Hydrothermal Processing in Wastewater Treatment

James Oyler
President Genifuel Corporation
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jim@genifuel.com
Why Hydrothermal Processing?

• Solids Management is a critical issue in wastewater treatment and a source of significant cost
• Hydrothermal Processing addresses this issue by converting solids to renewable fuels
• Eliminates solids disposal cost and generates significant revenue
• Renewable fuels offset fossil fuels and associated new GHG
Background

- Process developed over 30 years by the US Dept. of Energy at Pacific Northwest National Lab
- Licensed exclusively to Genifuel
  - Both PNNL and Genifuel have contributed patents
- Over 100 feedstocks tested
  - Focus is now on wastewater solids
Technical Concept

- HTP is similar to the formation of fossil fuels, but in minutes rather than millions of years.
- Oil is similar to fossil crude but generally lower viscosity.

*Brontosaurus* by Charles R. Knight, 1897.
Hydrothermal Processing Overview

• Hydrothermal Processing (HTP) uses temperature and pressure to efficiently convert wet organic matter to biocrude oil and methane gas in less than an hour
  – Captures >85% of feedstock energy; uses <14% of fuel energy produced to run the system
  – \( T = 350^\circ C; \ P = 200 \text{ bar (20 MPa)} \)

• Eliminates biosolids and reduces operational costs
  – Significantly reduces GHG emissions vs. alternatives

• Accepts any type of wastewater solids—primary, secondary, both together, or post-digester biosolids
  – Can also co-process food waste and other wastes
Hydrothermal Overview (cont.)

- Unique process step precipitates phosphorus in the form of a dense clay-like solid; 98-99% removal
  - Converts to fertilizer in same way as phosphorus ore
- Effluent water clear and biologically sterile
  - COD <60 mg/L, mostly small acids, e.g. formic, acetic
  - Large molecules destroyed, e.g. pharmaceuticals, estrogens, pesticides, fire retardants, etc.
  - Contains N as ammonia; ongoing R&D to recover
- Systems or products often eligible for incentives
  - Solids management, P capture, valuable products, lower emissions, high efficiency, small size and incentives provide value to the plant owner
An Installed HTP System and Outputs

HTP Oil

Effluent Water
Wastewater Process Flow with Hydrothermal Processing

Pretreatment

- Influent
- Grit Removal

Primary Treatment

- Settling
- Activated Sludge
- Effluent Water

Secondary Treatment

- Mechanical Dewatering
- 3% Solids
- Effluent Water to Headworks or Secondary Irrigation if CHG (Future Ammonia Recovery)

Pretreatment

- Centrate To Headworks

Primary Treatment

- Sludge 15 to 25% Solids
- Separations

Secondary Treatment

- Biocrude
  - Sell Oil
- Precipitate with Phosphorus
- CHG Gas
  - Generate Electricity Or Sell Gas
System is Well-Characterized: Mass Flow Diagram for 1 t/d dry (equivalent) solids*

- **Feed Sludge**
  - 33.3 t slurry
  - 3% solids
  - 10% ash
  - 32.3 t water
  - 1 t dry solids

- **Centrifuge**
  - Water to Headworks
  - 28.3 t water
  - 5 t slurry (4 t water 1 t dry sludge)
  - 20% solids

- **HTL (Oil) Stage**
  - Offgas 17.5 kg mix of CO\(_2\) + H\(_2\)S (<1% H\(_2\)S, or 34 L)
  - To H\(_2\)S sponge
  - 450 kg oil (119 gal)
  - 11.3 kg solids (inc. 98% of phosphorus = 0.63 kg)

- **Solid Precipitate**
  - 11.3 kg solids (inc. 98% of phosphorus = 0.63 kg)

- **Biocrude Oil**
  - Power Supply
  - 460 V 100 A

- **Centrate**
  - To H\(_2\)S sponge

- **Cake**
  - HTL Effluent
  - 4 t water
  - 522 kg residual feed

- **CHG (Gas) Stage**
  - HTL Effluent
  - 4 t water
  - 323 kg ash inc. 44 kg ammonia
  - CHG gas
  - 199 kg gas
  - 153 m\(^3\) gas
  - 65/35 vol. ratio CH\(_4\)/CO\(_2\)
  - 66 kg CH\(_4\)

- **Secondary use or return to plant**

*All units metric unless shown otherwise. Mass unit of t/d = 1000 kg/day
Comparison to Other Technologies

Organic Material

Thermochemical
- Dry
  - Pyrolysis
  - Gasification
  - Incineration
- Wet
  - Hydrothermal

Biological
- Fermentation (e.g., Anaerobic Digestion)

Much Higher Temperatures Than HTP

HTP

Wet Residuals
Comparison to Other Technologies (cont.)

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th>COMPARISON</th>
</tr>
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</table>
| Anaerobic Digestion               | • AD app. 2x footprint of HTP  
• HTP one hour vs. 20-30 days for AD  
• HTP 80% to 120% more fuel energy  
• AD leaves 40-50% of feedstock as biosolids; HTP none |
| Thermal Hydrolysis (e.g. CAMBI)   | • Pre-process for AD, not a conversion process  
• Increases yield and decreases time for AD  
• Increased methane needed for CAMBI, little net gain |
| Incineration                      | • Eliminates solids  
• Limited resource recover—some heat and some ash  
• Expensive to eliminate regulated air emissions |
| Pyrolysis or gasification         | • Very high temperature can create reliability problems  
• Low yield and low quality if pyrolysis oil is produced  
• Produces syngas rather than methane—lower specific energy |
The LIFT Study of HTP by WERF

• The LIFT study produced a 185-pg. third-party report by Leidos, Inc.
• The report was reviewed by utilities and industry experts…

… and recommended installation at a utility

Available free from WERF
Continuing Improvements in HTP

- Pacific Northwest National Laboratory, which ran the LIFT test, ran additional tests with Detroit sludge, and installed major new test equipment
# Results from Wastewater Sludge Tests

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil as % feedstock solids (mass/mass)</td>
<td>35% to 45%</td>
</tr>
<tr>
<td>COD of effluent water after gasification</td>
<td>&lt;60 mg/L</td>
</tr>
<tr>
<td>Feedstock carbon recovered into fuels</td>
<td>85%</td>
</tr>
<tr>
<td>% of output fuel energy needed to run the system</td>
<td>14%</td>
</tr>
<tr>
<td>Siloxane and H₂S levels in CHG gas</td>
<td>Negligible</td>
</tr>
<tr>
<td>Ammonia level in CHG water, before removal</td>
<td>1% to 1.5%</td>
</tr>
<tr>
<td>Complex molecules remaining (pesticide, pharma)</td>
<td>Negligible</td>
</tr>
<tr>
<td>Operating conditions</td>
<td>350°C, 200 bar</td>
</tr>
<tr>
<td>Preferred solids concentration</td>
<td>20% solids in water; range 15 to 25%</td>
</tr>
</tbody>
</table>

* Sludge samples from Metro Vancouver and Detroit
Metro Vancouver’s Interest in HTP

- After working on LIFT, Metro Vancouver saw the HTP pilot project recommendation as a way to gain experience with solutions to key issues
  - Rising cost of solids management and increasing distance to disposal 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
Metro Vancouver’s (MV) Project

- The MV system will process 10 metric t/d of sludge at 20% solids
- Serves satellite site with population of 30,000
- Initially oil only (875 L/d), with gas later
- Commission late 2018

Annacis Island System Site
## Analysis of MV Project—HTP vs. AD

<table>
<thead>
<tr>
<th>MEASURE</th>
<th>VALUE</th>
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</thead>
<tbody>
<tr>
<td>Footprint</td>
<td>HTP is 44% of AD</td>
</tr>
<tr>
<td>GHG Reduction</td>
<td>HTP reduces GHG 3X as much as AD</td>
</tr>
<tr>
<td>20-year NPV* Cost</td>
<td>HTP is 55% of AD Cost</td>
</tr>
</tbody>
</table>

*NPV = Net Present Value
HYPOWERS Is the Next New Project

- HYPOWERS is a two-phase project partly funded by Dept. of Energy for demonstration with wastewater
- Size is planned at 20 metric tons/day, or 60,000 pop.
- Host facility is Central Contra Costa Sanitary District (“Central San”), east of San Francisco

Central San System Site
About Central San

- 145 Sq. Mile Service Area
- >480,000 Population Served
- >1,500 Miles of Sewer
- 19 Pump Stations
- 1 Treatment Plant
- Average Flow: 32 Million Gallons Per Day (MGD)
- Solids: ~200 Wet Tons Per Day
Central San Embarked on a Comprehensive Wastewater Master Plan

- Aging Infrastructure
- Capacity
- Regulatory
- Sustainability
Existing Solids Handling System

- 1980s Waste to Energy
- Furnaces in Good Condition
- Support Equipment & Building Requires Upgrades
- Emissions Controls Improvements Needed
- Regulatory Risks
- Plans to De-couple Waste Heat Recovery System from Secondary Aeration Blowers
Solids Handling Goals

• Continue with Furnaces
  • Near-Term Upgrades
  • Address Vulnerabilities

• Plan for Furnace Replacement (Possibly in Phases)
  • Strive for Net Zero Energy
  • Reduce Greenhouse Gas Emissions
  • Embrace Innovation
Universe of Alternatives

- Incineration
  - MHFs (existing)
  - Fluidized Bed Reactor
- Anaerobic Digestion + SSI
  - MAD + SSI
  - Thermal Hydrolysis + SSI
  - TPAD + SSI
  - Biological hydrolysis + SSI
- Stand Alone Digestion
  - MAD + Drying
  - Thermophilic Anaerobic Digestion
  - AG Anaerobic
- Drying
  - Direct drying
  - Indirect drying
- Composting
- Solids Stabilization Processes
- Alkaline stabilization
- Aerobic Digestion

Explore Innovative Solutions like Hydrothermal Processing & Consider Phasing with P3 Opportunities

Conventional Approach as a Placeholder for Master Planning

Emerging/Embryonic Technologies
- Pyrolysis
- Gasification
- Biofuel production (KORE, etc.)
- Hydrothermal Liquefaction
- Supercritical Water Oxidation
Central San Process Flow with Hydrothermal Processing

1. **Pretreatment**
   - Influent
   - Grit Removal
   - Centrate To Headworks
   - Sludge ~25% Solids
   - Side Stream to HTP
   - Hydrothermal Processor

2. **Primary Treatment**
   - Setting
   - Centrifuges
   - 3% Solids
   - DAF
   - Centrate
   - Effluent Water

3. **Secondary Treatment**
   - Activated Sludge
   - CHG Water to Headworks or Secondary Irrigation
   - Biocrude
   - CHG Gas
   - Generate Electricity or Sell Oil and Gas
   - Ammonia (TBD)
   - Phosphate
   - Incinerator Furnace
The HYPOWERS Team
Equipment Installation for HTP

- **HTP system is skid-mount and factory-built**
  - Shipped to site by truck
  - May be containerized for sea shipment
- **Site installation requires pad, utilities (electricity, water, drain), and cover (roof or building)**
- **Need supply of sludge or biosolids**
  - Sludge can be delivered by pipe, biosolids likely not
  - Sludge will need to be dewatered to 20% (range 15-25%)
- **Need disposition of effluent water and storage tank for oil (weekly pickup)**
- **Odor control simple because very small amounts**
Conclusion

• Only hydrothermal process with both liquefaction and gasification in same system
• Optimized process produces high quality outputs
  – Oil—no char, low oxygen
  – Gas—H₂S and siloxanes below detection limit
  – Water—no organisms or pharmaceuticals
• Unique process step automatically captures phosphorus for direct conversion to fertilizer
• Successful scale-up now at small commercial size
• More than $50 million invested in R&D by both government and private parties
• All IP owned or licensed exclusively to Genifuel
Hydrothermal Processing in Wastewater Treatment

Thank you!
Additional Slides
James Oyler, President—Brief CV

- Built and managed energy practice for Booz, Allen & Hamilton, worldwide consultants (1972-1976)
- Sector President for Harris Corporation, a Fortune 500 Company (1976-1993)
- President and CEO for E&S, a NASDAQ technology company sold to Rockwell Collins (1994-2006)
- 24 issued or pending patents
Conclusion

• Successful testing with wastewater solids has created significant learning for equipment design, expected performance, and cost reduction

• Critical next step is to demonstrate continuous 24/7 operation at operating wastewater utility
  – Current longest operation is app. three months
  – Planned projects at MV and Central San
  – Sharing of data and results with wastewater industry

• Will need new investment for operations

• Would like utility partner in UK/Europe for demonstration plant
System is Well-Characterized: Energy Flow Sankey for 100 kg/d dry solids

Energy Flow Diagram for HTP of 100 kg of Dry Sludge Solids

- Electrical Power: 4,458 MJ = 1,238 kWh for initial heatup (startup)
- Electrical Power: 242 MJ = 67.2 kWh for normal operation
- Heat Loss: 210 MJ
- Electricity: 160 MJ = 44.4 kWh

Note: If HTP is configured for gas only, electricity is 1,339 MJ = 372 kWh

- Methane: 400 MJ
- Heat Loss: 80 MJ
- Biocrude Oil Output: 1,330 MJ
- Effluent Water with Ammonia: 104 MJ
- Phosphorus: 16 MJ
- Centrate Water: Return to Headworks 2,833 L
- Dewatered Sludge: 20% solids, 100 kg solids, 400 L water, 2,060 MJ
- 3,333 kg Sludge

Centrifuge

Hydrothermal Unit with both HTL (oil) and CHG (gas) conversion

CHP

Usable heat: 160 MJ

To Refinery
Solubility of Calcium Sulfate and Calcium Phosphate in Water