Logistical Support and Modeling Efforts in Pretreatment Research

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NEOTERICS INTERNATIONAL
Using Technology to Create Business Innovation

NREL

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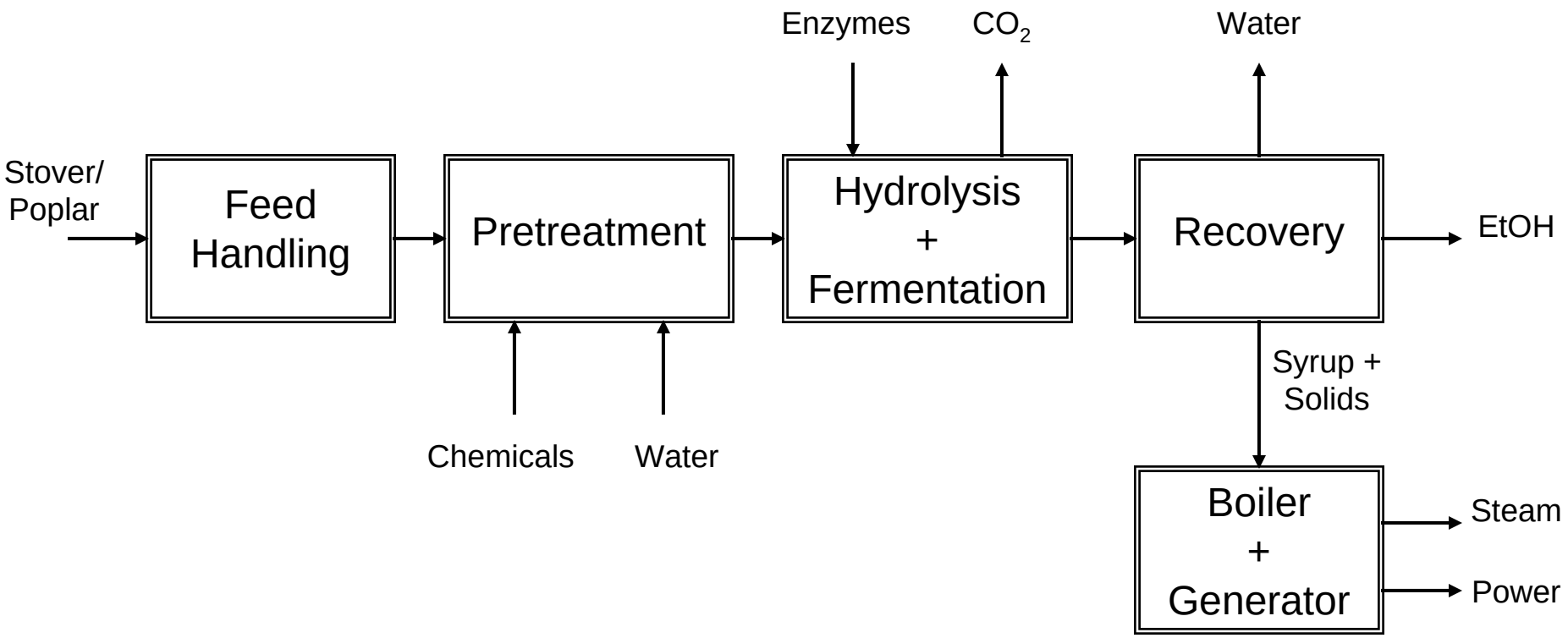
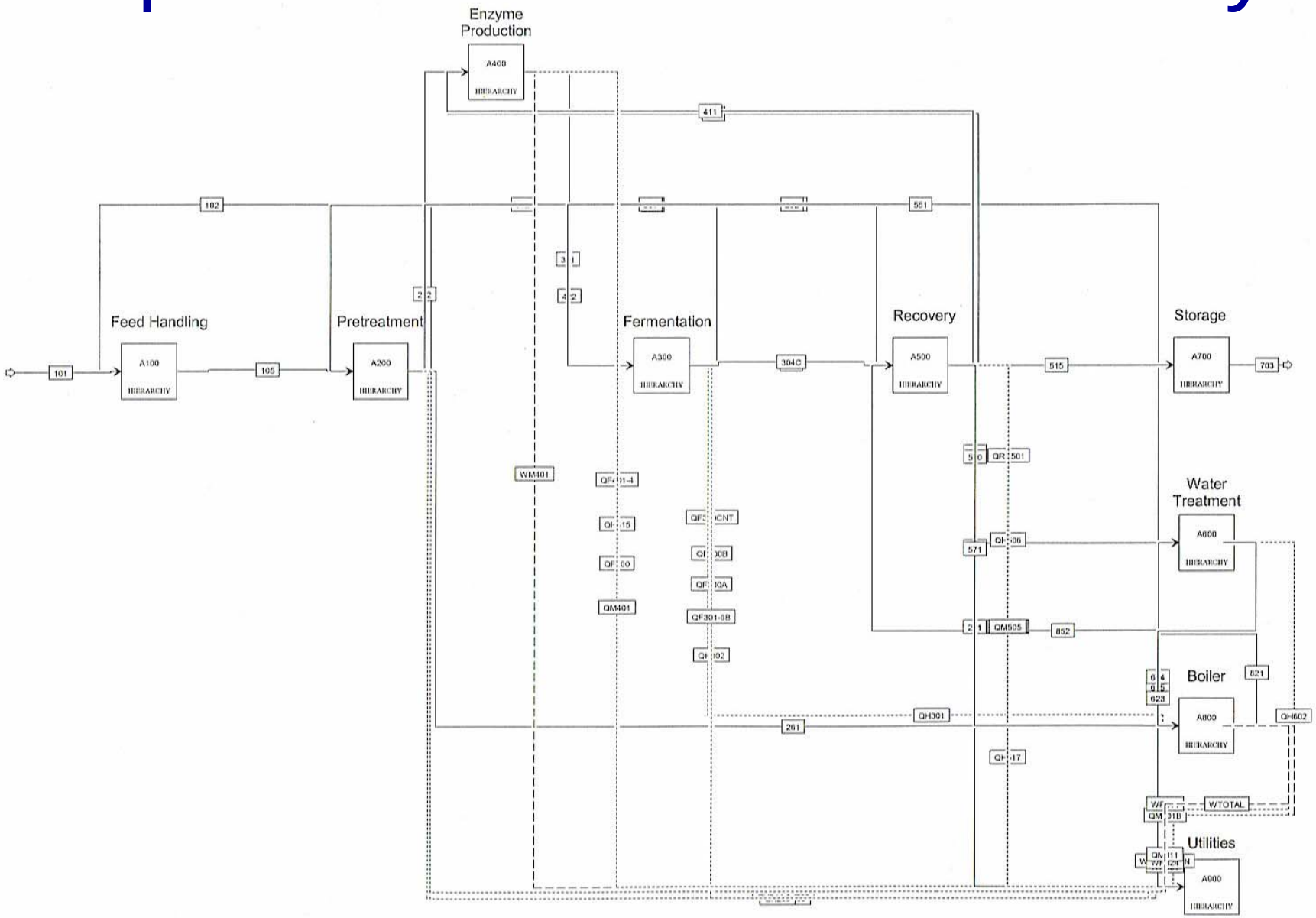
Block Flow


Enzymes
CO_2
Water
Stover/
Poplar
Feed
Handling
Pretreatment
Hydrolysis
+
Fermentation
Recovery
EtOH
Syrup +
Solids
Chemicals
Water
Boiler
+
Generator
Steam
Power

Aspen Plus – GUI w/ Hierarchy



Economic Modeling

Capital Costs

Fixed - Direct
Purchased Equipment
Installation
- Indirect
- Contingency
- Start-up

Working

Operating Costs

Variable – Biomass
Enzymes
Other

Fixed - Labor
Maintenance
Insurance
Depreciation

Revenues

Ethanol Sales
Electricity Sales

Discounted Cash Flow

2.5 yr Construction, 0.5 yr Start-up 20 yr Operation
100% Equity, No Subsidy
Rational EtOH Pricing Rather Than Market Pricing
10% Real After Tax Discount Rate

Performance Measures

Total Fixed Capital Per Annual Gallon of Capacity
Plant Level Cash Costs
Minimum Ethanol Selling Price (MESP)

Current vs. Goal

- Current: Laboratory Performance
  - Pretreatment
  - Conditioning
  - Enzymatic Hydrolysis
  - Fermentation
- Goal: Likely Performance of Above Steps at Commercial Scale

Results (Interim)

MESP, $/gal

	Stover		Poplar	
	Current	Goal	Current	Goal
Ideal Pretreatment	1.49	0.81	1.42	0.77
Acidic				
Neutral pH				
Alkaline				
No Pretreatment	12.86	7.84	36.73	19.63

Case Study

- Poplar Goal Case - Ideal Pretreatment

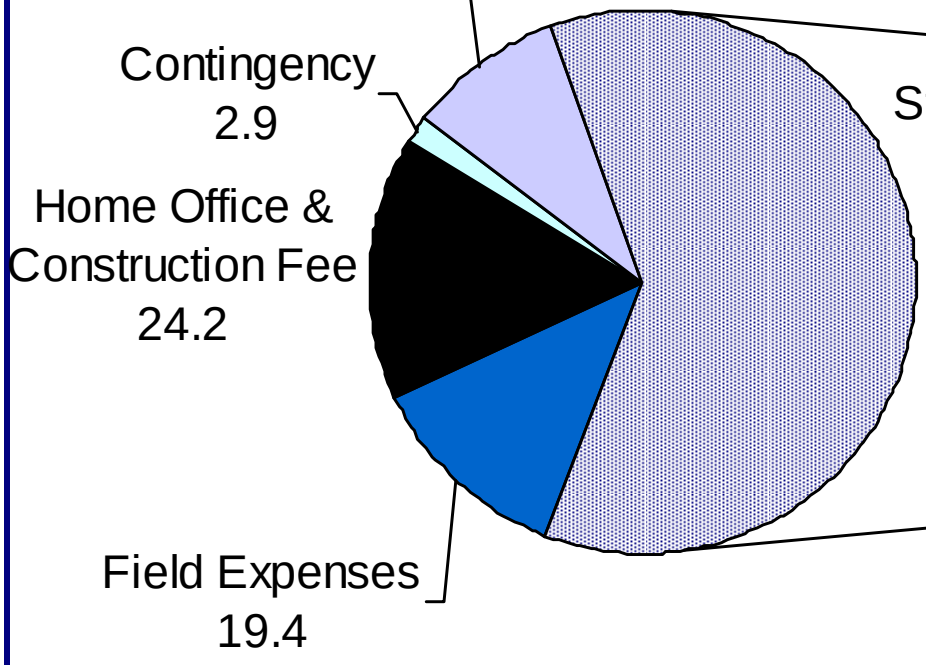
- Sensitivities
  - Pretreatment+Hydrolysis Yield
  - Beer Concentration
  - Pretreatment Fixed Capital
  - Financial Assumptions
  - Other

Fixed Capital

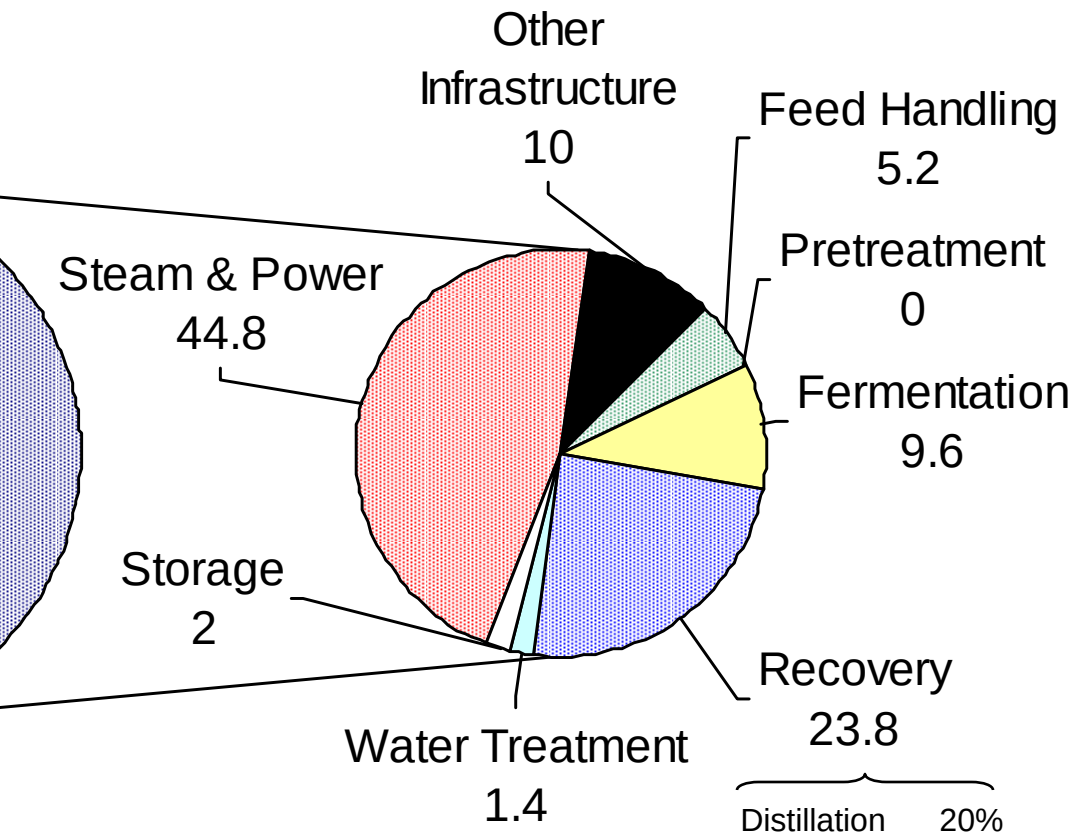
Values are $MM (US Location, 2002)

Biomass CAFI Refining

Total Fixed



Direct Fixed



Distillation 20%
Evaporation 65%
Mole Sieve 14%
Vent Scrubber 1%

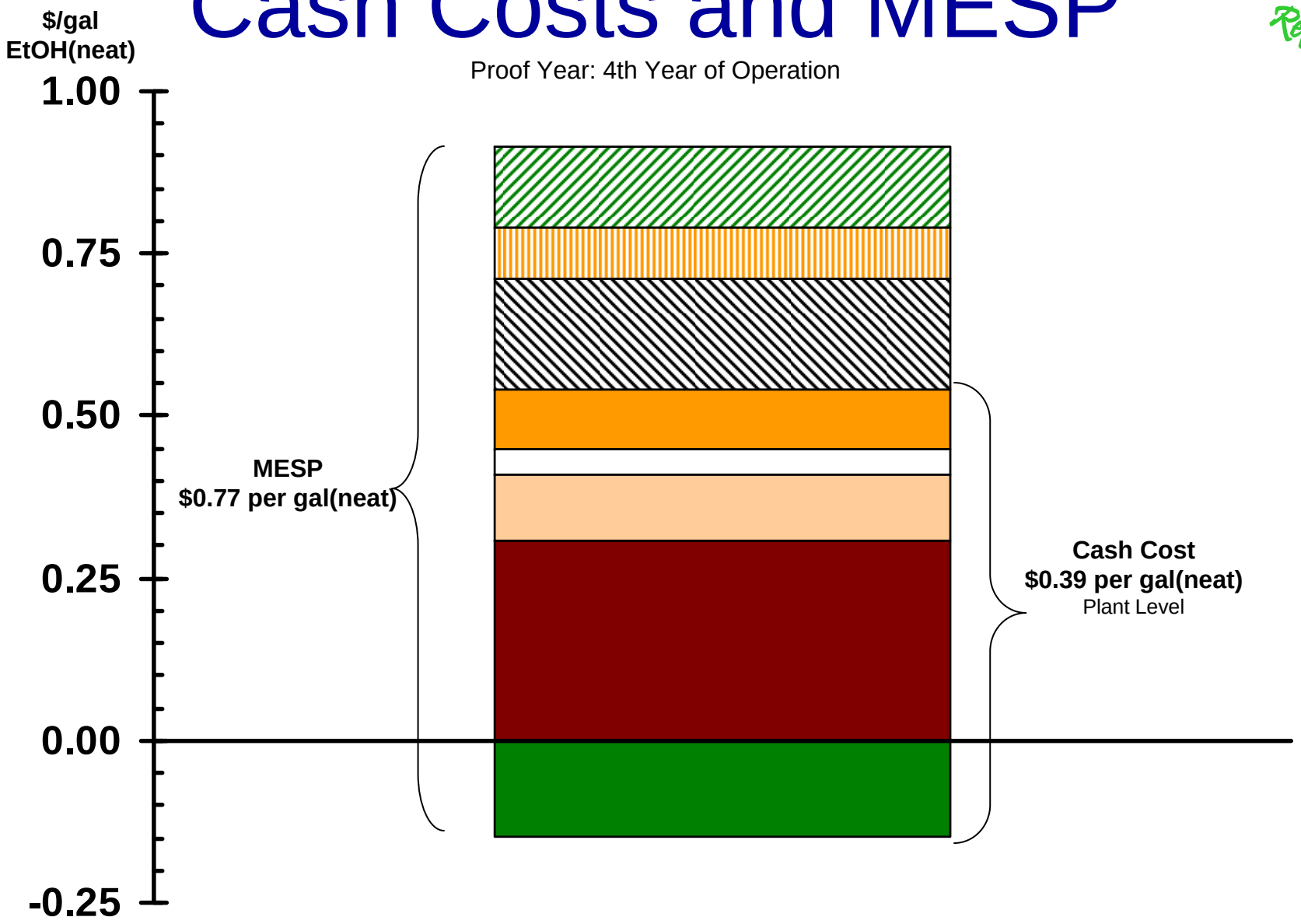
	$MM
Directs	**96.8**
Indirects	**60.8**
Total	**157.6**

157.6/75.7 = $2.08 per annual gal(neat)

Actual Goal Cases have $2.50-$3.50 per annual gal (neat)

Cash Costs and MESP

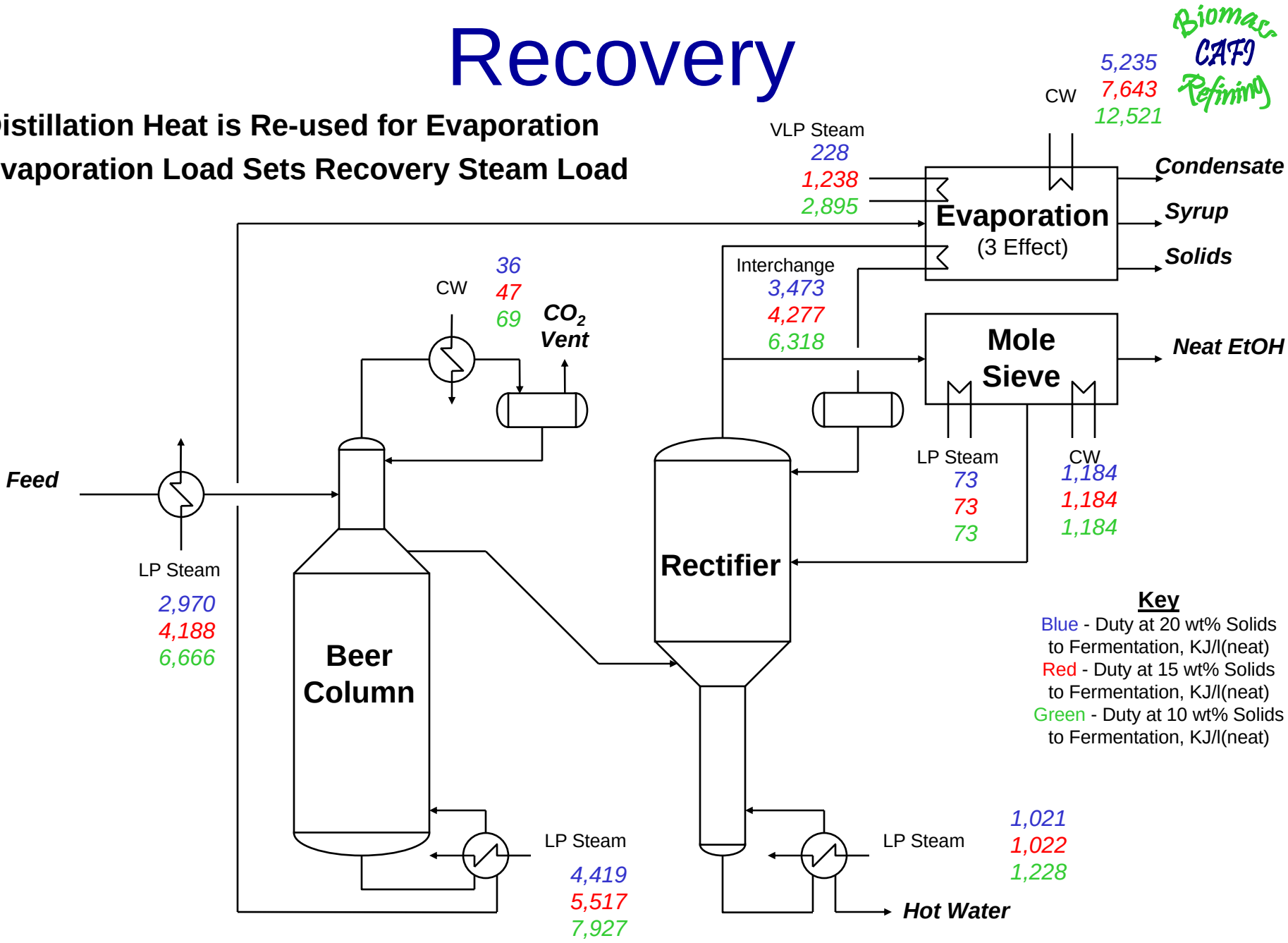
Proof Year: 4th Year of Operation



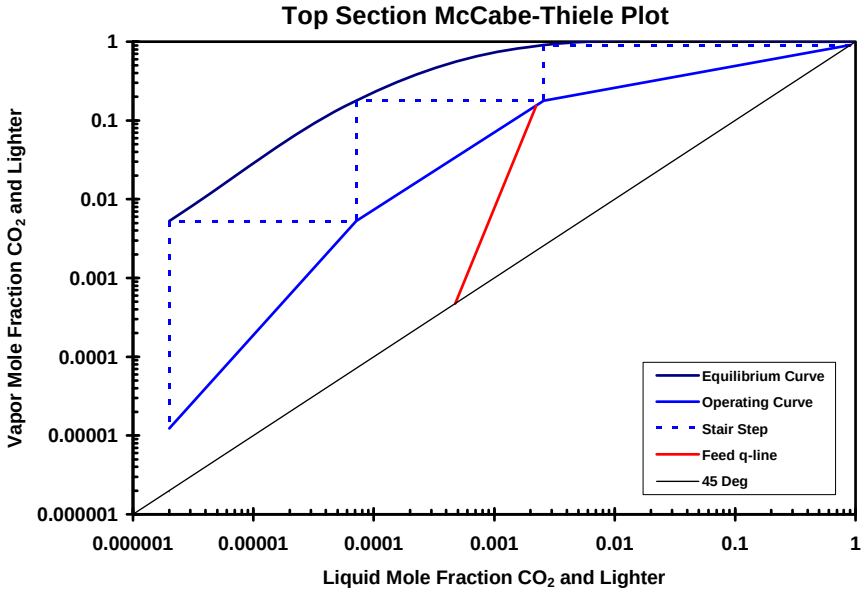
Recovery

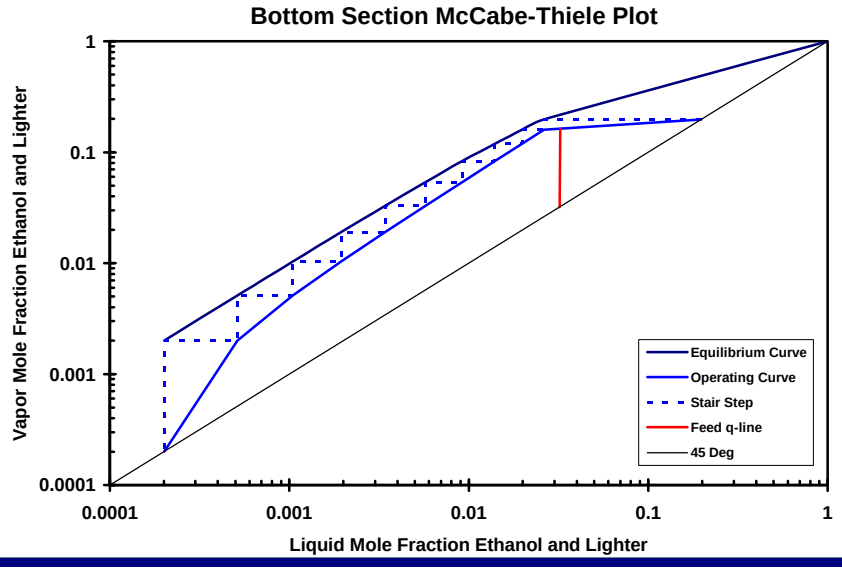
Distillation Heat is Re-used for Evaporation

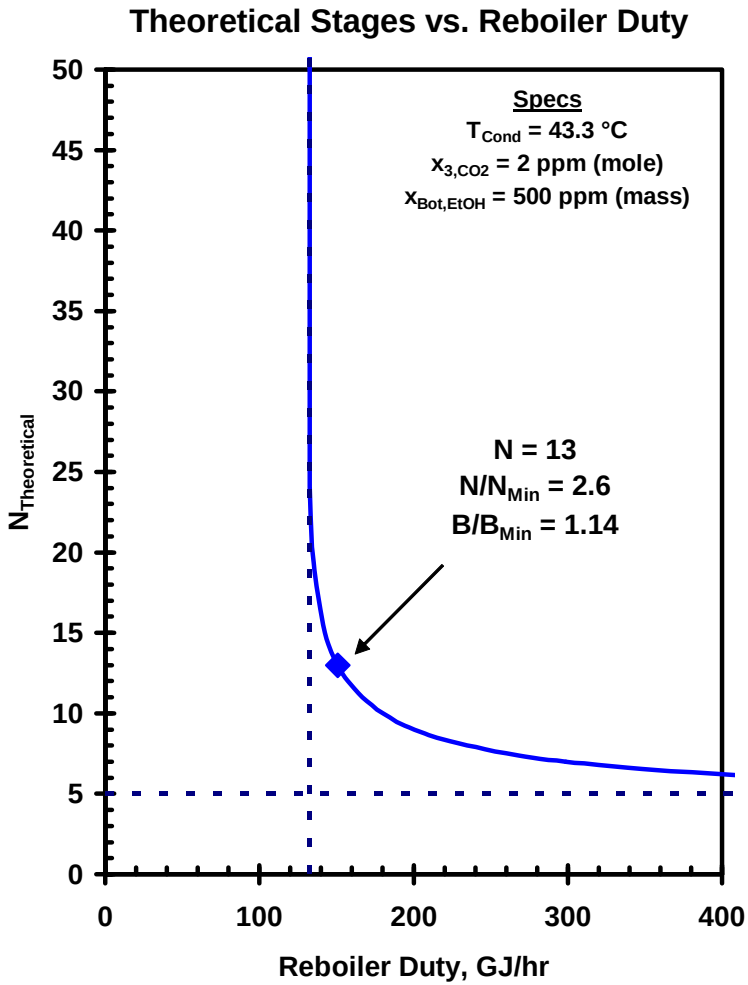
Evaporation Load Sets Recovery Steam Load



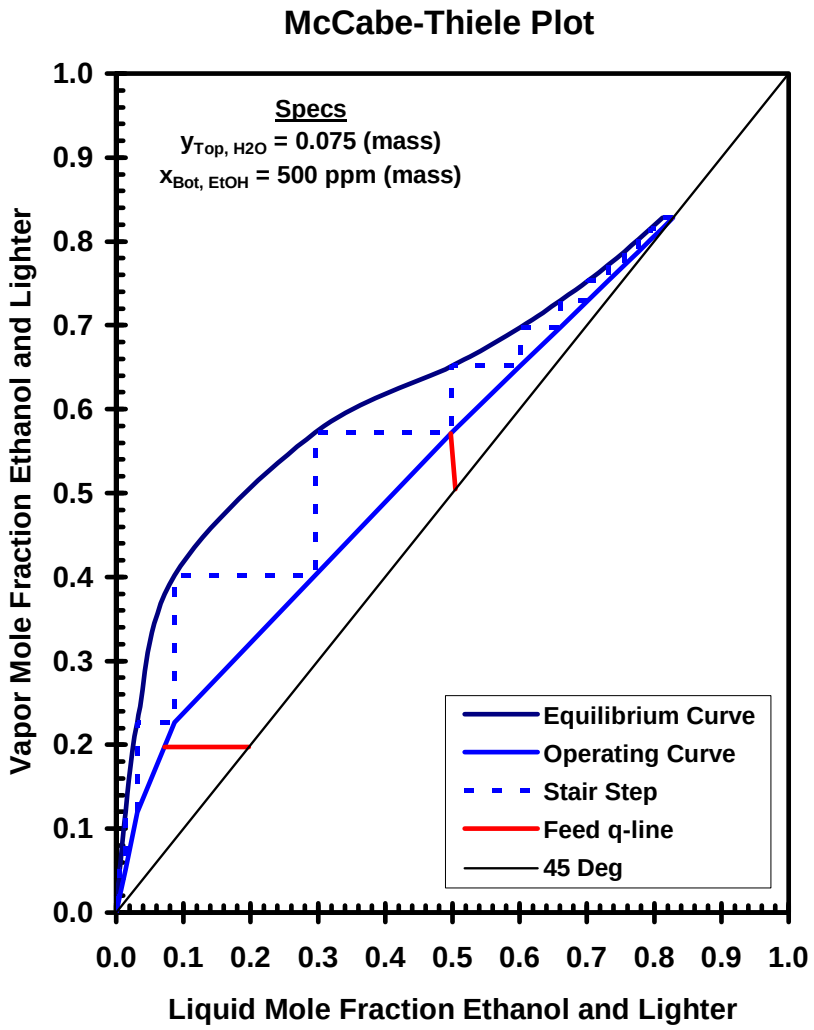
Beer Column

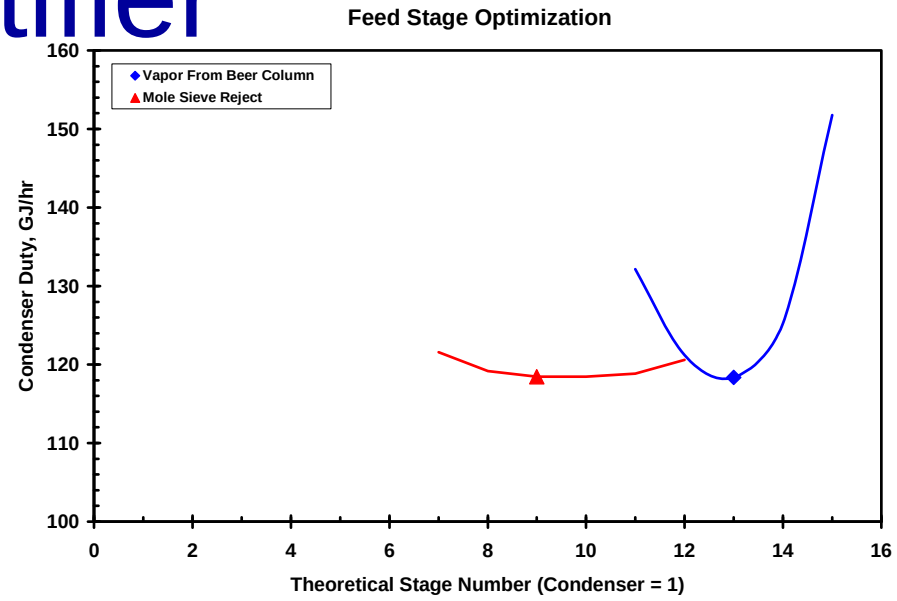

Top Section McCabe-Thiele Plot
Vapor Mole Fraction CO_2 and Lighter
Liquid Mole Fraction CO_2 and Lighter
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
Equilibrium Curve
Operating Curve
Stair Step
Feed q-line
45 Deg

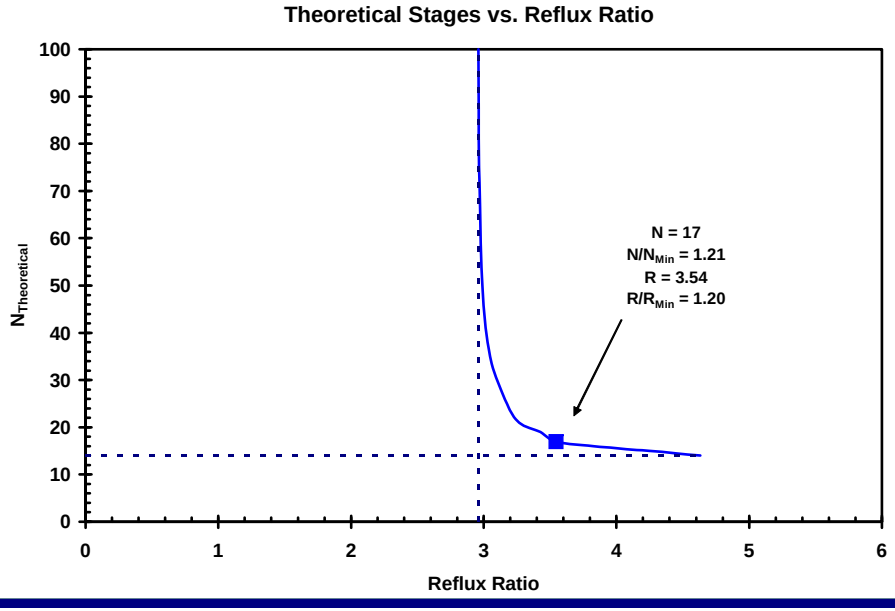

Bottom Section McCabe-Thiele Plot
Vapor Mole Fraction Ethanol and Lighter
Liquid Mole Fraction Ethanol and Lighter
1
0.1
0.01
0.001
0.0001
Equilibrium Curve
Operating Curve
Stair Step
Feed q-line
45 Deg


Theoretical Stages vs. Reboiler Duty
$N_{Theoretical}$
Reboiler Duty, GJ/hr
Specs
T_{Cond} = 43.3 °C
$x_{3,CO2}$ = 2 ppm (mole)
$x_{Bot,EtOH}$ = 500 ppm (mass)
N = 13
N/N_{Min} = 2.6
B/B_{Min} = 1.14
0
5
10
15
20
25
30
35
40
45
50
0
100
200
300
400

Rectifier

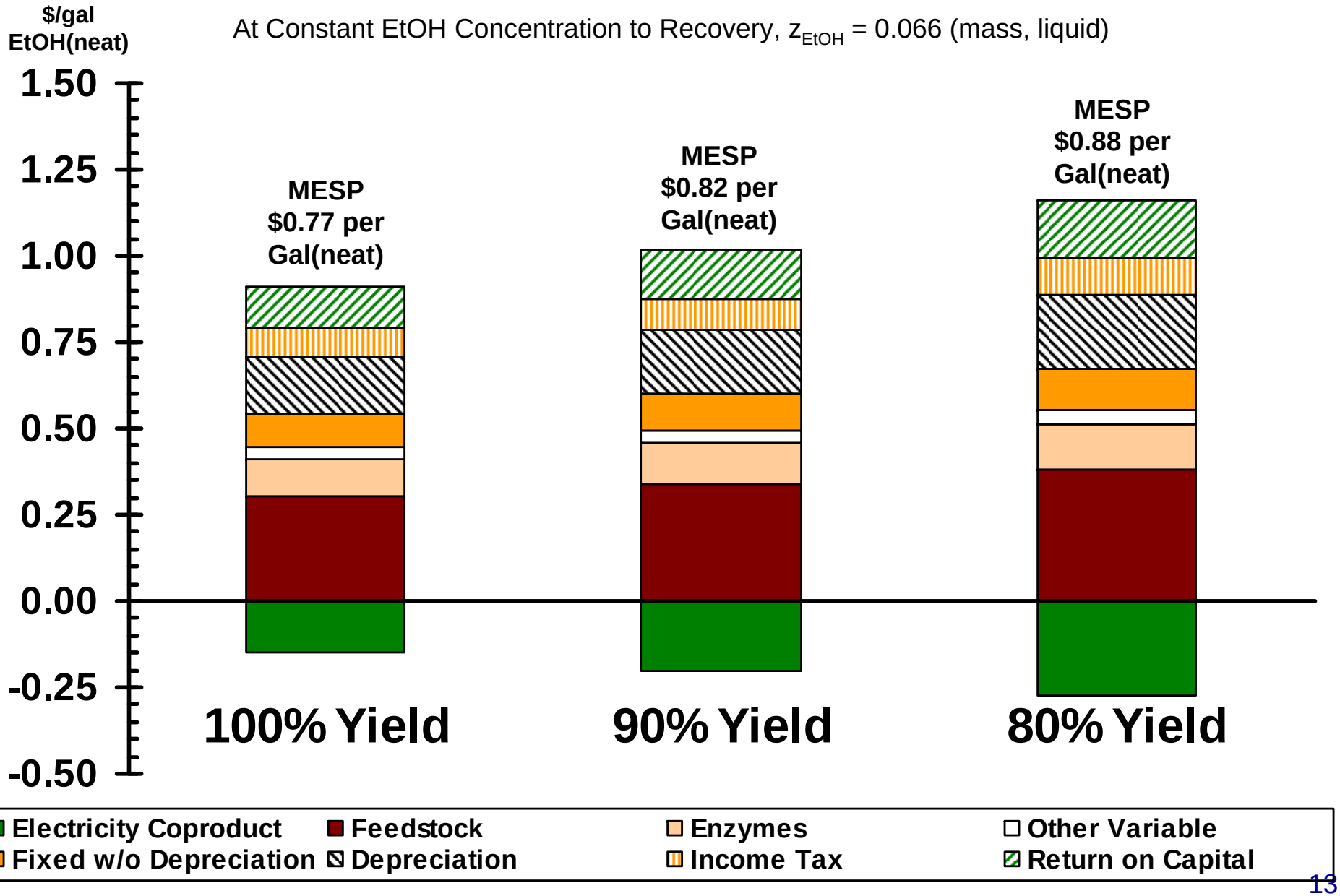

McCabe-Thiele Plot
Specs
$y_{Top, H2O}$ = 0.075 (mass)
$x_{Bot, EtOH}$ = 500 ppm (mass)
Vapor Mole Fraction Ethanol and Lighter
Liquid Mole Fraction Ethanol and Lighter
Equilibrium Curve
Operating Curve
Stair Step
Feed q-line
45 Deg


Feed Stage Optimization
Vapor From Beer Column
Mole Sieve Reject
Condenser Duty, GJ/hr
Theoretical Stage Number (Condenser = 1)


Theoretical Stages vs. Reflux Ratio
N = 17
N/N_{Min} = 1.21
R = 3.54
R/R_{Min} = 1.20
$N_{Theoretical}$
Reflux Ratio

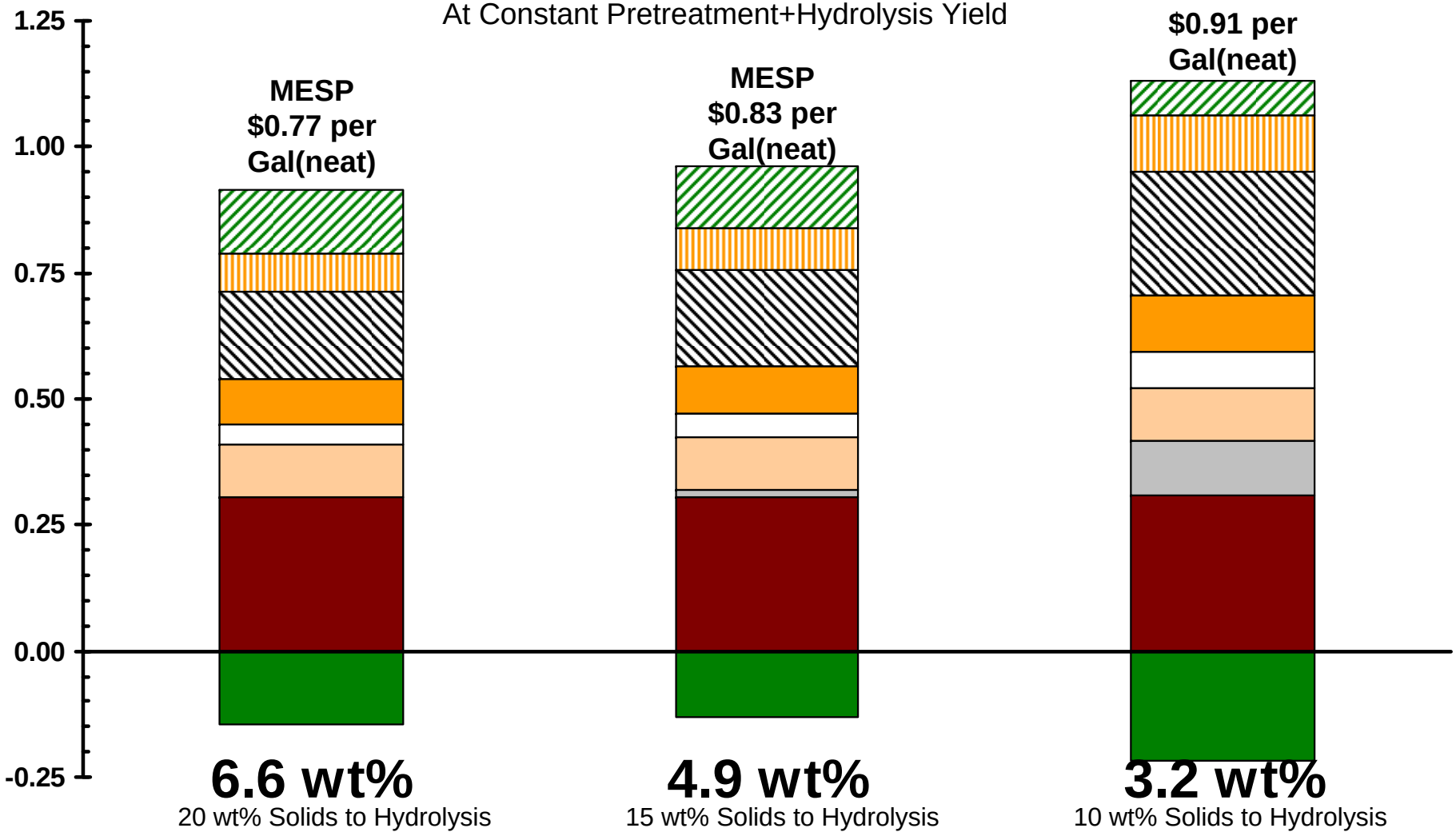
Pretreatment+Hydrolysis Yield

At Constant EtOH Concentration to Recovery, z_{EtOH} = 0.066 (mass, liquid)

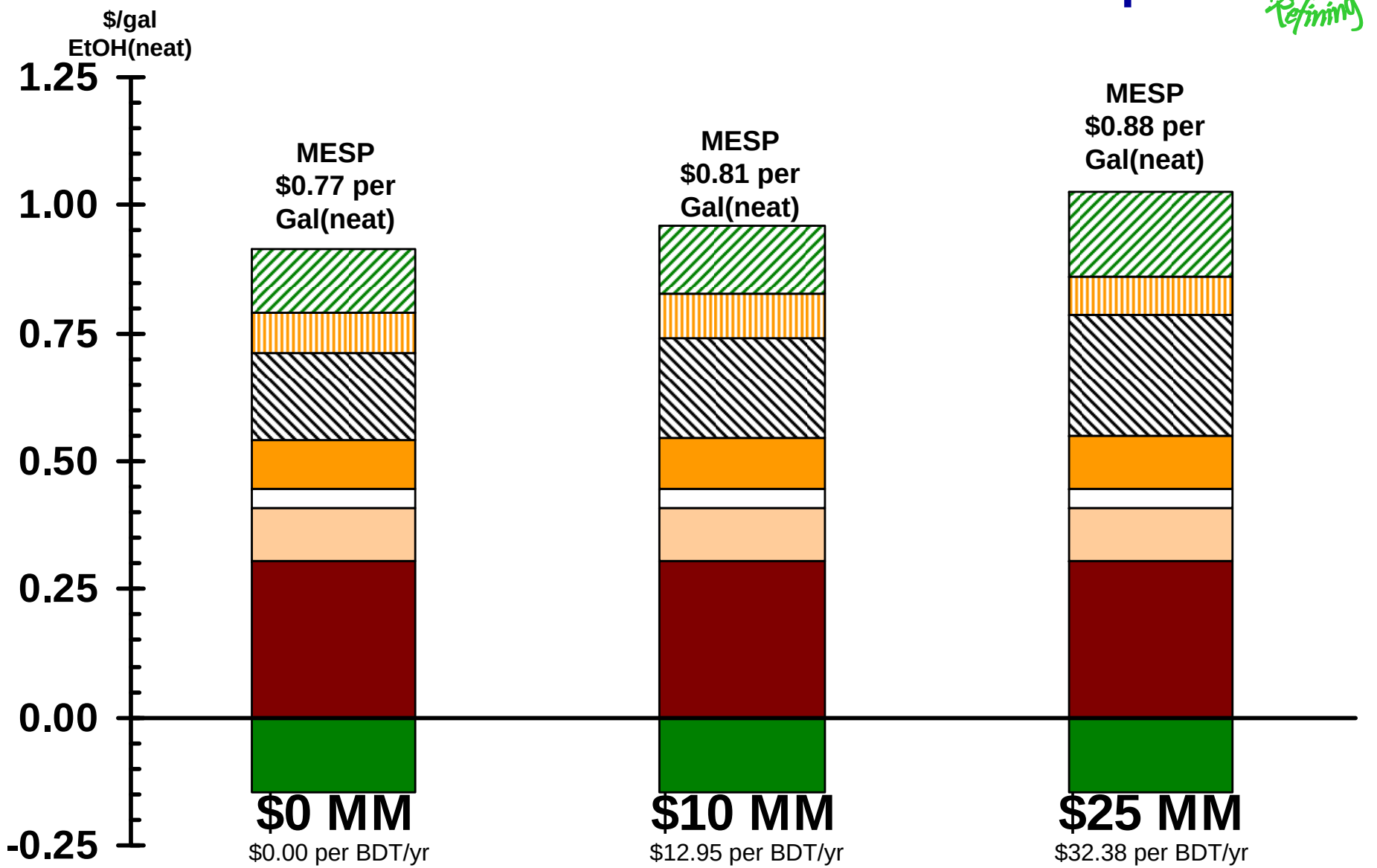


Beer Concentration

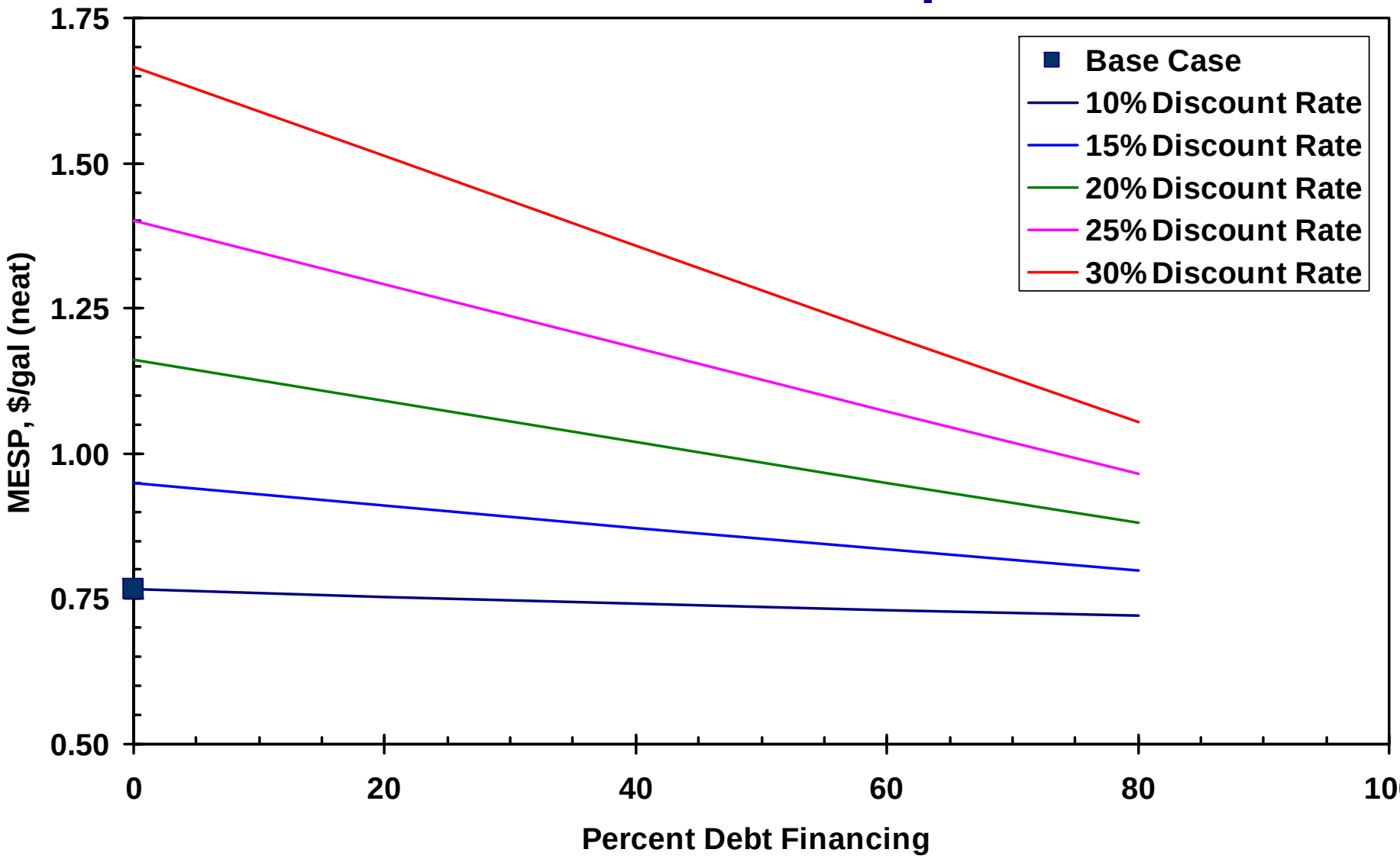
At Constant Pretreatment+Hydrolysis Yield



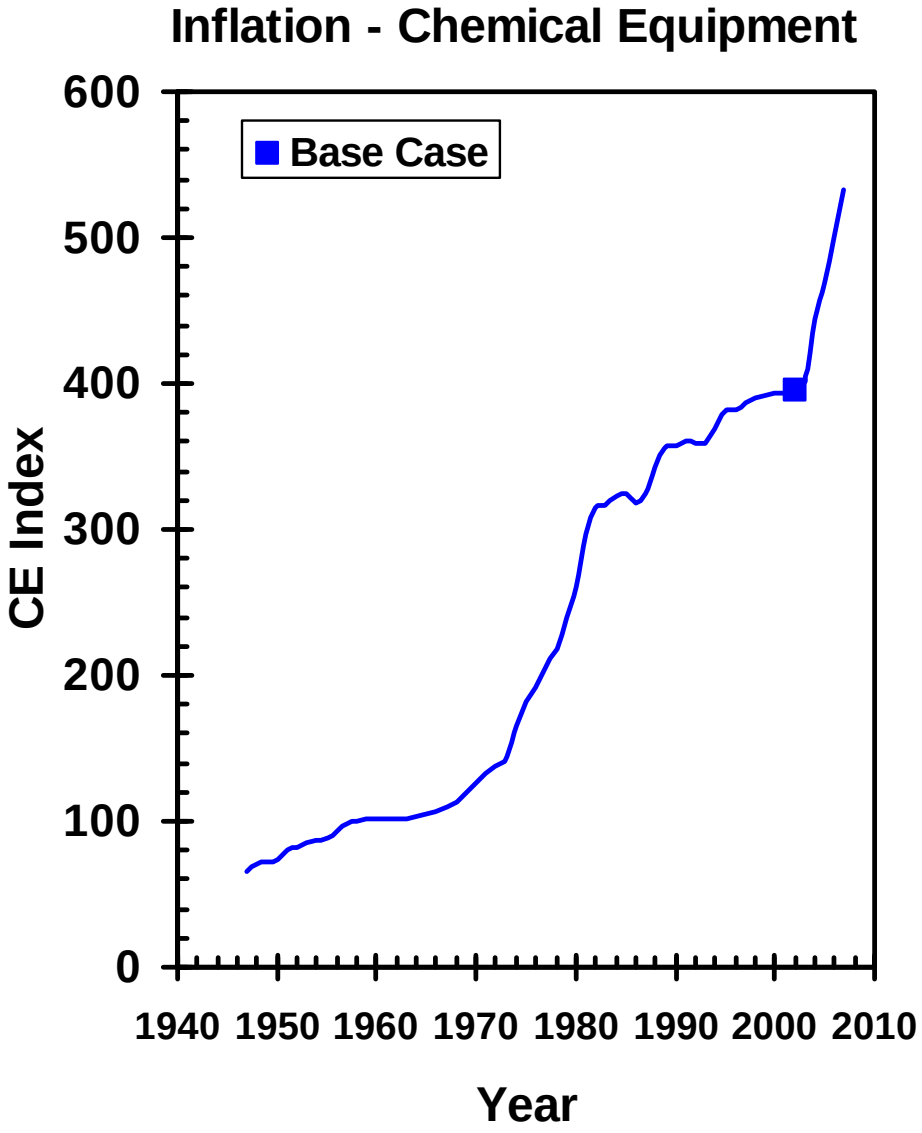
Pretreatment Direct Fixed Capital

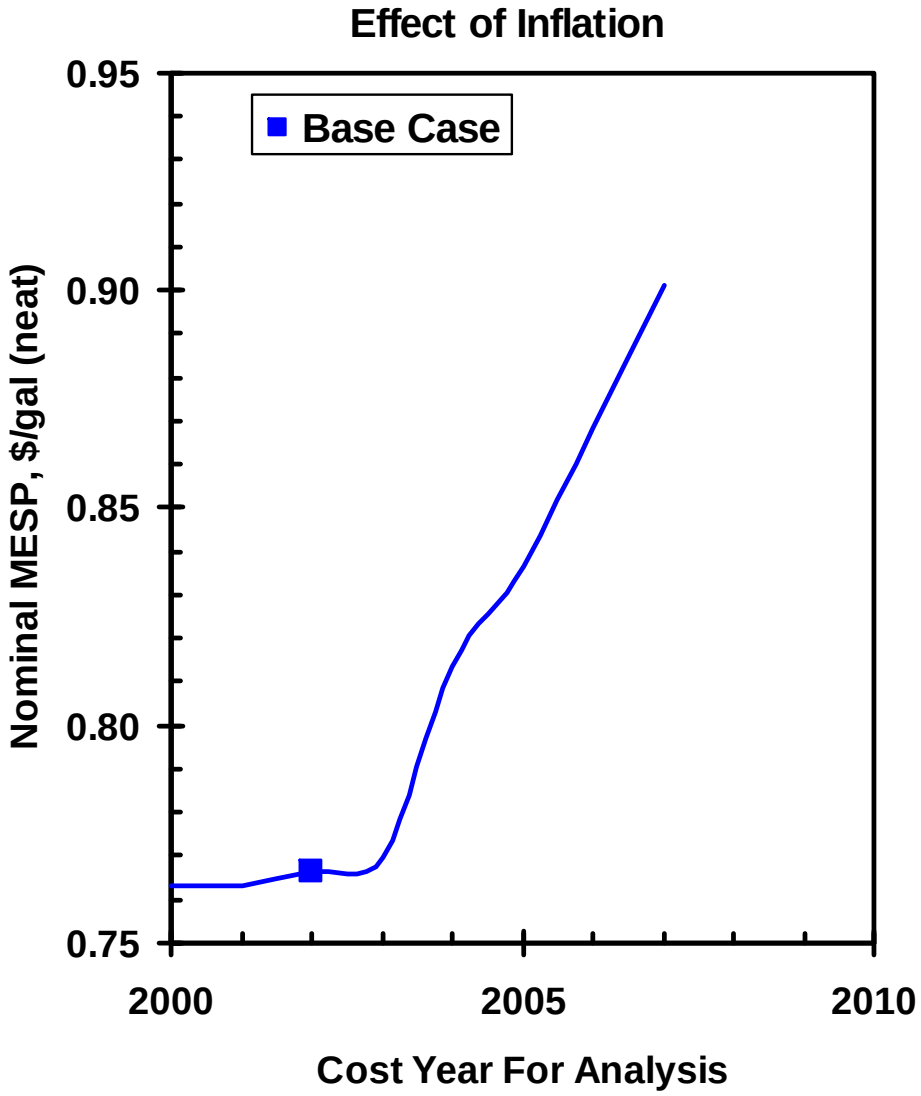


Financial Assumptions



Financial Assumptions





Other Assumptions

- Feedstock Price
  - Basis: $30 per BDT
  - Direct Impact on MESP and Cash Costs
- Enzyme Price/Usage
  - Basis: ~$0.10 per gal EtOH (neat)
  - Direct Impact on MESP and Cash Costs
- Lignin Solubilization
  - Negligible Impact on MESP and Cash Costs
- Utilities
  - Incremental Steam: $3.13 per 1000 lbs
  - Power: $0.04 per KWh (2007 Dollars)

Conclusions

- Consistent Methods
- Pretreatment Related Cost Drivers
  - Hydrolysis Yield
  - Solids Concentration to Hydrolysis
- Non-Pretreatment Cost Drivers are Also Important
- Sensitivity Analysis for Useful Bounds

Acknowledgements

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- Natural Resources Canada
- Genencor International

Biomass CAFI Refining

Project Institutions

Auburn University

Dartmouth

Genencor International

Michigan State University

NREL National Renewable Energy Laboratory

UBC

Purdue University

Texas A&M University

University of California Riverside