
  - –Disregards possible variation in Inputs

- Stochastic
  - –Maximizes the Net Present Value
  - inpu



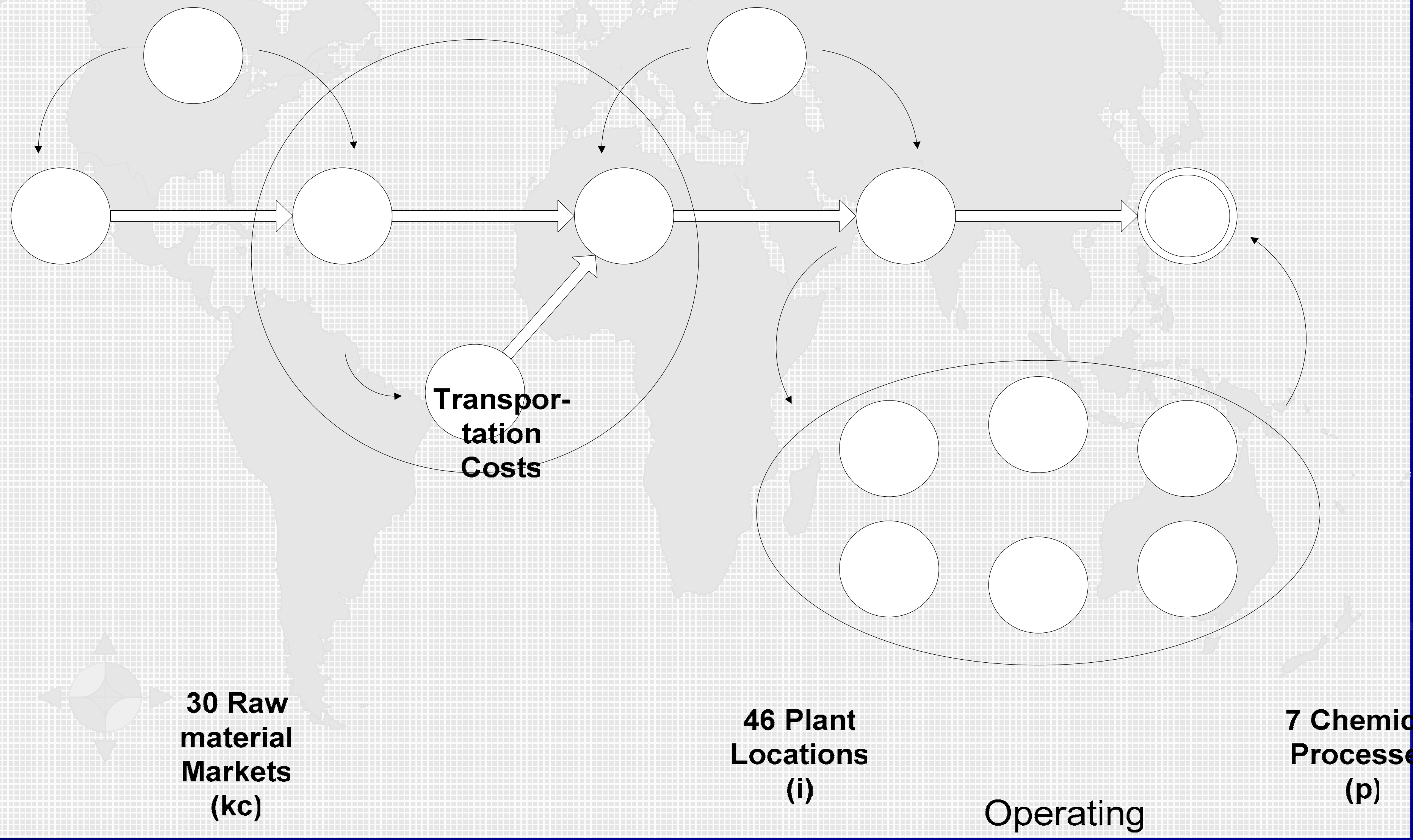


Mathematical Models

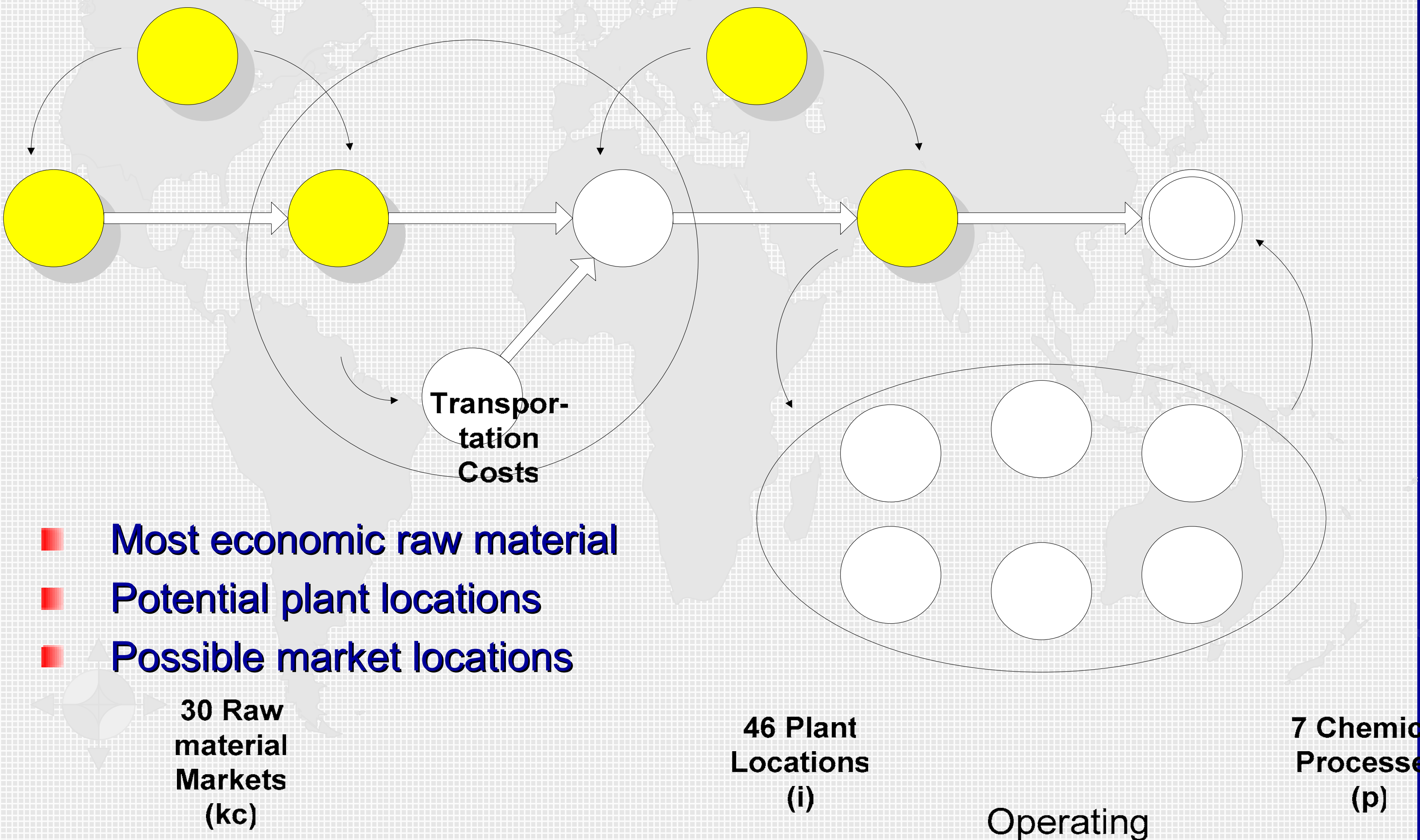
Two mathematical models:

- Biorefining
  - Seven different processes
- Ethyl lactate
  - Research analysis on one product (ethyl lactate)

Mathematical Model

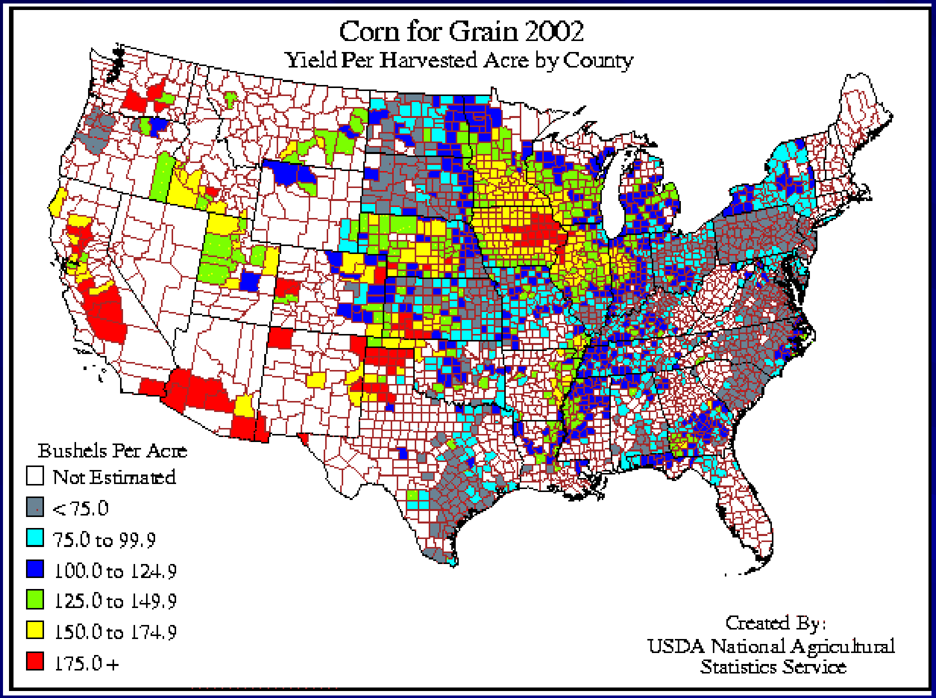


Mathematical Model: Locations



- Most economic raw material
- Potential plant locations
- Possible market locations

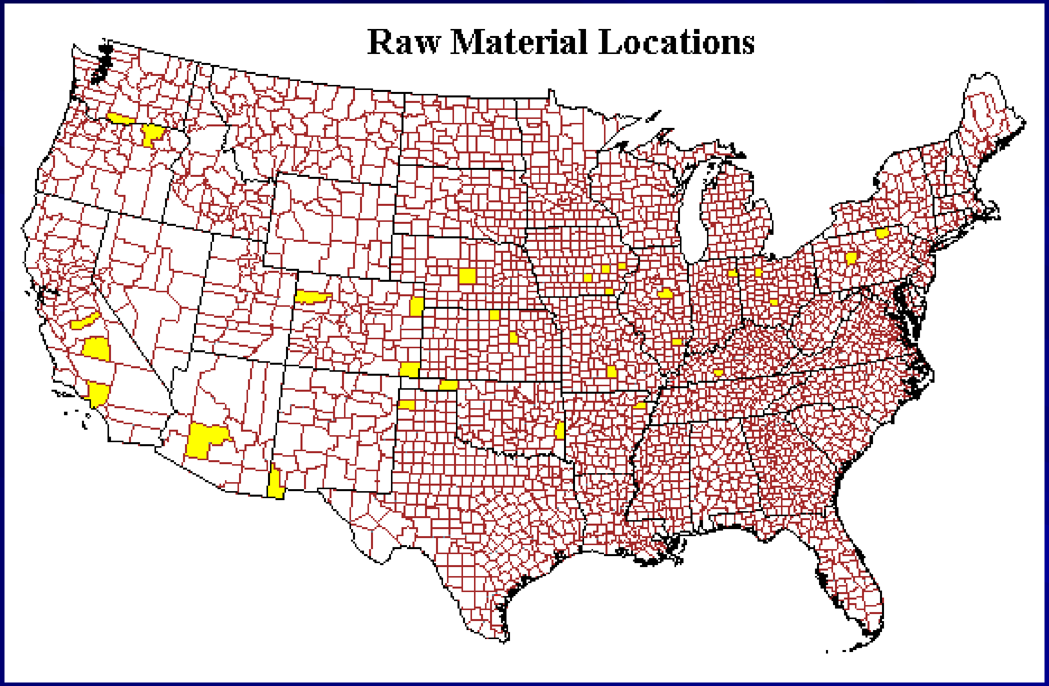
Raw Material Locations



http://www.usda.gov/nass/aggraphs/cropmap.htm

- Raw material density graphs were used to determine potential locations of raw material supply
- USDA-NASS: Crop yield by county for 2002
- Data was obtained for each of the 5 raw materials considered
  - Wheat
  - Oats
  - Corn
  - Rice
  - soybeans

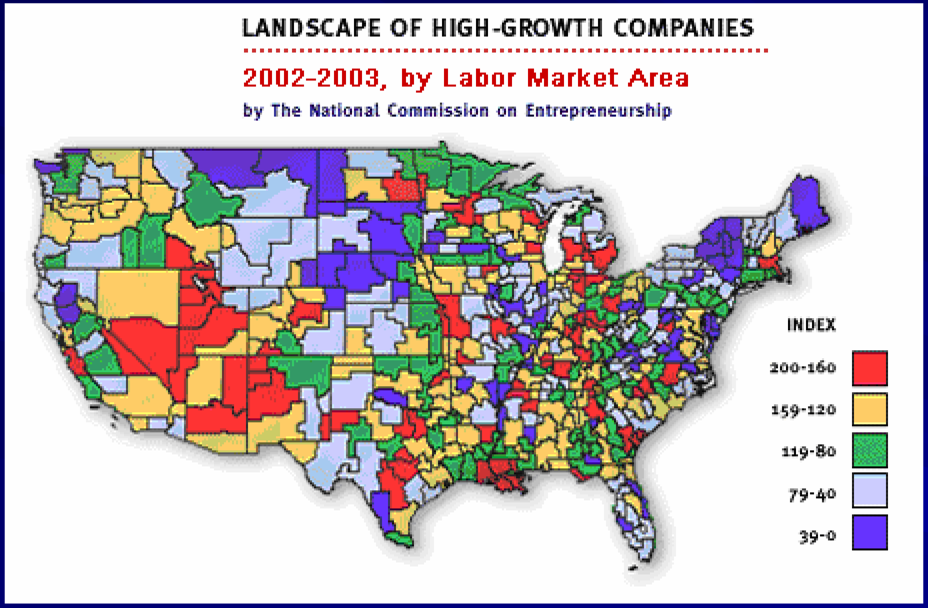
Raw Material Locations



- 30 locations were considered as possible sources for raw material supply
- Locations were chosen based on crop yield of raw materials

- 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

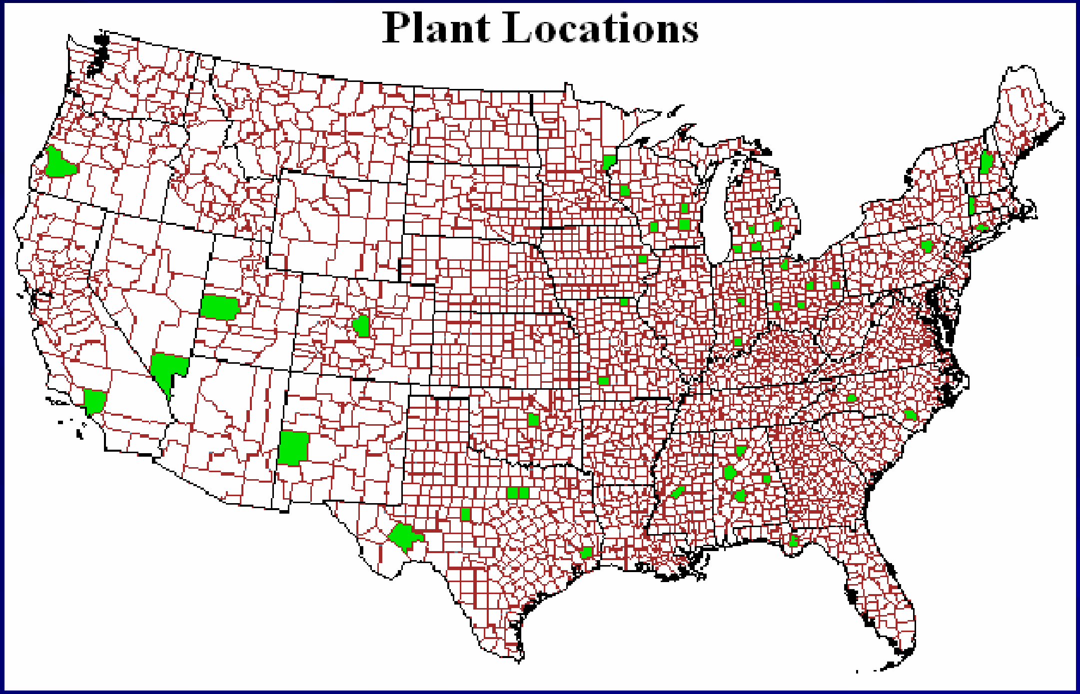
Potential Plant Locations



http://www. www.publicforuminstitute.org/nde/reports/lma.pdf

- Economic growth of cities was used to determine potential plant locations
- Plant locations considerations
  - Population
  - Number of existing companies in area
  - Expected rate of area growth

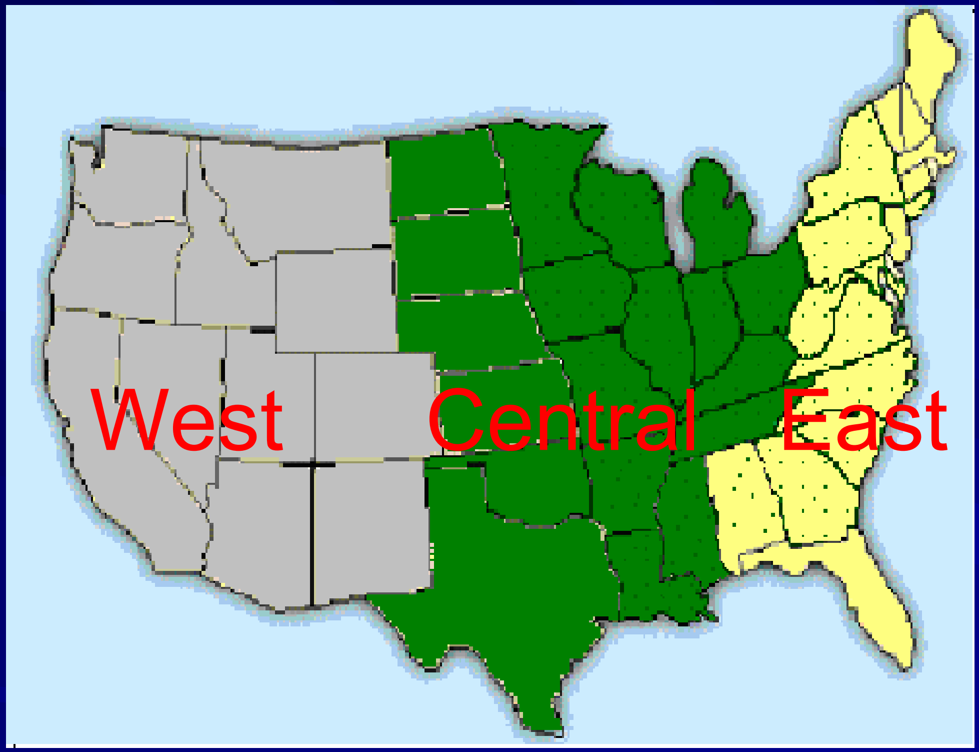
Potential Plant Locations



- 46 Potential plant locations
- Location choices Based on:
  - Agricultural supply
  - Economic growth of location

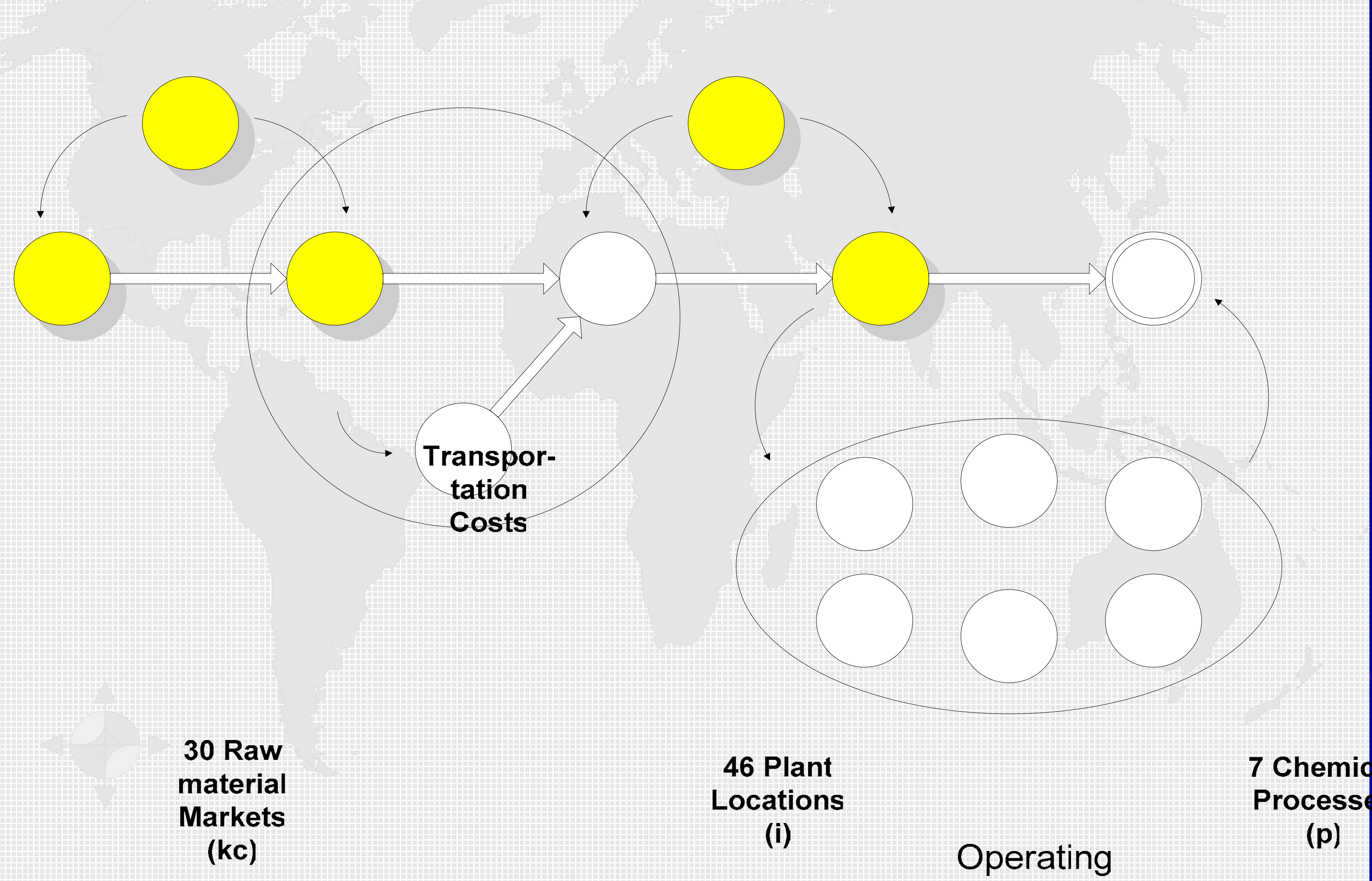
- Anniston, Tuscaloosa, Gadsden, Talladega, Hot-Springs, Los-Angeles, Dubuque, Ottumwa, Fort-Wayne
- South-Bend, Columbus, Monroe, Detroit, Grand-Rapids, Kalamazoo, Minneapolis, St-Cloud, Fergus-Falls
- Mankato, Joplin, Tupelo, Greensboro, Hickory, Manchester, Keene, Cleveland, Dayton, Toledo
- Youngstown,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

Product Market Locations

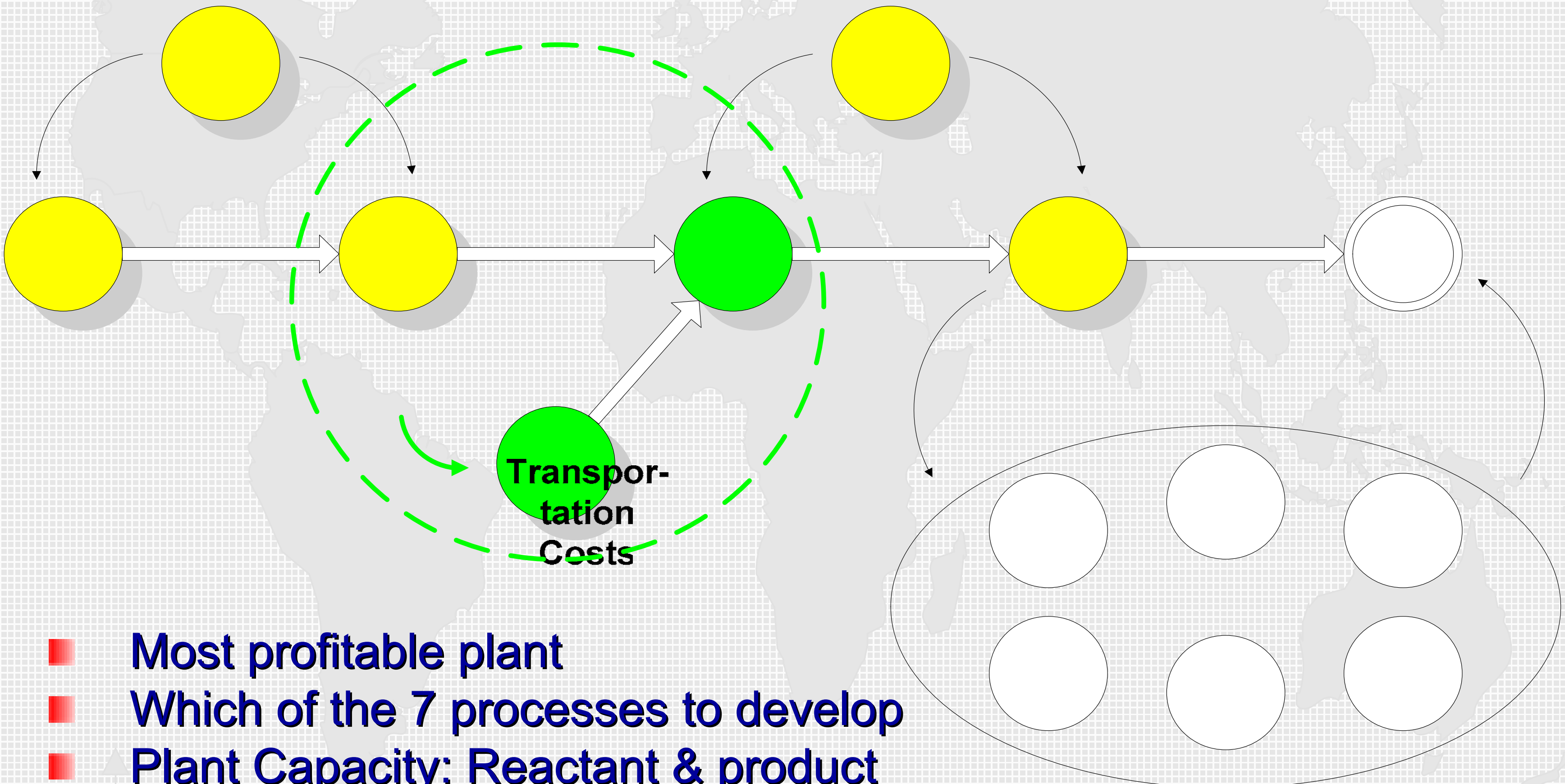


- Markets broken down by the following Regions:
  - *West*
  - *Central*
  - *East*
- The markets are for all 7 processes

Mathematical Model: Locations



Mathematical Model: Process



- Most profitable plant
- Which of the 7 processes to develop
- Plant Capacity: Reactant & product flow rates

Material Balance Equations

$$aA + bB \rightarrow cC + dD$$

- Mass flow rate of *product/reactant* = stoichiometric coefficient * mass flow rate of *reactant*

- Mass flow rate of *product/reactant* = Σ of the process' mass flow rate of chemicals from one process to another + Σ of mass flow rate of *sold/purchased* chemicals

Reactants

	Reactants					
Process	*H2O*	*Glucose*	*Salt*	*Air*	*Cal Hyd*	*Sulf Acid*
Succinic Acid	2.3	3	0.36	4.22	1.65	3.93
Citric Acid	2.2	3	3.14	6.14	2.93	3.69
Lactic Acid	2.1	3	3.10	5.41	-	-
Ethanol	2.3	3	3.10	5.41	-	-
Acetic Acid	2.3	3	2.05	3.37	-	-
Propionic Acid	2.4	3	1.30	4.13	-	-
Fumaric Acid	2.1	3	2.36	5.18	-	-

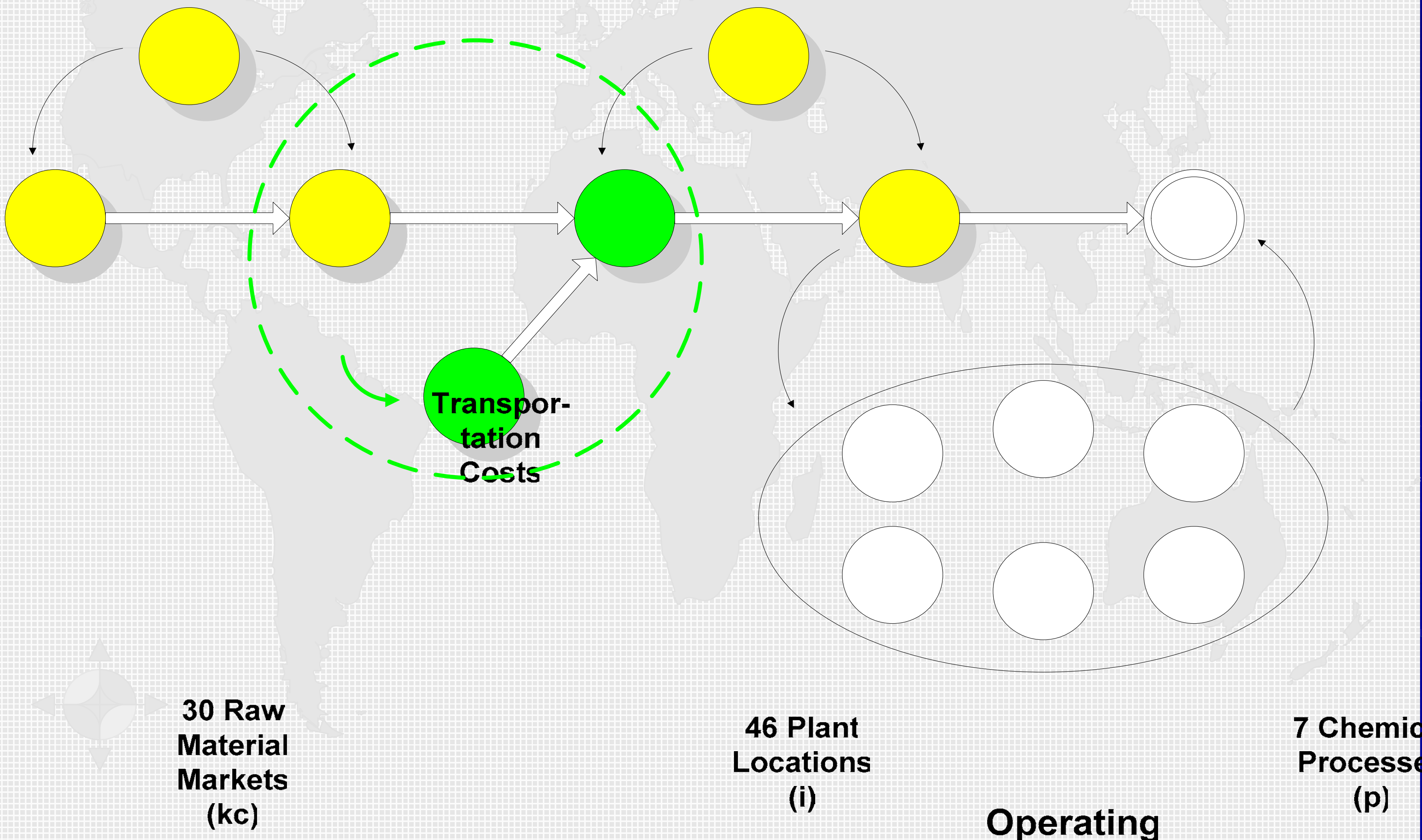
- This relationship is based on the reaction coefficient of each material
- Compared to the main chemical & the conversion data for the reaction.

Products

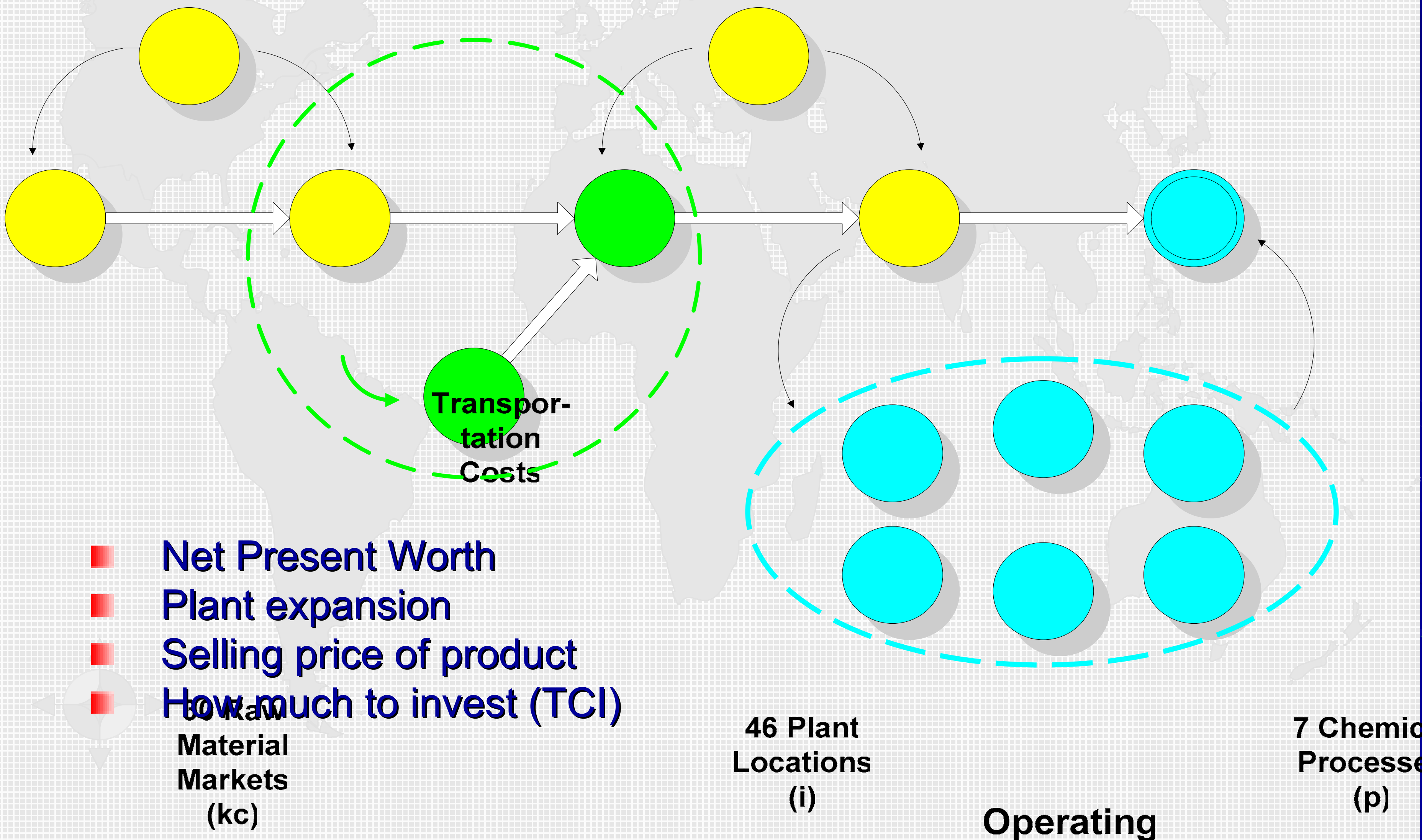
	Products			
Process	*Product*	*CO_2*	*Gypsum*	*Calcium*
Succinic Acid	1	0.067	0.63	-
Citric Acid	1	0.141	0.74	0.089
Lactic Acid	1	0.101	-	-
Ethanol	1	0.101	-	-
Acetic Acid	1	0.069	-	-
Propionic Acid	1	0.134	-	-
Fumaric Acid	1	0.101	-	-

- Relationship between the main chemical and other products in the reaction
- The relationship is based on mass balance rather than mole balance
- All the main chemical will have *mu* value of 1

Mathematical Model: Process



Mathematical Model: NPW



- Net Present Worth
- Plant expansion
- Selling price of product
- How much to invest (TCI)

Model Constraints

- Constraint on Capacity: Capacity of the process ≥ mass flow rate of the product
- Constraint on expansion: it must be over $10,000 FCI
- Supply of chemicals ≥ sum of the process' mass flow rate of purchased chemicals
- Demand of chemicals ≥ sum of the process' mass flow rate of sold chemicals
- Limit on TCI: Manually defined for set maximum TCI

Model Equations

- Cash Flow = Revenue – (Revenue – Depreciation)*Taxes
- Revenue = Sales – Total Costs
- Total Costs = Raw Material Costs + Operating Costs
- Operating Costs = operation cost based on capacity ($/lbm) * mass flow rate of product + fixed investment + transportation costs

Objective Function to Maximize

$$NPW = \sum_{plant} \left(\sum_{tp} \frac{CF_{plant,tp}}{(1+i)^{tp}} + \frac{(Vs_{plant} + Iw_{plant}) * FCI_{plant}}{(1+i)^{tp}} - TCI_{plant} \right)$$

CF = Cash Flow

tp = time period, 1 time period is 2 years

total of 11 time periods from 2005-2027

i = nominal interest rate, 5%

Vs = salvage value, 10% of FCI

Iw = working capital, 15% of FCI

Project Lifetime – 22 years

Ethyl Lactate Overview

- Extension of Previous Study
- 2 Processes: Ethanol & Lactic Acid
  - Esterification-Pervaporation
    - Ethyl Lactate
- Create Real World Fit Model
  - Biomass/Waste Water
  - CO_2 Production/Disposal
  - Mathematical Model Considerations
  - Provide insight to large process model

Biomass/Waste Water

- Biomass Waste Possibilities
  - Return to fermentation unit for reuse
  - Sale biomass product to markets
- Waste Water
  - Capital cost for water purification exceed storage cost
  - Municipal water storage $100,000/yr
- Mathematical Model Input
  - Biomass sales and waste water costs
- Net Increase in NPV by 0.1%

CO_2 Analysis

- Sale and Shipping of CO_2
  - 500 ton/yr CO_2 - $75/ton
    - Minimal profit
  - CO_2 Recovery unit
    - $20 million capital cost
- Release CO_2 into Atmosphere
  - Aug. 23, 2003, President Bush: *Clean Air Act* says that CO_2 can't be regulated as a pollutant
  - Petroleum based products emit 4000X ethanol processes

Model Considerations

- Raw materials
  - Corn, wheat, barley, oat, beets, rice
    - Cost at markets
  - Raw material to glucose conversions

Transportation Modeling

- Transportation Cost
  - Cost to ship raw materials and products
    - Linearly variable with distance
  - Distance to raw material and product markets determined
  - Amount shipped

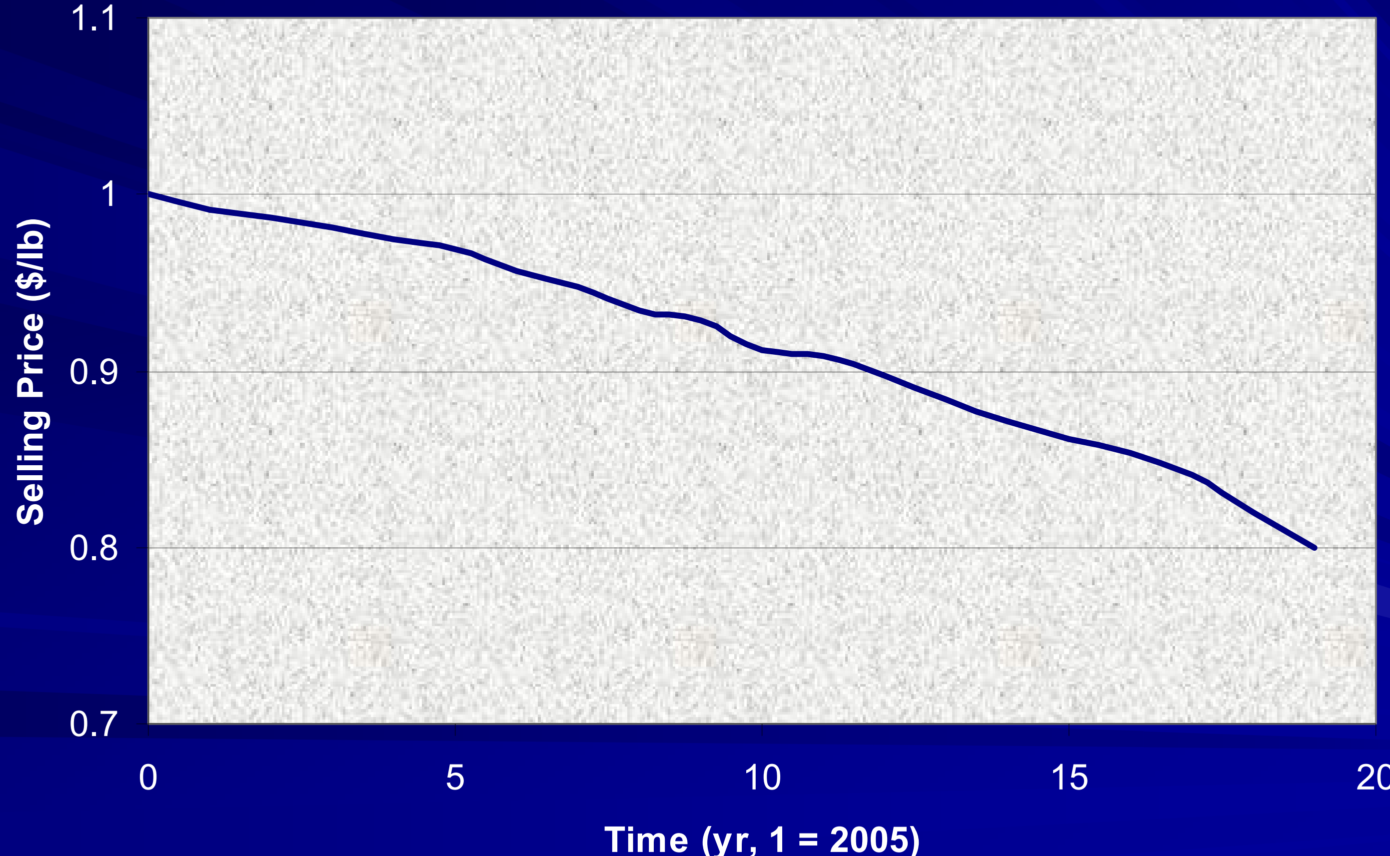
Market Demand/Capacity

- Demand
  - Determined for each product market
  - 1 year later
    - More competition
  - Assumed 80% of Demand Supplied to Market
  - Actual demand determined by model
- Capacity Constraints/Expansion
  - No expansion first two years
  - Cannot expand 2 years consecutively

Depreciation/Investing

- Depreciation
  - Continuous straight line depreciation
  - Equipment depreciable for 10 year period
- Capital Investments
  - 1 initial capital investment
  - Revenue used to re-invest in capital investments for future expansions

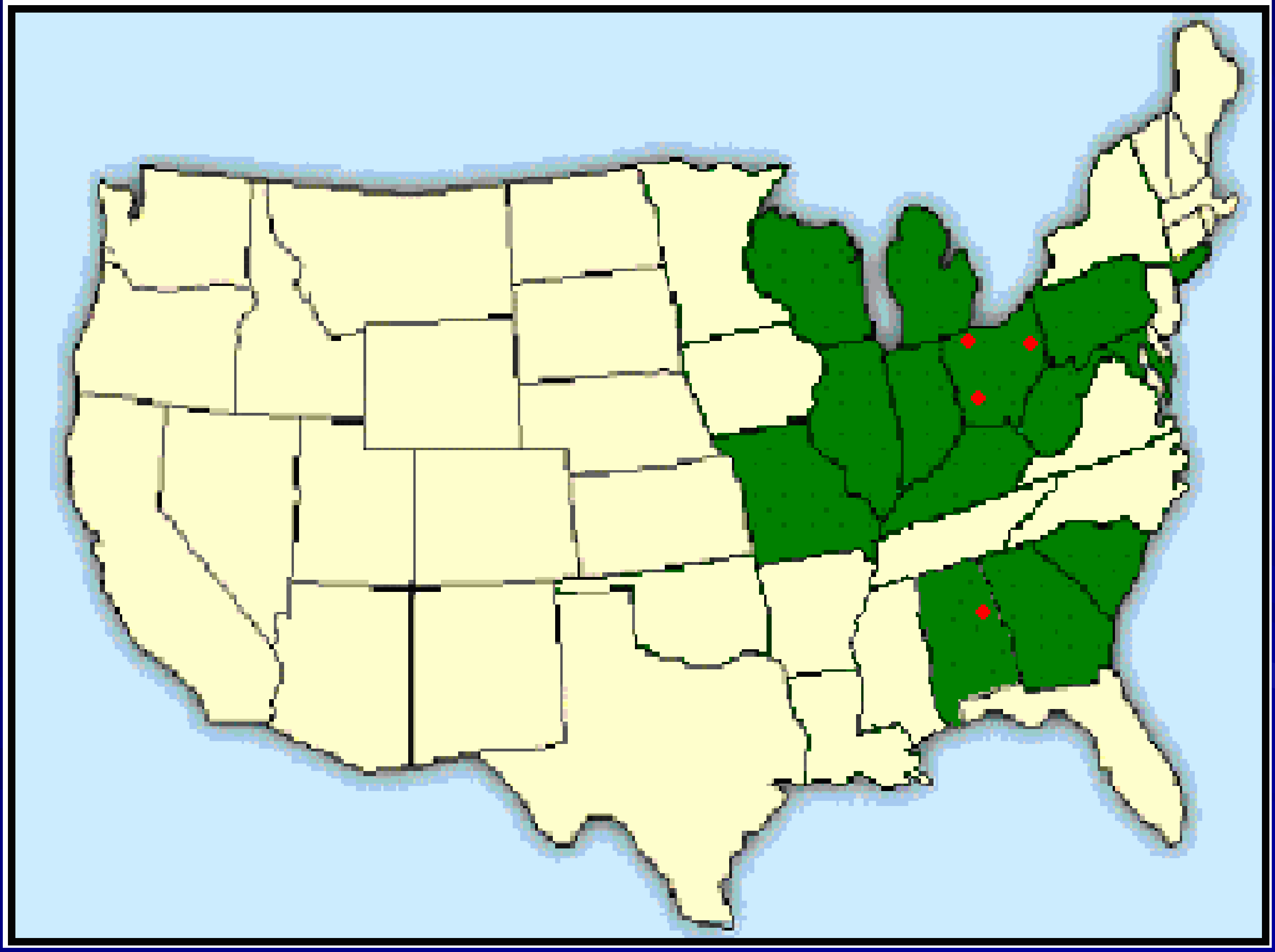
Estimated Sale Price



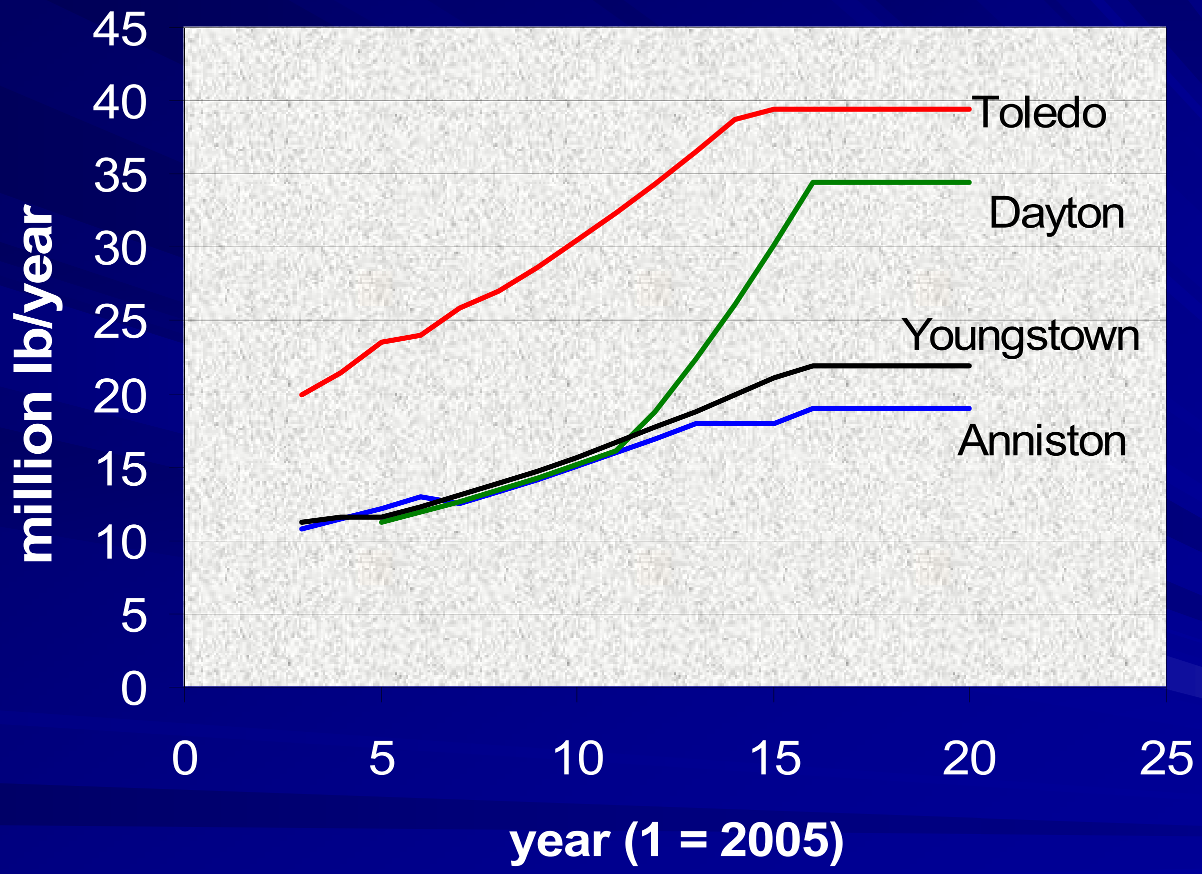
Results

- Single Raw Material:
  - Corn
- Build three plants immediately:
  - Youngstown, OH
  - Toledo, OH
  - Anniston, AL
- Build one plant in year #5:
  - Dayton, OH
- NPW = $38.8 million
- Investment = $40.2 million
- ROI = 4.8%

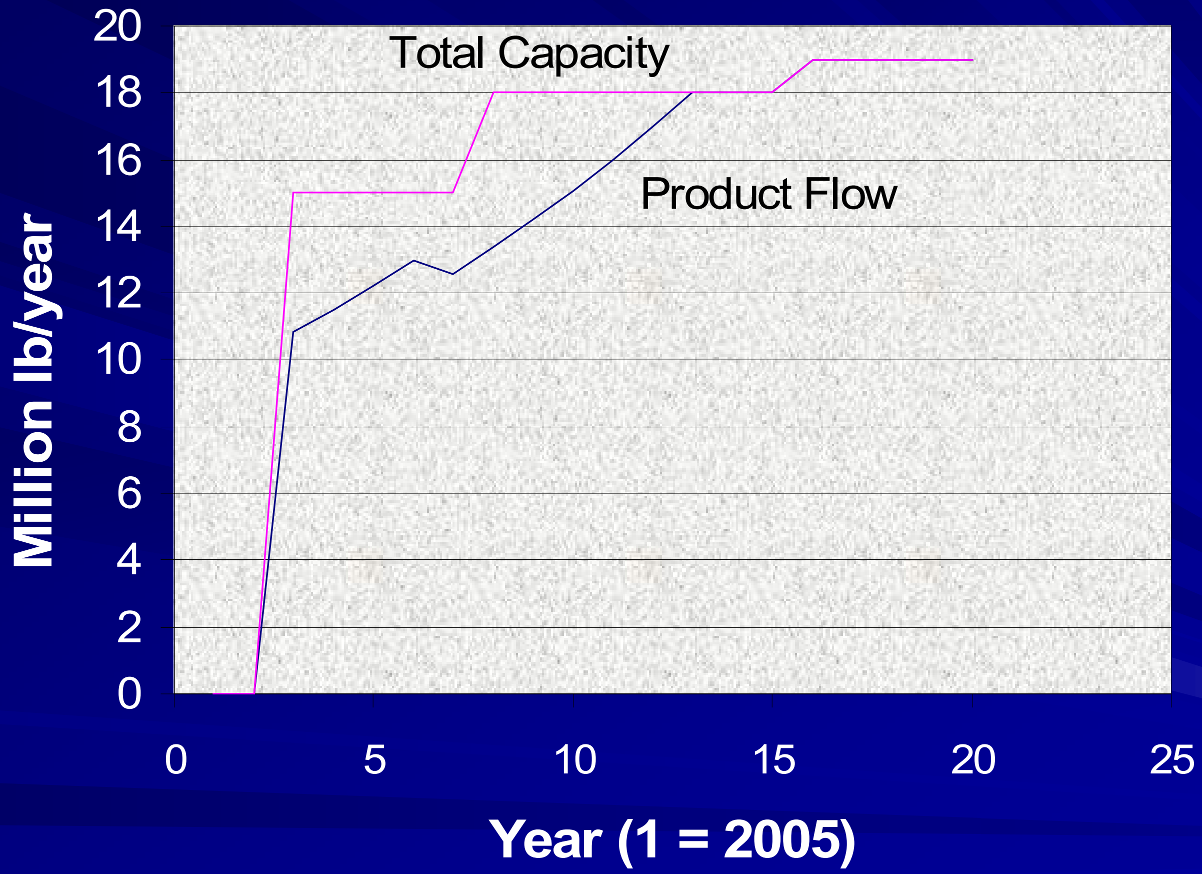
Locations



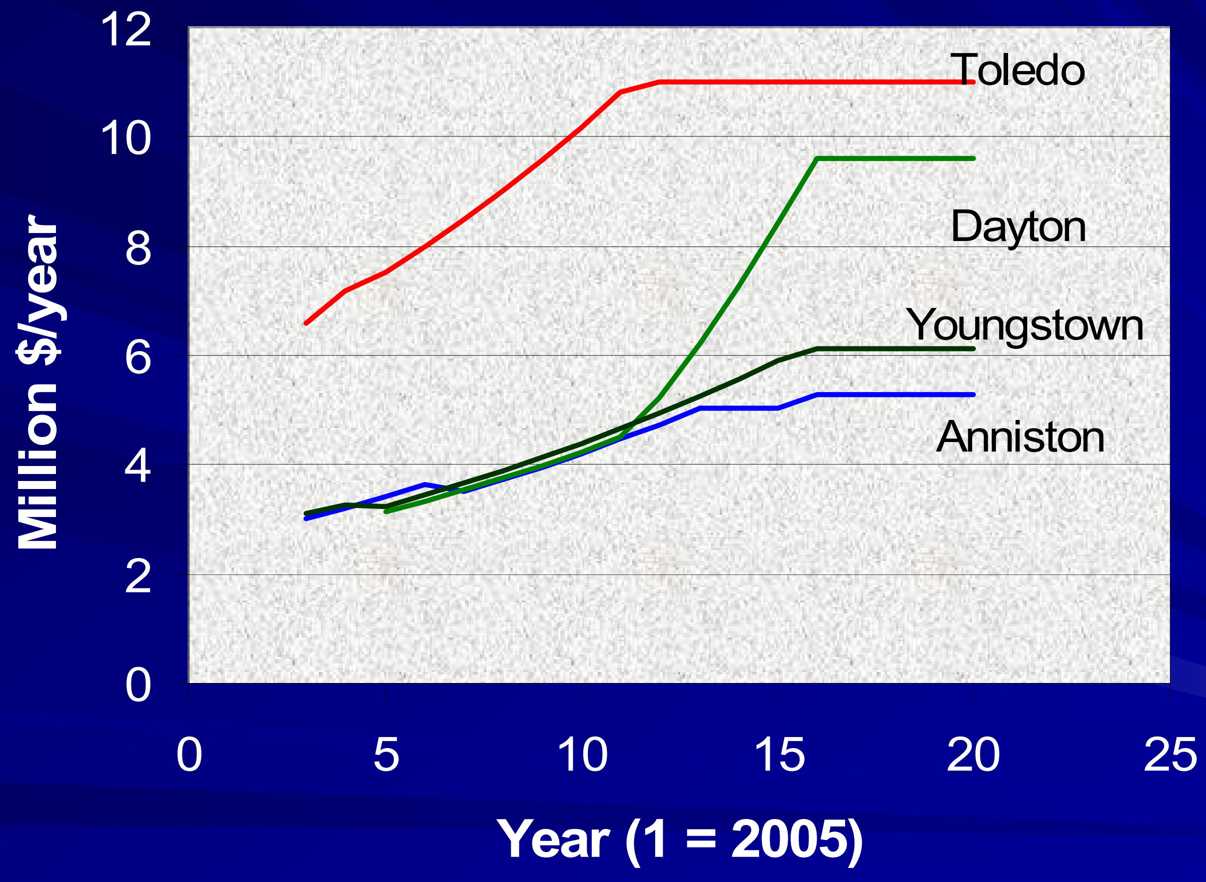
Total Product Flow Rate



Capacity vs. Flow - Anniston



Plant Operating Costs

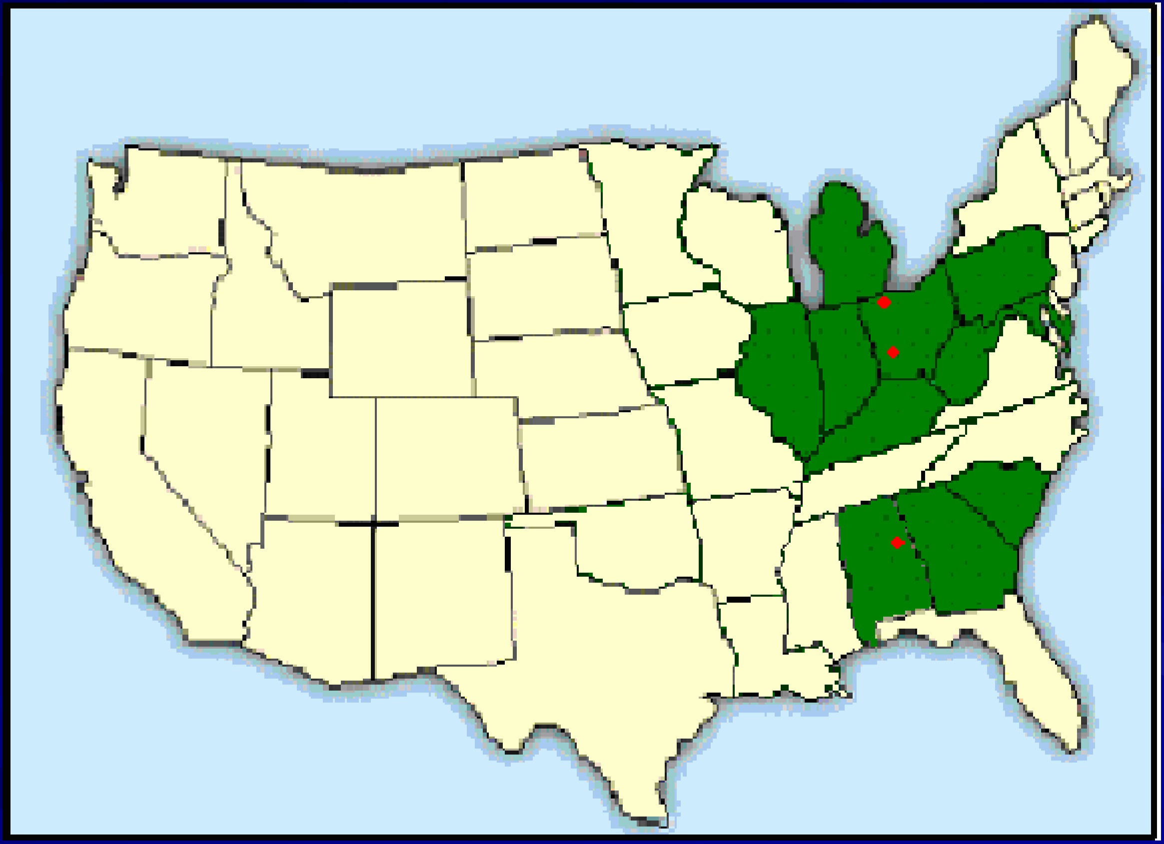


Uncertainty Results

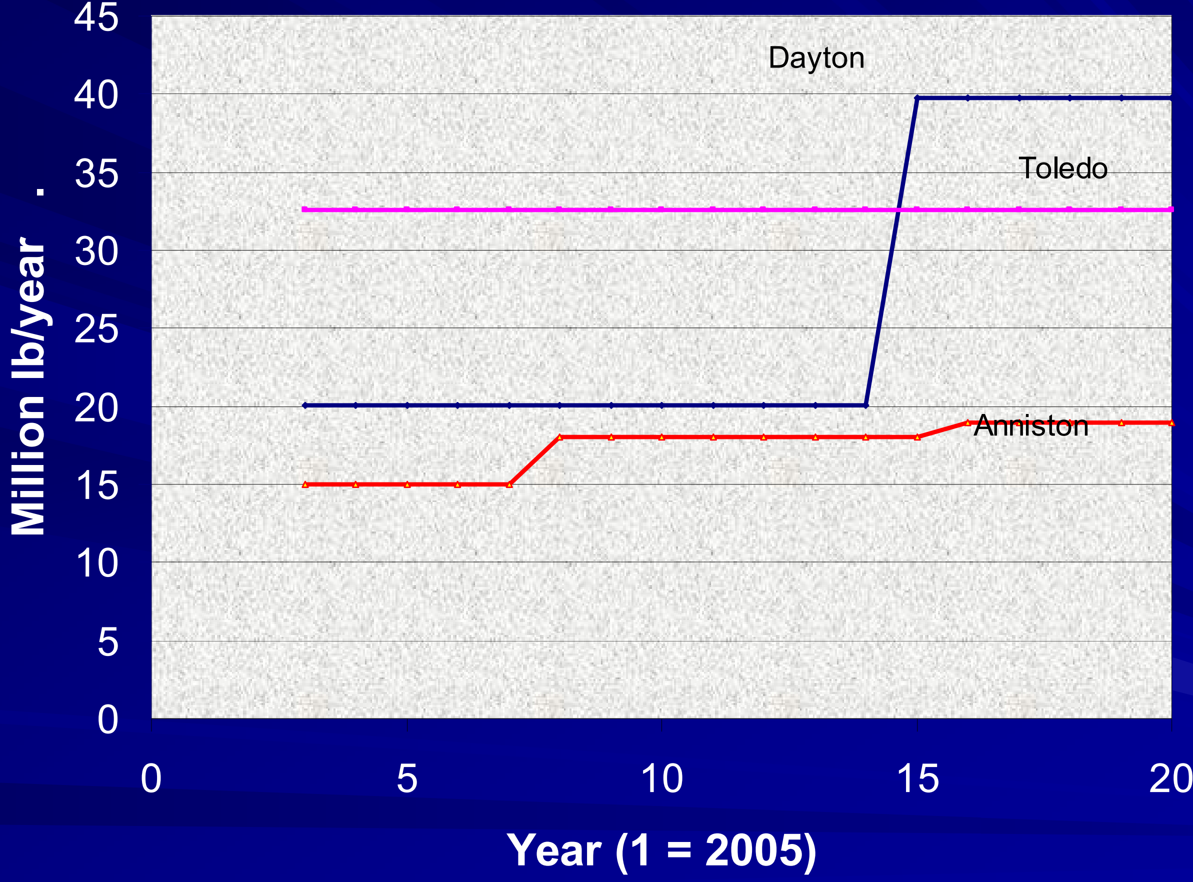
- Single Raw Material:
  - Corn
- Build three plants immediately:
  - Toledo, OH
  - Dayton, OH
  - Anniston, AL

- ENPV = $34.4 million
- ICI = $44.0 million
- ROI = 3.9%
- Value at Risk at 5% = $14.3 million

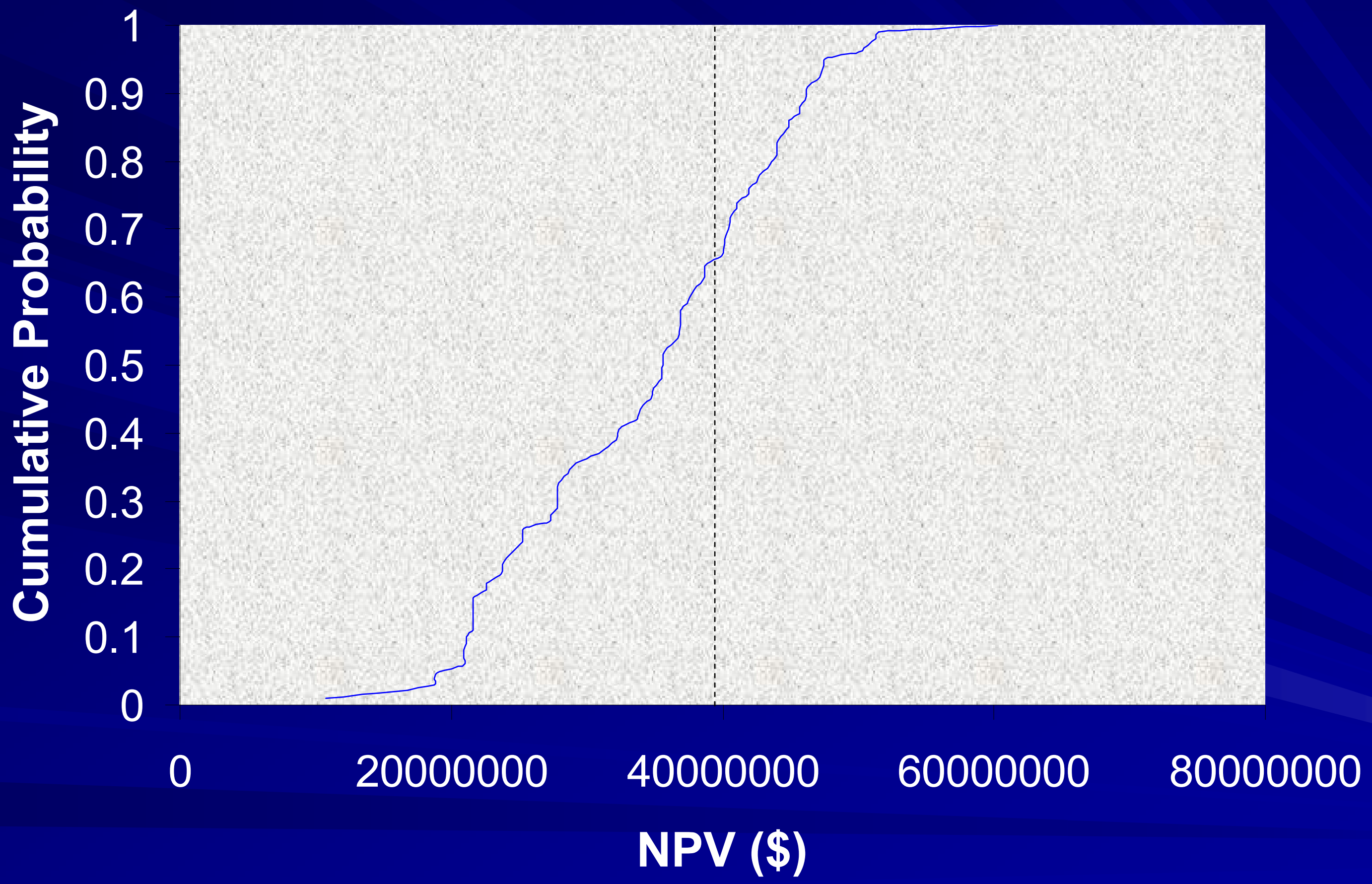
Locations



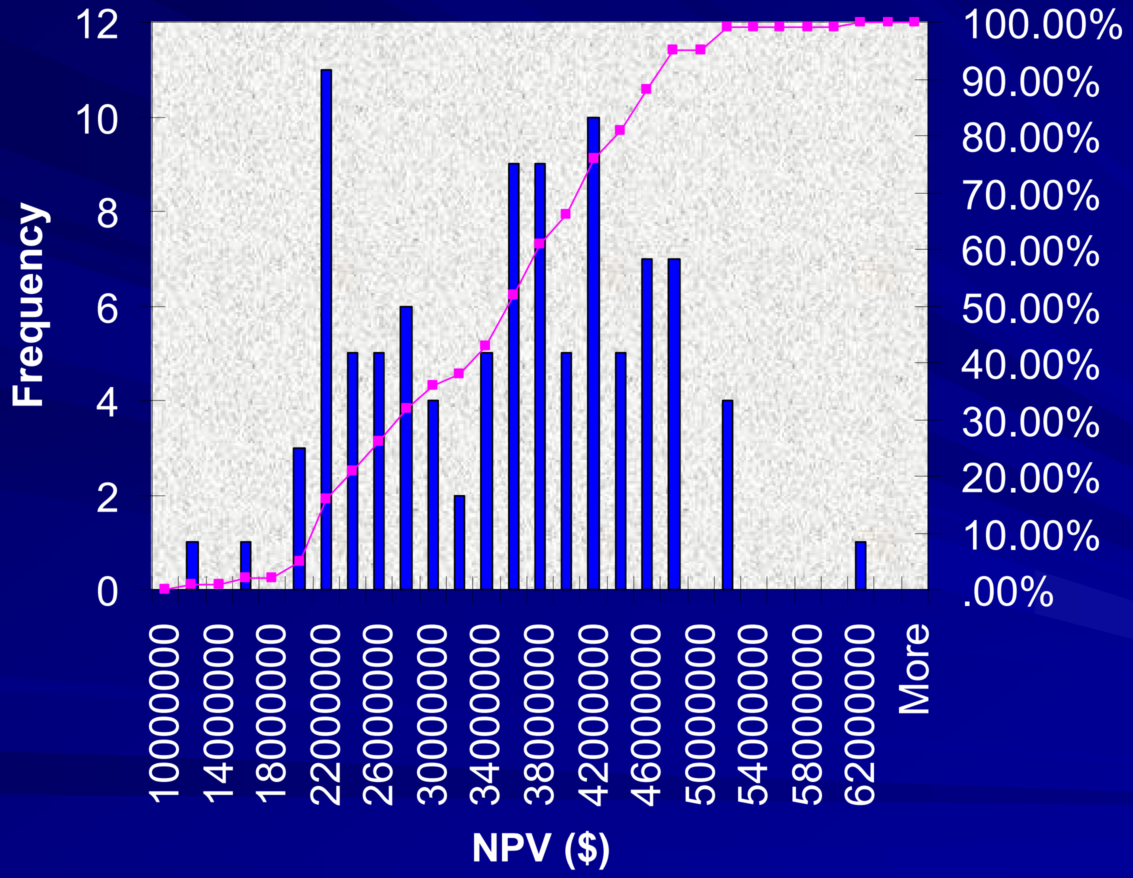
Product Flow Rate



Risk Analysis – Ethyl Lactate



Risk Histogram – Ethyl Lactate



Ethyl Lactate Conclusion

- With uncertainty
  - 3 plants
  - NPV = $34.4 million
  - ICI = $44.0 million
- Use this model for all processes

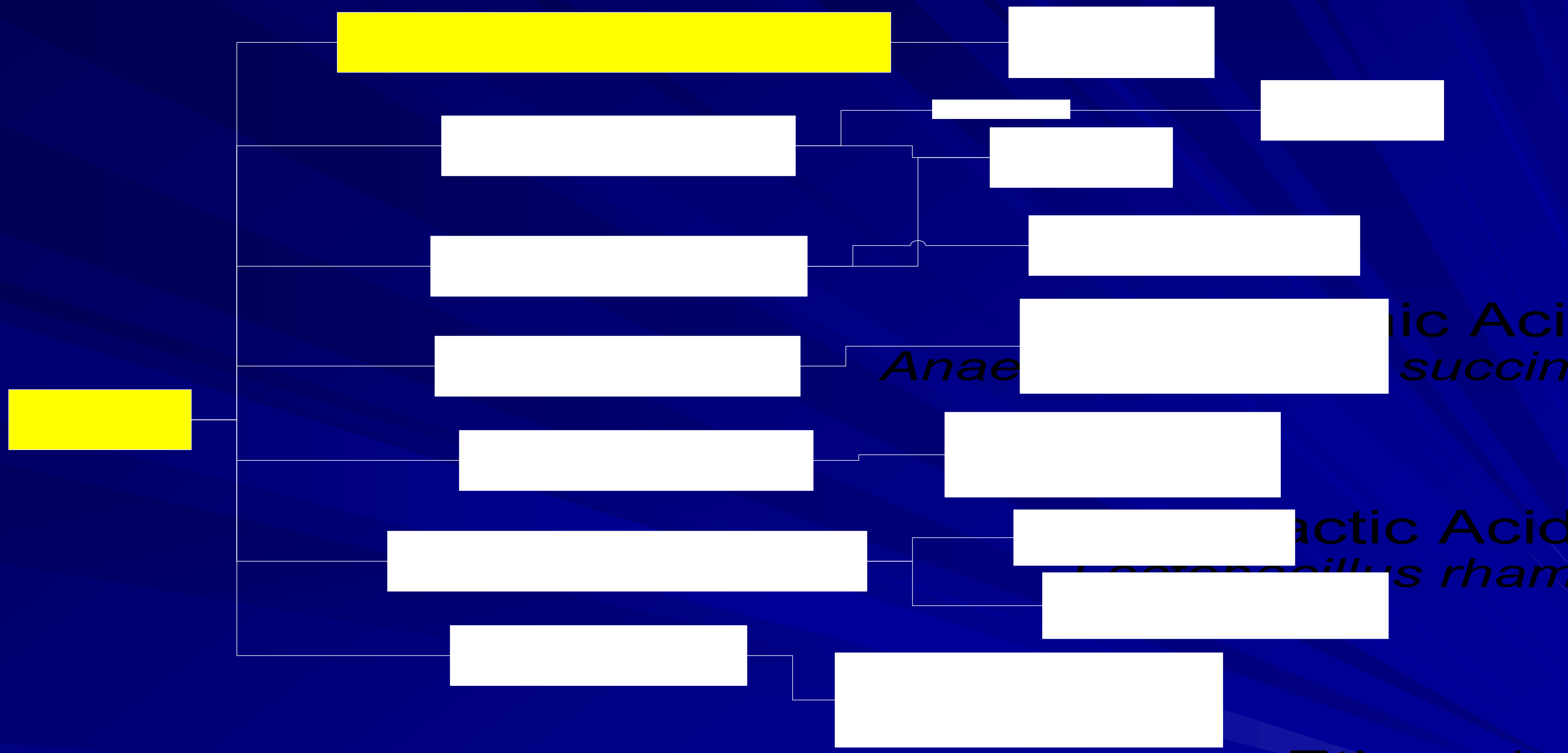
Mathematical Model Results

- Plant Location
  - Dubuque, Iowa
- Raw Material
  - Corn
- Maximum Initial Capital Available
  - $150 million
- Net Present Value
  - $295 million
- Return on Investment
  - 10%

Potential Plant Production

- 7 Potential Products
- Venture Will Include Production of 4

Plant Production Specifications



- Succinic Acid
  - Annual Production: 63 million pounds
  - Fixed Capital Investment: $120,000,000
  - Annual Operating Cost: $40,000,000

Ethanol

Citric Acid

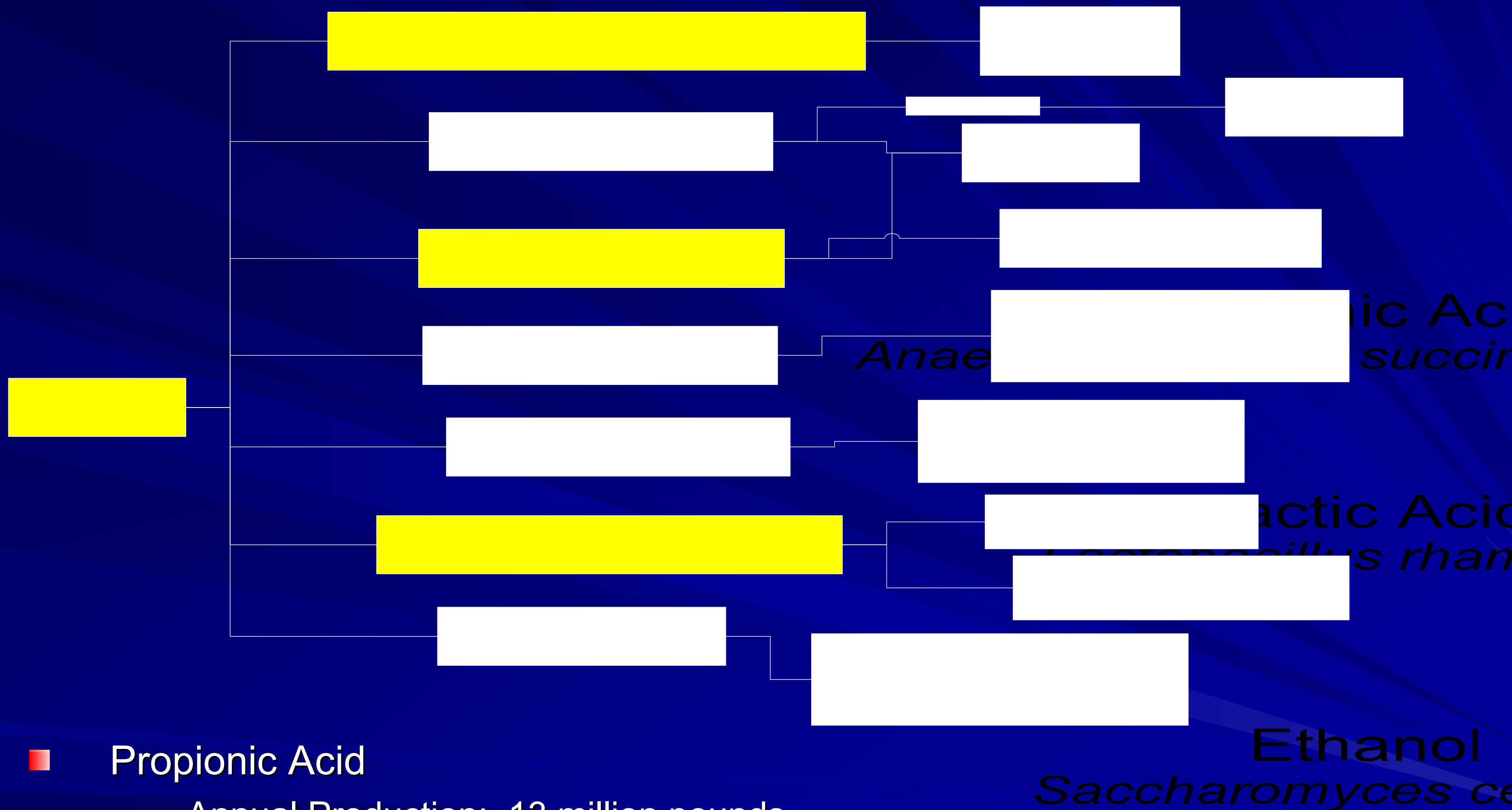
Plant Production Specifications

- Ethanol
  - Annual Production: 81 million pounds
  - Fixed Capital Investment: $130,000,000
  - Annual Operating Cost: $42,000,000

Ethanol
Saccharomyces ce

Citric Acid
Aspergillus nig

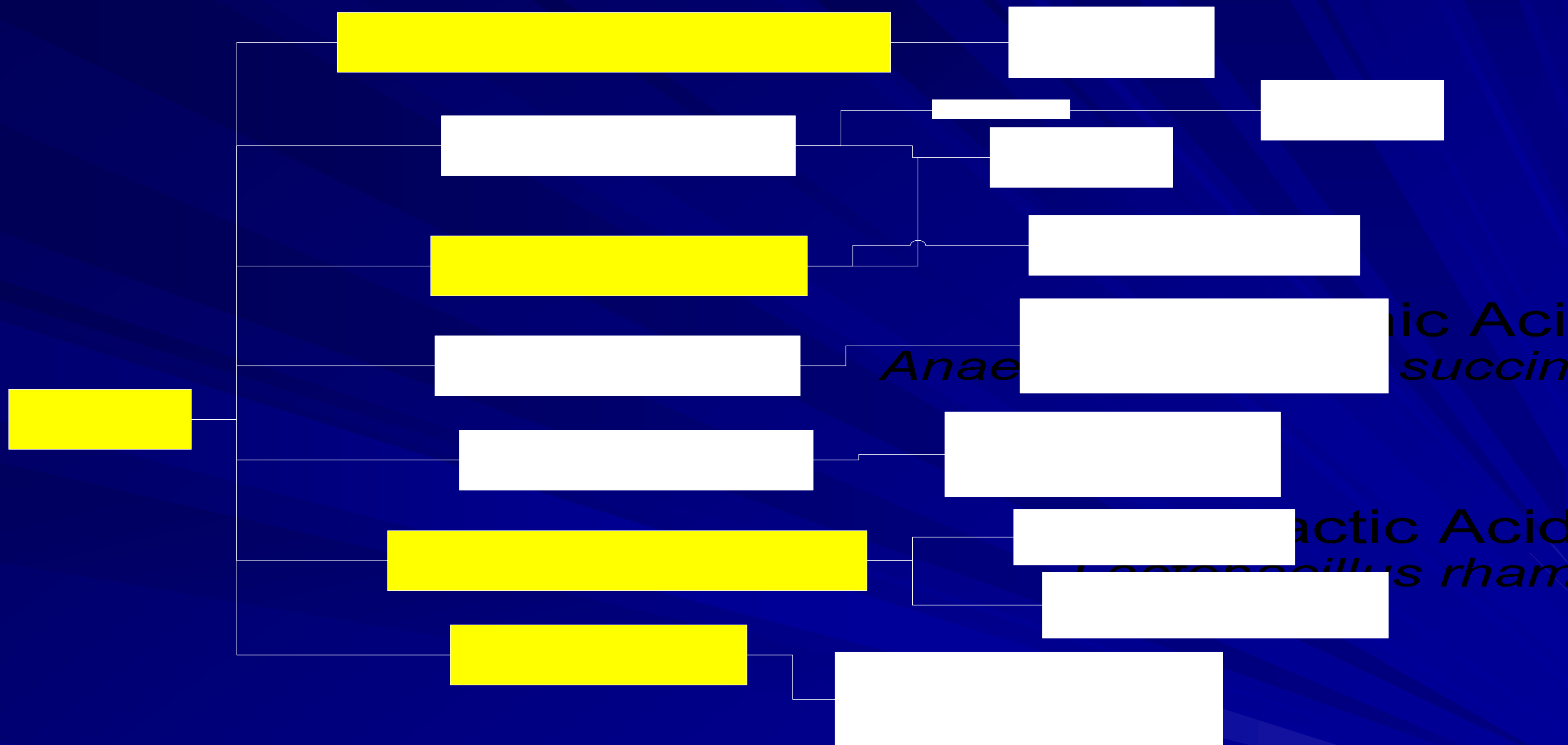
Plant Production Specifications



- Propionic Acid
  - Annual Production: 13 million pounds
  - Fixed Capital Investment: $9,600,000
  - Annual Operating Cost: $3,000,000

Citric Acid
Aspergillus nig

Plant Production Specifications

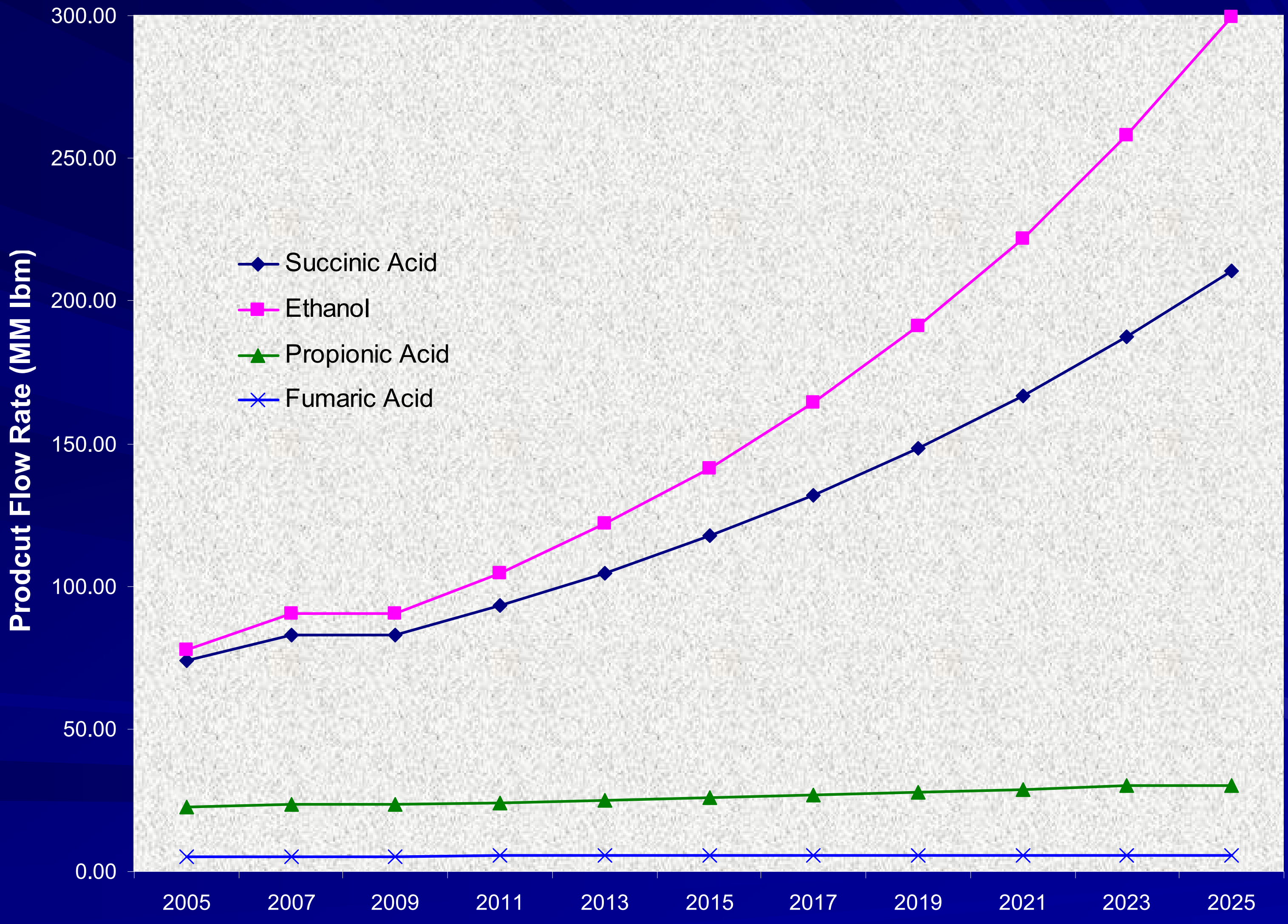


- Fumaric Acid
  - Annual Production: 3 million pounds
  - Fixed Capital Investment: $2,200,000
  - Annual Operating Cost: $600,000

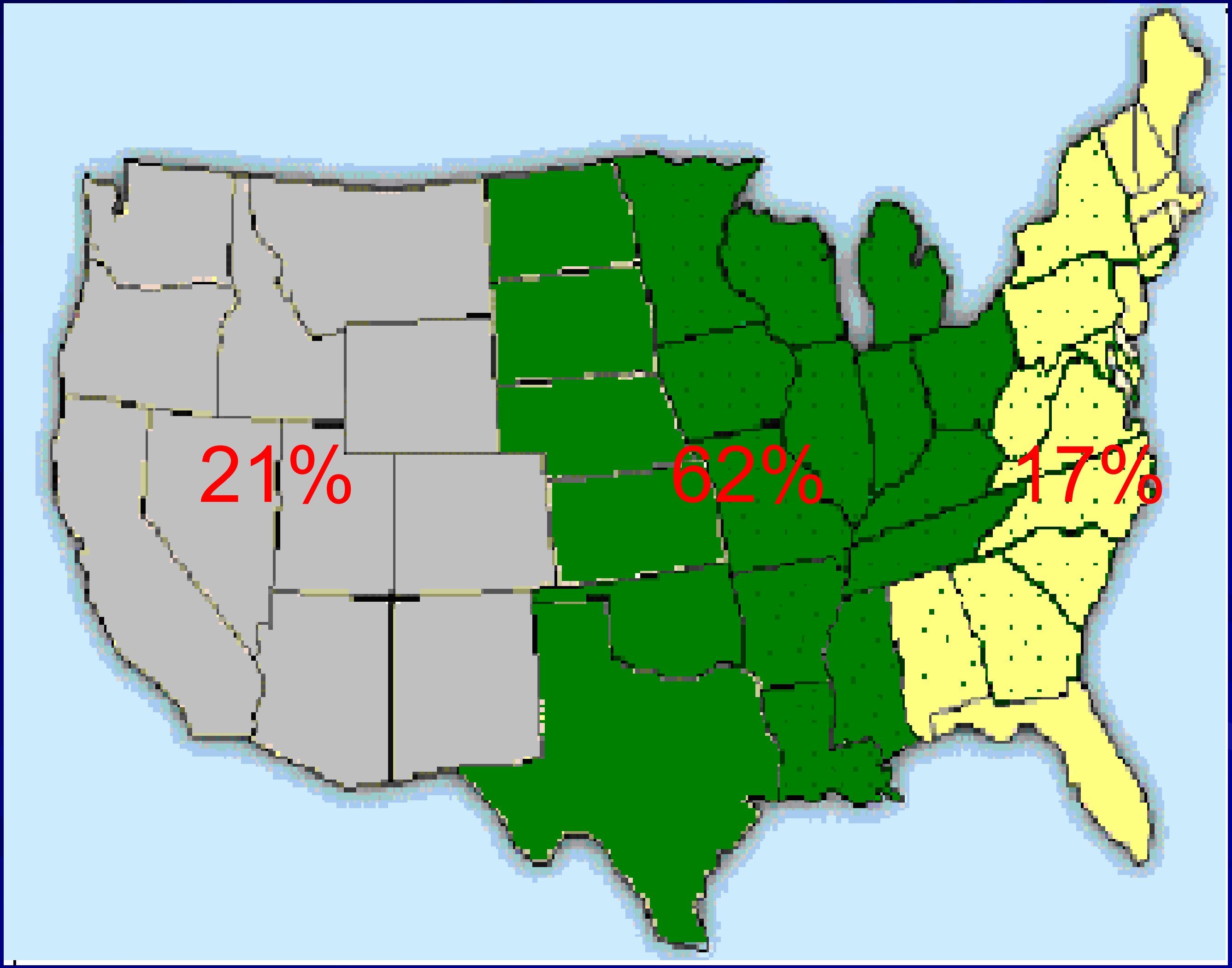
Ethanol
Saccharomyces ce

Citric Acid
Aspergillus nig

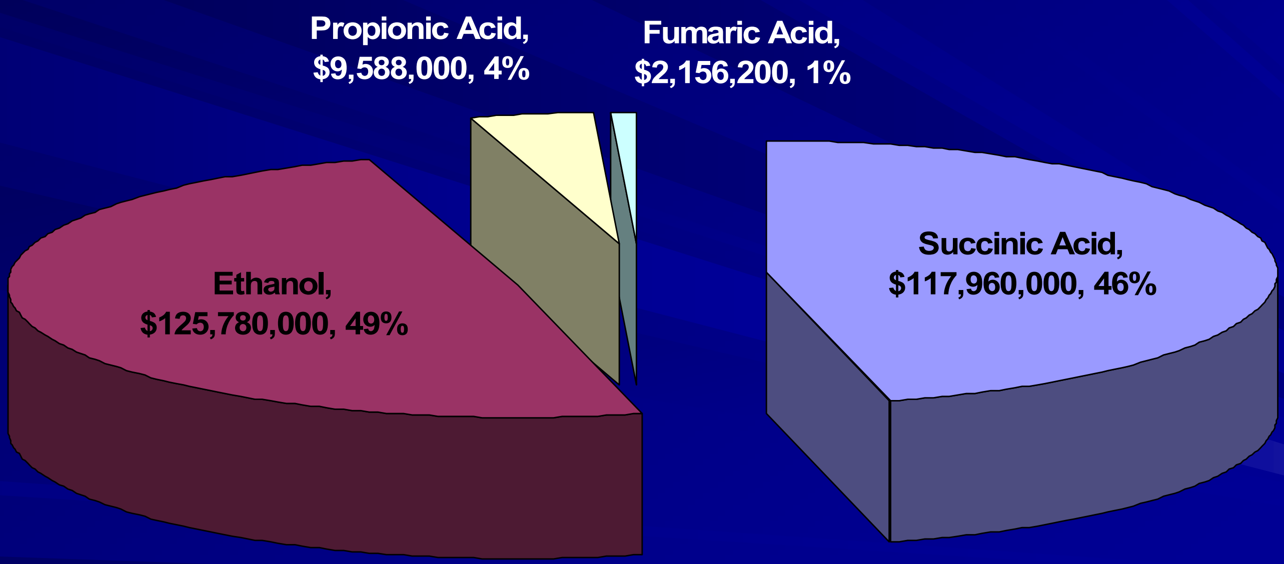
Plant Production



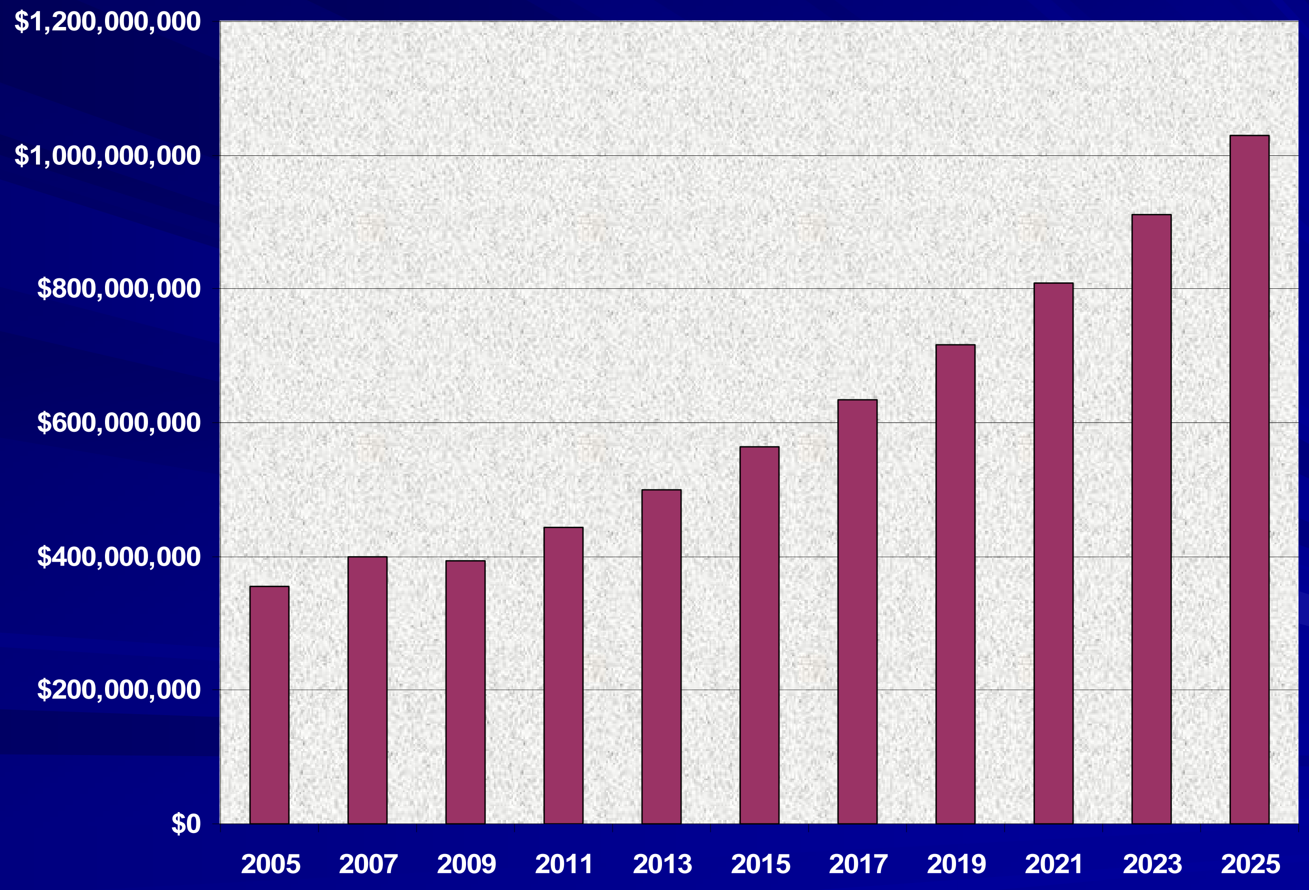
Market Distribution



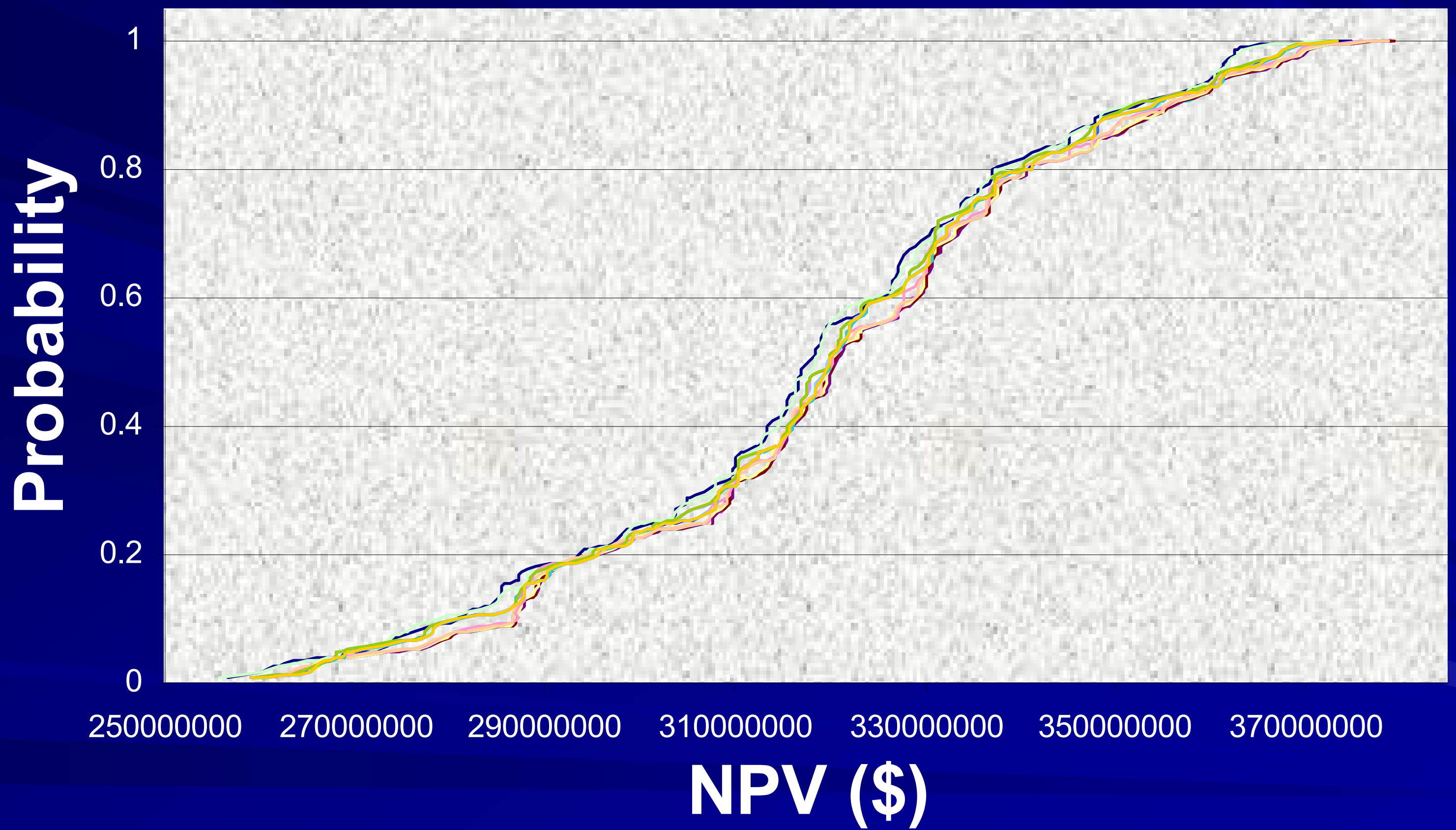
Capital Investment Distribution



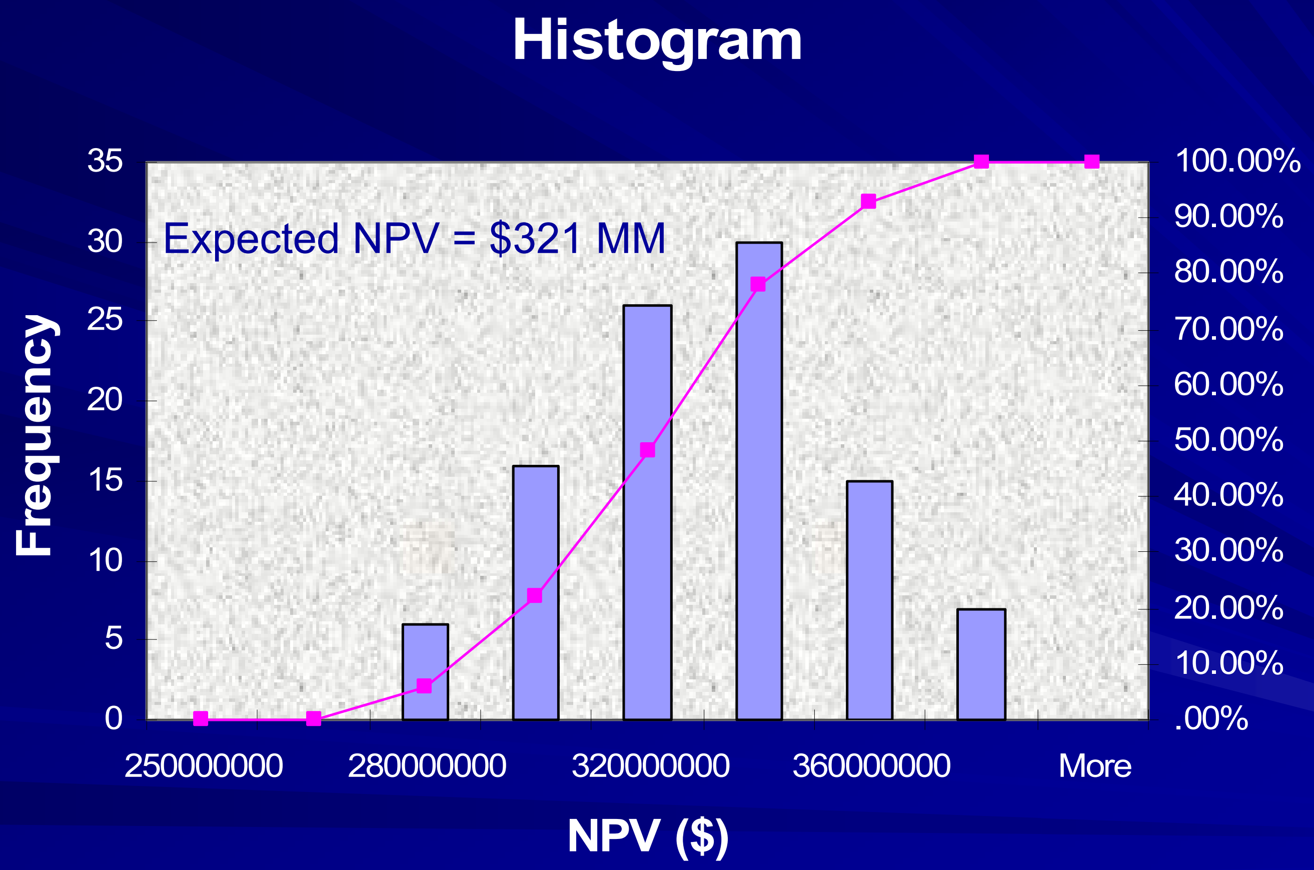
Revenue From Product Sales



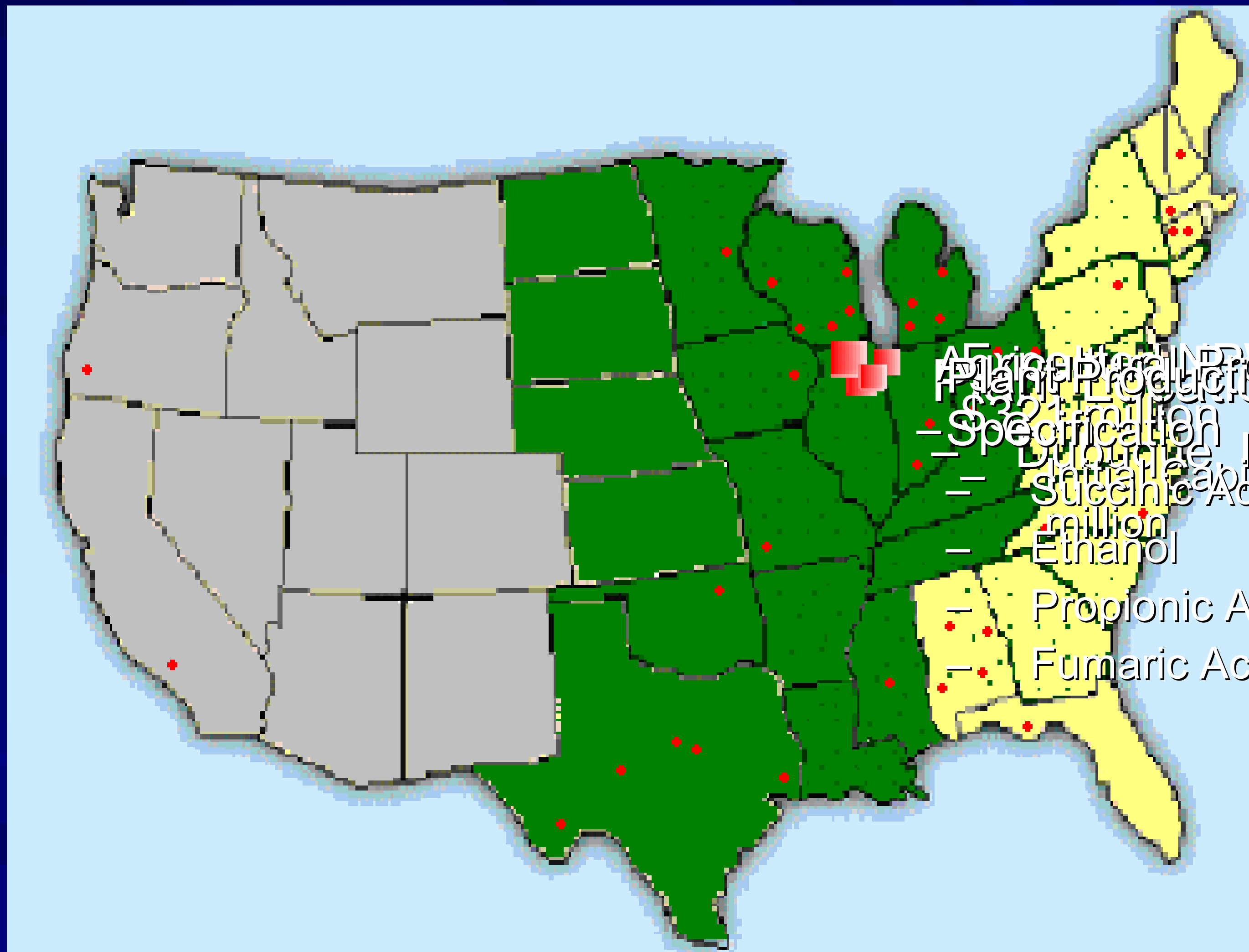
Uncertainty Analysis



Risk Histogram-Biorefining



Conclusion



- Annual NPW of Plant Production: $321 million
- Finished Product Specification
  - Succinic Acid
  - Ethanol
  - Propionic Acid
  - Fumaric Acid
- Plant Location: Dubuque, IA
- Initial Capital: $150 million

Further Questions…