Optimization and Modeling of Phosphoric-Acid-Pretreated Sugarcane Bagasse

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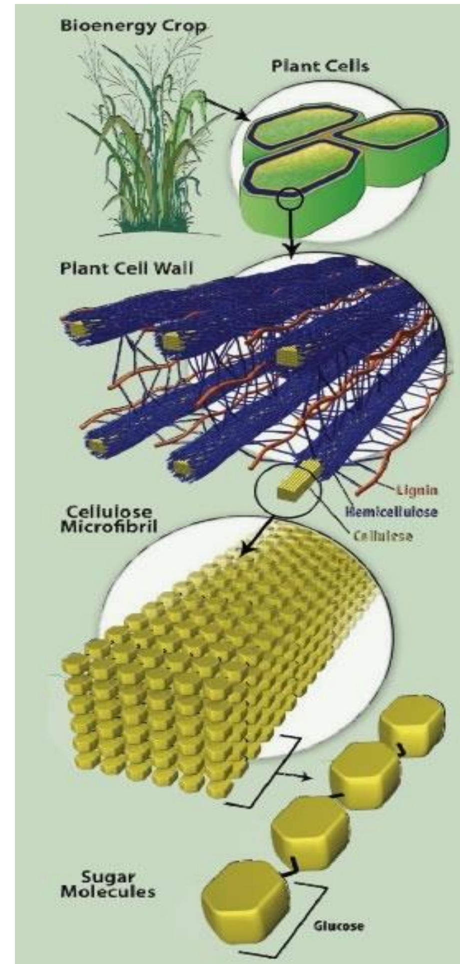
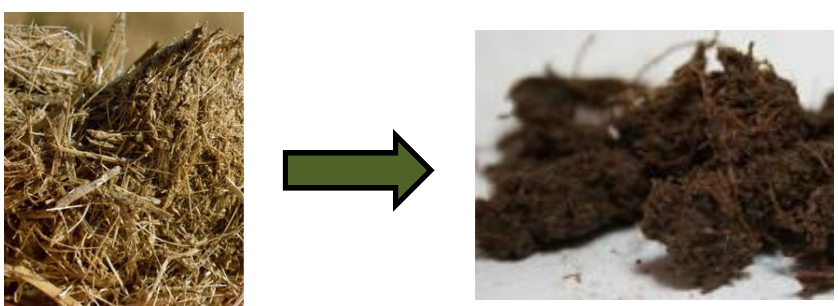
Introduction

- Lignocellulosic biomass as energy source
  - Abundant resource
  - High sugar content
- Resistant to degradation
- Pretreatment is essential for downstream processes



Introduction

Composition Analysis of Raw Sugarcane Bagasse



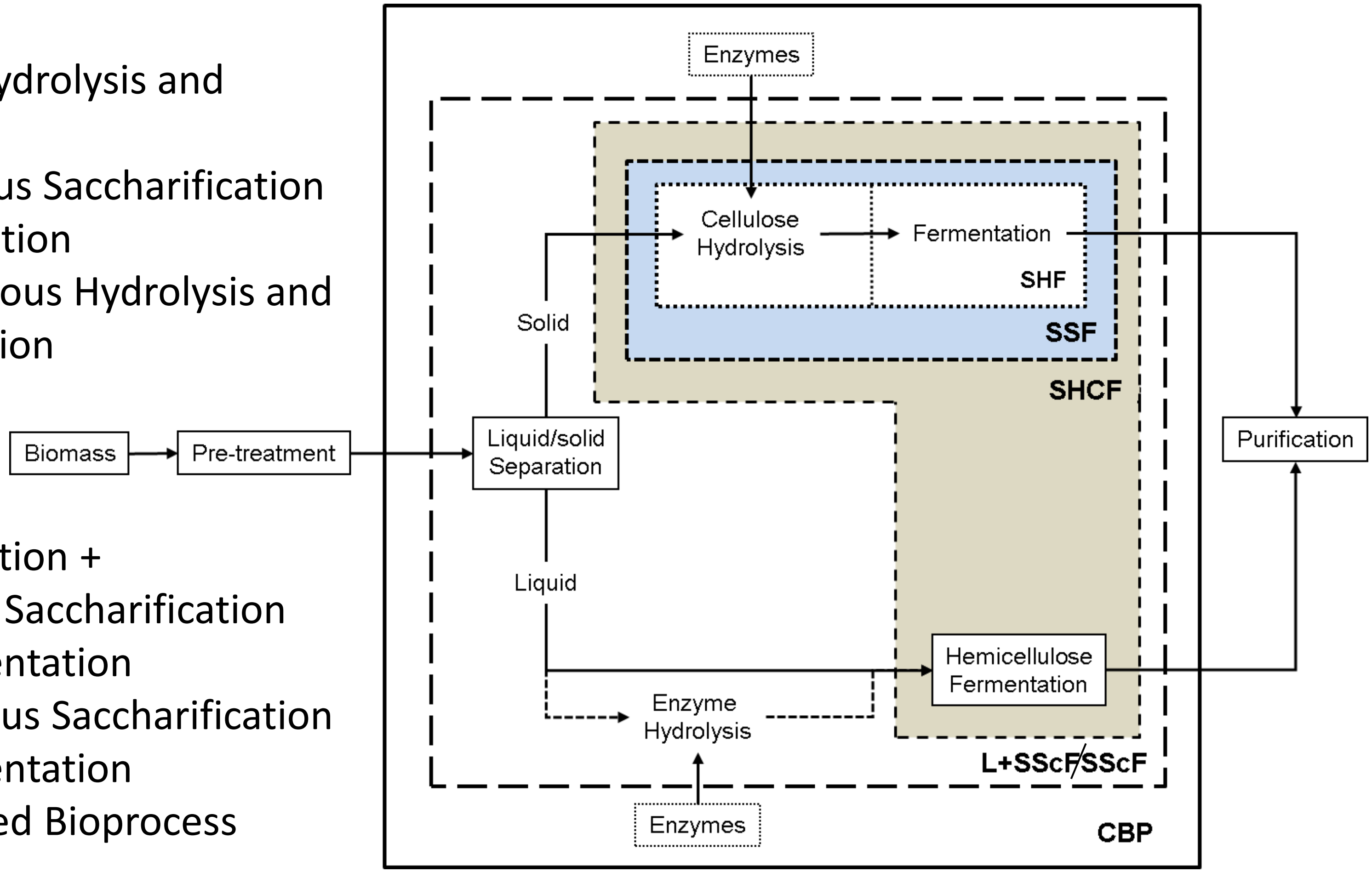
Sugar	Percentage of Dry Weight
Glucan	43.2 ± 0.8
Xylan	22.8 ± 0.8
Galactan	2.2 ± 1.4
Arabinnan	2.1 ± 0.6
Total Sugars	**70.3 ± 1.9**

Introduction

SHF – Separate Hydrolysis and Fermentation

SSF – Simultaneous Saccharification and Fermentation

SHCF – Simultaneous Hydrolysis and Co-Fermentation



L+SScF – Liquefaction + Simultaneous Saccharification and Co-Fermentation

SScF –Simultaneous Saccharification and Co-Fermentation

CBP – Consolidated Bioprocess

Curr. Opin. Biotechnol. 22, 312-319

Process Simplification

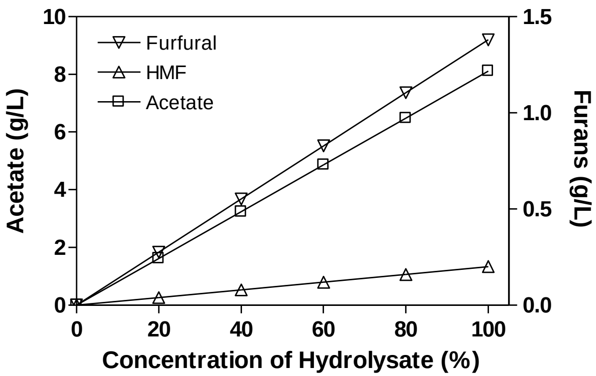
Research Advances Required for Process Simplification:

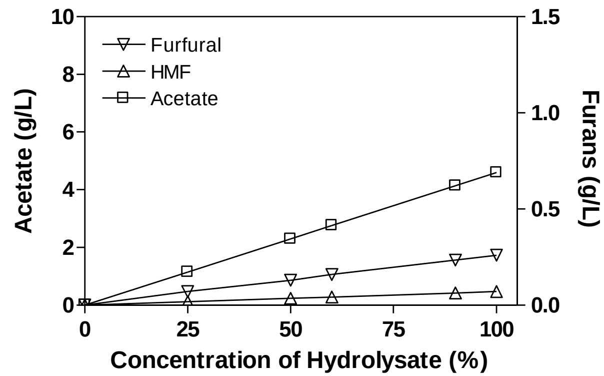
1. Replace Sulfuric with less aggressive acid
2. Solve mixing and pumping issues with high fiber solids
3. Develop biocatalysts with improved resistance to hemi toxins
4. Develop process using only fertilizer chemicals
   a. (N, P, K, Mg, S, trace metals)

Process Simplification

Replace sulfuric acid with phosphoric acid

- Eliminate Zirconium
- Lower the level of inhibitors





- Gypsum piles replaced with crop fertilizer

Bioresour. Technol. 101, 1851–1857

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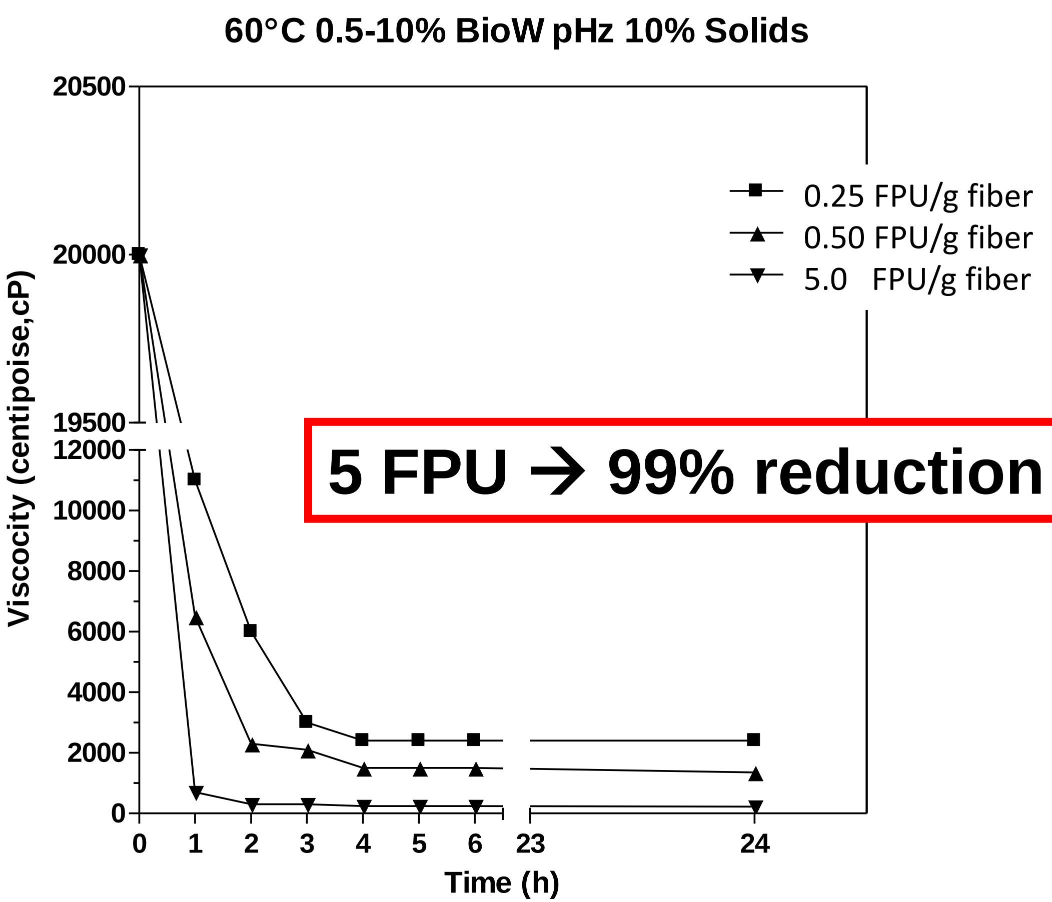
Process Simplification

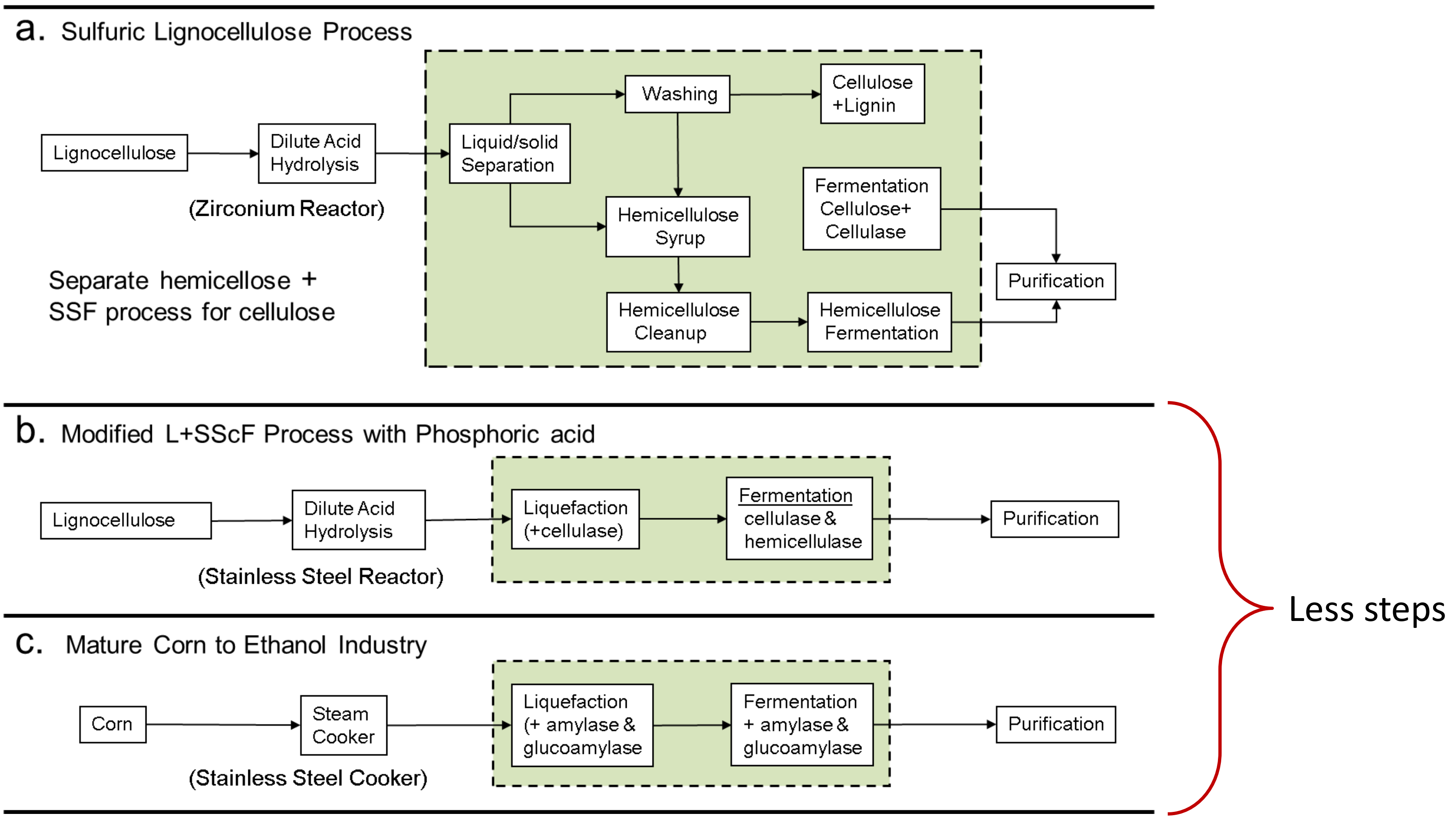
Liquefaction with cellulases



5 FPU → 99% reduction in viscosity

Bioresour. Technol. 101, 9128–9136

Process Simplification



Bioresour. Technol. 102, 2702-2711.

Process Simplification

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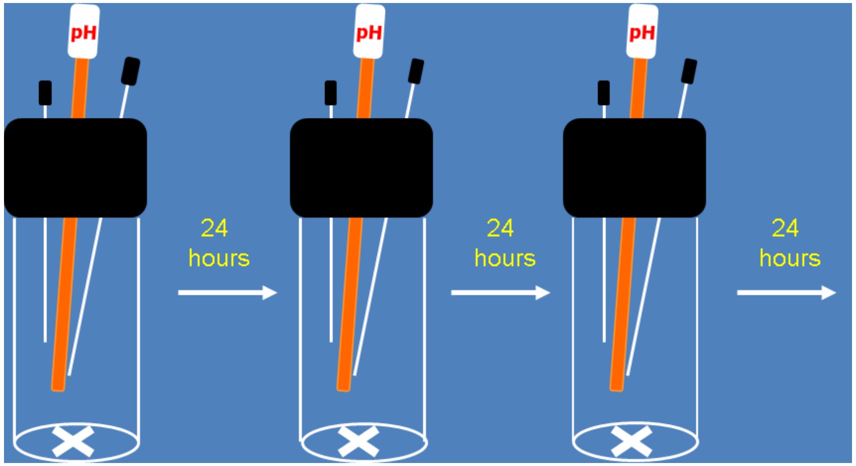
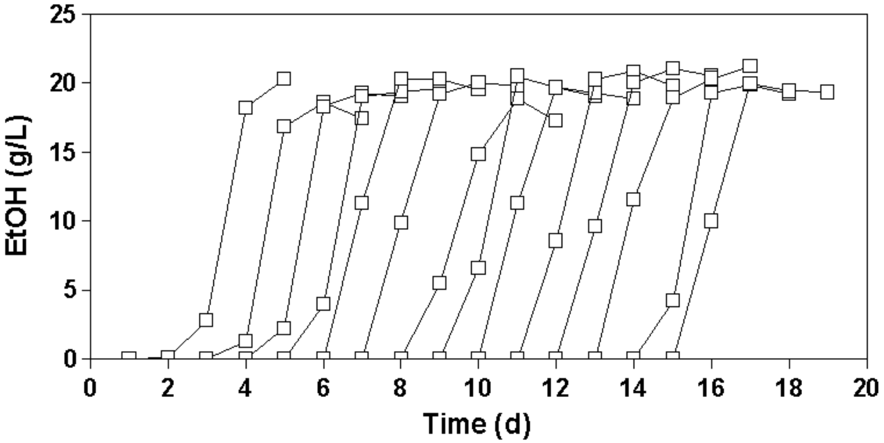
    a. (N, P, K, Mg, S, trace metals)

Process Simplification

Strong biocatalyst developed through metabolic evolution

- Derived from KO11 strain
- Increased tolerance to inhibitors
- High ethanol yields (> 95%)
- Co-fermentation of pentose and hexose sugars





Process Simplification

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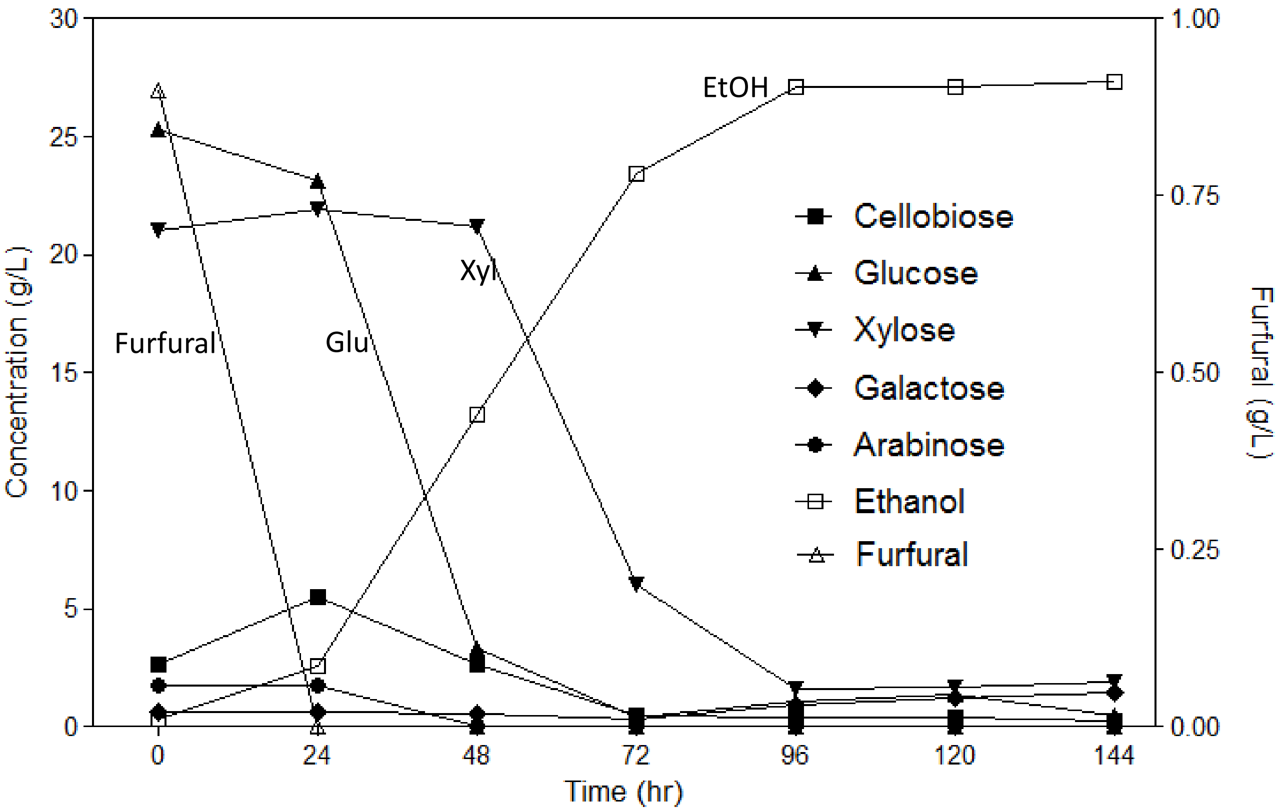
Process Simplification

Fermentation scale-up to 80 L



Yields;

- ✓ 0.27 g EtOH/g bagasse
- ✓ 342 L/tonne
- ✓ 90 gal/tonne
- ✓ 82 gal/US ton

Bioresour. Technol. 102, 6959-6965

Process Simplification

- Still need further process simplification
  - Minimize need for nutrients
    - Modify AM1 media
  - Eliminate need added sugar
    - Use sugars present in hydrolysate
  - Need to grow seed in hydrolysate
    - Use the hydrolysate generated during pretreatment
- Start with pretreatment optimization

Pretreatment

- Temperature
  - 180 °C, 190 °C, 200 °C
- Acid concentration
  - 1%, 0.5%, 0.25%, 0.1%, 0.05%, 0.01%
- Residence time
  - 5, 10, and 30 min
- Measure sugars and inhibitors

Pretreatment

Thanks to Dr. Guido Zacchi, Lund University

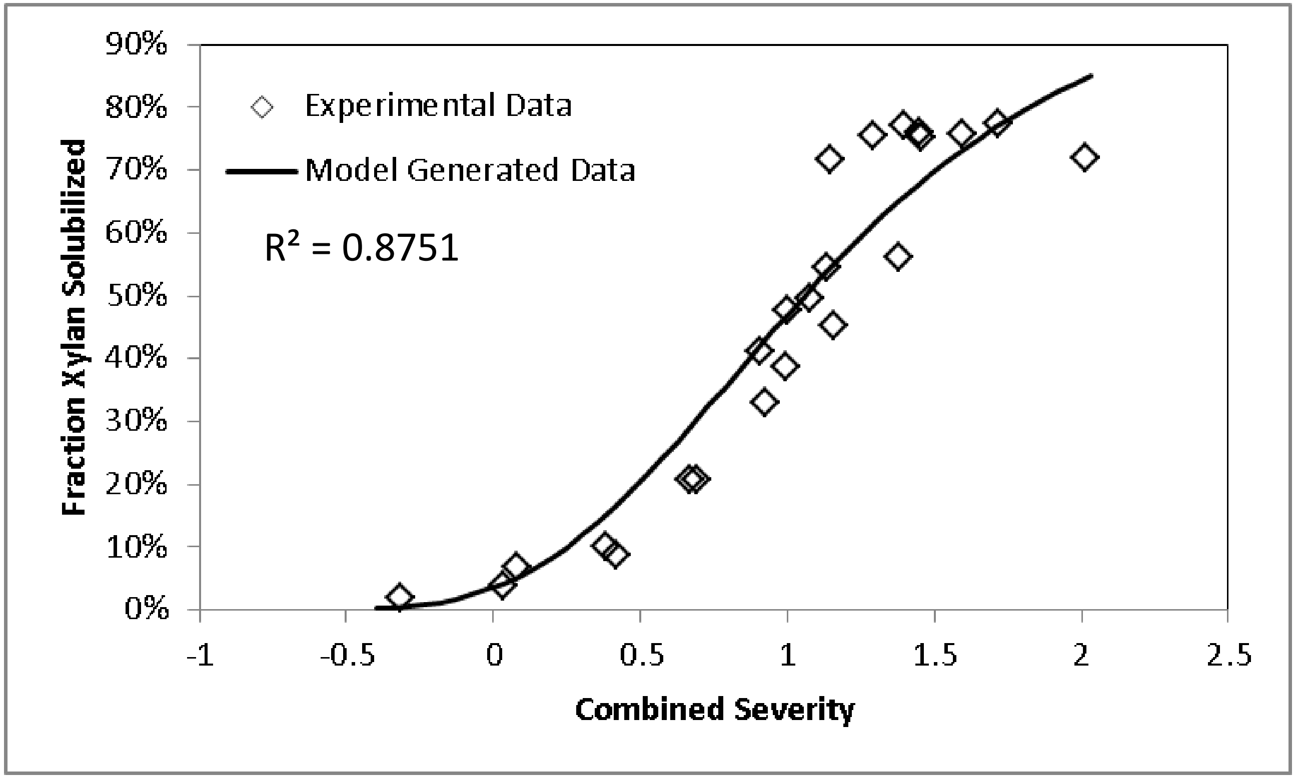
Pretreatment Results

Duration (min)	Temp (°C)	Acid Conc (%)	Concentration (g/kg DW)										
			Dimers	Glucose	Xylose	Galactose	Arabinose	HMF	Furfural	Acetic	Formic	Total Inhib	Total Sug
5	180	0.5	50.13	5.40	84.22	4.55	12.27	0.12	1.04	7.01	0.87	9.04	156.57
5	**190**	**0.5**	**41.31**	**13.71**	**181.53**	**8.27**	**16.42**	**0.07**	**4.15**	**18.59**	**2.16**	**24.97**	**261.24**
5	200	0.5	22.50	19.65	188.37	8.39	14.43	0.52	7.32	26.09	2.96	36.90	253.34
10	180	0.01	10.30	1.37	4.91	1.43	10.50		0.37	5.88	1.65	7.90	28.50
10	180	0.05	19.78	1.23	9.40	1.31	9.35		0.42	4.30	0.86	5.58	41.06
10	180	0.1	38.69	1.71	25.35	1.58	9.23		0.77	4.88	2.43	8.07	76.57
10	180	0.25	56.59	5.26	104.56	4.45	8.05		2.13	10.91	0.94	13.98	178.92
10	**180**	**0.5**	**44.70**	**8.21**	**125.06**	**6.07**	**13.54**		**3.26**	**14.59**	**1.78**	**19.62**	**211.06**
10	180	1	20.30	17.19	187.82	6.87	15.27	0.39	6.91	29.66	2.39	39.35	247.45
10	190	0.01	39.91	2.92	17.01	2.68	12.75		0.66	10.84	1.97	13.46	75.27
10	190	0.05	30.00	1.60	21.18	1.75	7.00		1.56	5.62	0.93	8.11	61.53
10	190	0.1	40.05	3.07	51.22	2.77	8.21		2.34	7.07	1.09	10.49	105.32
10	190	0.25	30.28	6.47	110.49	3.53	10.79		6.81	16.44	1.31	24.56	161.56
10	190	0.5	19.69	17.64	188.30	8.37	15.38		8.79	30.37	2.97	42.13	249.38
10	190	1	6.87	27.40	185.53	5.58	12.18	1.09	14.86	39.19	2.74	57.87	237.56
10	200	0.01	57.49	3.38	47.45	2.97	7.77		6.00	17.09	3.63	26.73	119.06
10	200	0.05	53.97	5.24	92.41	4.03	10.22		7.50	18.83	2.55	28.88	165.86
10	200	0.1	37.27	10.11	131.84	6.37	11.71		9.47	24.03	2.43	35.93	197.30
10	200	0.25	22.50	23.58	185.33	9.10	9.03		14.22	36.85	2.80	53.87	249.54
10	200	0.5	12.00	26.81	178.64	7.90	15.40	0.42	17.69	40.85	4.07	63.02	240.75
10	200	1	6.55	45.01	166.42	4.85	12.65	1.41	19.71	47.94	3.47	72.54	235.48
30	180	0.1	46.46	6.58	112.20	5.70	13.51	0.46	11.03	34.96	0.71	47.16	184.46
30	190	0.1	17.26	12.81	119.83	5.81	10.47	1.45	25.42	21.61	1.90	50.38	166.18
30	200	0.1	14.38	12.94	63.45	3.49	7.78	2.31	25.27	30.51	2.74	60.82	102.04
30	200	0	21.52	9.65	66.57	3.25	6.08	0.03	22.71	38.88	7.47	69.10	107.07

Pretreatment Model

- Combine process parameters of *T*, *t*, and *C*
- Relationship between severity and hemicellulose solubilization
- Model based on derivation by Chum, et al. (1990). Appl. Biochem. Biotechnol. 24-25, 1-14

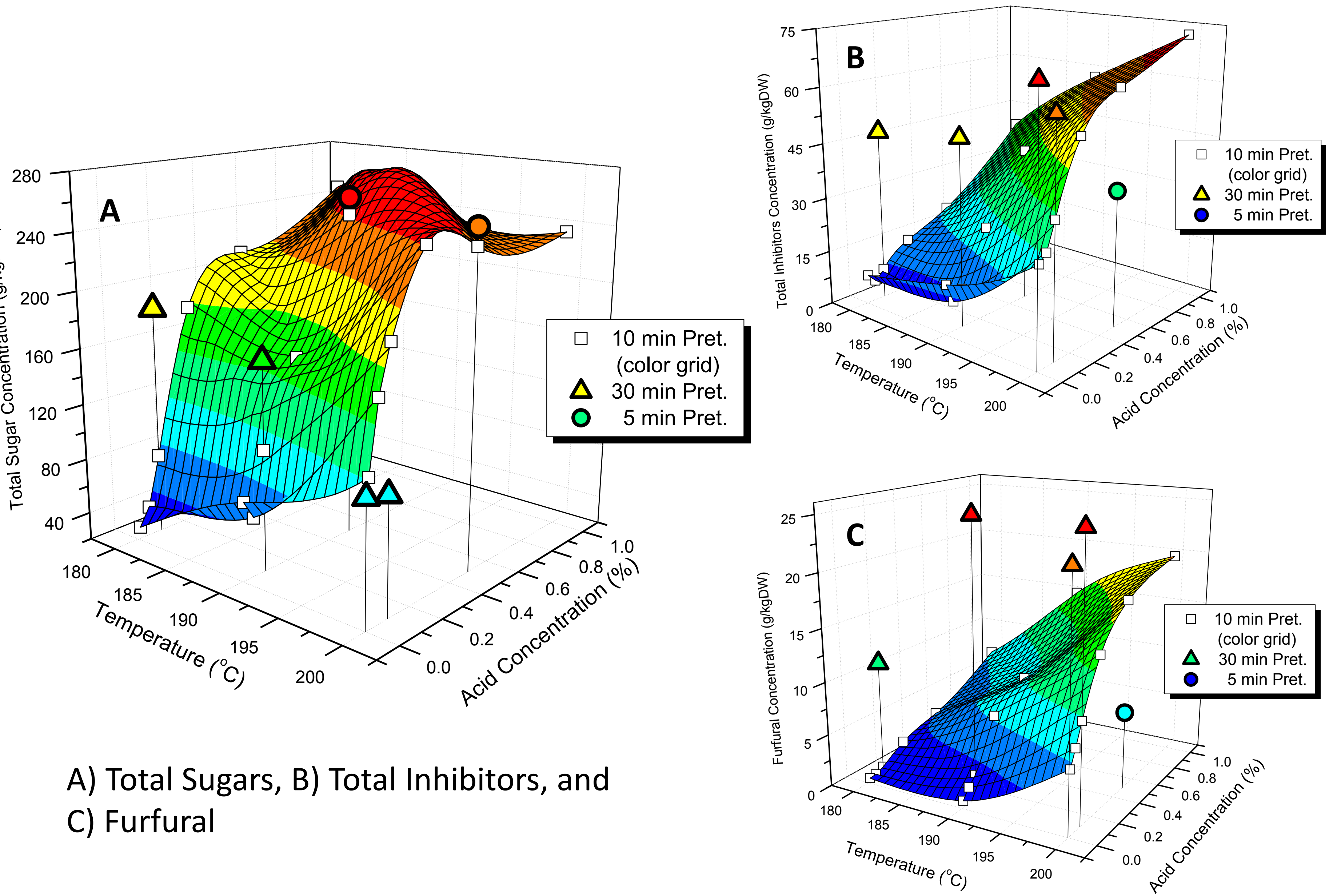
Pretreatment Model



$$R_o = t * e^{\frac{T_r - 100}{14.75}} \quad \ln[-\ln(1-\alpha)] = \log R_o - pH$$

R_o = Severity coefficient; t = Time (min); T_r = Pretreatment temperature; α = Fraction of hemicellulose remaining

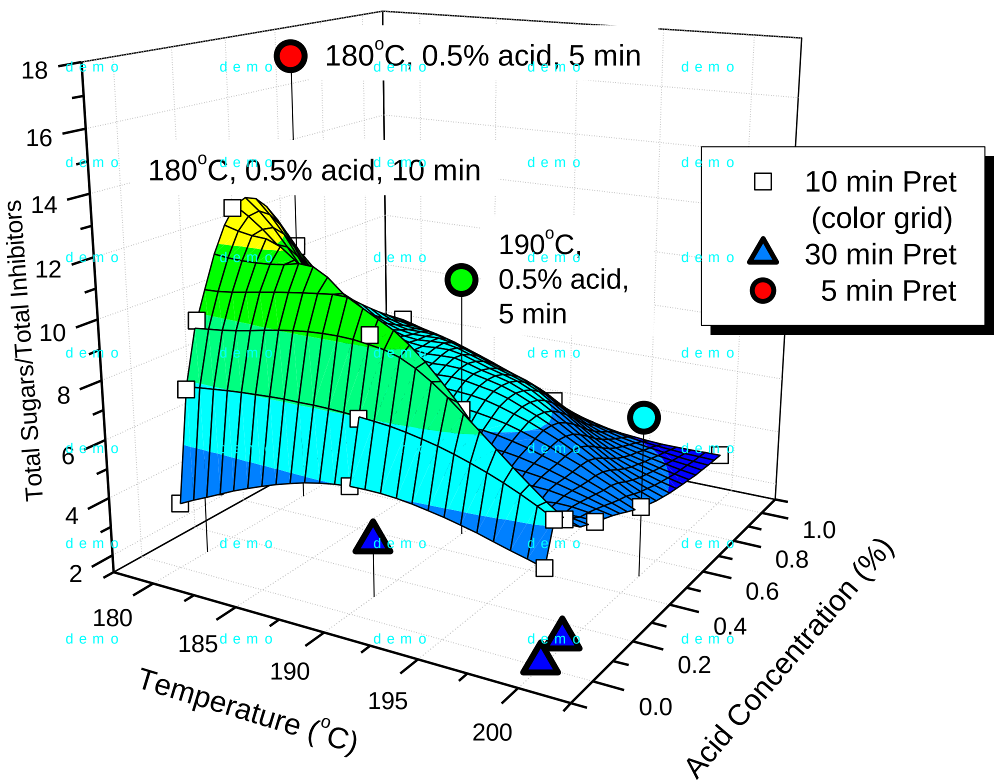
Pretreatment



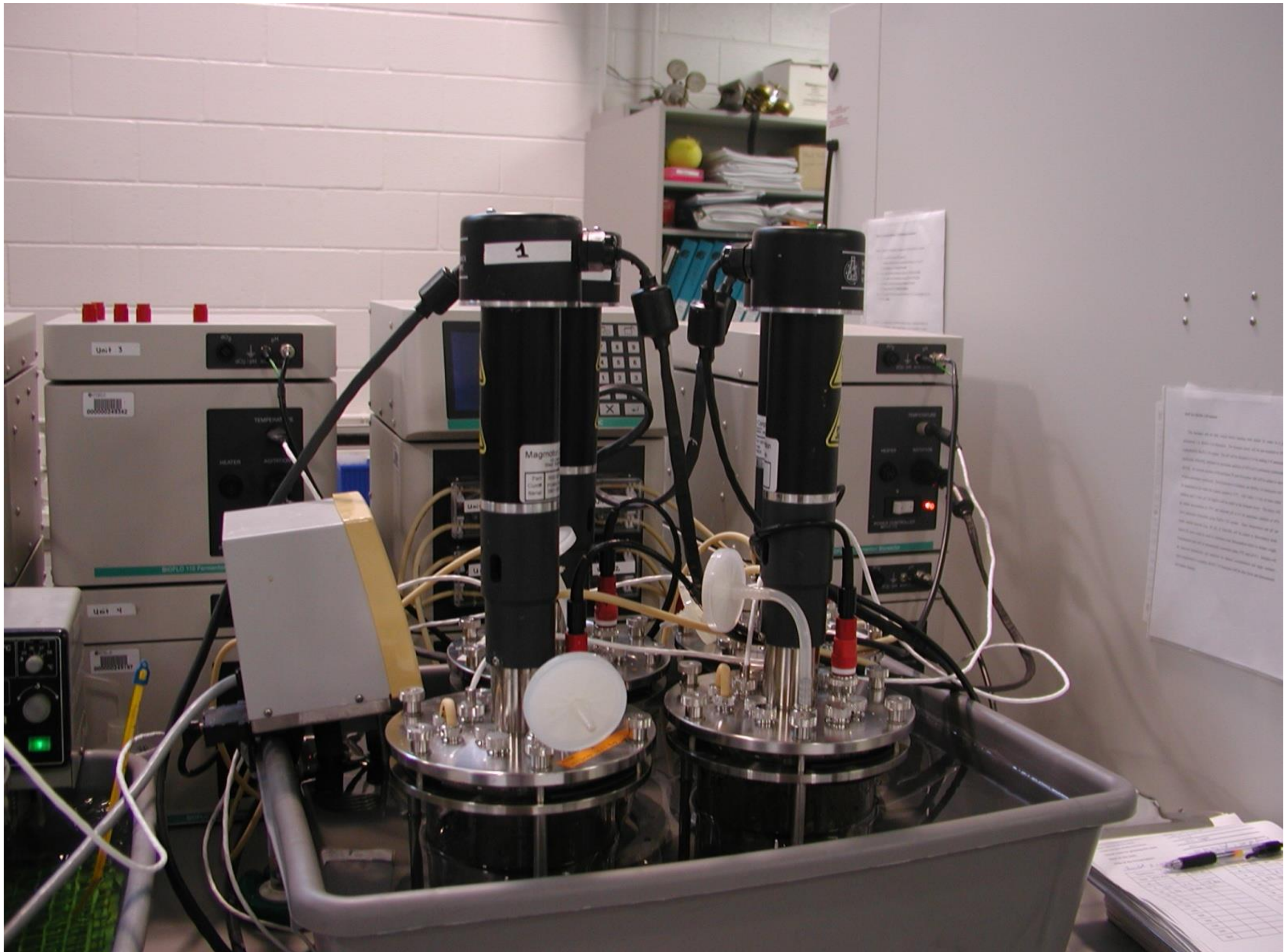
A) Total Sugars, B) Total Inhibitors, and C) Furfural

Pretreatment

Temperature (°C)	Acid Concentration (%)	Residence Time (min)	Total Sugars (g/kg)	Ratio Sugars to Inhibitors
180	0.5	5	157	17.3
190	0.5	5	261	10.5
180	0.5	10	211	10.8

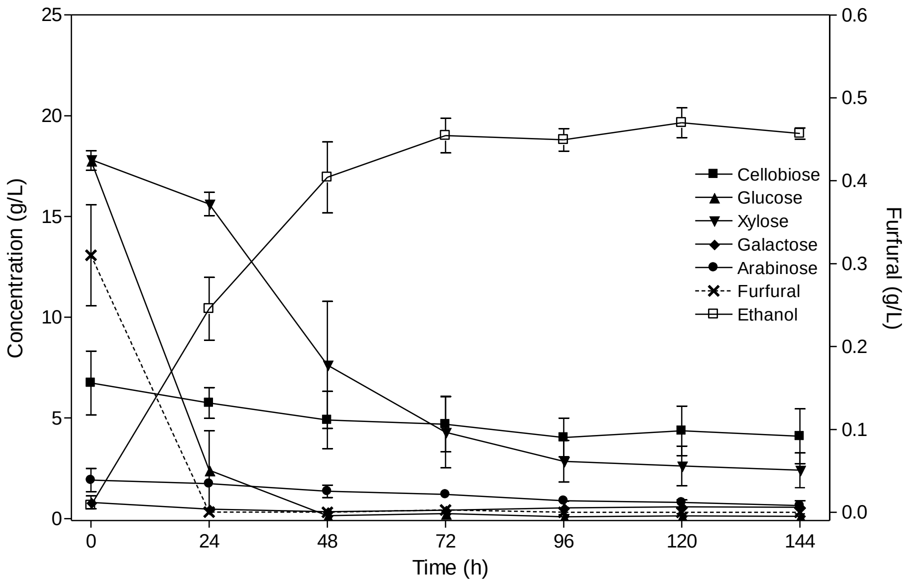


Fermentation

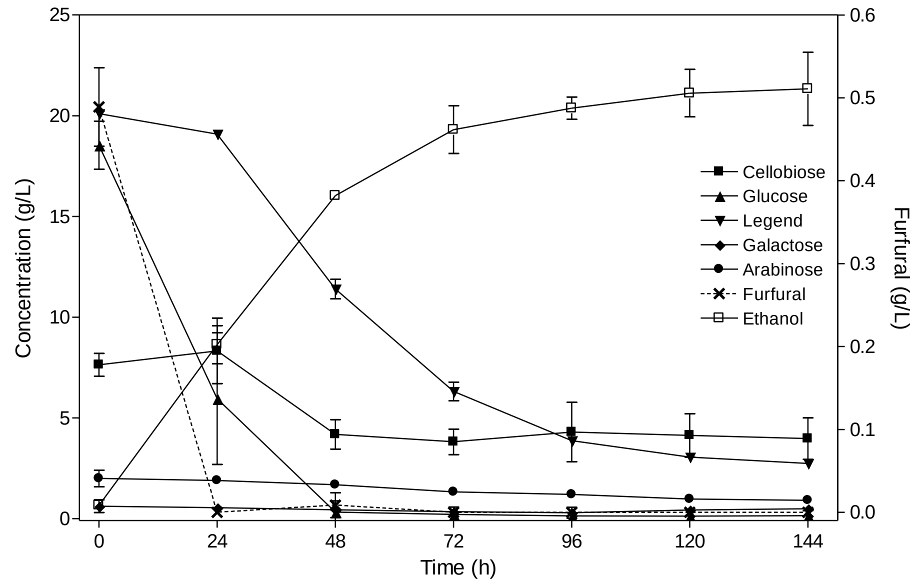


Fermentation

180 °C, 0.5% acid, 10 min



190 °C, 0.5% acid, 5 min



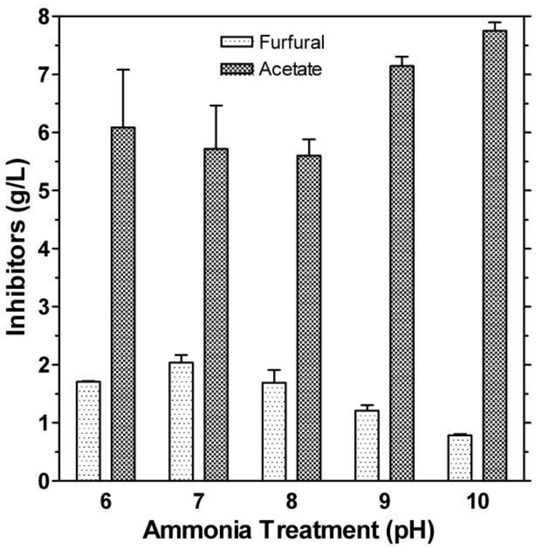
Slightly better ethanol yields for the 190 °C, 0.5% acid, 5 min bagasse.

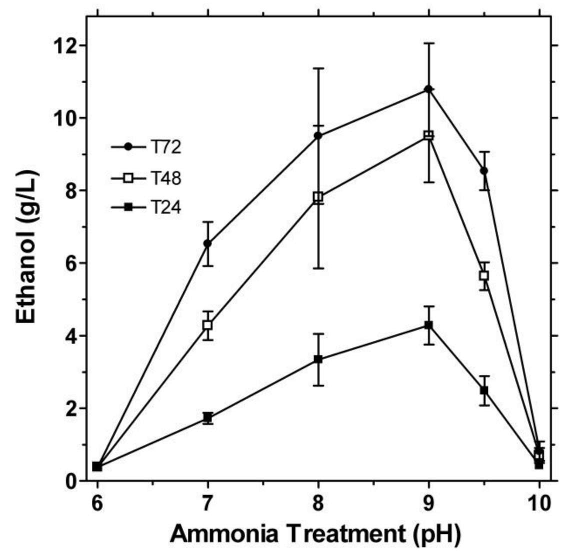
Process Simplification

- Still need further process simplification
  - Minimize need for nutrients
    - Modify AM1 media
  - Eliminate need added sugar
    - Use sugars present in hydrolysate
  - Need to grow seed in hydrolysate
    - Use the hydrolysate generated during pretreatment
- Continue with seed train development

Seed Train Development

Hydrolysate conditioning using NH_4OH

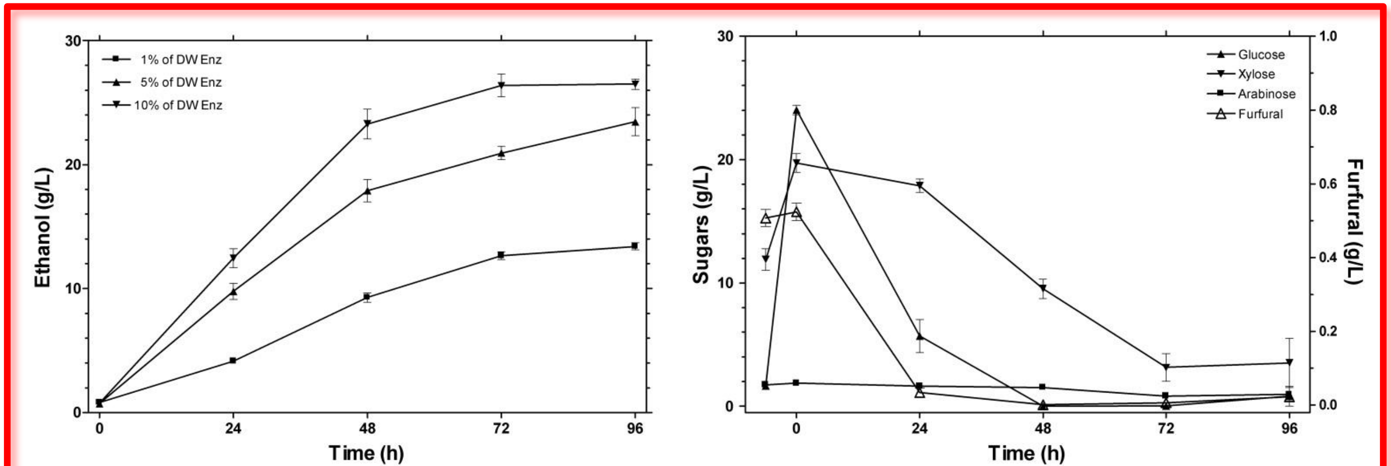




Only add trace metals, $MgSO_4$, and sodium metabisulfate

Seed Train Development

Sugarcane Bagasse



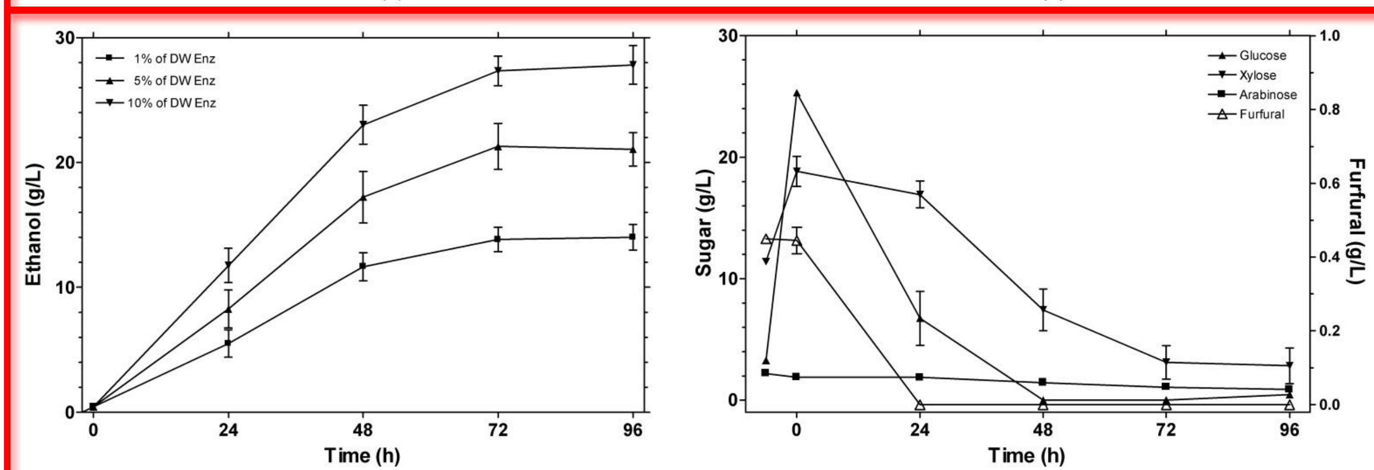
Max Yields;

0.277 g EtOH/g bagasse

351 L/tonne

93 gal/tonne

84 gal/US ton



Max Yields;

0.309 g EtOH/g bagasse

392 L/tonne

103 gal/tonne

94 gal/US ton

Sorghum Fiber

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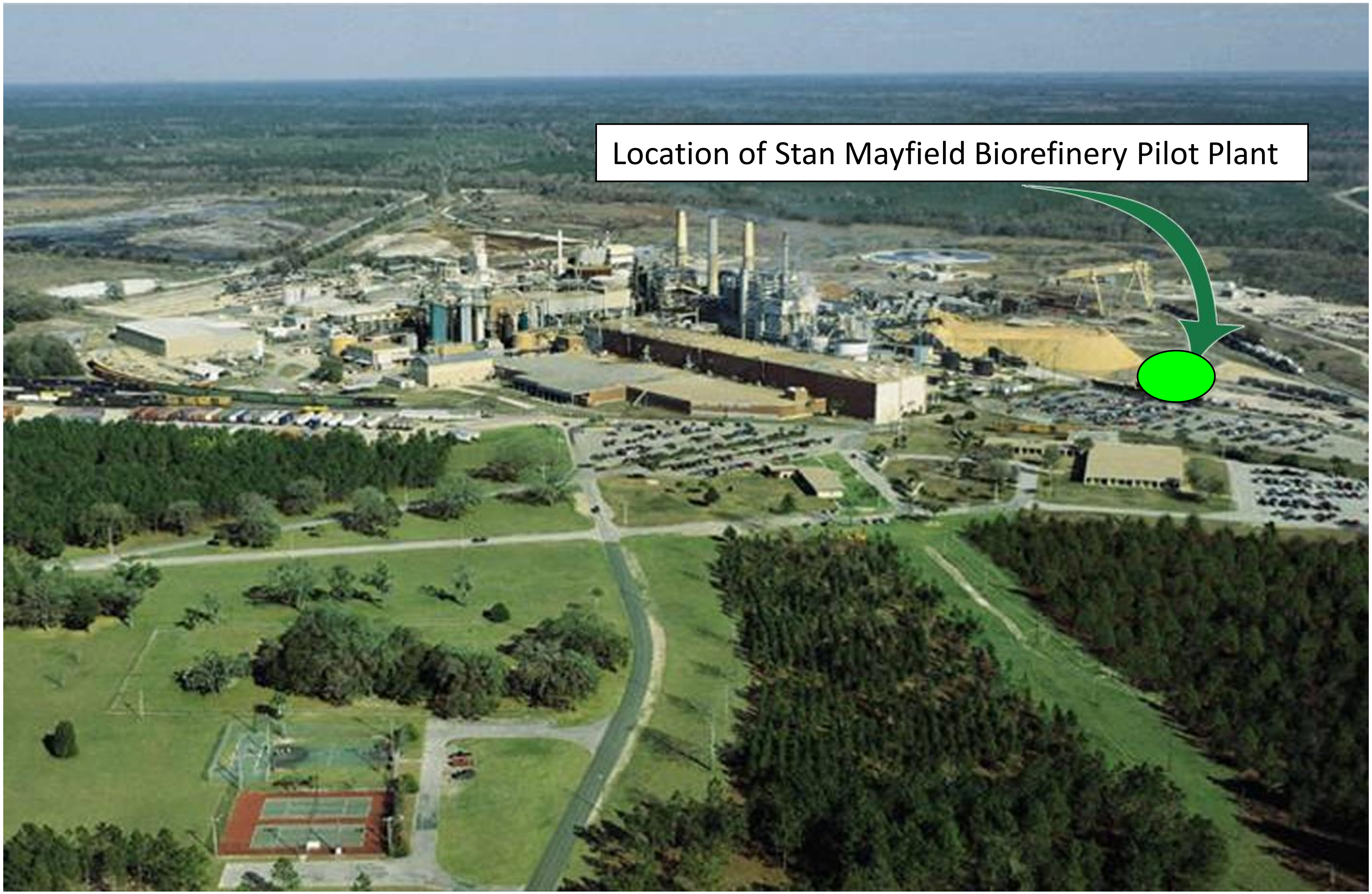
BUCKEYE
TECHNOLOGIES INC.

Buckeye Technologies, Perry, Florida



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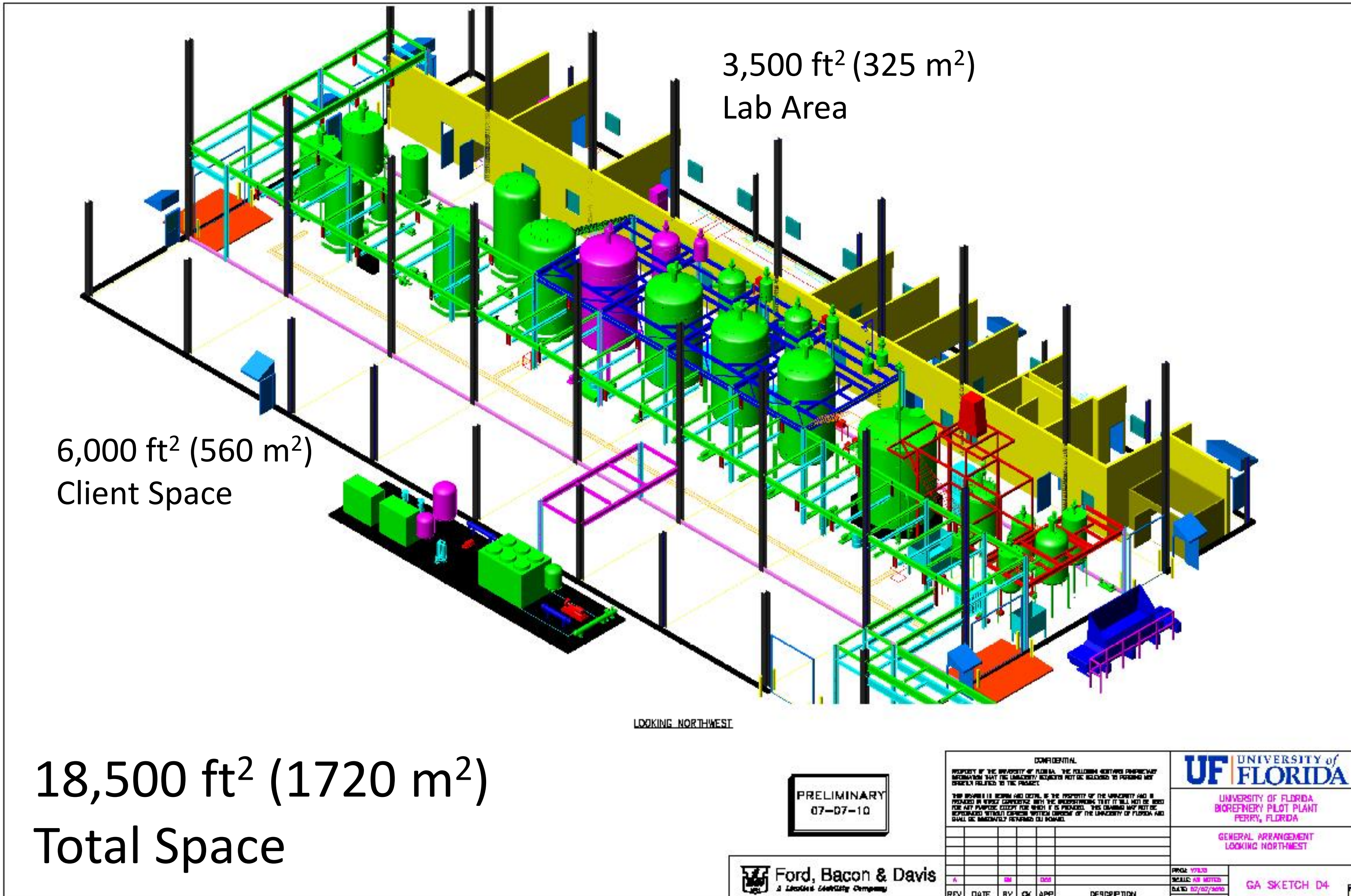

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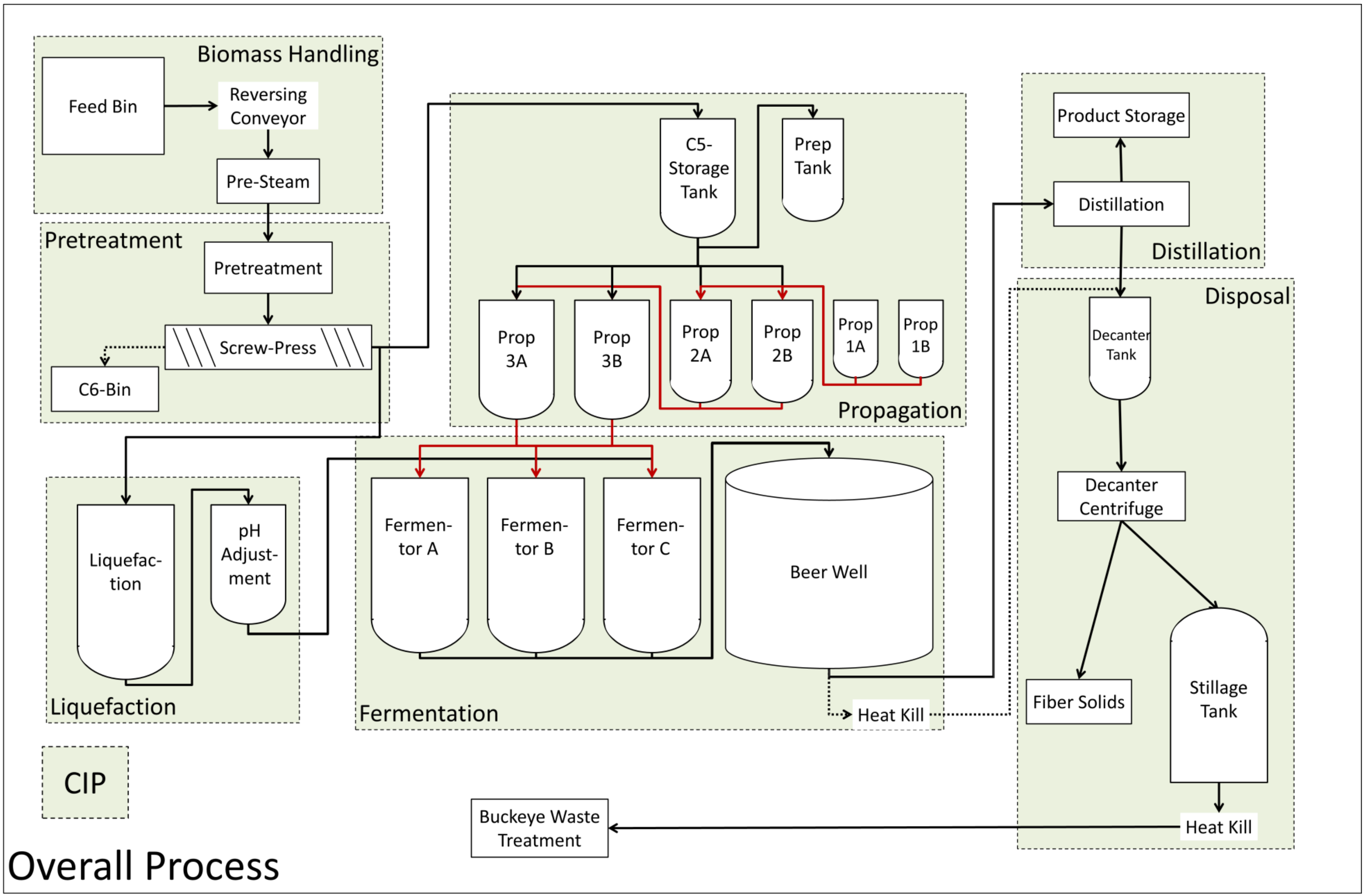

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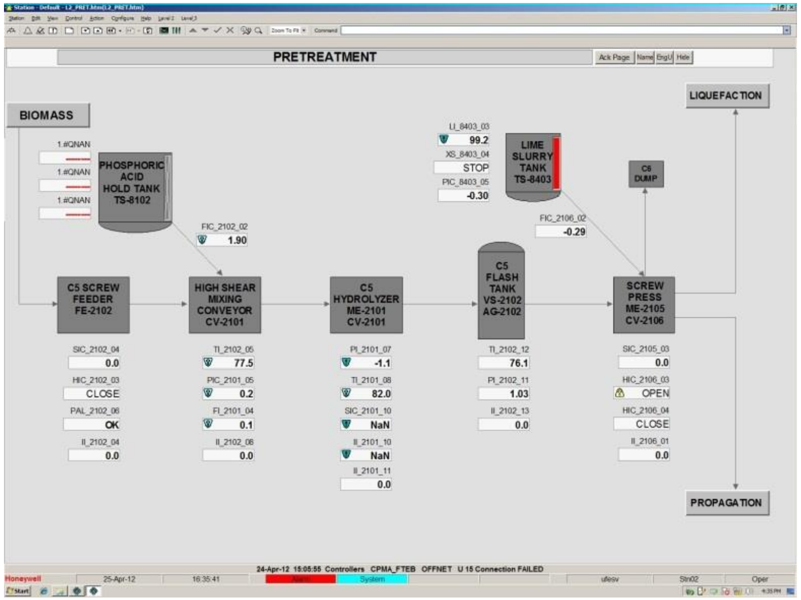

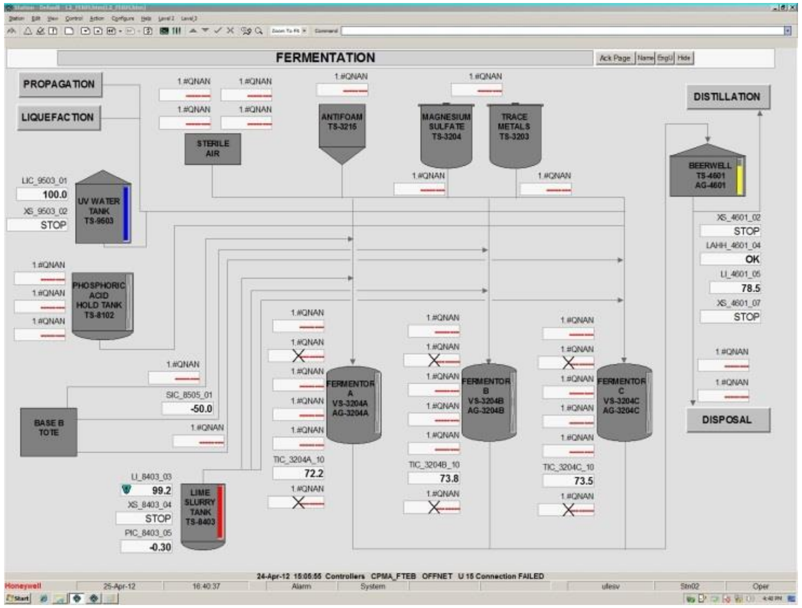

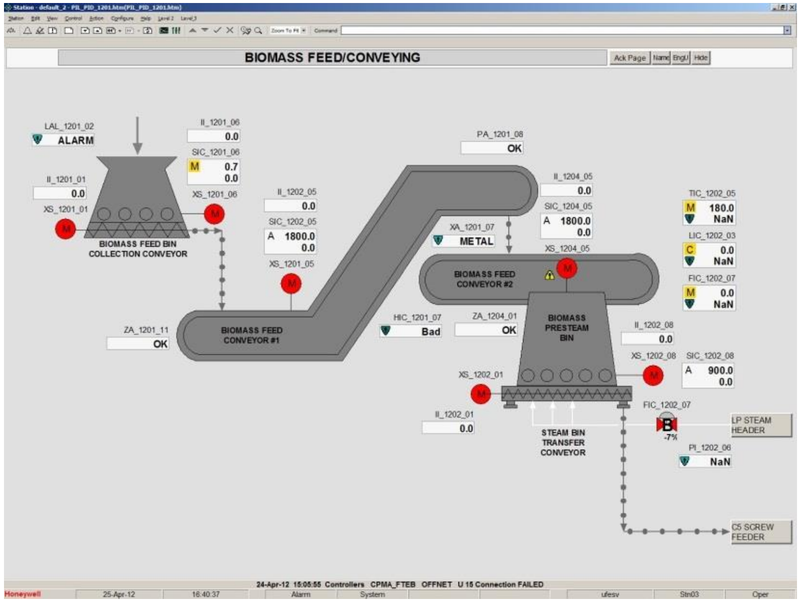

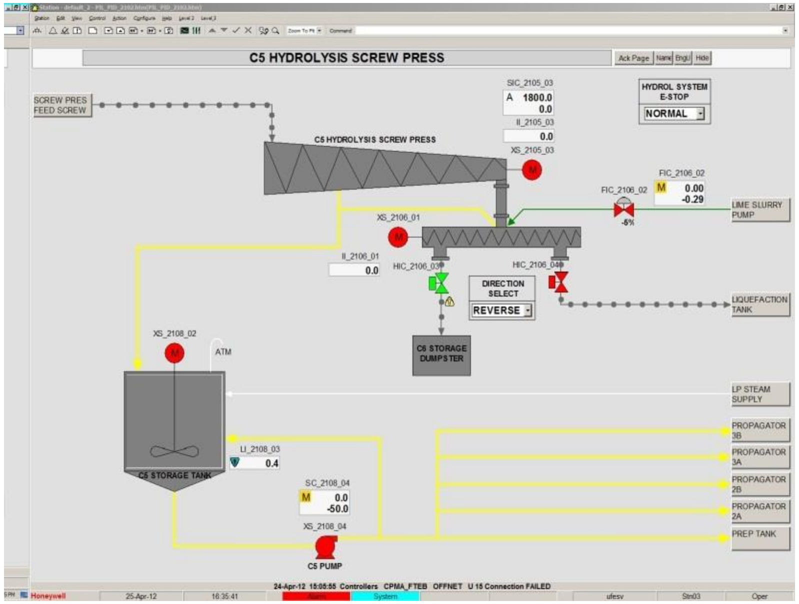

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