“Novel Algae Technology to Utilize CO$_2$ for Value Added Products”
DE-FE0031710

PI: Frederick Harrington, PhD
Helios-NRG, LLC

August 30, 2021
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 – 7/31/22
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 2 high value products
• Improve dewatering technology
• Perform LCA and TEA
• Achieve projected net CO2 capture cost at commercial scale of <$30/ton
Commercial Schematic of Technology

Coal Power Plant

Post FGD flue gas

Sunlight

~1% CO2

Algae MSC Process for CO2 capture

Dewatering

Algae Slurry

HTL + Upgrading

Bio-fuels

Residue

Waste water

nutrients

Make-up water
& nutrients

Water + Nutrient
Recycle

Water

Algae for nutraceuticals

Dewatering

Commercial Extraction

Nutraceuticals

Algae for Animal feed

Dewatering

Feed Blending

Feed Products
## Technical Approach/Project Scope

<table>
<thead>
<tr>
<th>Project Area</th>
<th>Detail</th>
<th>Completed</th>
<th>To Be Done</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capture Technology</strong></td>
<td>Gas Type: Sim Flue gas; Actual Flue gas</td>
<td>Sim Flue gas</td>
<td>Real flue gas at NCCC</td>
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<tr>
<td></td>
<td>Algae strain</td>
<td>H-1903 Selected</td>
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<tr>
<td></td>
<td>Capture System: Algae MSC</td>
<td>Designed, Built &amp; tested in GH</td>
<td>Test Outdoors &amp; at NCCC</td>
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<tr>
<td></td>
<td>Target 25 g/m2/d and 80% capture</td>
<td>Met in GH</td>
<td>Validate outdoors</td>
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<tr>
<td><strong>Dewatering</strong></td>
<td>Stage 1: Adv Gravity Table</td>
<td>50% reduction in energy on 2 species</td>
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<td></td>
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<td>Target perf exceeded</td>
<td></td>
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<td></td>
<td></td>
<td>Use of recycle water in growing validated</td>
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<td></td>
<td>Stage 2: Dewatering membrane</td>
<td>Surface modified membrane developed</td>
<td>Complete regen process</td>
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<tr>
<td></td>
<td></td>
<td>Lab module built &amp; tested</td>
<td>Build &amp; test larger module</td>
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<tr>
<td><strong>Products</strong></td>
<td>Algae type</td>
<td>Strains H-0326 &amp; H-1601 selected</td>
<td>Enhance culturing</td>
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<tr>
<td></td>
<td>Components</td>
<td>Multiple components identified</td>
<td>Increase product levels</td>
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<tr>
<td></td>
<td>Separation</td>
<td>New extraction process conceived</td>
<td>Improve recovery</td>
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</tbody>
</table>
Technology Background - MSC

- Multi-stage continuous process
- Top lit closed system
- Stable algae concentrations
- High productivity & capture efficiency
- Predictable, controllable operation
- Can be tailored to application
  - e.g. Natural gas power plants

Integrated MSC test unit in greenhouse
MSC Evolution

- Needs to operate in variable sunlight
  - Initial lab development in constant light
  - Next moved to GH - sunlight
  - Highest light intensity is outdoors (future)

- Algae must survive and grow in flue gas with high CO2, acid gases and heavy metals

- PBR design varied over time used to improve productivity and capture efficiency

### Evolution in MSC Development

<table>
<thead>
<tr>
<th>Tank Type</th>
<th>Light Facility</th>
<th>Intensity Avg (Lux)</th>
<th>Feed Gas</th>
<th>Post FGD Cont</th>
<th># of Stages</th>
<th>Overall Performance</th>
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</thead>
<tbody>
<tr>
<td>E</td>
<td>Lab</td>
<td>~9,000</td>
<td>CO2</td>
<td>N/A</td>
<td>3</td>
<td>14.1 54%</td>
</tr>
<tr>
<td>R</td>
<td>Lab</td>
<td>~9,000</td>
<td>CO2</td>
<td>N/A</td>
<td>3</td>
<td>19.9 80%</td>
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<tr>
<td>H</td>
<td>GH</td>
<td>~11,000</td>
<td>CO2</td>
<td>SOX/NOX + HM</td>
<td>3</td>
<td>21.2 73%</td>
</tr>
<tr>
<td>C</td>
<td>GH</td>
<td>~14,500</td>
<td>CO2</td>
<td>SOX/NOX + HM</td>
<td>2</td>
<td>30.8 74%</td>
</tr>
</tbody>
</table>
**Project Progress - MSC**

- Integrated 3-stage MSC fabricated with improved closed raceway design
- Advanced control system enables unattended operation
- Stable GH operation 60+ days
- Various process options mapped
- Performance validated in sunlight
- Transitioning from GH to outdoors
- Components enclosed for outdoors
- Readying system for transport to NCCC

**Integrated Raceway-MSC at Greenhouse**

Species: H-1903; Tank Design: G; Gas: 12% CO2 (simulated flue)
Dewatering and Products

- 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

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

Diagram showing the process of dewatering from Algae Culture to Algae Solid with stages 1, 2, and 3, and water recovery rates.
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
Dewatering Membrane Rationale and Approach

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

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

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

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<th>Cleaning solution</th>
<th>Solution permeance (LMH/bar)</th>
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<tr>
<td></td>
<td>Water</td>
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<tr>
<td>Pure Water</td>
<td>1268</td>
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<tr>
<td>HCl pH~3</td>
<td>1282</td>
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<tr>
<td>NaOH pH~11</td>
<td>1203</td>
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<tr>
<td>0.04% NaClO</td>
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Project Progress - Nutraceuticals

**Algae Strain: H-0326**
- Requires induction
- Products similar to those found in prior work

**Algae Strain: H-1601**
- Requires no induction
- **Product A** - Food & pharma applications
- **Product B** - High value lipids
- **Product C** - Potential for food coloring & pharma applications
Project Progress – Nutraceuticals
2 phase product extraction

- Enables recovery of added products

- Step 1: extract soluble material in fraction S

- Step 2: Insoluble fraction P used for second extraction
Plans for future development

MSC CO₂ Capture:

- Implement dynamic process control
- Develop in-ground system that will be the building block for commercial application
- Integrate MSC with dewatering and operate with high recycle rate
- Utilize municipal WW for purchased nutrient reduction & significant remediation credits

Utilization:

- **Biofuels:** Optimize HTL process for higher efficiency & reduced costs
- **Animal Feed:** Develop feed applications
- **Nutraceuticals:** Utilize commercial extraction, advance purification & define products
Summary

• First of a kind integrated MSC system designed, built and tested
  – Stable long term operation achieved
  – Capture efficiency and productivity targets met in GH/outdoors operations

• Good progress in de-watering technology
  – Stage 1 targets exceeded
  – Dewatering membrane lab module fabricated

• Nutraceutical production from new strains looks promising
  – Multiple compounds identified
  – Advanced extraction process conceived

• System being readied for NCCC field test
Acknowledgement

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# Gantt Chart

## DOE Award Number DE-SC0031710

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Organization: Helios-NRG, LLC