Impact of Microalgae/Cyanobacteria Co-culture on Sugar Mill Effluents:
Water Treatment and Added Value Assessment

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Advisors: M.T. Gutierrez-Wing and Ronald Malone

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Research Objectives

• Characterize water effluents of a biomass processing facility (sugar mill used as surrogate)
• Determine suitability of effluents for algal cultivation
• Determine biomass production, nutrient uptake, and organic consumption
• Develop water quality model for biomass processing facility
Background

- 11 sugar mills in LA
- Milling season (Oct-Dec)
- Water and solid waste products
  - Wash water
  - Evaporator water
  - Ash slurry
  - Filter mud → Fertilizer
  - Bagasse → Energy to mill

Image: American Sugar Cane League
**Wash water**

- 1000-1500 gal/ton cane processed
- Rinse incoming cane and milling equipment
- Retention ponds

**Evaporator water**

- 2300 gal/ton cane processed
- High sugar content
- High temperature
- Aerated and discharged daily
# Water Treatment Requirements

Louisiana sugar mill regulations for facilities that impound all wastewaters for discharge after the milling season (State Guidelines – LAC 33:IX.707.D.2.c).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Daily Average (mg/L)</th>
<th>Daily Maximum (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD$_5$</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>TSS</td>
<td>---</td>
<td>50</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>4.0</td>
<td>3.0 (minimum)</td>
</tr>
<tr>
<td>pH</td>
<td>*</td>
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</tr>
</tbody>
</table>

*Treated water must have pH between 6.0-9.0.*
Case Study: Alma Plantation Sugar Mill

- Surrogate for multi-feedstock biomass processing facility
- Evaporator water pond and raceway
- 8 wash water retention ponds
- 10 month sampling plan
  - Water quality
  - N, P, COD
- Bayou Fusilier and Discharge Bayou
- 1.56 million tons cane (2013)
Water Quality

Conductivity Comparison

D.O. Comparison

pH Comparison

ORP Comparison
Nitrogen and Phosphorus Characteristics

Total Nitrogen

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>10/13</th>
<th>11/13</th>
<th>12/13</th>
<th>1/14</th>
<th>2/14</th>
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<th>5/14</th>
<th>6/14</th>
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<tbody>
<tr>
<td>mg-N/L</td>
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<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
<td>0</td>
<td>20</td>
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NH₄-N

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Total Phosphorus

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<tbody>
<tr>
<td>mg-P/L</td>
<td></td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>10</td>
<td>20</td>
<td>30</td>
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PO₄-P

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Chemical Oxygen Demand

Pond 4 COD

Evaporator Pond COD

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Department of Civil & Environmental Engineering
Dual role of algae in wastewater

1. Water treatment of effluents
   a) Remove N, P
   b) Reduce COD
   c) Oxygenate water

2. Accumulate valuable biomass
   a) Biofuels
   b) Bioproducts

Dalrymple et al., 2013
Algal growth experiments

• Co-culture of microalgae/cyanobacteria
  \((Chlorella vulgaris/Leptolyngbya\ sp.)\)
  – Native to Louisiana
  – Mixotrophic growth
1. Differing ratios of wash water and evap. water
   – 0:100, 25:75, 50:50, 75:25, 100:0
2. 100% wash water
   – milling vs. non-milling / filtered vs. unfiltered / inoculated vs. non-inoculated
Growth Rate and Biomass Productivity

Maximum Growth Rate

- Treatment 0:100: 1.21 d⁻¹
- Treatment 25:75: 0.77 d⁻¹
- Treatment 50:50: 0.77 d⁻¹
- Treatment 75:25: 0.77 d⁻¹
- Treatment 100:0: 0.77 d⁻¹

Biomass Productivity

- Treatment 0:100: 95 mg/L d
- Treatment 25:75: 20 mg/L d
- Treatment 50:50: 20 mg/L d
- Treatment 75:25: 20 mg/L d
- Treatment 100:0: 20 mg/L d

Wash water: Evaporator water
BBM = Bold’s Basal media control
Maximum Growth Rate

Biomass Productivity

a: milling season 100% wash water
b and c: post-milling 100% wash water
F = filtered, UF = unfiltered
I = inoculated, NI = non-inoculated
# Theoretical Biomass Yields

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Experimental Temp (°C)</th>
<th>Mixed Water Temp (°C)</th>
<th>P&lt;sub&gt;max&lt;/sub&gt; (mg/L d)</th>
<th>*Theoretical Yield (ton/ha yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100:0</td>
<td>25 ± 2</td>
<td>15.7 ± 4</td>
<td>95-186</td>
<td>157-308</td>
</tr>
<tr>
<td>75:25</td>
<td>25 ± 2</td>
<td>21.5 ± 3</td>
<td>72-140</td>
<td>119-232</td>
</tr>
<tr>
<td>50:50</td>
<td>25 ± 2</td>
<td>27.3 ± 2</td>
<td>59-115</td>
<td>98-190</td>
</tr>
<tr>
<td>BBM</td>
<td>25 ± 2</td>
<td>25 ± 2</td>
<td>20</td>
<td>33</td>
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</table>

*Based on 300 day operating season and 50 cm cultivation pond depth

1 acre: 31 tons/yr

4 acres: 324 tons/yr

8 acres: 648 tons/yr

Reclaimed water
Nutrient Uptake Effects

70-89% TN (filtered) removal
Control: 30%

85-94% TP (filtered) removal
Control: 13%
83-94% TP (filtered) removal

63-84% TN (filtered) removal
Organic Carbon Consumption/Transformation

COD (filtered)
Milling season: 67-76% removal
Post-milling: 18-48% removal
Water Quality Model
Water Quality Model

- Series of stabilization ponds modeling COD, N, and P removal/transformation over time
- Time consideration: beginning of milling season to 7 months after milling ends (~300 days)
- STELLA modeling software
## Model Description

<table>
<thead>
<tr>
<th>Component</th>
<th>Governing Equation</th>
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</table>
| Volume                    | \[
dV_i / dt = Q_{in} + Q_{prec} - Q_{evap} - Q_{transp} - Q_{out}\]
| Total Nitrogen            | \[
dN_i V_i / dt = Q_{i-1} N_{i-1} - Q_i N_i - \left[ \frac{K_A^N N_i V_i}{(K_{1/2}^N + N_i + c_{i} L_i^{1.5})} \right]\]
| Total Phosphorus          | \[
dP_i V_i / dt = Q_{i-1} P_{i-1} - Q_i P_i - \sigma_{p} P_i V_i\]
| Chemical Oxygen Demand (COD) | \[
dL_i V_i / dt = Q_{i-1} L_{i-1} - Q_i L_i - \left[ \frac{K_i^L X_i L_i V_i (1 - Y)}{(K_{1/2}^L + L_i)} \right] + \gamma_{A_i} A_i V_i\]
| Heterotrophic biomass     | \[
dX_i V_i / dt = Q_{i-1} X_{i-1} - Q_i X_i + \left[ \frac{K_i^L X_i L_i V_i}{(K_{1/2}^L + L_i)} \right] - K_d X_i V_i\]
| Autotrophic biomass (algae) | \[
dA_i V_i / dt = \left[ \left( \frac{K_A^T A_i V_i}{K_{1/2}^A + A_i} \right) \left( \frac{K_A^T + L_i / \lambda_i}{N_i / K_N + N_i} \right) \right] - K_{net} A_i V_i\]
| Temperature               | \[
K_T^T = K_T^{20*C} \theta_v^{T-20}\]
Model Calibration

Total Nitrogen

Total Phosphorus

COD

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