

SENIOR CAPSTONE/
SENIOR DESIGN EXPERIENCE
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Synergize: Biodegradable Caffeine Pouch

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Agricultural and Biological Engineering

Objective

To design a biodegradable, cognitive-enhancing oral cellulose pouch containing caffeine, L-theanine, and other natural ingredients while addressing associated economic, environmental, and ethical considerations.

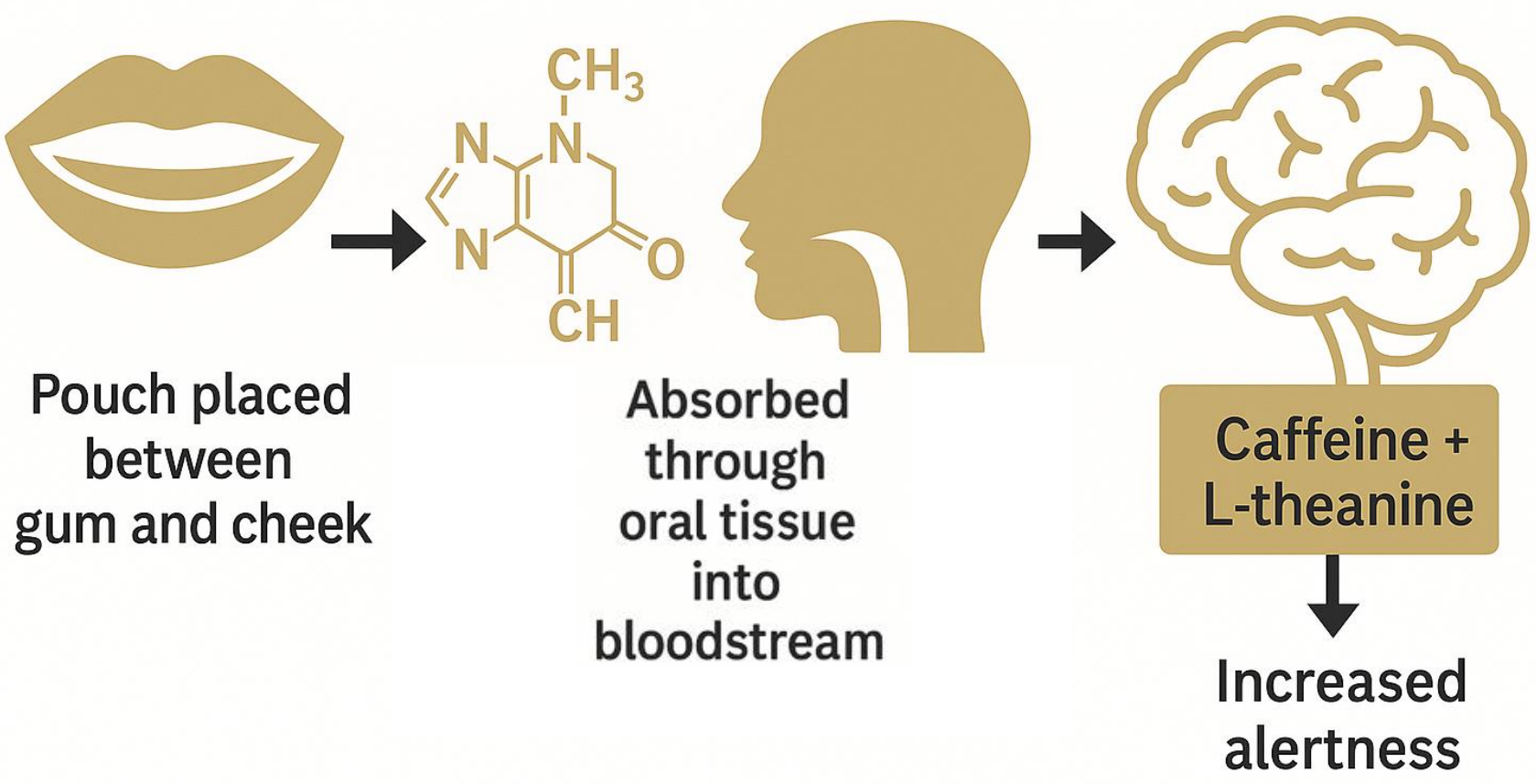
Design Considerations

- Balanced Cognitive Enhancement with Caffeine and L-Theanine
- Biodegradable Packaging Using Cellulose
- Ethical and Environmentally Responsible Ingredient Sourcing

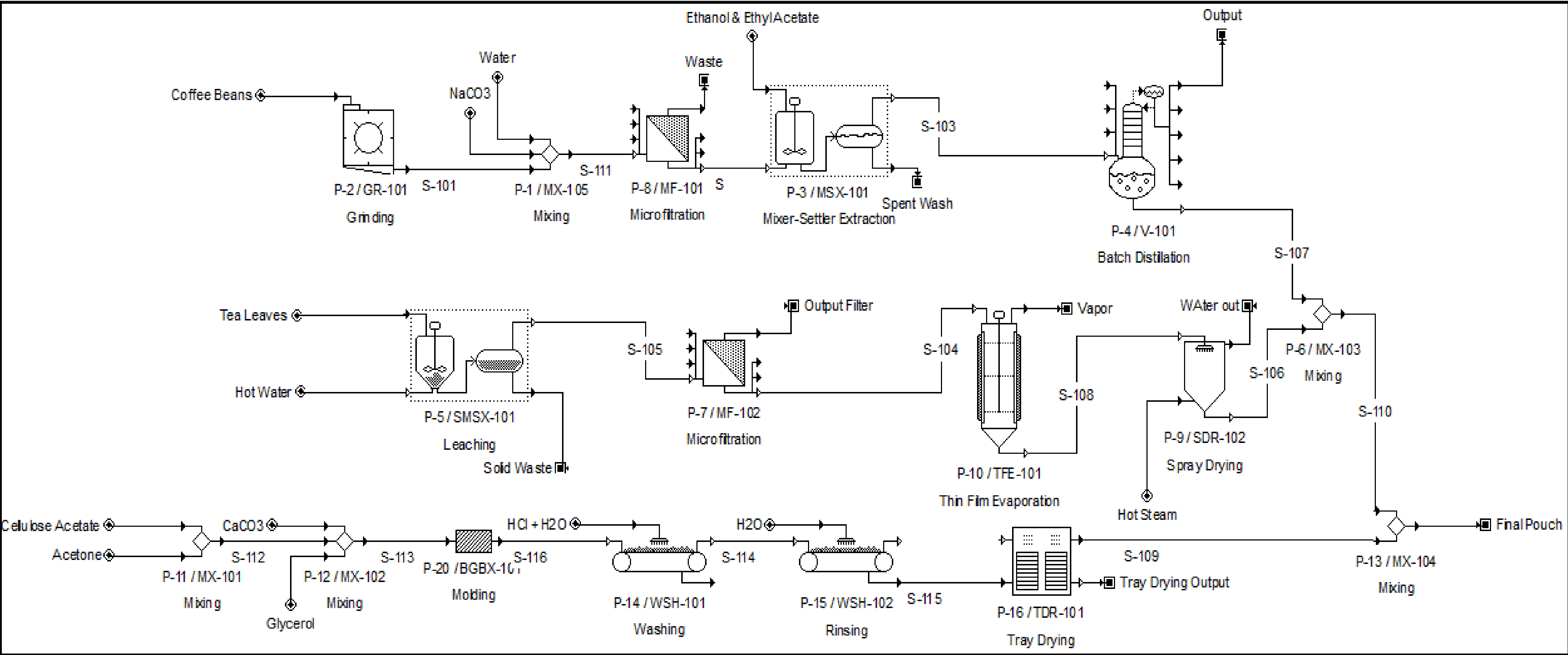
Market Analysis

- Cellulose Packaging**
 - Projected to grow 5% over 10 Y (Future Market Insights)
- Nicotine Pouch Surge**
 - Sales rose 641% from 2019-2022 (CDC, 2024)
- Youth Usage**
 - 2.8M U.S. students use nicotine products
- Health-Conscious Alternative**
 - Meets demand for stimulants that offer alertness without nicotine or excessive caffeine side effects

Mechanism of Action



Process Flow Diagram

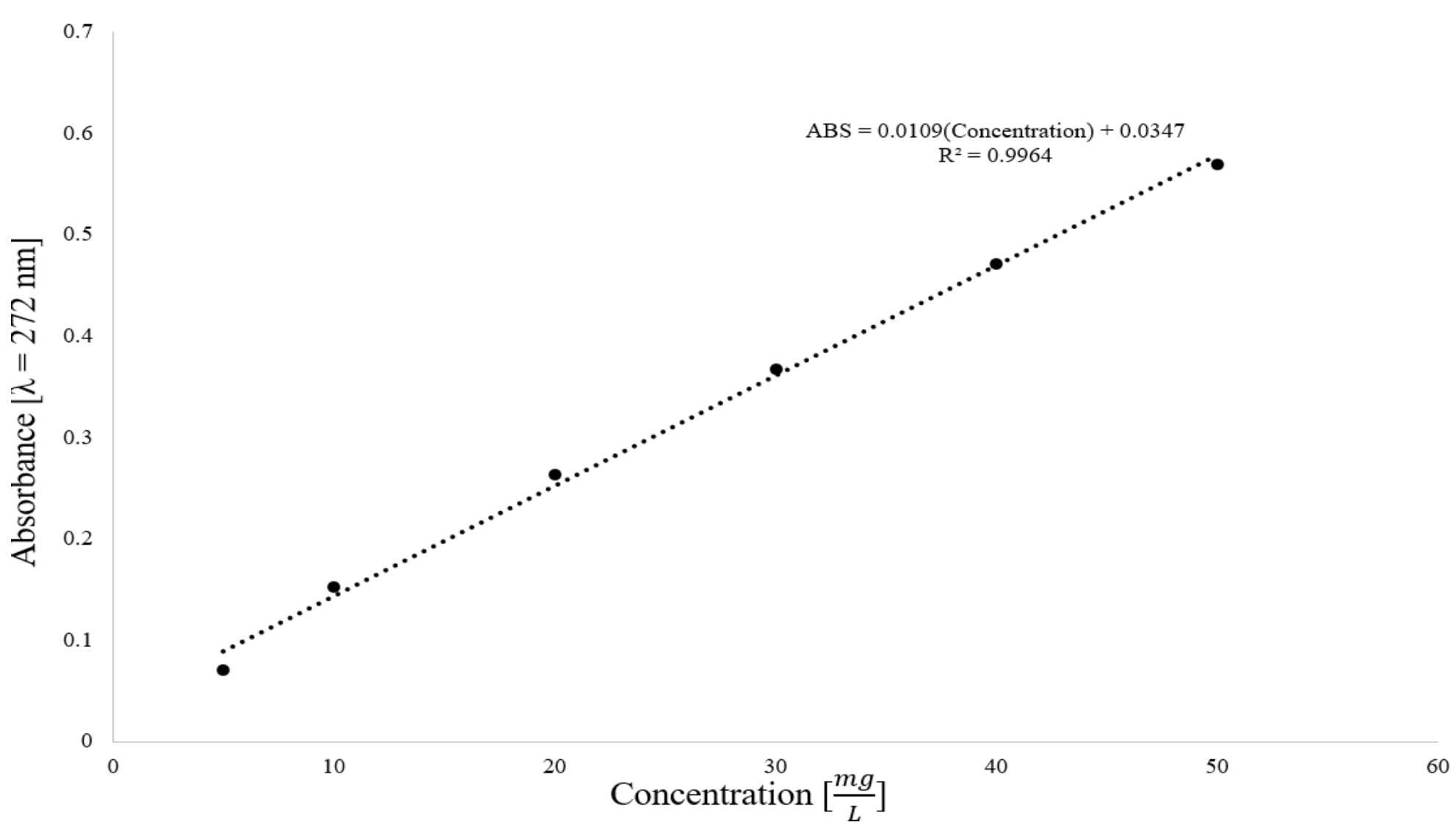


Experimental Design

- L-theanine from Green Tea
- Caffeine from Coffee Beans
- Cellulose from Wood Pulp
- Pouch Construction



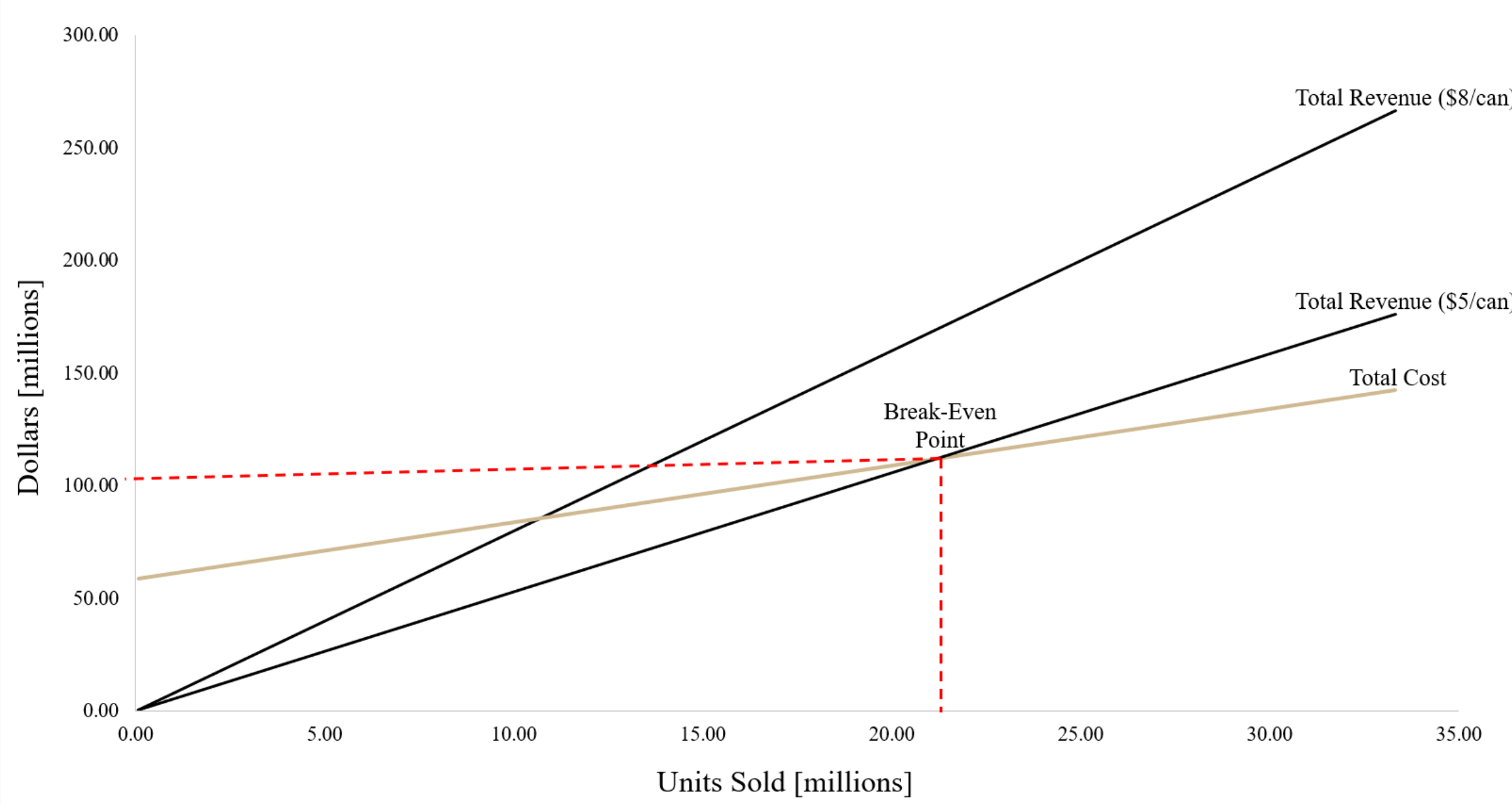
Caffeine Purity



Extracted Caffeine Purity: 49.05%

Operations	Alternatives
Mixing: Mixer	Static Mixer, High Shear Mixer
Drying: Spray Drying, Tray Drying, Thin-Film Evaporation	Freeze Drying, Drum Drying
Distillation: Batch Distillation	Continuous Solvent-Recovery Distillation Column, Multi-Effect Evaporator
Separation: Microfiltration	Ultrafiltration, Centrifugation

Manufacturing & Plant Design

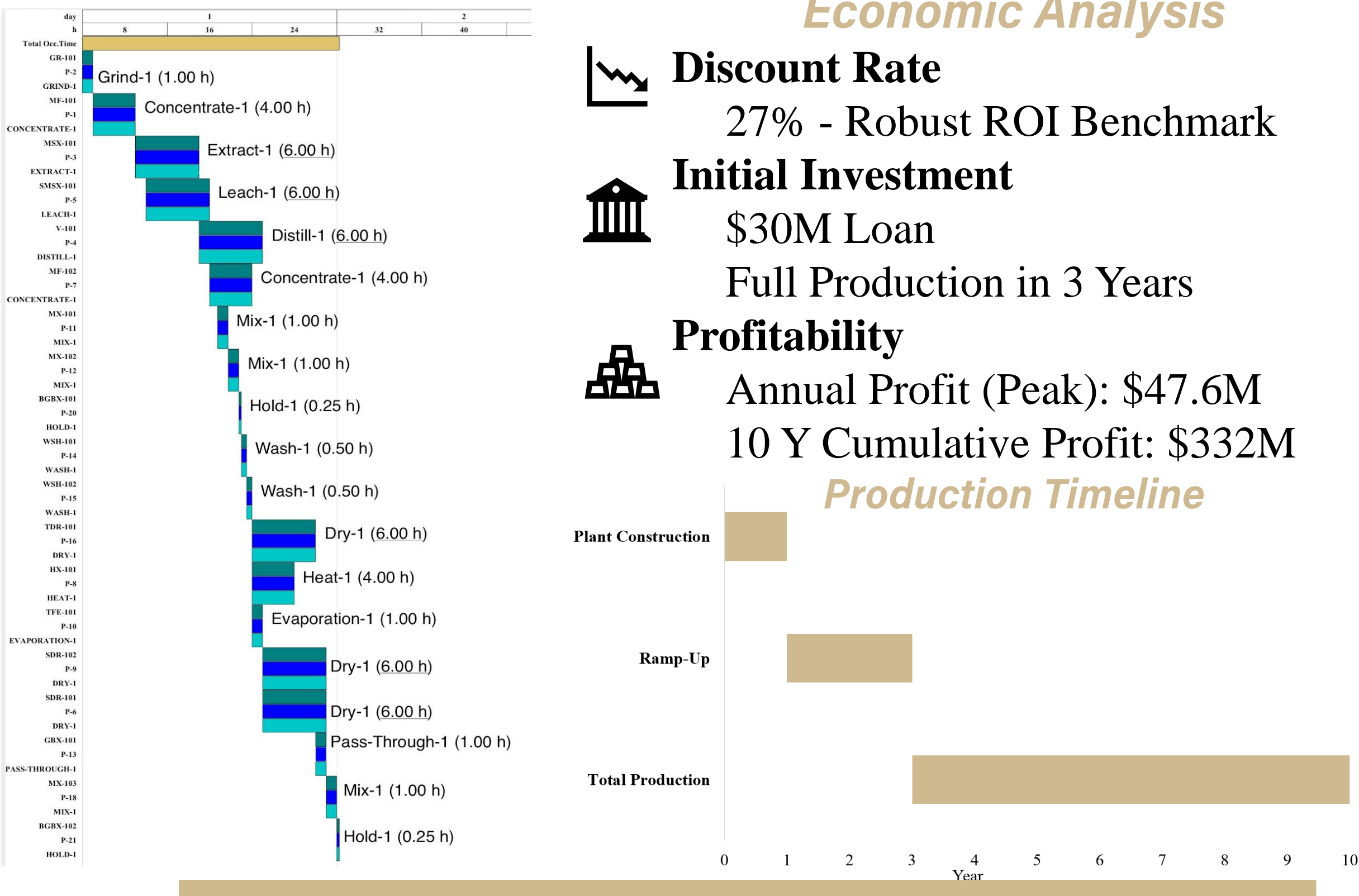


Cost	Value
Total Capital Investment	\$13,841,538.66
Product Cost & Manufacturing	\$27,697,082.35
Materials, Labor & Utilities	\$113,597,004.80
Total Can Cost	\$4.28
Selling Cost	\$5.29

Economic Analysis

- Discount Rate**
 - 27% - Robust ROI Benchmark
- Initial Investment**
 - \$30M Loan
 - Full Production in 3 Years
- Profitability**
 - Annual Profit (Peak): \$47.6M
 - 10 Y Cumulative Profit: \$332M

Production Timeline



Future Work and Improvements

- Further Optimization**
 - Minimize raw material expenses through cheaper alternatives
 - Improve purity of caffeine and L-theanine extractions
- Additional Sustainability Measures**
 - Water and solvent purification, treatment, and reuse
 - Energy minimization through alternative energy sources

Acknowledgments: Thank you to Dr. Martin Okos, Daniel Hauersperger, and Mandy Limiac

References:

Cellulose film packaging market growth analysis report to 2034, Future Market Insights, (2024, January 22)
Centers for Disease Control and Prevention. (2024, October 17). Tobacco product use among middle and high school students - national youth tobacco survey, United States, 2024. Centers for Disease Control and Prevention
Temple, J. L., Bernard, C., Lipshultz, S. E., Czachor, J. D., Westphal, J. A., & Mestre, M. A. (2017). The Safety of Ingested Caffeine: A Comprehensive Review, *Frontiers in psychiatry*, 8, 80.