LIFT: Converting Biosolids into Biocrude

WEFTEC 2016
Innovation Pavilion
September 27, 2016
Agenda

Introduction
Raj Bhattarai, City of Austin (Moderator)

Genifuel Hydrothermal Processing Bench Scale Technology Evaluation
Philip Marrone, Leidos, Inc.

Hydrothermal Processing in Wastewater Treatment: Planning for a Demonstration Project
Jim Oyler, Genifuel

Project Participant Perspectives
Paul Kadota, Metro Vancouver

Q&A / Discussion
Project Background

- Spring 2014: LIFT B2E Focus Group Presentation by Genifuel
- Summer 2014: Project Concept Developed
- Fall 2014: Project Funding Assembled
- Independent Evaluator Selected
- Feb 2015: Project Kickoff
- April 2016: Project Completed

Funding Partners:
- City of Calgary
- City of Orlando
- City of Santa Rosa
- Delta Diablo Sanitation District
- Eastman Chemical Company
- Melbourne Water Corporation
- Metro Vancouver
- Silicon Valley Clean Water
- Toho Water Authority
- US EPA
- US DOE (in-kind)

Project Subcommittee:
- Mo Abu-Orf, AECOM
- Bob Forbes, CH2M Hill
- Angela Hintz, ARCADIS
- Bryan Jenkins, Univ. of CA - Davis
- Patricia Scanlan, Black & Veatch
- Jeff Tester, Cornell University
Genifuel Hydrothermal Processing Bench Scale Technology Evaluation

WEFTEC 2016
September 27, 2016

Philip A. Marrone
Leidos
Introduction

• Assess the potential of the Genifuel hydrothermal process technology (HTP) for handling municipal wastewater sludge

• **HTP** is a thermochemical process where water is used as the medium for the breakdown and reconstituting of organic matter into relatively simpler chemical compounds at elevated temperatures and pressures
  
  - No drying of feed needed
  
  - Utilizes all components of feed

• Proof-of-concept bench-scale tests were performed at Pacific Northwest National Laboratory (PNNL)
Sludge Types Tested (one HTL + CHG test each):
- Primary
- Secondary
- Post-digester (Digested Solids)

Sludge Provider:
Metro Vancouver – Annacis Island WWTP

Sludge Preparation:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>4.5 wt%</td>
<td>Filter press (40 psi for 20 min; 300 μm filter), followed by hand press</td>
<td>Yes (121°C for 5 hrs)</td>
<td>26.0 wt%</td>
<td>Yes</td>
<td>11.9 wt%</td>
</tr>
<tr>
<td>Secondary</td>
<td>3.9 wt%</td>
<td>55 L Dewatering bags for 48 hrs</td>
<td>Yes (121°C for 5 hrs)</td>
<td>10.9 wt%</td>
<td>No</td>
<td>10.0 wt%</td>
</tr>
<tr>
<td>Digested Solids</td>
<td>28 wt%</td>
<td>None</td>
<td>None</td>
<td>28 wt%</td>
<td>Yes</td>
<td>16.4 wt%</td>
</tr>
</tbody>
</table>
Sludge Feed Procurement/Preparation

Primary (11.9 wt % solids)

Secondary (10.0 wt% solids)

Post-digester (16.4 wt % solids)

Sludge Feeds
Hydrothermal Processing Tests - Equipment

PNNL Bench-scale HTL System

PNNL Bench-scale CHG System

DUAL ISCO SYRINGE PUMPS (3000 PSIA)

FEED TANK

STIRRED TANK REACTOR WITH ELECTRIC HEAT

(350°C) + insert
Vol: 415 ml

HORIZONTAL OIL JACKETED REACTOR (NEW)
0.5 inch 300 ml

OIL JACKETED FILTER (350°C)
1000 ml

LIQUID COLLECTOR BYPASS FOR DIRECT PRESSURE LET DOWN
(alternative to separator vessels)

CONTAINER FOR LIQUID OVERFULL FROM FLOAT TRAPS

SAMPLE WTM

FLOAT TRAP

BACK PRESSURE REGULATOR (20 to 60 °C)

EXHAUST

PNNL Bench-scale CHG System

Band heated Aluminum Block around 12' of 1/2' tubing

Tube in tube HX with building chilled water

DUAL ISCO SYRINGE PUMPS (3000 PSIA)

PRV 3200 psi

Precipitator

PRV 5 psi

BACK PRESSURE REGULATOR ~3000 psi (ambient °C)

EXHAUST

WTM

FLOAT TRAP

PRODUCT
Hydrothermal Processing Tests – Observations

- HTL steady state liquid effluent
- Separated biocrude
- CHG (far left) and liquid effluent samples
- CHG aqueous effluent
- Solids from filter vessel
Test Results - Biocrude

HTL Biocrude Yield (total mass basis)

All yield values are normalized per appropriate mass balance

HTL Carbon Yields

Algae data for comparison from other PNNL studies (Elliott et al., 2013 and Elliott et al., 2014)
# Test Results - Biocrude

## HTL Biocrude Quality

<table>
<thead>
<tr>
<th>Data</th>
<th>Biocrude from Sludge</th>
<th>Biocrude from Algae</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Secondary</td>
</tr>
<tr>
<td>wt% Carbon (dry)</td>
<td>76.5</td>
<td>72.5</td>
</tr>
<tr>
<td>wt% Hydrogen (dry)</td>
<td>10.1</td>
<td>8.7</td>
</tr>
<tr>
<td>H:C molar ratio</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td>wt% Oxygen (dry)</td>
<td>8.1</td>
<td>6.5</td>
</tr>
<tr>
<td>wt% Nitrogen (dry)</td>
<td>4.3</td>
<td>5.1</td>
</tr>
<tr>
<td>wt% Sulfur (dry)</td>
<td>0.63</td>
<td>0.90</td>
</tr>
<tr>
<td>wt% Ash (dry)</td>
<td>0.38</td>
<td>6.3</td>
</tr>
<tr>
<td>wt% Moisture</td>
<td>13.0</td>
<td>1.0</td>
</tr>
<tr>
<td>TAN (mg KOH/g)</td>
<td>65.0</td>
<td>44.8</td>
</tr>
<tr>
<td>Density (g/ml)</td>
<td>1.000</td>
<td>0.985</td>
</tr>
<tr>
<td>Kinematic viscosity (cSt)</td>
<td>571</td>
<td>624</td>
</tr>
<tr>
<td>Heating Value (MJ/kg)</td>
<td>37.8</td>
<td>34.8</td>
</tr>
</tbody>
</table>
Test Results - Methane

CHG Carbon Yields

CHG gas effluent comprised mostly of methane

Yield values are normalized per carbon balance
Test Results - CHG Aqueous Effluent

• Organic Removal

COD (units in ppm)

<table>
<thead>
<tr>
<th>Sludge Feed</th>
<th>HTL Feed</th>
<th>Post-HTL</th>
<th>Pre-IX</th>
<th>Post-IX</th>
<th>Post-CHG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>187,000</td>
<td>41,000</td>
<td>40,800</td>
<td>20,300</td>
<td>54</td>
</tr>
<tr>
<td>Secondary</td>
<td>153,000</td>
<td>73,000</td>
<td>72,300</td>
<td>21,700</td>
<td>25</td>
</tr>
<tr>
<td>Digested Solids</td>
<td>203,000</td>
<td>48,200</td>
<td>49,900</td>
<td>23,700</td>
<td>19</td>
</tr>
</tbody>
</table>

> 99% reduction in COD over HTL-CHG process

• Sulfate / Catalyst Performance

<table>
<thead>
<tr>
<th>Sludge Feed</th>
<th>Total Sulfur (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raney Ni</td>
</tr>
<tr>
<td>Primary</td>
<td>4100</td>
</tr>
<tr>
<td>Secondary</td>
<td>16,000</td>
</tr>
<tr>
<td>Digested Solids</td>
<td>9900</td>
</tr>
</tbody>
</table>

Water Quality

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Regulatory Limit</th>
<th>CHG Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>&lt; 60 ppm</td>
<td>√ (&lt; 26 ppm)</td>
</tr>
<tr>
<td>cBOD</td>
<td>&lt; 15 ppm</td>
<td></td>
</tr>
<tr>
<td>Total N</td>
<td>&lt; 2 ppm</td>
<td>X (&gt; 1100 ppm)</td>
</tr>
<tr>
<td>Total P</td>
<td>&lt; 0.2</td>
<td>√ (&lt; 1 ppm)</td>
</tr>
</tbody>
</table>

Ru Catalyst active at end of each CHG test (52-85 hrs exposure), but total sulfur concentrations on catalyst indicate poisoning per PNNL (> 1000 ppm)

CHG effluent may be capable of meeting regulatory requirements for discharge except for nitrogen
Test Results - CHG Gas

Siloxanes

- Found in biogas; silica formed in combustion is abrasive and insulating
- Analyzed gas effluent for 7 specific siloxanes and 2 precursors by laboratory used by Silicon Valley Clean Water WWTP

<table>
<thead>
<tr>
<th>Feed</th>
<th>Test</th>
<th>Siloxane Conc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>HTL</td>
<td>All &lt; 263 ppb</td>
</tr>
<tr>
<td>Post-Digester</td>
<td>HTL</td>
<td>All &lt; 2886 ppb</td>
</tr>
<tr>
<td>Primary</td>
<td>CHG</td>
<td>All &lt; 22.7 ppb except trimethylsilanol = 43.3 ppb</td>
</tr>
<tr>
<td>Secondary</td>
<td>CHG</td>
<td>All &lt; 43 ppb</td>
</tr>
<tr>
<td>Post-Digester</td>
<td>CHG</td>
<td>All &lt; 40 ppb</td>
</tr>
</tbody>
</table>

- Gas engine fuel specifications:
  - GE Jenbacher - < 3 ppm
  - MWM Caterpillar - < 800 ppb
- All CHG gas siloxane concentrations met engine specs
- Si partitions mostly into aqueous phase effluent
### Test Results - HTL Solids

<table>
<thead>
<tr>
<th></th>
<th>Primary</th>
<th>Secondary</th>
<th>Post-digester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge Feed (g/hr)</td>
<td>1541</td>
<td>1499</td>
<td>1570</td>
</tr>
<tr>
<td>Sludge Ash (wt%)</td>
<td>7.5</td>
<td>16.2</td>
<td>28.0</td>
</tr>
<tr>
<td>HTL Solids (g/hr)</td>
<td>17.4</td>
<td>29.8</td>
<td>88.9</td>
</tr>
<tr>
<td>HTL Solids Ash (wt%)</td>
<td>64.4</td>
<td>64.5</td>
<td>73.3</td>
</tr>
<tr>
<td>HTL Solids Weight Reduction (%)</td>
<td>99</td>
<td>98</td>
<td>94</td>
</tr>
</tbody>
</table>

- Post-digester sludge generated the highest amount of solids and %ash
- HTL process results in high solids reduction relative to sludge feed weight
Key Conclusions and Recommendations

- Biocrude and methane successfully generated from all 3 sludge types.
- No difficulties pumping sludge feeds; potential to process at higher concentrations.
- Biocrude quality comparable to that from other biomass feeds (e.g., algae).
- Had > 99% COD reduction in effluent and 94-99% solids reduction relative to feed.
- Siloxane concentrations in the CHG product gas were below engine limits.
- The CHG aqueous effluent is capable of meeting regulatory limits except total N.
- Sulfur poisoning of CHG catalyst occurred.

The overall results of this proof-of-concept test program are sufficiently promising to justify further investigation of the HTL-CHG technology for application to sludge.

- Determine optimal, representative sludge feed concentrations.
- Perform long-term operation tests on a single, integrated HTL-CHG system at pilot-scale that is representative of the equipment and design that would be installed at a WWTP.
- Perform energy balance, site specific economic analysis, and GHG reduction analysis to verify economic viability for installation/operation of a HTL-CHG system at a WWTP.
Acknowledgments

• Jeff Moeller and WE&RF staff

• Members/Organizations of LIFT Project Subcommittee and Steering Committee

• Metro Vancouver

• Silicon Valley Clean Water

• Pacific Northwest National Laboratory

• U.S. Department of Energy

• U.S. Environmental Protection Agency
Hydrothermal Processing in Wastewater Treatment

Demonstration Project at Metro Vancouver

Paul Kadota

James Oyler
Metro Vancouver’s Interest in HTP

• MV sees HTP pilot project as a way to explore solutions to key issues
  – Rising cost of solids management and increasing distance to end-use sites
  – High cost of installing AD at smaller sites
  – New technology for future system upgrades to improve process and reduce cost
  – A pathway to meet environmental goals for lower emissions and greater energy recovery

• The MV system will process wastewater solids equivalent to a population of app. 30,000 people
MV is 5x Larger Than Previous HTP System
Will Be Located at Annacis Island Plant
MV Will Process Undigested Solids Into Biocrude Oil

Influent → Grit Removal → Settling → Activated Sludge → Effluent Water

Centrate To Headworks

Sludge ~20% Solids

Hydrothermal Processor → Separations → CHG Water to Headworks

3% Solids from AD Side Stream

Biocrude → To Refinery
Benefits of HTP

• Economical compared to Anaerobic Digestion
• Eliminates sludge and related management costs
• Process is complete in 45 minutes; short retention time means small size
• Substantial reduction in greenhouse gas emissions
• Destroys organics such as pesticides, pharmaceuticals, flame retardants, etc.
• Phosphorus can be recovered as by-product
• Biocrude oil can be sold to refinery to produce gasoline, kerosene, and diesel
Conclusions

• Pilot project follows recommendation from LIFT project
• Pilot will provide valuable data and experience with hydrothermal processing
• Successful project can form basis of large scale commercial implementation
• A potentially disruptive technology for the wastewater industry
Thank You!

www.werf.org/lift