Improving the cost-effectiveness of algal CO2 utilization by synergistic integration with power plant and wastewater treatment operations

Department of Energy Cooperative Agreement No: DE-FE0032098

National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 15 - 19, 2022
Project Overview

- **DOE Funding Program DE-FOA-0002403: Engineering-Scale Testing & Validation of Algae-Based Technologies & Bioproducts (AOI 1)**
  - Upscaling & integrating unit processes for algal carbon capture & utilization

- **End of Project Objectives & Goals:**
  - **BP1 Goal** (Oct 2021 - Mar 2023) 180 m² cultivation system installed and achieves at least 10 g/m²/d productivity with coal flue gas CO₂
  - **BP2 Goal** (April 2023 – Sept 2024) Cultivation system has an average productivity of 14.3 g/m²/d with coal flue gas CO₂
  - **End Goal:** TEA with key performance parameters supporting a required selling price below market value of protein conc. w/ a $0 CO₂ capture credit

<table>
<thead>
<tr>
<th>Budget Period</th>
<th>Work</th>
<th>Start</th>
<th>End</th>
<th>Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Design, Construction and Startup</td>
<td>10/1/2021</td>
<td>3/31/2023</td>
<td>$1,897,532</td>
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<tr>
<td>II</td>
<td>Testing and Optimization</td>
<td>4/1/2023</td>
<td>9/30/2024</td>
<td>$601,564</td>
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</tbody>
</table>
Project Overview - Participants

PI: Dr. Lance Schideman  
Illinois Sustainable Tech. Center  
Prairie Research Institute  
University of Illinois  
Project management and integration of wastewater nutrients.

Global Algae Innovations:  
Design and construction of algae cultivation system

City Water Light and Power:  
Host Site
Technology Background - Block Flow Diagram

- Flue Gas (Post Emission Control)
  - CO₂ absorption via carbonation vessel
  - Cultivation
  - Harvesting
  - Algae dewatering

- Algal Biomass

- Municipal wastewater with organics removed [contains N, P, and metals]
  - Polished Wastewater
  - Discharge
Technology Background

GAI's 8-wet acre Kauai Algae Farm - CO$_2$ from a naptha-fueled power plant
Technology Background- CO₂ Capture Process Integration with Algae Cultivation

Previous CO₂ Absorber Column by GAI
Technical Approach

Project Strategy: Combine Key Advantages from Previous Projects

- Top Tier Algae Cultivation System from GAI
- First Demonstration with GAI System Using Coal Flue Gas
- Improvement of Economics with Use of Wastewater Nutrient Inputs and Higher Value Co-Products
## Technical Approach

<table>
<thead>
<tr>
<th>Task / Subtask</th>
<th>Milestones</th>
</tr>
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<tbody>
<tr>
<td>1/1.1</td>
<td>Submit Updated Project Management Plan (PMP)</td>
</tr>
<tr>
<td>1/1.2</td>
<td>Submit Initial Technology Maturation Plan (TMP)</td>
</tr>
<tr>
<td>2</td>
<td>Cultivation system installed &amp; operational achieving &gt; 10 g/m²/d productivity with coal flue gas CO₂</td>
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<tr>
<td>3</td>
<td>Absorber system installed and operational and achieves at least 75% carbon capture efficiency</td>
</tr>
<tr>
<td>4</td>
<td>Harvesting and drying system installed and operational and produces algae powder with less than 10% moisture content</td>
</tr>
<tr>
<td>5</td>
<td>Algae protein meal with at least 50% protein</td>
</tr>
<tr>
<td>6</td>
<td>Demonstrate ability to replace at least 50% of nutrients in algal inoculation cultures</td>
</tr>
<tr>
<td>7</td>
<td>Interim TEA and LCA confirming costs for baseline performance</td>
</tr>
<tr>
<td>8</td>
<td>Integrated system has average CO₂ capture efficiency of &gt;80%,</td>
</tr>
<tr>
<td>8</td>
<td>Cultivation system has an average productivity of 14.3 g/m²d with coal flue gas CO₂</td>
</tr>
<tr>
<td>9</td>
<td>Demonstrate ability to use power plant waste heat to extend algae growing season and increase cold weather productivity</td>
</tr>
<tr>
<td>10</td>
<td>Determine projected value of algal biomass based on live chicken digestion tests</td>
</tr>
<tr>
<td>11</td>
<td>Final TEA incorporating averages of key performance parameters projects a required selling price that is less than the market price of the protein concentrates at a scale of 5000-acres with $0 credit for CO₂ capture and mitigation</td>
</tr>
<tr>
<td>12</td>
<td>Final LCA incorporating averages of key performance parameters projects at least a 50% reduction in GHG for the target products</td>
</tr>
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</table>

**Completed Milestones shaded in light blue**
Project Overview

Site plan at CWLP host site for this Algae project and other related projects
Project Achievements

- Algae Production System Design Substantially Complete
  - Zero Discharge Design
- Procurement of Major Equipment Complete
- Delivery Ongoing
- Construction Contractors Scheduled
- Algae pilot raceway pond area totaling in 180 m²
Project Achievements - Construction Mobilization & Algae Production Equipment Procurement/Delivery

Absorber Stand

Zobi Harvester®

Tanks for Algae Propagation & Nutrient Media Supply
Project Achievements

Demonstrated good growth of target strain of *Spirulina* with 50% of nutrients provided from a municipal wastewater source

- Working to acclimate cultures to higher proportion of wastewater
Animal Feed Product Testing

Animal Feed Rationale
- Large Market Economic Demand: Scales with CO$_2$ capture
- Global Animal Feed Market > 800 Million Tons/yr

University of Illinois - Department Animal Sciences
- Conducting feed characterization
- In-vitro and live animal feed testing- Poultry and Cattle
- Estimation of animal feed market value

Industrial Advisory Board Feedback
- Representatives from animal feed industry

Animal Feed Testing and Regulatory Collaboration
High-Value Spirulina Algal Product: C-PhycoCyanin (C-PC)

- C-PC value depends on purity (A620/A280)
  - Value ranges from $300/kg to >$100,000/kg
  - Grade 1: 0.50-1.50 (Food level) (Used as a Dye);
  - Grade 2: 1.50-2.50 (Cosmetic level) (Used as a Dye);
  - Grade 3: 2.50-3.50 (Reagent level) (Used as Dye and Biomarker);
  - Grade 4: Above 4.00 (Analytical level) (Medical Applications)
- Extraction & purification methods need optimization
  (Guan S.C., 2016)

<table>
<thead>
<tr>
<th>Extraction method</th>
<th>C-PC extraction yield (mg/g)</th>
<th>C-PC purity (A620/A280)</th>
<th>Residue yield (%)</th>
<th>Time (h)</th>
<th>Energy Input</th>
<th>Cost ($/L)</th>
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<tbody>
<tr>
<td>Freeze-thaw</td>
<td>65.8</td>
<td>0.475</td>
<td>63.2</td>
<td>5</td>
<td>Medium</td>
<td>2.8</td>
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<tr>
<td>Shear</td>
<td>54.5</td>
<td>0.415</td>
<td>48.7</td>
<td>0.3</td>
<td>Medium</td>
<td>0.3</td>
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<tr>
<td>Lysozyme</td>
<td>67.6</td>
<td>0.361</td>
<td>62.6</td>
<td>10</td>
<td>Low</td>
<td>7.5</td>
</tr>
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</table>
• Large scale algae cultivation of >1500 ac. is possible in the vicinity of Springfield, IL by utilizing a combination of land from local utilities and private farmland.

• Would require a network of flue gas & water pipelines (Approx. 5-10 miles each).
Summary

- Project Summary: Construction Underway

- Key Project Advantages:
  - Incorporate Wastewater Nutrients to Improve Economics
  - Demonstrate State-of-the-Art Algae Production System with Coal Power Plant Flue Gas and Wastewater Nutrient Inputs
  - Project Targeting Algae Product Market Development
  - Live Animal Testing to Support High Volume Product Markets
    - Use of Algae for Animal Feed Avoids Losses Associated with Biofuel Conversion Process
  - Improve Phycocyanin Pigment Extraction Methods for High Value Product Markets
Appendices:

1. Organizational Chart
2. Gantt Chart
Project Participants and Roles

**PRIME CONTRACTOR**
University of Illinois (UI)
PI: Dr. Lance Schideman
Responsibilities:
- Project management
- Routine operation of the integrated algae cultivation system after start-up
- Analysis of water and air samples from the integrated cultivation system for process performance quantification
- Algae biomass characterization and testing for animal feed applications
- Techno-economic and Life-cycle analysis

**INDUSTRIAL ADVISORY BOARD**
Managers and Design Consultants from the Power and Wastewater Industries
Responsibilities:
- Host site supplying coal flue gas (CWLP)
- Advise on current industry drivers/issues
- Review plans for integration with existing infrastructure facilities
- Review comment on project results

**SUBAWARDEE - Global Algae Innovations [GAI]**
Responsibilities:
- Design & construction of integrated algae cultivation system including raceway ponds, carbon capture, dewatering and drying
- Startup and training staff for routine operations of the integrated algae cultivation system
- Commercialization strategy
- Baseline data for techno-economic and life-cycle analysis

Intellectual Property:
- Flue-gas adapted algal strains
- Patents and other proprietary knowledge for the integrated algae cultivation system components