Biological conversion of solid and liquid streams

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WTERT 2014
Brief overview of biological waste treatment

- Solids, inerts separation
- Aerobic C & N removal
- Recycle of bacteria
- Disinfection and discharge

- A high fraction of WWT energy goes to aeration
- $MM in organic chemical purchase
- Bacteria could produce unwanted products ($N_2O$)
Shifting from Resource Removal to Resource Recovery

Article by K. Chandran, Columbia Magazine, Fall 2012
K. Chandran, 2014, Elsevier
Engineered Resource Recovery from ‘Waste’ Streams
Recovery of C, N and P
All based on anaerobic technologies

• Engineering microbial processes for synthesizing commercial products

Biofuels  Biogroup, SmartSoils®

Bioplastics  Biofertilizers

Commercial chemicals

Electricity
Anaerobic digestion

- Three stages
  - Hydrolysis
  - Fermentation
  - Methanogenesis

  - Slowest and most sensitive step
‘Direct’ energy is not the only endpoint
Dual-Phase Digestion and Fermentation of AS

- Fermentation of PDS to produce VFA
  - Used mainly for denitrification
  - Kinetics higher than MeOH
- Acid-digestion of surface froth and scum
  - Reduced foaming
  - VFA recovery

PDS fermentation and storage at 26th Ward WPCP in New York City, 2002
Anaerobic Fermentation

- Two stages
  - Hydrolysis
  - Fermentation
Fermentation as a platform

- VFA for N and P removal
  - Using different types of biomass
  - Including food waste
- Chemicals
  - solvents, pharmaceuticals
- Biofuels
- Methanogenesis still can be conducted downstream
  - And probably needs to be conducted
Organic sludge to biodiesel

VFA as a central intermediate

- Using the lipid content of sludge
- Using MeOH for fuel production
A novel and extremely flexible platform technology which can be used to convert different organic feed stocks including food waste, sewage sludge, or industrial high-strength organic waste into biodiesel.

Based on our results, and combined with in-situ extraction of lipids from the waste, up to 40% increase in the final yield of biodiesel can be achieved. Further increase is possible through improvements in the VFA yield from the fermenter.

Multiple endpoints can be achieved in conjunction using VFAs produced from anaerobic digestion of waste streams.
## Alternate chemicals from sewage sludge or wastewater

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Price</th>
<th>Platform technology</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Succinic acid</td>
<td>$9.9</td>
<td>Fermentation</td>
<td>Nutraceutical</td>
</tr>
<tr>
<td>Ethyl acetate</td>
<td>$5.64</td>
<td>Fermentation</td>
<td>Solvent</td>
</tr>
<tr>
<td>Methyl acetate</td>
<td>$5.39</td>
<td>Fermentation</td>
<td>Solvent</td>
</tr>
<tr>
<td>1,3 propanediol</td>
<td>$8.83</td>
<td>Fermentation</td>
<td>Industrial monomer</td>
</tr>
<tr>
<td>Butyric acid and butanol</td>
<td>$3.00 - $6.80</td>
<td>Fermentation</td>
<td>Biofuel</td>
</tr>
</tbody>
</table>
The connection to food
• Concomitant oxidation of CH$_4$ and CO$_2$ fixation
• Prospect of combining C & N cycles
Recycle Streams with High Ammonia - Sidestream

- 1% of Total Plant Influent Flow
- Rich in Nitrogen & Phosphorus
- 15 to 25% of the Total Plant TN load
- Ammonium Conc. 800 to 1,500 mg-N/L
- Temperature 30 - 38°C
- Alkalinity insufficient for complete nitrification
- Insufficient carbon for denitrification

For a Bio-P plant with no iron addition:
  - Centrate TP = 200-800 mg/L
Engineered N-removal

- N-removal results in doubling of aeration energy

\[
\begin{align*}
\text{NH}_4^+ - N &\quad (\text{N}(-III)) \\
\text{NO}_2^- - N &\quad (\text{N}(+III)) \\
\text{NO}_3^- - N &\quad (\text{N}(+V)) \\
\text{N}_2 &\quad (\text{N}(0))
\end{align*}
\]

- Nitrification step I: 1.5 mol O\textsubscript{2}/mol N
- Nitrification step II: 0.5 mol O\textsubscript{2}/mol N
- Denitrification step I: 1.15 mol COD/mol N
- Denitrification step n: 1.71 mol COD/mol N

- 25% savings in air $
- 40% savings in COD $

- Nitrogen fixation

- 25% savings in air $
- 40% savings in COD $
Conventional Nitrification-Denitrification

**Autotrophic Bacteria**
Aerobic Environment

- 1 mole Ammonia ($\text{NH}_3$ / $\text{NH}_4^+$)
- 75% $\text{O}_2$ (energy)
- ~100% Alkalinity

**Nitrite Oxidizing Bacteria (NOB)**

- 1 mole Nitrite ($\text{NO}_2^-$)
- 25% $\text{O}_2$ (energy)

**Ammonia Oxidizing Bacteria (AOB)**

- 1 mole Nitrate ($\text{NO}_3^-$)
- 40% Carbon (BOD)

**Heterotrophic Bacteria**
Anoxic Environment

- 1 mole Nitrite ($\text{NO}_2^-$)
- 60% Carbon (BOD)

- $\frac{1}{2}$ mol Nitrogen Gas ($\text{N}_2$)
Nitritation-Denitritation = “Nitrite Shunt” (2.0)

Autotrophic Bacteria
Aerobic Environment

Heterotrophic Bacteria
Anoxic Environment

1 mole Ammonia
(NH₃/ NH₄⁺)

25% O₂ (energy)

Nitrite Oxidizing Bacteria (NOB)

1 mole Nitrate
(NO₃⁻)

40% Carbon (BOD)

Ammonia Oxidizing Bacteria (AOB)

1 mole Nitrite
(NO₂⁻)

60% Carbon (BOD)

½ mol Nitrogen Gas
(N₂)

Advantages:
• 25% reduction in oxygen demand (energy)
• 40% reduction in carbon (e⁻ donor) demand
• 40% reduction in biomass production
Partial Nitritation-Anammox = “Deammonification” (3.0)

ANAMMOX
“Anaerobic” Ammonia Oxidation - (New Planctomycete - Strous et al, 1999)

\[
\text{NH}_4^+ + 1.32 \text{NO}_2^- + 0.066 \text{HCO}_3^- + 0.13 \text{H}^+ \rightarrow \\
0.26 \text{NO}_3^- + 1.02\text{N}_2 + 0.066 \text{CH}_2\text{O}_{0.5}\text{N}_{0.15} + 2.03 \text{H}_2\text{O}
\]

Advantages:
• 63% reduction in oxygen demand (energy)
• Nearly 100% reduction in carbon demand
• 80% reduction in biomass production
• No additional alkalinity required
• Sewage treatment in NYC
• Flow: 1.2 billion gallons per day
  – 1860 tons of organic carbon per day
  – 280 tons of N(-III) per day
  – 60 tons of P(+V) per day
Possible flowsheet for C, N and P recovery

- C-recovery
- N-removal or recovery
- P- recovery (not discussed)

- How to monetize recovery of energy or chemical resources with environmental process objectives
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