Novel Algae Technology to Utilize CO₂ for Value Added Products

DE-FE0031710

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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 15 - 19, 2022
Project Overview

• Project Partners:
  • University at Buffalo
  • Linde, Inc
  • Northwestern University
  • Membrane Technology & Research
  • National Carbon Capture Center

• DOE Federal Project Manager: Naomi O’Neil

• Project Funding:
  • Total: $1,734,486    Government: $1,387,588    Cost Share: $346,898

• Project Period: 5/1/19 – 7/31/23
Overall Project Objectives

• Design, build and operate a first-of-a-kind integrated MSC system
• Achieve high performance in outdoors operation
• Conduct NCCC field test on real flue gas
• Develop algae technology for high value products
• Improve dewatering technology
• Perform LCA and TEA
• Achieve projected net CO$_2$ capture cost at commercial scale of <$30$/ton
Commercial Schematic of Technology

Coal Power Plant

Post FGD flue gas

Algae MSC Process for CO2 capture

Sunlight ~1% CO2

Dewatering

Algae Slurry

HTL + Upgrading

Bio-fuels

Residue

Make-up water & nutrients

Waste water nutrients

Water + Nutrient Recycle

Algae for nutraceuticals

Dewatering

Commercial Extraction

Nutraceuticals

Algae for Animal feed

Dewatering

Feed Blending

Feed Products

Dewatering
Technical Approach/Project Scope

• Capture Technology
  • Novel algae technology converts CO₂ to biomass
  • Capture technology has evolved significantly over the years
  • Stable operation on simulated flue gas with contaminants validated
  • Final test on coal utility flue gas

• DeAqua
  • Stage 1 dewatering
  • Stage 2 dewatering

• High-value Products to Offset Cost of Capture
• LCA and TEA
Technology Background - MSC

• Multi-stage process
• Top lit closed system
• Stable operation
• Predictable, controllable operation
• High productivity & capture efficiency
• Efficient upstream/downstream integration
• Can be tailored to application
  • e.g. Natural gas power plants

Integrated MSC test unit in greenhouse
MSC Evolution

- Needs to operate in natural sunlight
  - Initially validated in non-integrated lab tests - fixed light
  - Integrated system tested in greenhouse - sunlight
  - Integrated operation validated in outdoors tests - sunlight
- Ability of algae to grow in flue gas with high CO₂, acid gases and heavy metals validated
- MSC reactor and system design has evolved significantly leading to better performance

<table>
<thead>
<tr>
<th>MSC Type</th>
<th>Location</th>
<th>Feed Gas</th>
<th>Overall Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CO2</td>
<td>Contaminants</td>
</tr>
<tr>
<td>E</td>
<td>Lab</td>
<td>12%</td>
<td>N/A</td>
</tr>
<tr>
<td>R</td>
<td>Lab</td>
<td>12%</td>
<td>N/A</td>
</tr>
<tr>
<td>H</td>
<td>GH</td>
<td>12%</td>
<td>SOX/NOX + 5HM</td>
</tr>
<tr>
<td>C</td>
<td>GH</td>
<td>12%</td>
<td>SOX/NOX + 5HM</td>
</tr>
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DeAqua (Dewatering) and Products

- Products represent CO₂ utilization
- Several products possible with a range of market sizes/prices
  - Biofuels
  - Animal feed
  - Nutraceuticals

- Dewatering is a key, enabling technology
- Must be low energy
- As water is removed, rheology changes
- Extent of dewatering dictated by needs of downstream product
Project Progress - MSC

- Integrated 3-stage MSC built - 2\textsuperscript{nd} Gen unit
- Advanced controls enable unattended operation
- Stable GH operation 100+ days
- Various process options mapped
- Outdoors test achieved project targets
- Field test underway at NCCC

<table>
<thead>
<tr>
<th>MSC Type</th>
<th>Location</th>
<th>Sim. Flue Gas Contaminant</th>
<th>Nutr-WW Replacement</th>
<th>Normalized Algae Prod</th>
<th>Avg CO2 Capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>GH-1 Indoor</td>
<td>SOX/NOX + 5HM</td>
<td>50%</td>
<td>92%</td>
<td>59%</td>
</tr>
<tr>
<td>C</td>
<td>Outdoor</td>
<td>N/A</td>
<td>N/A</td>
<td>139%</td>
<td>81%</td>
</tr>
<tr>
<td>C</td>
<td>Outdoor</td>
<td>SOX/NOX + 5HM</td>
<td>80%</td>
<td>141%</td>
<td>76%</td>
</tr>
<tr>
<td>G</td>
<td>Outdoor</td>
<td>N/A</td>
<td>N/A</td>
<td>142%</td>
<td>77%</td>
</tr>
<tr>
<td>FE-0031710 Target</td>
<td>NCCC SSTU Flue Gas</td>
<td>N/A</td>
<td>100%</td>
<td>80%</td>
<td></td>
</tr>
</tbody>
</table>

Integrated MSC in outdoors operation
Project Progress – NCCC Field Test

• Field test underway at NCCC
• Inoculum system setup at indoor laboratory
• Bench-scale site to demonstrate performance on actual utility flue gas
• Flue gas from mixture of natural gas and coal-fired operations, post FGD
• Acid gas levels much below Helios in-house tests
**Project Progress – Stage 1 DeAqua**

<table>
<thead>
<tr>
<th>Project</th>
<th>Conc Ratio</th>
<th>Performance Index</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior work</td>
<td>3-6</td>
<td>0.12-0.37</td>
<td>70%</td>
</tr>
<tr>
<td>Initial Project Target</td>
<td>3-6</td>
<td>1.5</td>
<td>80%</td>
</tr>
<tr>
<td>Current work</td>
<td>20-25</td>
<td>5.0-12.5</td>
<td>80-95%</td>
</tr>
</tbody>
</table>

Conc Ratio = Product Algae Conc

Feed Algae Conc

Perf Index = \( \frac{\text{Conc Ratio}}{\text{Time}} \)

Significant progress in Stage 1 through culture modification:
- Now removes >90% water vs ~70% in prior projects
- Goal of 4X improvement in Perf Index greatly exceeded
- Validated water re-use from dewatering step
Stage 2 DeAqua – Membrane Progress

• Membrane is energy-efficient
• But fouling is a critical challenge

Advantages:
• Surface modification reduces fouling
• Simple process at 23°C, aqueous solutions
• Covalent bonds to achieve long-term stability
• Post-modification of commercial modules possible
Project Progress - DeAqua Membrane

- Surface modification decreases pure water permeance
- But improves the performance in algae dewatering

Setup of M20 Plate and Frame Module

- Membranes being tested in prototype module
Nutraceutical Products From Algae (H-1601)

Increased product from pre-treatment
M = Molecular Weight Markers
1 = extract w/o pretreatment
2 = extract w/ pretreatment

Left Panel – cells separated from media
Middle Panel – product recovered from media
Right Panel – high value product from cell extract
Nutraceutical Progress Summary

Improvements

• Developed two phase extraction for recovery of increased number of products
• Developed pretreatment for enhanced yield
• Species grown on MSC slipstream to decrease flue gas contaminants

**H-0326**

• Analyzed time course of required induction
• Three high value products verified

**H-1601**

• Requires no induction
• Product A - Food & pharma applications (No cell extraction required, recovered from media)
• Product B - High value lipids (extract phase 2)
• Product C - Potential for food coloring, pharma applications (extract phase 1)
TEA - Linde Commercial CO₂ Technology

- Evaluate technologies for flue gas injection into algae based on effectiveness and cost
- Linde reviewed portfolio/other SOA systems and proposed an optimal solution
- Based on the optimal recommendation, Linde will evaluate costs of the gas injection system and assist in TEA

<table>
<thead>
<tr>
<th>Linde technology</th>
<th>Highlights</th>
<th>CO₂ Flowrate Range (kg/hr)</th>
<th>Product Image</th>
</tr>
</thead>
</table>
| SOLVOCARB® mobile | - Minimum power consumption  
                   - Ease of maintenance  
                   - Low CAPEX and OPEX | 15-45          | ![Product Image](image1) |
| SOLVOCARB® venturi | - Easily retrofitted to existing hydraulic systems  
                      - Ensures consistent performance while requiring low maintenance | 10-400         | ![Product Image](image2) |
| SOLVOCARB® diffusion hoses (most cost-effective, practical option for pilot testing) | - Very low maintenance  
                                  - Fast and easy installation  
                                  - Ideal for temporary and long-term use | 20-60 (per 40 m of hose) | ![Product Image](image3) |
| SOLVOCARB® reactor | - Most versatile product, working in a full range of temperatures, flowrates, and pressures  
                       - Suited for inline or sidestream use | 30-2,000       | ![Product Image](image4) |
| SOLVOCARB® in-line reactor | - Eliminates need for static mixer in most cases due to high solubility and reaction rates of pressurized CO₂ | 10-50          | ![Product Image](image5) |
Summary

• Outdoors MSC tests achieved project targets 25 g/m²/d and 80% capture

• Dewatering technology has potential to dewater to varying degrees depending on product requirements

• Utilization of algae for products generates revenue and significantly offset the cost of capture
Plans for future development

Advance MSC CO₂ Capture:
• Implement dynamic process control
• Develop in-ground system - the building block for commercial application
• Integrate MSC with dewatering and operate with high recycle rate
• Utilize municipal WW for purchased nutrient reduction & remediation credits

Advance Utilization:
• Biofuels: Optimize process & test product
• Animal Feed: Develop/test feed applications
• Nutraceuticals: Advance extraction & purification; define products
Acknowledgement

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