SENIOR CAPSTONE/
SENIOR DESIGN EXPERIENCE
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CORN-BASED ETHANOL FUEL PRODUCTION

Group 14: David Kim[1], James Lin[1], Matthew Trotter[1]

[1]Bioloigical Engineering (Cellular & Biomolecular Engineering)

PURDUE UNIVERSITY
Agricultural and Biological Engineering

Objective

The objective of this project was to design and optimize a scalable process for manufacturing ethanol fuel from corn to reduce reliance on non-renewable fuel sources.

Background

GHG Emissions

Well-optimized processes can produce ethanol with a 30–40% lower emission profile than the energy equivalent of gasoline. This is significant because the transportation sector accounts for 29% of total U.S. emissions, making fuel-grade ethanol an important tool for reducing carbon output.

Potential for Advancement

In the US, the refining stage of ethanol production still accounts for approximately 45% of the ethanol's life-cycle greenhouse gas emissions. Optimizing this stage can seriously reduce its emission profile.

Corn as a Substrate

In 2024, the US produced 14.9 billion bushels of corn, making it a constant and reliable substrate, especially in the Midwest.

Market Analysis and Ethics

Market Size

In 2023, the US produced 18 billion gallons of fuel ethanol, of which approximately 95% used a corn feedstock. Its market size is around $30 billion today and is estimated to reach around $60 billion by 2030, with a compounding annual growth rate of 9%. (Coherent Market Insights, 2025)

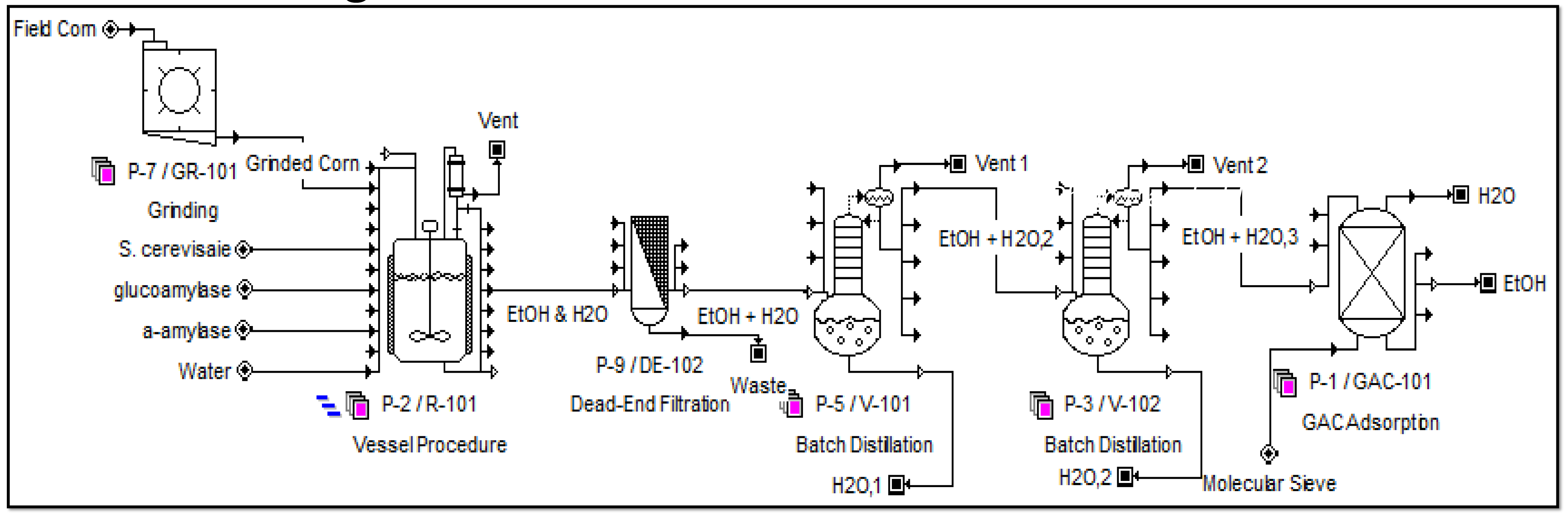
Energy Security

Ethanol biofuel production strengthens energy security by reducing dependence on imported petroleum and promoting the use of domestic, renewable resources.

Food vs Fuel

There are concerns that the ongoing increase in biofuel production could hurt the global food supply. To mitigate this, the industry can explore increasing the use of non-food feedstocks, improve farming efficiency, increase co-product use, and enforce sustainability standards in fuel production.

Process Design



Experimental Design and Results

- **Saccharification and Liquefaction:** Water was added at a 2:1 (w/w) ratio to corn mass, followed by the addition of α-amylase (0.2% w/w) and glucoamylase (0.3% w/w), relative to corn mass, to hydrolyze starch into simple sugars.
- **Fermentation:** Used *Saccharomyces cerevisiae* to ferment at room temperature for a minimum of 72 hours.
- **Filtration:** Filtered out solids to increase distillation efficiency.
- **Distillation:** Used lab scale distillation unit to reach >90% purity.
- **Adsorption:** Increased purity to >99% using 3A zeolite molecular sieves.

Corn Mass, g	Final Ethanol %	Theoretical Yield, g	Actual Yield, g
251	>99	~80	58.02

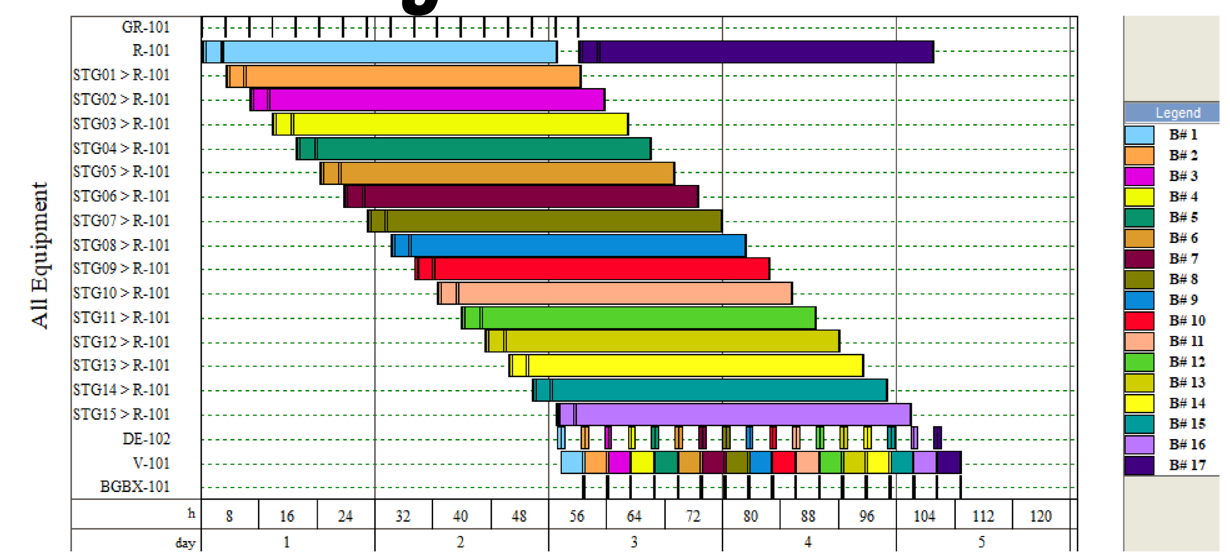
Optimization

Milling: Feed rate optimized via Bond's Law to minimize energy.
Liquefaction: Jet cooker temp tuned (~90°C) for high conversion and low steam (Gaussian).
Saccharification: Enzyme dosage minimized for ≥85% yield (Michaelis-Menten).
Fermentation: Fermenter volume adjusted to lower cost (batch + utility).
Distillation: Balanced reflux ratio, tray # and related costs.
Dehydration: Regeneration temp optimized to reduce energy in sieve system.

Design of Process Operations

- **Production Target:** ~65 million gallons/year of fuel-grade ethanol, continuous 365-day operation.
- **Key Unit Operations:** Milling, liquefaction, saccharification, fermentation, distillation, dehydration, molecular sieve regeneration.
- **Process Overview:** Corn is milled, enzymatically converted to sugars by *α-amylase* and *glucoamylase*, fermented by S. cerevisiae, and purified via distillation and dehydration.
- **Simulation and Analysis:** Superpro Designer used for material and energy balances, batch scheduling, and utility modeling.
- **Optimization Focus:** Minimizing enzyme usage, reducing utility costs, and maximizing coproduct revenues (DDGS)
- **Energy Considerations:** Focused on fermentation cooling, distillation reboiler duty, and sieve regeneration energy usage.
- **Alternative Designs:** Continuous fermentation was considered for higher throughput but rejected due to complexity and sterility challenges.

Scheduling

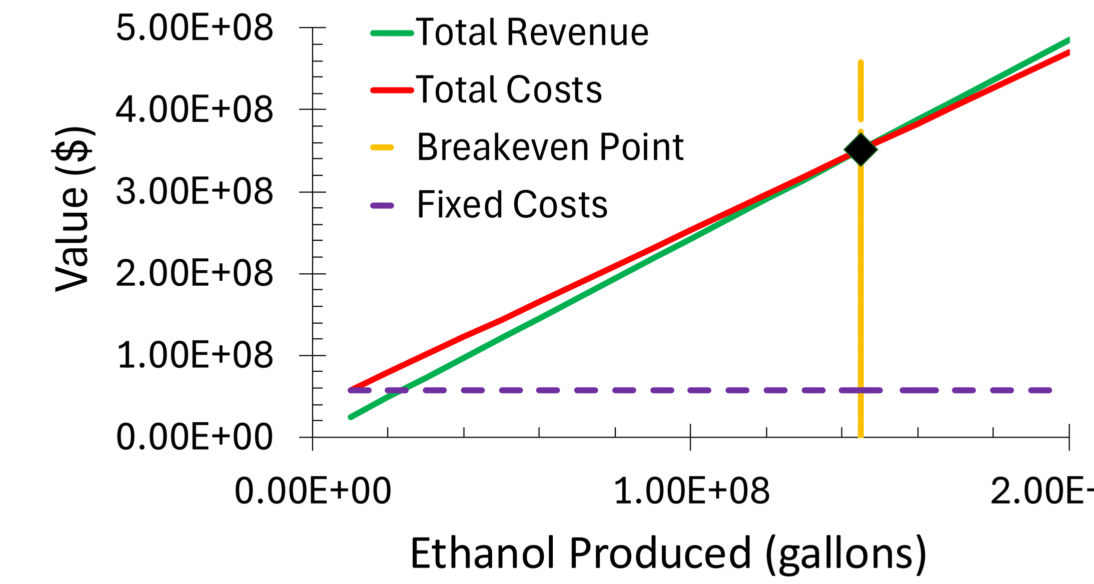


- Superpro optimized scheduling of 16 fermenters in staggered parallel for continuous process with little turnaround time
- For Scale-Up, 32 fermenters of 300,000 L will be used

Economic Analysis

Total revenue reached total costs at around 145 million gallons produced. At a rate of 65 million gallons a year, it was reached after approximately 2 years and 3 months.

Total Capital Investment ($)	35,426,906
Total Operating Cost ($/yr)	141,376,606
Annual Production (gal/yr)	65,000,000
Breakeven Point (gal)	145,000,000
Average Market Rate ($/gal)	1.77



Proposed Next Steps

- Perform distillation with lab scale setup that can account for reflux, allowing one to test how different values affect efficiency.
- Implement water recycling into plant design to reduce environmental impact.
- Implement heat recovery systems to maximize energy efficiency.

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