Life Cycle Assessment and Cost Analysis of Anaerobic Co-Digestion of Food Waste at a Medium-Scale Water Resource Recovery Facility

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Our question(s):

• Does it make sense to have resource recovery in wastewater treatment plants?
• Does anaerobic digestion make sense for food waste disposal?
  – Is it better than other options
  – Under what conditions
  – At what scale
  – Are there any trade-offs
Study Objectives

• Assess environmental and cost impact of:
  – Expanding anaerobic digester (AD) capacity for food waste co-digestion.
  – Installing combined heat and power (CHP).
  – Variable digester performance.
  – Avoided waste scenarios.
Life Cycle Approach

• Assess cradle-to-grave impacts for all processes, products, and services associated with the system for the following metrics:
  - Cost [U.S. Dollars 2016]
  - Global climate change potential [kg CO2 equivalent (eq.)]
  - Eutrophication potential [kg N. eq]
  - Cumulative energy demand [MJ (renewable and non-renewable)]
  - Particulate matter formation potential [kg PM2.5 eq.]
  - Smog formation potential [kg O3 eq.]
  - Acidification potential [kg SO2 eq.]
  - Water use [cubic meters water]
  - Fossil depletion potential [kg oil eq.]

• Standardize annual facility impacts to a functional unit basis of a cubic meter of wastewater treated.
Process Flow Diagram

- Wastewater Influent
- Screening & Grit Removal
- Primary Clarifier
- Primary Sludge
- Gravity Thickener
- Anaerobic Digestion
- Biogas
- Fugitive and Biogas Flaring
- Filtrate
- Gravity Belt Thickener
- Sodium Hypochlorite & Sodium Bisulfate
- Chlorination & Dechlorination
- Polymer
- Centrifuge
- Pellet Drying
- Energy Recovery
- Combustion Emissions
- Land Application or Landfill
- Diesel
- Transportation, Field and Landfill Emissions
- Effluent Discharge in River
- Nitrous Oxide Emissions from Receiving Stream
- Process GHG Emissions
- Return Activated Sludge
- Process Air Emissions
- Liquid Flow
- Solid Flow
- Source Separated Organics

KEY
- On-site wastewater treatment plant processes
- Upstream energy and material inputs
- Process Flow Diagram
### Waste Scenarios Analyzed

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Waste Type</th>
<th>Quantity (gpd)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All Scenarios</strong></td>
<td>Septage</td>
<td>80,000</td>
</tr>
<tr>
<td></td>
<td>Municipal Solids*</td>
<td>8,000</td>
</tr>
<tr>
<td><strong>Scenario 1: Base (2016)</strong></td>
<td>Primary &amp; WAS</td>
<td>172,000</td>
</tr>
<tr>
<td></td>
<td>SSO</td>
<td>-</td>
</tr>
<tr>
<td><strong>Scenario 2: 50% SSO Capacity</strong></td>
<td>Primary &amp; WAS</td>
<td>179,000</td>
</tr>
<tr>
<td></td>
<td>SSO</td>
<td>46,000</td>
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<tr>
<td><strong>Scenario 3: 100% SSO Capacity</strong></td>
<td>Primary &amp; WAS</td>
<td>188,000</td>
</tr>
<tr>
<td></td>
<td>SSO</td>
<td>92,000</td>
</tr>
</tbody>
</table>

*Municipal Solids*: Trucked in primary and waste activated sludge.
# Septage, Primary Sludge, WAS and SSO Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Feedstock</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Septage&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td>15,000</td>
<td>mg/L</td>
</tr>
<tr>
<td>VSS</td>
<td>10,000</td>
<td>mg/L</td>
</tr>
<tr>
<td>VSS/TSS</td>
<td>67</td>
<td>%</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>750</td>
<td>mg N/L</td>
</tr>
<tr>
<td>Total P</td>
<td>375</td>
<td>mg P/L</td>
</tr>
<tr>
<td>COD</td>
<td>17,000</td>
<td>mg COD/L</td>
</tr>
<tr>
<td>Density</td>
<td>1,020</td>
<td>kg/m³</td>
</tr>
<tr>
<td></td>
<td>Trucked Municipal Solids&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td>22,500</td>
<td>mg/L</td>
</tr>
<tr>
<td>VSS</td>
<td>16,500</td>
<td>mg/L</td>
</tr>
<tr>
<td>VSS/TSS</td>
<td>73</td>
<td>%</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>600</td>
<td>mg N/L</td>
</tr>
<tr>
<td>Total P</td>
<td>210</td>
<td>mg P/L</td>
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<tr>
<td>COD</td>
<td>29,000</td>
<td>mg COD/L</td>
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<tr>
<td>Density</td>
<td>1,030</td>
<td>kg/m³</td>
</tr>
<tr>
<td></td>
<td>SSO&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td>137,000</td>
<td>mg/L</td>
</tr>
<tr>
<td>VSS</td>
<td>124,000</td>
<td>mg/L</td>
</tr>
<tr>
<td>VSS/TSS</td>
<td>90</td>
<td>%</td>
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<tr>
<td>Total Nitrogen</td>
<td>3,800</td>
<td>mg N/L</td>
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<tr>
<td>Total P</td>
<td>620</td>
<td>mg P/L</td>
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<tr>
<td>COD</td>
<td>216,000</td>
<td>mg COD/L</td>
</tr>
<tr>
<td>Density</td>
<td>1,050</td>
<td>kg/m³</td>
</tr>
</tbody>
</table>

<sup>1</sup> (U.S. EPA 1984)

<sup>2</sup> (Tchobanoglous et al. 2014), assumes 67 percent primary solids and 37 percent WAS by mass.

<sup>3</sup> personal communication with Lauren Fillmore
## AD Performance Scenarios

<table>
<thead>
<tr>
<th>Description</th>
<th>Base AD Performance</th>
<th>Low AD Performance</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base</td>
<td>Partial Capacity</td>
<td>Full Capacity</td>
</tr>
<tr>
<td>VS reduction</td>
<td>55%</td>
<td>69%</td>
<td>72%</td>
</tr>
<tr>
<td>Biogas yield</td>
<td>17.4</td>
<td>18.4</td>
<td>18.5</td>
</tr>
<tr>
<td>Biogas, methane content</td>
<td>59.2</td>
<td>59.4</td>
<td>59.9</td>
</tr>
<tr>
<td>Fugitive methane loss</td>
<td></td>
<td>5% for all scenarios</td>
<td></td>
</tr>
<tr>
<td>Biogas production</td>
<td>413</td>
<td>1,170</td>
<td>1,870</td>
</tr>
<tr>
<td>Flared biogas</td>
<td>20%</td>
<td>10%</td>
<td>10%</td>
</tr>
</tbody>
</table>

1 [Decrease in Low AD parameter value, relative to base scenario]
Cumulative Energy Demand
(Base AD Results by Process Category)

![Diagram showing energy demand by process category for baseline, partial capacity, and full capacity.
Legend includes categories such as Electricity, Unit Process Emissions, Avoided Water, Avoided Electricity, CHP, Land Application, and others.
Net impact highlighted for each category.]
Cumulative Energy Demand
(Base AD Results by Treatment Group)

![Bar chart showing cumulative energy demand by treatment group.](chart.png)
## Energy Production vs. Use

<table>
<thead>
<tr>
<th>Energy Indicator</th>
<th>Base</th>
<th>Partial Capacity</th>
<th>Full Capacity</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas energy recovery(^1)</td>
<td>78%</td>
<td>81%</td>
<td>71%</td>
<td>of produced biogas energy</td>
</tr>
<tr>
<td>Electricity demand satisfaction</td>
<td>-</td>
<td>80%</td>
<td>100(^2)</td>
<td>of total facility demand</td>
</tr>
<tr>
<td>Heat demand satisfaction</td>
<td>79%</td>
<td>100%</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Includes energy loss associated with fugitive biogas/methane.

\(^2\) The facility produces approximately 6.1 GWh of excess electricity annually.
CED Take-Away Message

• Full Capacity-Base AD scenario makes the facility a net energy producer.
• Avoided electricity production is the largest contributor to reduced energy demand.
• Avoided SSO disposal leads to increased CED.
Global Climate Change Potential
(Base AD Results by Process Category)
Global Climate Change Potential
(by Treatment Group)

kg CO₂ eq/m³ wastewater treated

Baseline | Partial Capacity | Partial Capacity | Full Capacity | Full Capacity

Base AD | Base AD | Low AD | Base AD | Low AD

- Influent Pump Station
- Biological Treatment
- Plant Water and Disinfection
- Pellet Drying
- Building Operation
- Net Impact

0.36 | 0.01 | 0.19 | -0.05 | -0.28

DRAFT
Avoided EOL Process Sensitivity

![Graph showing CO2 emissions for different processes in baseline and full capacity scenarios.](image_url)

- Baseline
  - Influent Pump Station
  - Biological Treatment
  - Plant Water and Disinfection
  - Pellet Drying
  - Building Operation
  - Net Impact

- Full Capacity
  - Ma Mix
  - Preliminary/Primary
  - Sludge Dewatering
  - Anaerobic Digestion and CHP
  - Pellet Land Application
  - Effluent Release

- Full Capacity Landfill - 100%
- Full Capacity WTE - 100%

Values in the graph:
- Baseline: 0.36 kg CO2 eq/m3 wastewater treated
- Full Capacity Ma Mix: -0.28 kg CO2 eq/m3 wastewater treated
- Full Capacity Landfill - 100%: -1.2 kg CO2 eq/m3 wastewater treated
- Full Capacity WTE - 100%: 0.18 kg CO2 eq/m3 wastewater treated
Climate Change Take-Away Message

• Clear GCCP benefit from acceptance of SSO.  
  – Particularly compared to landfill disposal.
• Diverting food waste from WTE production yields a net reduction in GCCP impact, despite GCCP benefit associated with WTE combustion.
• Avoided natural gas and electricity consumption and EOL disposal all contribute considerably to reduced GCCP.
Eutrophication Results
(by Treatment Group)
Analysis of Effluent Response to 20,000 gallons of SSO

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**SE NH3 (mg/L)**


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**F-Eff P (mg/L)**

Other Environmental Results

• AD expansion yields *potential reductions in environmental impact* for acidification (acid rain) potential and particulate matter formation potential (human health indicator).

• AD expansion yields *potential environmental benefits* in fossil fuel depletion, smog formation potential and water use.
Cost Analysis Results

- Indicate a 7 and 14 year payback period for the investment in AD and CHP systems for the full and partial capacity scenarios.
So, does it make sense?

- Yes, if steps are taken to control effluent nutrient concentrations.
  - Model appears conservative based on available effluent data.
- Yes, water resource recovery facility can be a net energy producer.
- Anaerobic co-digestion leads to reduced, plant GCCP and CED.
  - Trend is always towards decreasing impact as co-digestion increases.
  - Magnitude of decrease is sensitive to avoided treatment processes and AD performance
- Life cycle cost analysis indicates reasonable payback period at this scale.
Disclaimer

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Key Environmental Assumptions

• 5% of produced biogas lost as fugitive emissions
• Flaring rate (currently between 10 and 20%)
• CHP efficiency
  – Electrical efficiency: 40%
  – Thermal efficiency: 39%
• Biogas Use Hierarchy
  – Flared fraction
  – Second satisfy pellet drier demand
  – The rest is sent to CHP