Catalytic Hydrothermal Gasification (CHG) is a proven process which efficiently converts wet organic matter into methane/carbon dioxide in a single step—essentially “catalytic thermo-chemical digestion” with much higher yields than anaerobic digestion.

CHG AND NAABB

- Feedstock is organic material made into slurry
  - Most algae make ideal feedstocks—easy to prepare and easy to gasify
  - Can gasify whole algae or algae biomass after lipids are extracted (Lipid-Extracted Algae or LEA)
- Reactions are fast (< 1 hour) and complete (>99%)
  - Can gasify either whole algae or algae biomass after lipids are extracted (Lipid-Extracted Algae or LEA)
  - Most algae make ideal feedstocks—easy to prepare and easy to process over 30-year period at PNNL.

CONTRIBUTION OF CHG AND NAABB

- Process developed over 30-year period at PNNL
- Reactions are fast (< 1 hour) and complete (>99%)
  - Can gasify either whole algae or algae biomass after lipids are extracted (Lipid-Extracted Algae or LEA)
  - Most algae make ideal feedstocks—easy to prepare and easy to process over 30-year period at PNNL.

CLOSED-LOOP NUTRIENT CYCLE

- A key advantage of CHG is nutrient recycle
  - Nutrients are recovered from the algae biomass and can be recycled to the growth ponds (or PBR)
    - Nitrogen, phosphorus*, potassium (NPK), and micro-nutrients (iron, copper, zinc, etc.) are recovered
  - Carbon dioxide can also be recycled
    - Sterile output water is saturated with CO₂
    - Recovered CO₂ can also be sparged into growth ponds
- Energy in the methane produced from gasification of LEA equals the energy in the algal lipids assuming 25% lipid content, 75% LEA biomass
  - Assuming the methane is immediately used to make electricity, then under reasonable price assumptions the methane will increase the total algal fuel value by 60%

OUTPUT VALUES FOR 1 T/D DRY WEIGHT ALGAE*

<table>
<thead>
<tr>
<th>ITEM</th>
<th>QUANTITY/DAY</th>
<th>PRICE/UNIT</th>
<th>ANNUAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>1,600 kWh/d</td>
<td>$0.12/kWh</td>
<td>$192,000</td>
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<tr>
<td>CO₂</td>
<td>0.81 t/d</td>
<td>$19/t</td>
<td>$1,536</td>
</tr>
<tr>
<td>Nitrogen (NH₃)</td>
<td>16 t/y</td>
<td>$231/t</td>
<td>$3,698</td>
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<tr>
<td>Potash</td>
<td>9 t/y</td>
<td>$875/t</td>
<td>$8,109</td>
</tr>
<tr>
<td>Process Heat</td>
<td>7.2 MMBtu/d</td>
<td>$6.00</td>
<td>$43,645</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>$55,587</td>
</tr>
</tbody>
</table>

*Note: No value assigned to phosphorus because processing cost to recover fertilizer not yet known.

ANNUAL TOTAL OF OPEX AND CAPEX: $55,587

ANNUAL PROFIT/TON/DAY DRY ALGAE LEA: $43,645

*Note: No cost assigned to algae LEA feedstock; unit size 10,000 m³/d net methane output.

CONTRIBUTION OF CHG TO ALGAE BIOFUELS

- Energy in the methane produced from gasification of LEA equals the energy in the algal lipids assuming 25% lipid content, 75% LEA biomass
  - Assuming the methane is immediately used to make electricity, then under reasonable price assumptions the methane will increase the total algal fuel value by 60%

CONTINUOUS-FLOW PROCESSING RESULTS: ALGAE - SPIRULINA

Product Gas Composition on nitrogen-free basis

- COD reduced from 241,300 ppm (22.4 wt% DS) by 96.6%
- 8.3% ash
- 20.6 MPa, 1.4 LHSV @ 350°C, S scrub with Ru/C catalyst
- 1.2 L of a medium-Btu gas per gram carbon in aqueous phase
- 4.3% carbon loss with mineral

CHG POTENTIAL OUTPUT IN PERSPECTIVE

- If algae produced 10% of the US requirement for liquid transport fuels, production would be app. 20 billion gallons of algal lipids per year
- The algal biomass left after lipid extraction would be 207 million t/y dry weight
- This amount of algal biomass could produce 9% of the US production of electricity
  - Equivalent to more than 6× the amount of electricity from wind and solar combined (2009)
  - High-value electricity available any time

LABORATORY CHG SYSTEMS

- Mobile Unit
- Skid-Mount System

ACKNOWLEDGEMENTS

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Douglas C. Elliott and James R. Oyler