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

2023 Carbon Management Project Review Meeting
August 29, 2023 Pittsburgh, PA

University of Illinois at Urbana Champaign
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NATIONAL ENERGY TECHNOLOGY LABORATORY

Illinois Sustainable Technology Center | ILLINOIS

GLOBAL ALGAE

Project Overview

- DOE Funding Program DE-FOA-0002403: *Engineering-Scale Testing & Validation of Algae-Based Technologies & Bioproducts Area of Interest 1 (AOI 1)*
- Upscaling and integrating unit processes for algal carbon capture at a coal power plant site
- *End of Project Objectives & Goals:*
  - BP1 Goal- Cultivation system installed & operational achieving >10 $g/m^2/d$ productivity
  - BP2 Goal- Improved cultivation operations with productivity > 14.3 $g/m^2/d$ and reduced costs
  - Project End Goal: Techno-economic analysis at 5000-ac scale w/key performance parameters supporting a minimum selling price below market value of protein conc. and $0 CO_2 capture credit

Budget Period	Work	Start	End	Budget
1	Design and Construction	10/1/2021	9/30/2023*	$1,897,532
2	Testing and Optimization	10/1/2023	3/31/2025	$601,564

** Includes 6 mo No Cost Extension*

Project Overview - Participants

PI: Lance Schideman, PhD, PE
Illinois Sustainable Technology Center of the Prairie Research Institute
Project management and integration of wastewater nutrients.

Global Algae Innovations (GAI):
Design and construction of algae cultivation system

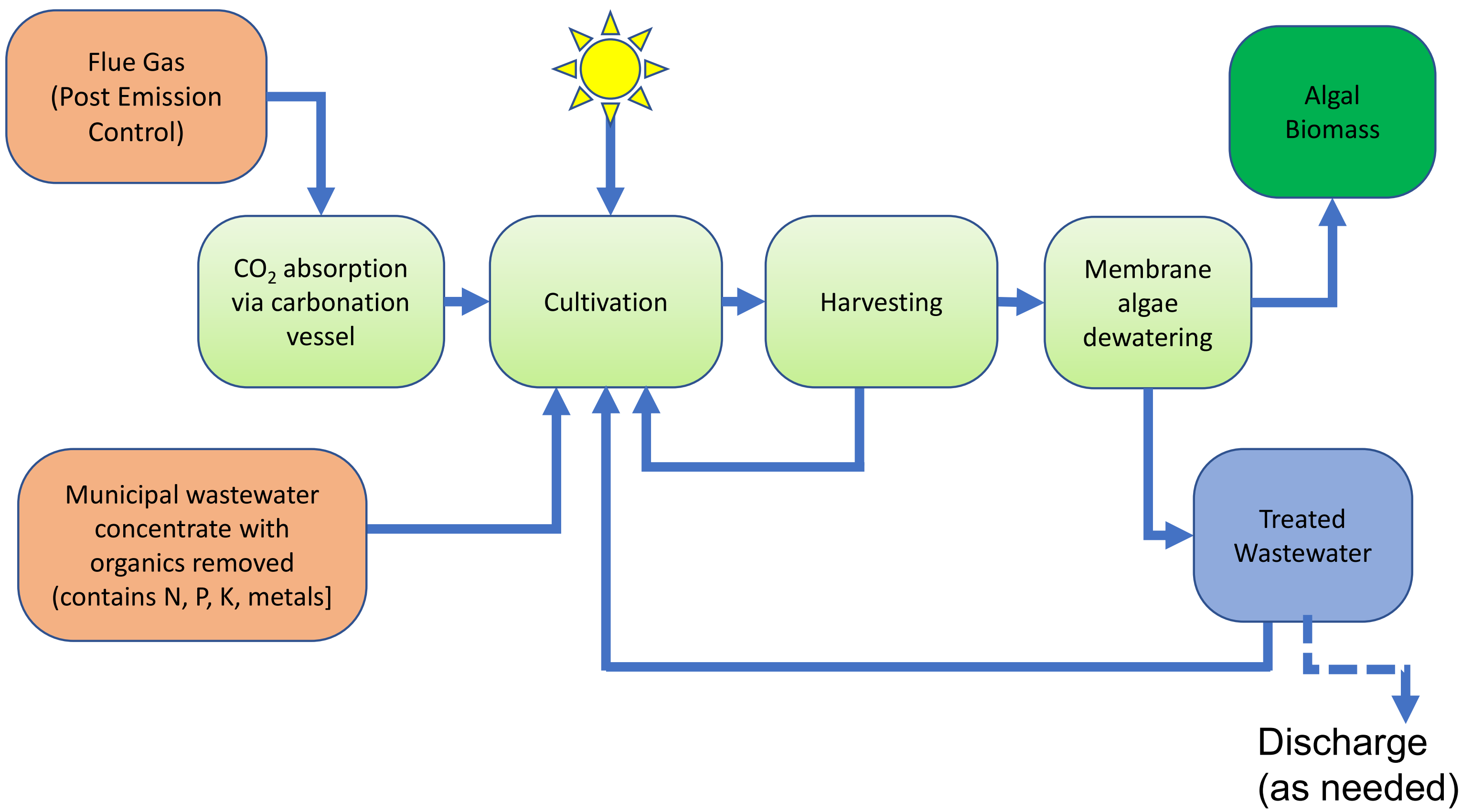
City Water Light and Power:
Host Site

Technical Approach

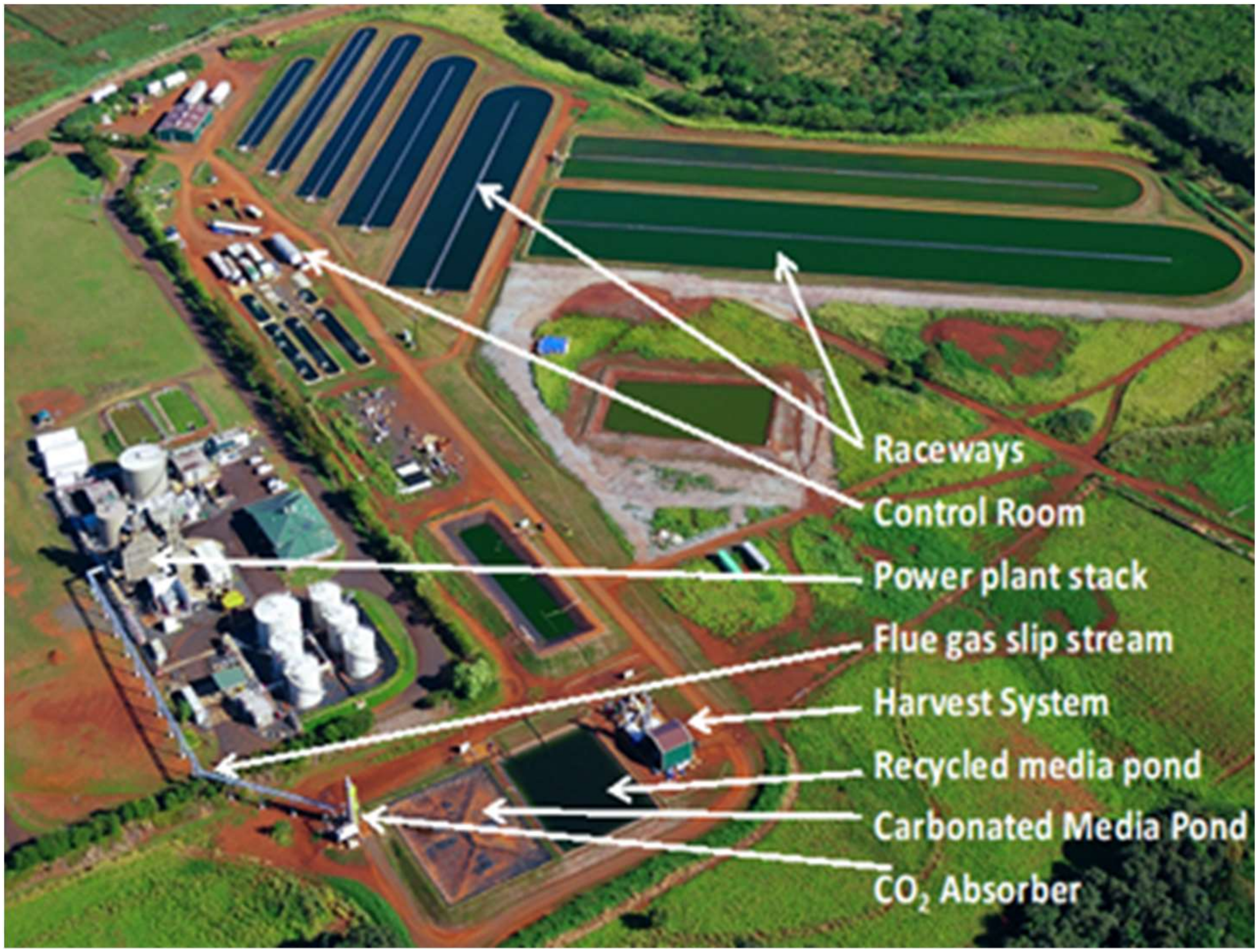
Project Strategy: Combination of Key Advantages

- Best in Class Algae Cultivation System from GAI — GLOBAL ALGAE
- First Demonstration with Global Algae Innovations (GAI) System Using Coal Flue Gas — **City Water Light and Power**
- Improvement of Economics with Use of Wastewater Nutrient Inputs and Animal Feed Testing — UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Technology Background- Simplified Process Flow Diagram



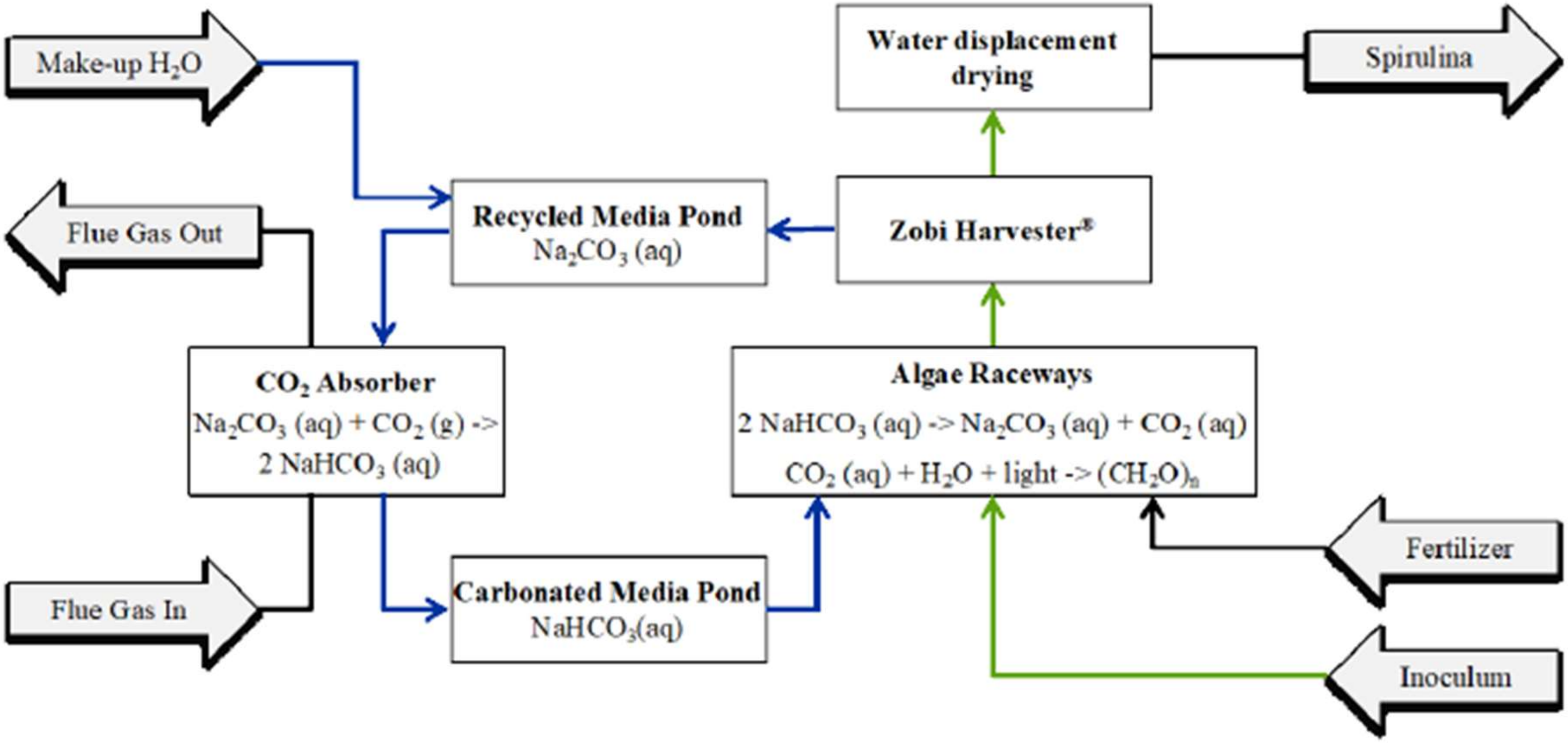
Technology Background



GAI's 8-wet acre Kauai Algae Farm
- CO_2 from a naptha-fueled power plant

Technology Background-
CO_2 Capture Process Integration with Algae Cultivation System

Previous
CO_2 Absorber
Column by GAI



Technical Approach

Complete

Task / Subtask	Milestones
1/1.1	Submit Updated Project Management Plan (PMP)
1/1.2	Submit Initial Technology Maturation Plan (TMP)
2	Cultivation system installed and operational achieves at least 10 g/m2/d productivity with coal flue gas CO_2
3	Absorber system installed and operational and achieves at least 75% carbon capture efficiency
4	Harvesting and drying system installed and operational and produces algae powder with less than 10% moisture content
5	Algae protein meal with at least 50% protein
6	Demonstrate ability to replace at least 50% of nutrients in algal inoculation cultures
7	Interim TEA and LCA confirming costs for baseline performance
8.	Integrated system has average CO_2 capture efficiency of >80%,
8	Cultivation system has an average productivity of 14.3 g/m^2d with coal flue gas CO_2
9	Demonstrate ability to use power plant waste heat to extend algae growing season and increase cold weather productivity
10	Determine projected value of algal biomass based on live chicken digestion tests
11	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
12	Final LCA incorporating averages of key performance parameters projects at least a 50% reduction in GHG for the target products

Project Overview

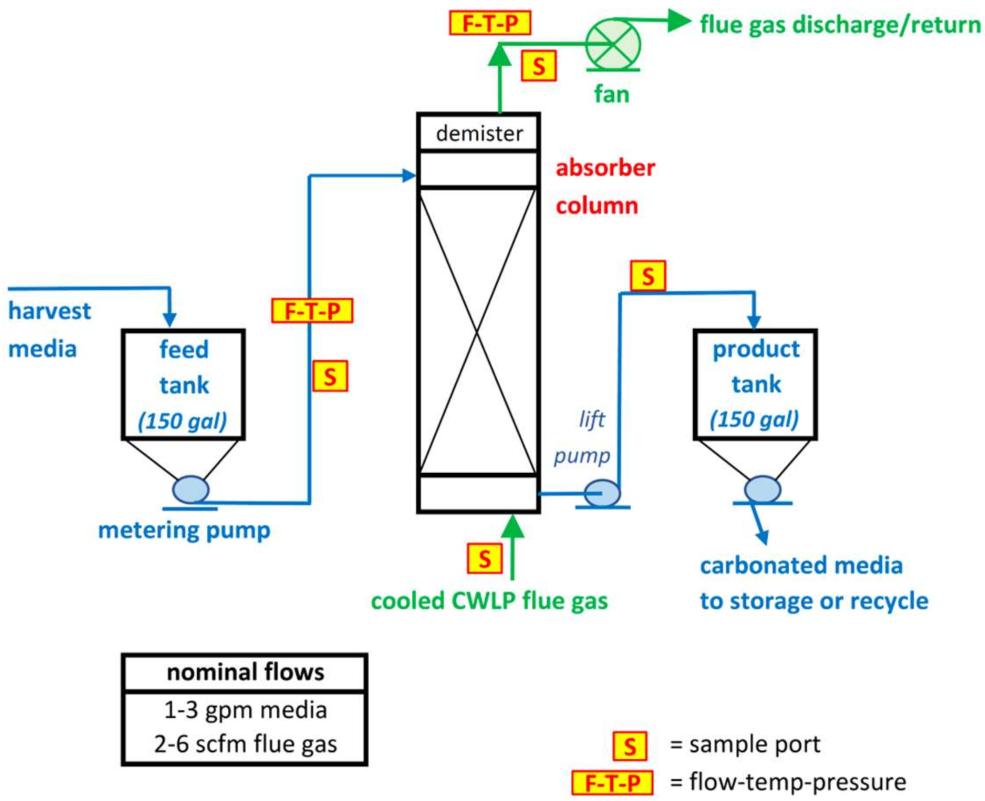
Overall CWLP power plant site showing current operations and proposed research and demonstration facilities

Project Achievements- System Construction

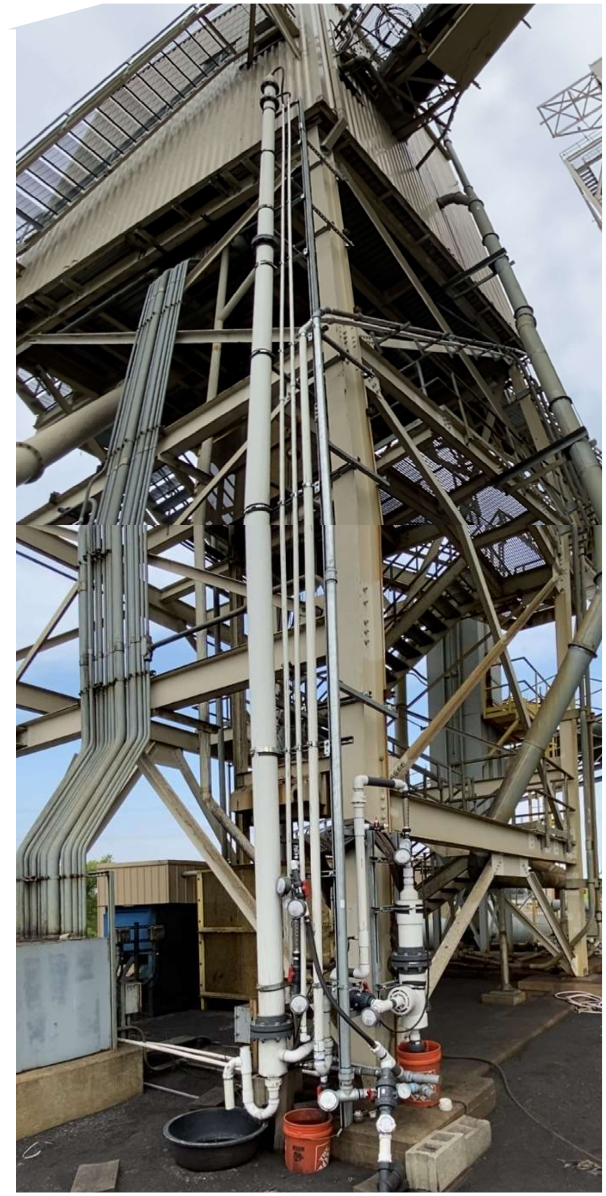
Design Layout

Constructed

Project Achievements Flue Gas Absorber System Design and Construction

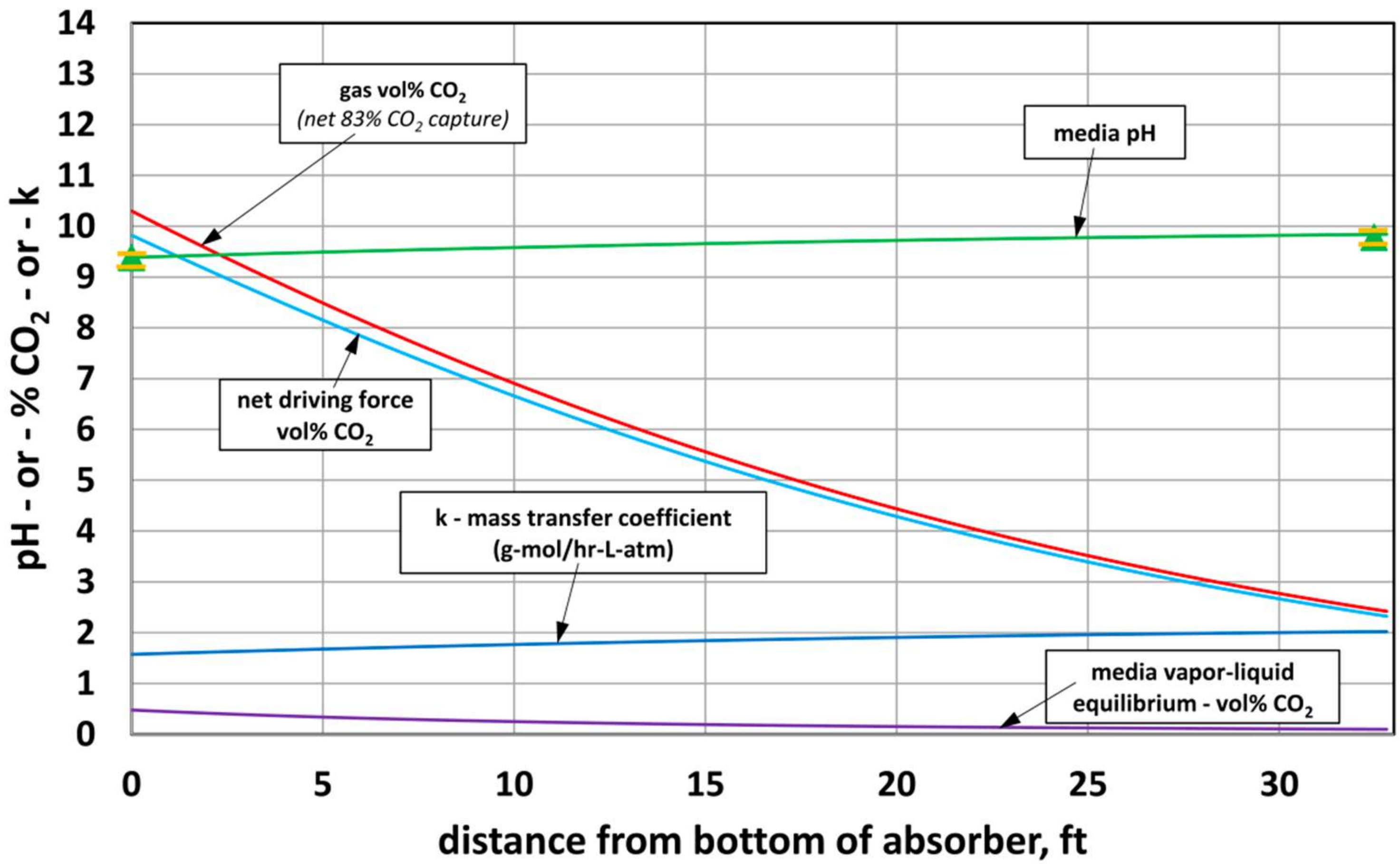


Process Flow Diagram



Project Achievements- 83% CO_2 Capture Based on pH Change Model

$$CO_2 + H_2O \rightarrow HCO_3^- + H^+$$

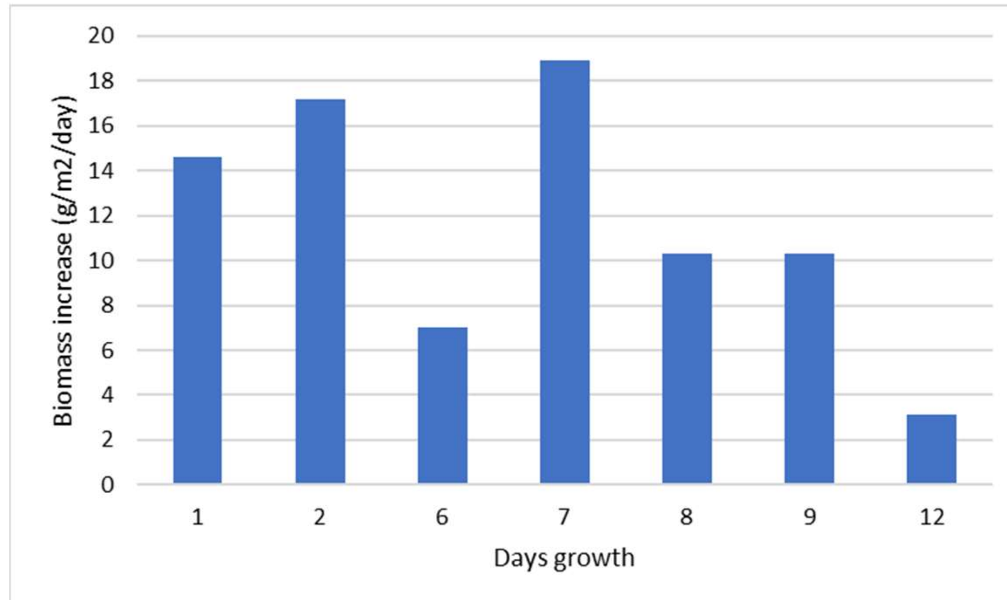


Project Achievements- Average Algae Productivity >10 g/m2-day Startup Target

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

- Working to acclimate cultures to higher proportion of wastewater .

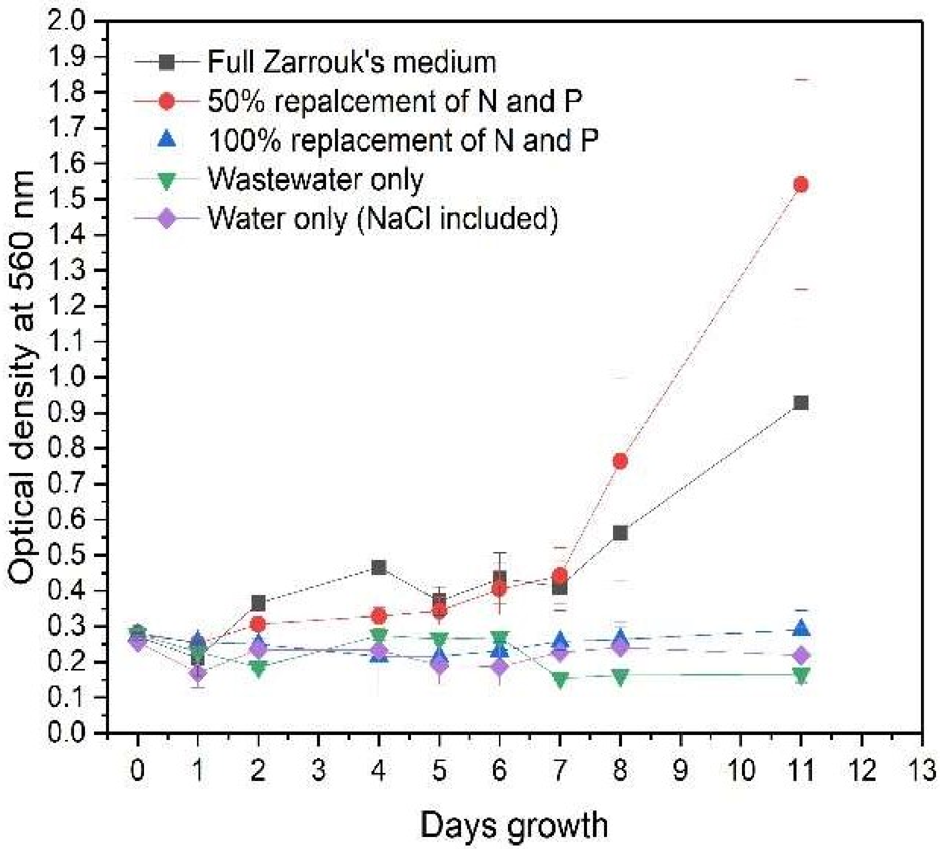
Small Raceways Used for Culture Upscaling

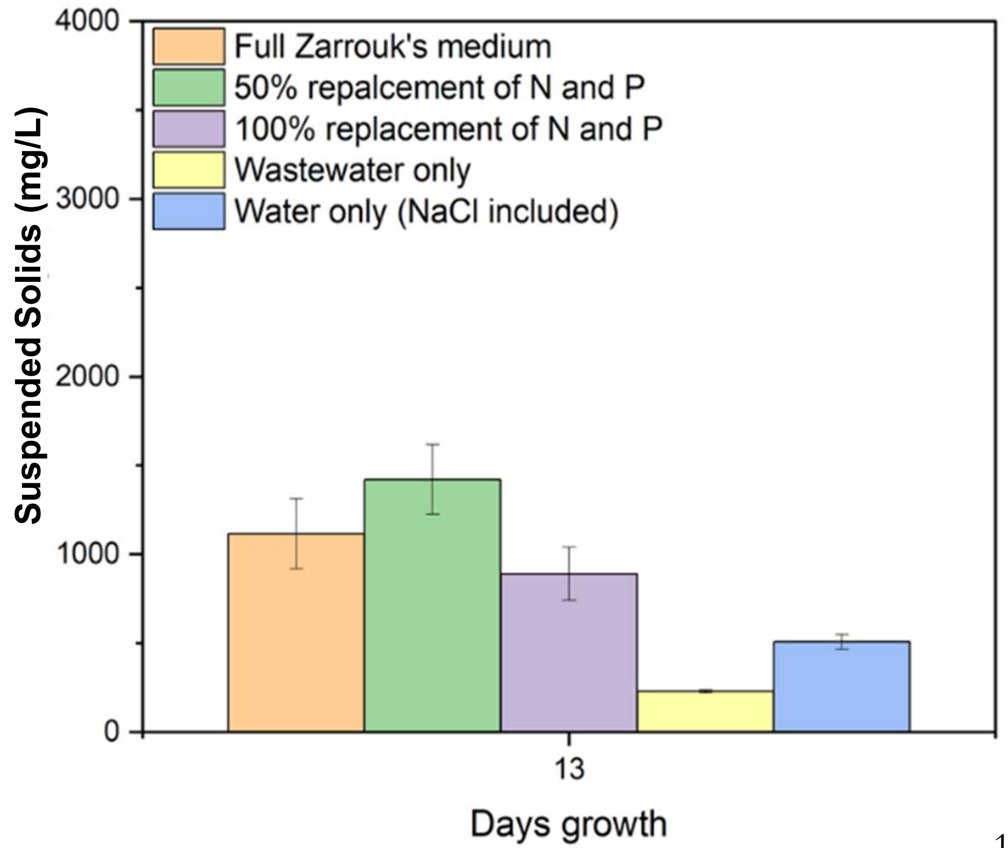


Daily Algae Biomass Productivity

Project Achievements

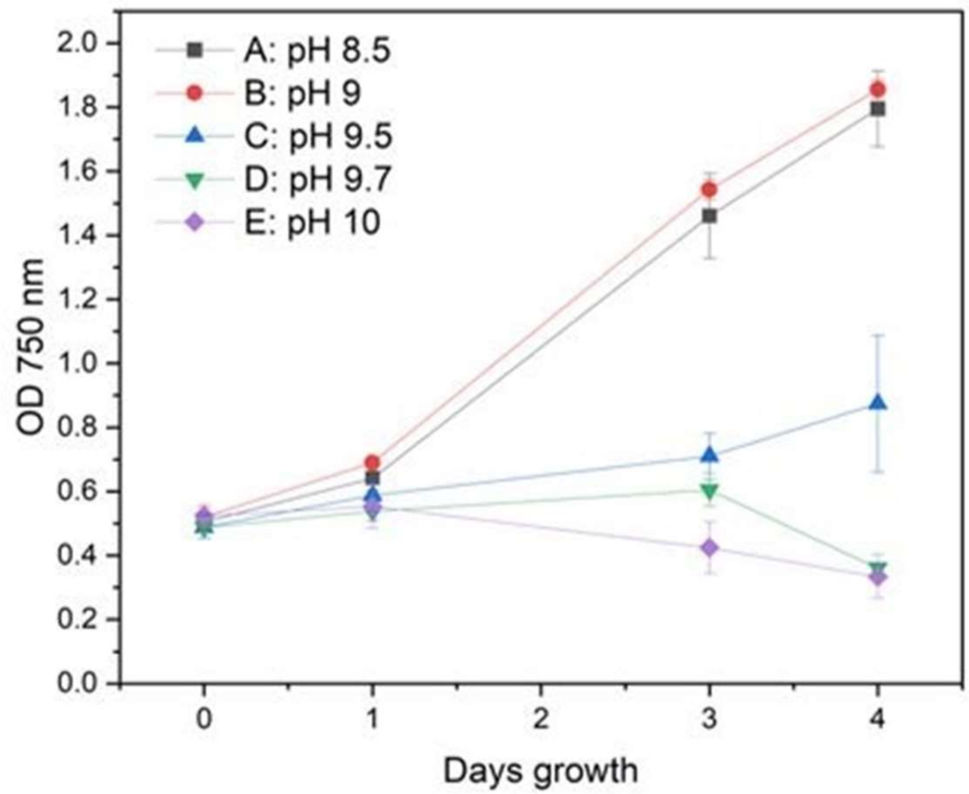
Demonstrated good growth of *Spirulina* with 50% of nutrients provided from a municipal wastewater source
- Working to acclimate cultures to higher proportion of wastewater .





Project Achievements- *Understanding relationship of pH and ammonia conc*

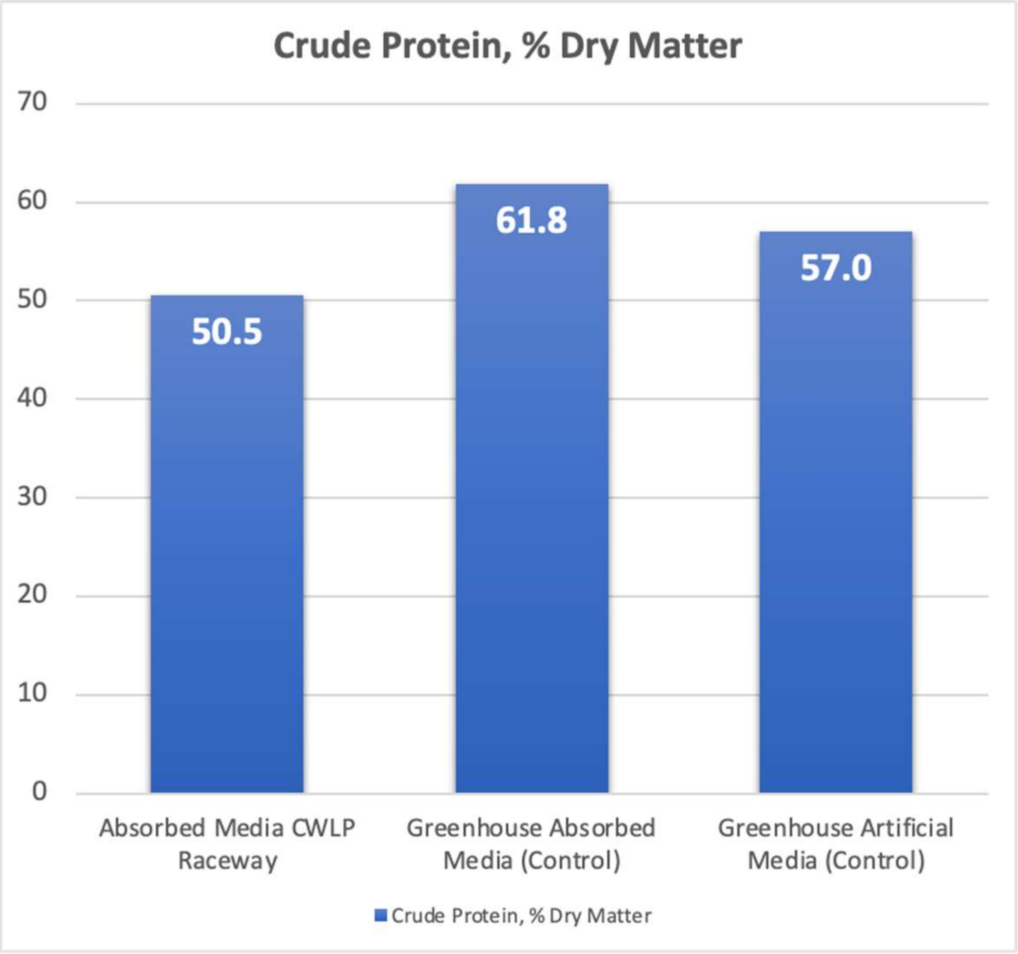
- Concentrated Wastewater N form is typically in the form of ammonia (NH_3)
- Experiments comparing algae growth at different combinations of levels of pH and NH_3 ($pk_a = 9.24$)
  - Data shown for 135 mg/L NH_3
  - Growth retarded pH 9.5 and above
- When operating > pH 9.3 need to control delivery of NH_3 to match algal uptake
  - Typical algal biomass is 10-15% N
- May be possible to gradually acclimate algae to higher NH_3 concentrations



Animal Feed Testing

Protein Content Analysis:

- Initial testing of algae biomass characteristics has shown that all cultivation medium can meet our 50% protein target
  - Absorbed Media made with flue gas CO_2
  - Artificial Media made with chemical HCO_3^-
- Outdoor raceway cultures have room for improvement to increase protein content



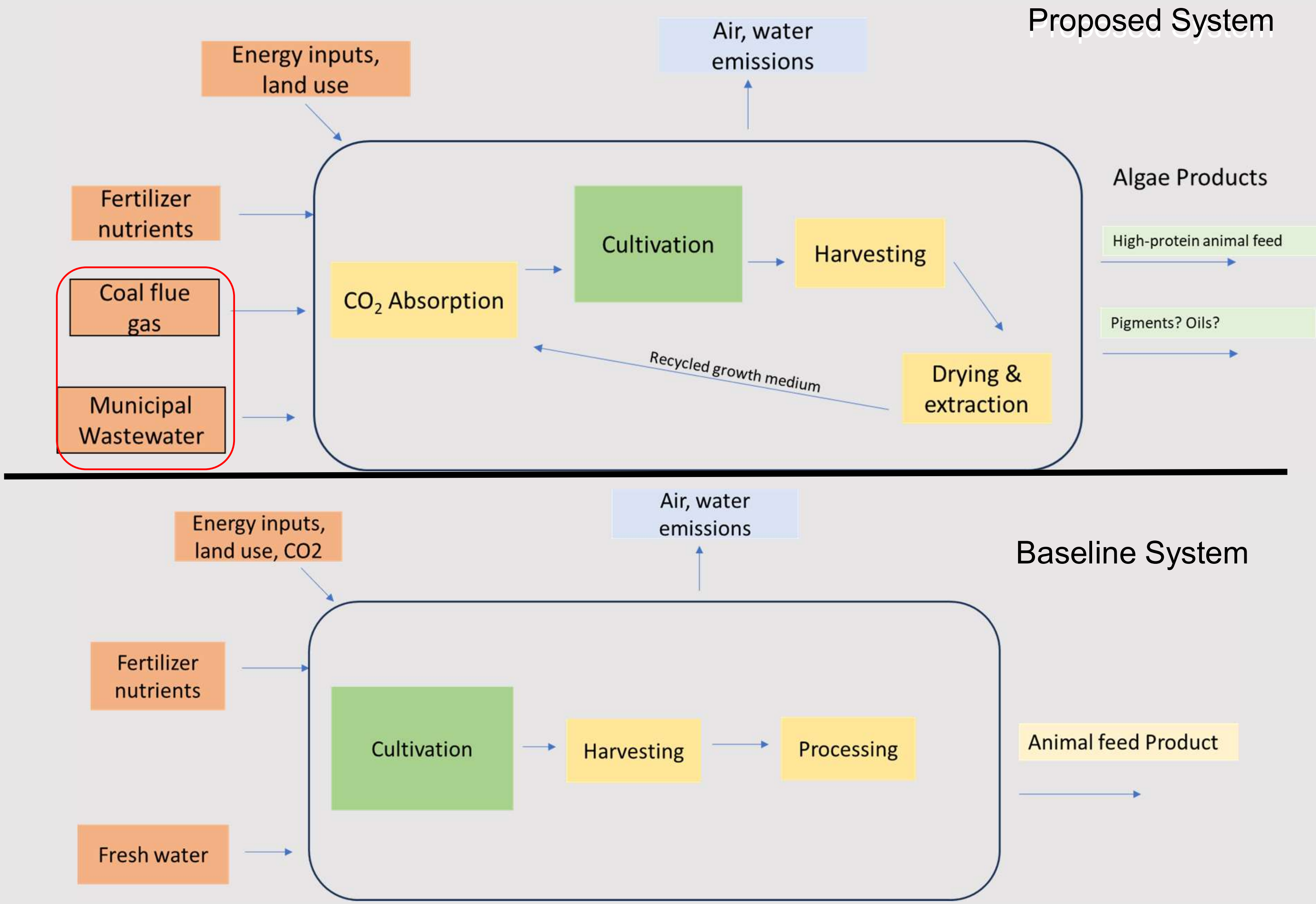
Animal Sciences
COLLEGE OF ACES

Baseline TEA for 5000-acre Algae Farm in IL

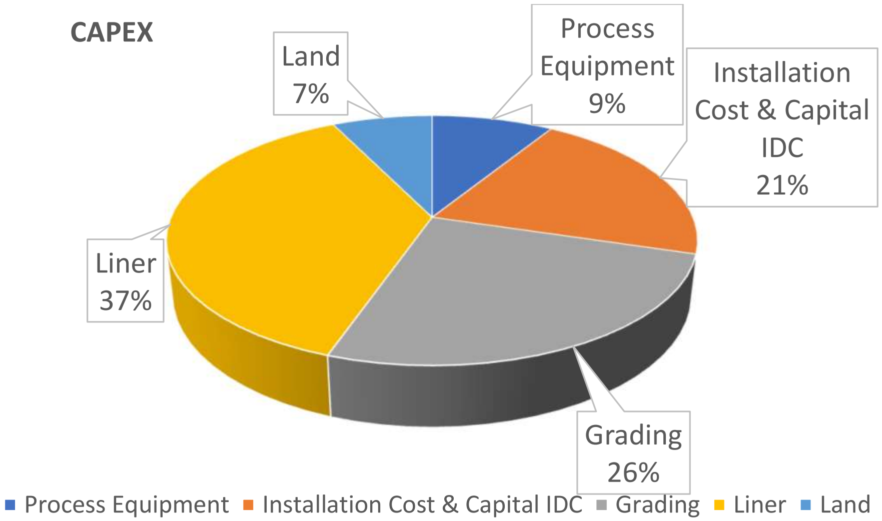
Daily Avg. CO_2 Captured from flue gas: 358 tonne/day (98 tonne C/day)
Daily Avg. Algae Production: 202 tonne/day(Ash Free Dry Weight), 8 tonne/day (Ash)

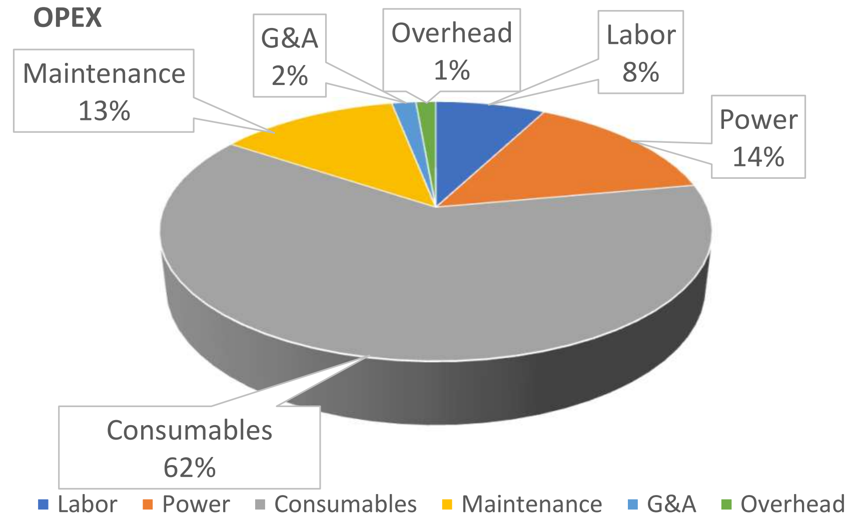
Parameter	5000-acre scale
Algal Culture	*Spirulina*
Gross / Net Power Plant Capacity (MW) – CWLP Dallman Unit 4	230/200
Power Plant CO2 emission (tonnes/MWh)	0.76
Power Plant Annual CO2 Emission (tonnes/year) (based on peak load capacity factor: 0.85)	1.53 Mil./1.3 Mil.
Target Carbon Dioxide Removal (%)	8.5% / 10 %
Avg. Algae Productivity (g/m^2-d)	10.4
Algae Cultivation Area (Acres)	5,000
Annual Avg. Algal Biomass Production (dry tonnes/yr)	74,000

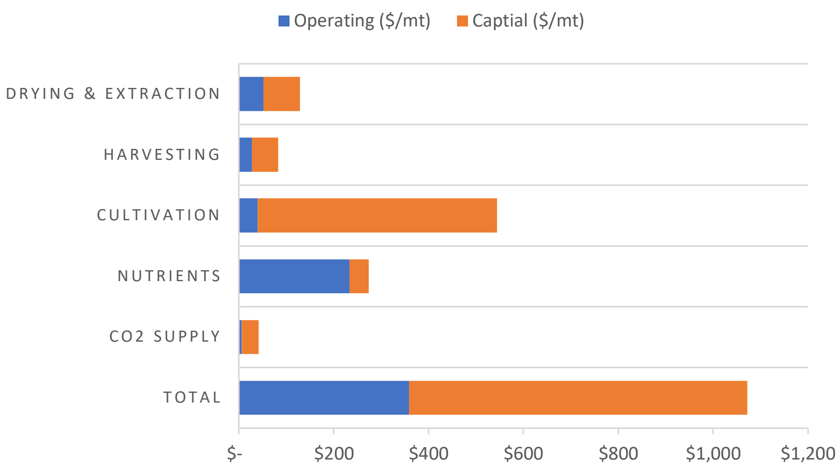
Techno Economic Analysis and Interim Life Cycle Analysis



Baseline Capital and Operating Expenses (CAPEX/OPEX)



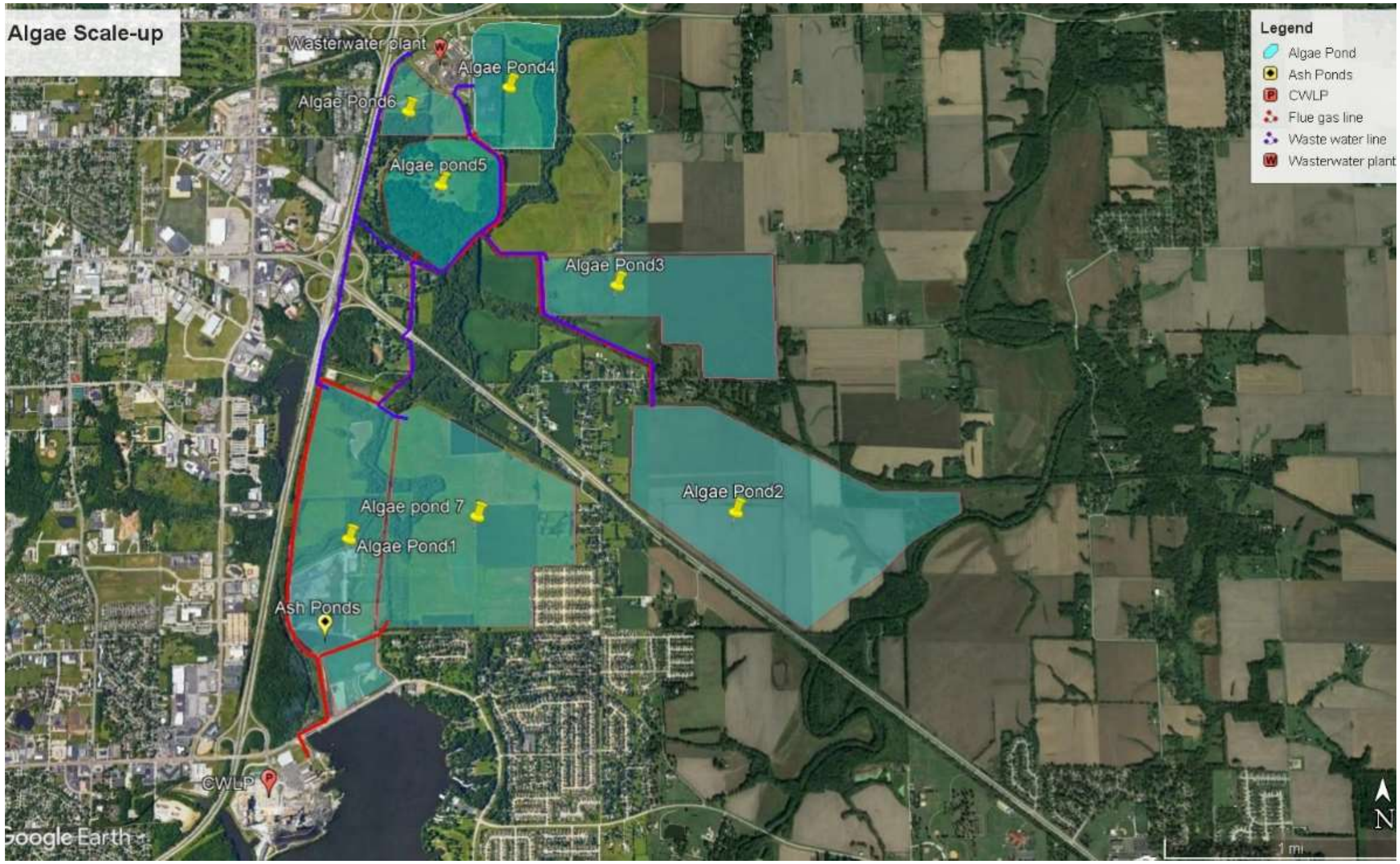




- Algal biomass production cost: $1,072/ton
- Protein concentrate target product value: ~$1,400/ton
- Other revenue sources:
  - Credits for wastewater nutrient removal or CO_2 utilization
- Further improvements for lower costs and higher productivity:
  - Extraction of high value algae bioproducts (e.g., pigments)
  - Reduced energy for algae mixing, harvesting and drying
  - Increasing wastewater use for cultivation media chemicals
  - These improvements included in the planned project testing

Scale Up Potential and Land Requirements

- Large scale algae cultivation >1500 ac. is possible @ Springfield, IL
- Need to use both local utility land AND private farm land
- Would require a network of flue gas & water pipelines (~10 mi. each)



Summary

- **Project Status:** Construction is complete, and systems are being transitioned to operational optimization phase (BP2).
- **Key Project Advantages:**
  - Wastewater nutrients can increase revenue and decrease costs
  - Selection of Spirulina has advantages of existing markets and high pH tolerance
  - Algae biomass productivity higher than conventional row crops (~ 2x increase)
- **Project Impact - Animal Feed:**
  - High protein content meal produced
  - Large offtake market (Soy >350 Mil tons/yr)
  - 100% use vs losses in fuel conversion

Extra Slides

Project Achievements – Absorber Test

Zobi Harvester