The Best Carbon for the Job
Rethinking Industrial “Waste”

To learn:

• Boulder’s WWTF
• Choosing Carbon Sources
• Challenges
• Updates and Next Steps
The Best Carbon for the Job: Rethinking Industrial Waste

City of Boulder 75th Street Wastewater Treatment Facility

Raw Influent
Primary Influent
Primary Effluent
A-Basin Effluent
RAS Flow
MLWAS Flow
Secondary Effluent
Final Effluent
Primary Sludge
Thickened Sludge
Cake Biosolids

City of Boulder Org Charts

PWks - Utilities

Arthur, Jeffrey
Director Of Public Works For Utilities
PWks/UII/Administration

Jacobsen, Jody
Manager
PWks/UII/Administration

Taddeucci, Joseph
Water Resources Manager
PWks/UII/Water Resources

Settle, Harry
Water Treatment Manager
PWks/UII/Water Treatment

Deuville, Christopher
Manager
PWks/UII/Wastewater Treatment

Gallo, Felix
Safety and Compliance Officer
PWks/UII/Watts/Bikeways

Linenfelter, Bret
Water Quality & Surface Water Manager
PWks/UII/Water Quality

Sullivan, Douglas
Engineering Project Manager (Acting Principal Engineer)
PWks/UII/Engineering

Noble, Anne
Flood and Greenways Engineering Coordinator (Acting Principal Engineer)
PWks/UII/Engineering
The Best Carbon for the Job: Rethinking Industrial Waste

City of Boulder Org Charts

Linenfelser, Bret
Water Quality & Environ Svcs Manager
PWks/Util/Water Quality
MGMT

Wind, Michelle
Drinking Water Program Supervisor
PWks/Util/Water Quality
MGMT

Sands, Russell
Watershed Sustainability and Outreach Supervisor
PWks/Util/Water Quality
MGMT

Dorsey, Edward
Laboratory and Industrial Pretreatment Supervisor
PWks/Util/Water Quality
MGMT

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MGMT
The Best Carbon for the Job: Rethinking Industrial Waste

75th St. WWTF Org Chart

Boulder’s Current and Future Nutrient Limits
The Best Carbon for the Job: Rethinking Industrial Waste

Effluent Nitrate Performance

Future Nitrate Limit of 17.9 mg N/L represented by dashed line.
Carbon Limited Denitrification

Not all Carbon is Created Equally
**Effluent Nitrate Performance**

Future Nitrate Limit of 17.9 mg N/L represented by dashed line

**How to get there**
How to get there

[Diagram showing a process flow with various stages and facilities labeled]

Protocol to Evaluate Alternative External Carbon Sources for Denitrification at Full-Scale Wastewater Treatment Plants

[Image of a report cover from WERF]
Phased Approach

Carbon Sources Considered

Cell Media

Brewery Weak Wort

Methanol

Tofu Whey

Acetic Acid
### The Best Carbon for the Job: Rethinking Industrial Waste

**4/14/2016**

Cole Sigmon, CWP

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#### Alternative Carbon

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Methanol</th>
<th>MicroC 2000</th>
<th>Pharma. Cell Media</th>
<th>Tofu Whey</th>
<th>Brewery Weak Wort</th>
<th>Acetic Acid (80%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost ($/lb ffCOD)</strong></td>
<td>4 ($0.15)</td>
<td>2 ($0.27)</td>
<td>5 ($N/A)</td>
<td>2 ($0.25)</td>
<td>5 ($0.10)</td>
<td>1 ($0.78)</td>
</tr>
<tr>
<td><strong>Reliability / availability</strong></td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td><strong>Quality / purity</strong></td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Quality / COD (mg ffCOD/L)</strong></td>
<td>5 (1,188,000)</td>
<td>5 (1,040,000)</td>
<td>3 (N/A)</td>
<td>3 (17,750)</td>
<td>3 (43,866)</td>
<td>5 (896,800)</td>
</tr>
<tr>
<td><strong>Health / safety</strong></td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td><strong>Handling and Storage</strong></td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td><strong>Environmental soundness</strong></td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total Score</strong></td>
<td><strong>24</strong></td>
<td><strong>30</strong></td>
<td><strong>25</strong></td>
<td><strong>27</strong></td>
<td><strong>32</strong></td>
<td><strong>23</strong></td>
</tr>
</tbody>
</table>

---

#### Table: Cost, Reliability, Availability, Quality, COD, Health, Safety, Handling, Storage, Environmental soundness, Total Score
### Life Cycle GHG Emissions

<table>
<thead>
<tr>
<th></th>
<th>Greenhouse Gas Emissions</th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g CO2e/L</td>
<td>g CO2e/ lb ffCOD</td>
<td>g CO2e/ kg ffCOD</td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td>605</td>
<td>231</td>
<td>508</td>
<td></td>
</tr>
<tr>
<td>MicroC2000</td>
<td>135</td>
<td>64</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>Brewery WW</td>
<td>2.8</td>
<td>29</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Tofu Whey</td>
<td>2.8</td>
<td>70</td>
<td>155</td>
<td></td>
</tr>
</tbody>
</table>

Mark Pitterle, NSEW, Inc., 2013

### Chemical Characterization: Phase I

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Brewery Waste</th>
<th>Tofu Whey</th>
<th>MicroC2000</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.46</td>
<td>5.85</td>
<td>5.5</td>
<td>SU</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.0382</td>
<td>1.0488</td>
<td>1.225</td>
<td>SC</td>
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<tr>
<td>TKN</td>
<td>N/A</td>
<td>39.7</td>
<td>4.5 (TN)</td>
<td>mg N/L</td>
</tr>
<tr>
<td>Ammonia</td>
<td>18.85</td>
<td>7.4</td>
<td>--</td>
<td>mg N/L</td>
</tr>
<tr>
<td>ortho-P</td>
<td>5.5</td>
<td>7.0</td>
<td>18.5</td>
<td>mg P/L</td>
</tr>
<tr>
<td>TP</td>
<td>N/A</td>
<td>N/A</td>
<td>24.5</td>
<td>mg P/L</td>
</tr>
<tr>
<td>COD</td>
<td>47,391</td>
<td>22,550</td>
<td>1,040,000</td>
<td>mg/L</td>
</tr>
<tr>
<td>sCOD</td>
<td>45,831</td>
<td>20,850</td>
<td>1,040,000</td>
<td>mg/L</td>
</tr>
<tr>
<td>ffCOD</td>
<td>43,866</td>
<td>17,750</td>
<td>950,000</td>
<td>mg/L</td>
</tr>
<tr>
<td>NO3</td>
<td>8.96</td>
<td>6.3</td>
<td>0</td>
<td>mg N/L</td>
</tr>
<tr>
<td>NO2</td>
<td>0.100</td>
<td>0.020</td>
<td>0</td>
<td>mg N/L</td>
</tr>
<tr>
<td>Total Solids</td>
<td>2.71</td>
<td>5.09</td>
<td>5</td>
<td>%</td>
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</tbody>
</table>
### Chemical Characterization: Phase II

<table>
<thead>
<tr>
<th>Metals concentration listed in mg/L</th>
<th>Methanol</th>
<th>MicroC 2000</th>
<th>Brewery Weak Wort</th>
<th>Acetic Acid</th>
<th>Boulder WWTF Permit Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver, PD</td>
<td>&lt; 6.0</td>
<td>&lt; 30</td>
<td>&lt; 30</td>
<td>&lt; 4.0</td>
<td>Report only 30-d avg / daily max</td>
</tr>
<tr>
<td>Arsenic, TR</td>
<td>&lt; 56</td>
<td>4850</td>
<td>385</td>
<td>&lt; 450</td>
<td>0.023 30-day avg</td>
</tr>
<tr>
<td>Cadmium, PD</td>
<td>&lt; 3.6</td>
<td>&lt; 18</td>
<td>&lt; 18</td>
<td>9.0</td>
<td>0.74 30-day avg</td>
</tr>
<tr>
<td>Cyanide, WAD</td>
<td>&lt; 30</td>
<td>&lt; 30</td>
<td>&lt; 30</td>
<td>NA</td>
<td>30 daily max</td>
</tr>
<tr>
<td>Copper, PD</td>
<td>&lt; 19</td>
<td>195</td>
<td>145</td>
<td>&lt; 15</td>
<td>19 / 28 30-d avg / daily max</td>
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<tr>
<td>Mercury, T</td>
<td>1.2</td>
<td>0.13</td>
<td>0.37</td>
<td>0.012</td>
<td>30-d avg</td>
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<tr>
<td>Manganese, D</td>
<td>29</td>
<td>190</td>
<td>180</td>
<td>10.0</td>
<td>Report only 30-d avg / daily max</td>
</tr>
<tr>
<td>Hex Chromium, D</td>
<td>&lt; 5</td>
<td>&lt; 5</td>
<td>&lt; 5</td>
<td>NA</td>
<td>13 / 18 30-d avg / daily max</td>
</tr>
<tr>
<td>Zinc, PD</td>
<td>&lt; 60.0</td>
<td>325</td>
<td>290</td>
<td>20.0</td>
<td>Report only 30-d avg / daily max</td>
</tr>
</tbody>
</table>

### Weak Wort Carbon Characterization

<table>
<thead>
<tr>
<th>Brewery Waste Storage Tank</th>
<th>Sample Date</th>
<th>Average Holding Time (days)</th>
<th>VFA (mg/L)</th>
<th>Ethanol (%)</th>
<th>sCOD (mg/L)</th>
<th>fCOD (mg/L)</th>
<th>Ethanol/ fCOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,900-gallon tank</td>
<td>1/24/2014</td>
<td>35</td>
<td>325</td>
<td>1.64%</td>
<td>70,150</td>
<td>64,150</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>1/29/2014</td>
<td>40</td>
<td>398</td>
<td>1.54%</td>
<td>63,900</td>
<td>61,800</td>
<td>0.25</td>
</tr>
<tr>
<td>2,450-gallon tank</td>
<td>1/24/2014</td>
<td>4</td>
<td>404</td>
<td>1.48%</td>
<td>70,350</td>
<td>69,000</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>1/29/2014</td>
<td>9</td>
<td>285</td>
<td>1.33%</td>
<td>65,250</td>
<td>61,100</td>
<td>0.22</td>
</tr>
<tr>
<td>Average</td>
<td>22</td>
<td>353</td>
<td>1.50%</td>
<td>67,413</td>
<td>64,013</td>
<td>0.23</td>
<td></td>
</tr>
</tbody>
</table>
Phased Approach

- Pre-Screening phase: Identification of possible C-alternatives
- Determine C-Alternative Pre-Screening score
- Chemical characterization (manufacture or test)
- Batch/Pilot testing
- Full scale testing
- Data Collection & Analysis
- Final Decision

Testing phase: Identification of Testing Type & Protocols

- Type of test
- Protocol

Decision phase: Identification of C-alternative for WWTP

- Availability
- Cost
- Quality/Perf/ODD
- Health/Ecology
- Green/Environmental soundness

WERF, 2010

Bench-Scale Testing: The NUR Test

Figure B.1. Typical Setup for NUR Tests.

WERF, 2010
Sample NUR Test Results

**Refrigerated Brewery Weak Wort**

Fraction rbCOD/COD = 16%
Sample NUR Test Results

Unrefrigerated Brewery Weak Wort
Fraction rbCOD/COD = 32%

Bench-Scale Results

<table>
<thead>
<tr>
<th>Carbon Source</th>
<th>WERF, 2010</th>
<th>NUR Tests 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SDNR</td>
<td>COD/N</td>
</tr>
<tr>
<td>Brewery Waste</td>
<td>7.8</td>
<td>3.0 - 6.2</td>
</tr>
<tr>
<td>MicroC</td>
<td>2.5</td>
<td>6.4</td>
</tr>
<tr>
<td>Methanol</td>
<td>2.3</td>
<td>3.6 - 4.8</td>
</tr>
</tbody>
</table>
**Full Scale Trial: Target Dose**

<table>
<thead>
<tr>
<th></th>
<th>COD (mg/L)</th>
<th>COD/N</th>
<th>Target Dose (m³/day)</th>
<th>Target Dose (kg ffCOD/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol</td>
<td>1,188,000</td>
<td>4.3</td>
<td>0.322</td>
<td>382</td>
</tr>
<tr>
<td>MicroC2000</td>
<td>1,040,000</td>
<td>5.1</td>
<td>0.439</td>
<td>456</td>
</tr>
<tr>
<td>Brewery WW</td>
<td>60,000</td>
<td>7.4</td>
<td>11.02</td>
<td>660</td>
</tr>
<tr>
<td>Acetic Acid 56%</td>
<td>627,760</td>
<td>4.0</td>
<td>0.568</td>
<td>356</td>
</tr>
</tbody>
</table>

**Full Scale Trial Setup**

- 9.3 m² and 3.8 m³ Brewery Weak Wort Storage Tanks
- Brewery Weak Wort 26 m³ Storage Tank
- Location for external carbon injection: Aeration Basin 3 Chimney Baffle
- MicroC 1 m³ totes, methanol and acetic acid 100-L drums
- Chemical Feed Pump for Methanol, MicroC and Acetic Acid
**Weak Wort Carbon Characterization**

<table>
<thead>
<tr>
<th>Brewery Waste Storage Tank</th>
<th>Sample Date</th>
<th>Average Holding Time (days)</th>
<th>VFA (mg/L)</th>
<th>Ethanol (%)</th>
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<th>fCOD (mg/L)</th>
<th>Ethanol/fCOD</th>
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<td>64,150</td>
<td>0.26</td>
</tr>
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<td>61,800</td>
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<td>69,000</td>
<td>0.21</td>
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<tr>
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<td>9</td>
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<td>1.33%</td>
<td>65,250</td>
<td>61,100</td>
<td>0.22</td>
</tr>
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<td></td>
<td>1.50%</td>
<td>67,413</td>
<td>64,013</td>
<td>0.23</td>
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</tbody>
</table>
### Full-Scale Trial Monitoring

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Wet Chemistry analyses</th>
<th>In-situ Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAS</td>
<td>NO₃, NO₂, NH₄, sCOD</td>
<td>DO, TSS, pH</td>
</tr>
<tr>
<td>ABI Channel</td>
<td>NO₃, NO₂, NH₄, sCOD, TKN</td>
<td>DO, TSS, pH</td>
</tr>
<tr>
<td>AB1, Z1</td>
<td>NO₃, NO₂, NH₄, sCOD</td>
<td>DO, TSS, pH</td>
</tr>
<tr>
<td>AB1, Z2</td>
<td>NO₃, NO₂, NH₄, sCOD</td>
<td>DO, TSS, pH</td>
</tr>
<tr>
<td>AB1, Z3</td>
<td>NO₃, NO₂, NH₄, sCOD</td>
<td>DO, TSS, pH</td>
</tr>
<tr>
<td>AB1, Z8</td>
<td>NO₃, NO₂, NH₄, sCOD, PO₄, TSS</td>
<td>DO, TSS, pH</td>
</tr>
<tr>
<td>AB3, Z1</td>
<td>NO₃, NO₂, NH₄, sCOD</td>
<td>DO, TSS, pH</td>
</tr>
<tr>
<td>AB3, Z2</td>
<td>NO₃, NO₂, NH₄, sCOD</td>
<td>DO, TSS, pH</td>
</tr>
<tr>
<td>AB3, Z3</td>
<td>NO₃, NO₂, NH₄, sCOD</td>
<td>DO, TSS, pH</td>
</tr>
<tr>
<td>AB3, Z8</td>
<td>NO₃, NO₂, NH₄, sCOD, PO₄, TSS</td>
<td>DO, TSS, pH</td>
</tr>
</tbody>
</table>

### Process Modeling

- Three secondary trains in parallel
- Four external carbon inputs
The Best Carbon for the Job: Rethinking Industrial Waste

Modeled Results vs Actual Performance

<table>
<thead>
<tr>
<th>Carbon Type</th>
<th>Carbon Dose (m³/d)</th>
<th>Modeled Δ Oxic Eff (mg N/L)</th>
<th>Modeled Δ w/ peaking factor (mg N/L)</th>
<th>Continuous Dose Grab (mg N/L)</th>
<th>Daytime Dose Grab (mg N/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Carbon</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.2</td>
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<tr>
<td>Methanol</td>
<td>0.121</td>
<td>0.38</td>
<td>0.44</td>
<td>0.9</td>
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</tr>
<tr>
<td>Methanol</td>
<td>0.151</td>
<td>0.45</td>
<td>0.52</td>
<td>1.0</td>
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<tr>
<td>Methanol</td>
<td>0.322</td>
<td>0.73</td>
<td>0.84</td>
<td>2.3</td>
<td>0.7</td>
</tr>
<tr>
<td>MicroC2000</td>
<td>0.189</td>
<td>1.13</td>
<td>1.30</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>MicroC2000</td>
<td>0.439</td>
<td>4.42</td>
<td>3.01</td>
<td>0.7</td>
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<tr>
<td>Brewery WW</td>
<td>10.22</td>
<td>1.88</td>
<td>2.16</td>
<td>2.2</td>
<td>1.6</td>
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<tr>
<td>Brewery WW</td>
<td>12.49</td>
<td>2.30</td>
<td>2.65</td>
<td>2.3</td>
<td>0.8</td>
</tr>
<tr>
<td>Brewery WW</td>
<td>20.06</td>
<td>3.67</td>
<td>4.22</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Acetic Acid (56%)</td>
<td>0.568</td>
<td>2.6</td>
<td>2.99</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Acetic Acid (56%)</td>
<td>0.704</td>
<td>3.22</td>
<td>3.70</td>
<td>1.4</td>
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<tr>
<td>Acetic Acid (56%)</td>
<td>0.795</td>
<td>3.63</td>
<td>4.17</td>
<td>1.9</td>
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</tr>
</tbody>
</table>

Full-Scale Performance

![Graph showing Modeled Results vs Actual Performance](image-url)
Decision

Brewery Weak Wort – Primary Source
• Locally available
• Waste as resource
• Potential for optimization

Acetic Acid – Chemical Backup
• Immediately effective
• Common industrial chemical
• Consistent strength and quality

Updates and Next Steps

• Nitrogen Upgrades Project

• Avery Brewing Company
  • Permit
  • Compliance (or lack thereof)
  • Logistics
Nitrogen Upgrades Project – Site Aerial