Sludge to oil: applying hydrothermal liquefaction in the wastewater treatment plant

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About Algae Systems

- **2009**
  - Company founded based on NASA OMEGA technology

- **2010**
  - Angel Financing
  - Green Fuels acquisition

- **2011**
  - Series A financing

- **2012**
  - R&D begins at SRI in Menlo Park

- **2013**
  - Pilot plant construction in Daphne, AL

- **2014**
  - Pilot plant commissioned
  - DOE grant awarded

- **2015**
  - Pilot plant operations
  - Scale-up engineering
Parallel development of two complimentary technologies:

- Algae wastewater treatment
- Hydrothermal liquefaction
Algae wastewater treatment

- Algae aerate wastewater and take up nutrients
- 92% NH3-N removal, 98% TP removal, 93% BOD removal with no mechanical mixing or aeration
- Offshore process limits land use impact
- Rapid production of high-quality biomass
- Fuel conversion via hydrothermal liquefaction
Hydrothermal Liquefaction (HTL)

(+) Works well for water-rich organic feedstocks (10-20% solids)
(+) Oil production from protein and carbohydrate fraction
(+) Sterilizes and concentrates solids to Class A standards
(+ ) Produces valuable liquid fuel, upgradable to diesel or other fuels
(+ ) Positive EROEI
Flexible feedstocks

HTL is a “feedstock agnostic” process: can handle any organic slurry

- **Lagoon Algae**
  - Readily available as concentrate
  - HTL of macroalgae also possible

- **Fats oils and grease**
  - Major liability in municipal treatment
  - High energy value

- **Agricultural waste**
  - Numerous waste feedstocks available
  - Dairies, slaughterhouses, canneries

- **Wastewater solids**
  - >8M tons/year produced
  - High energy content, high disposal cost
Process notes:
- Biocrude burned on-site or hydrotreated to finished fuel
- Potential to receive additional waste slurries
- Organic-rich aqueous phase sent to anaerobic digester
HTL of waste activated sludge

Reaction conditions:
- Waste activated sludge filtered to remove large debris
- Batch reactions
- Reaction at 1250psi and 300°C for 10 minutes

Results:
- Mass conversion independent of reaction time (10-90 minutes)
- 74% destruction of total solids
- >90% destruction of volatile solids
- 10% conversion of incoming solids to biocrude
- 21% of chemical energy converted to liquid fuel
HTL of FOGs

Reaction conditions:
- Homogenized fats, oils, and greases from interceptor
- Homogenized sample
- Reaction at 1250psi and 300°C for 10 minutes

Results:
- Production of biocrude and recovery of brown grease
- 33% solids destruction
HTL of waste activated sludge and FOGs

Reaction conditions:
- Combination of waste activated sludge and FOG
- Mass ratio of 10:1 WAS to FOG
- Reaction at 1250psi and 300°C for 10 minutes

Results:
- 79% total solids destruction
- >90% volatile solids destruction
- Addition of FOGS increases biocrude yield
## HTL aqueous phase

Aqueous phase composition, projected for 10% solids feedstock

<table>
<thead>
<tr>
<th>Product</th>
<th>Biosolids (mg/L)</th>
<th>FOGs (mg/L)</th>
<th>BS &amp; FOGs (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>59700</td>
<td>33750</td>
<td>61250</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>9750</td>
<td>1960</td>
<td>7031</td>
</tr>
<tr>
<td>NH3-N</td>
<td>3690</td>
<td>890</td>
<td>2990</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>2010</td>
<td>170</td>
<td>690</td>
</tr>
</tbody>
</table>

### Carbon partitioning in HTL aqueous (results from Tommaso et al. 2014)

- 84% of carbon accessible to anaerobic digestion
- 0.256 grams methane produced per gram incoming VSS
- Long term anaerobic digestion study initiated in Daphne

![Land application studies initiated in Daphne](image)
Energy balance

- EROEI heavily dependent on heat recovery and solids concentration
- Positive energy balance is possible even with low oil yield
- Process heat supplied via co-generation
Process comparison

Key assumptions:
- 38% VSS destruction for AD, 60% with thermal hydrolysis (from www.cambi.no)
- 65% biogas methane content
- 5.2kWh/kg for biosolids
- 0.256g methane/g VSS in HTL aqueous phase (from Tommaso et al. 2014)
HTL at Any Scale

Initial testing:
0.001 gallons/day
Batch system

Bench scale:
0.06 tons/day
30 gallons/day
Continuous flow

Commercial demo:
6 tons/day
3000 gallons/day
Continuous flow

Reproducible results at each scale
Next steps

Lab and bench scale
- Optimize process conditions
- Analyze products (fuel, water, solids)
- Anaerobic digestion studies

Commercial demo scale
- Materials handling and sludge pre-processing
- Confirm scale-up and mechanical reliability
- Land application studies

Pilot testing
- On-site testing
- Verify long-term reliability
- Analyze treatment plant integration
Conclusions

Biosolids HTL advantages

- Over 95% VSS destruction
- Projected to recover 79% of incoming chemical energy in usable forms
- Short residence time, small footprint
- Co-processing of FOGs and other waste streams
- Produces valuable liquid fuels
- Sterile and dry class A solids

Currently seeking partners for pilot testing (contact info@algaesystems.com)