A highly efficient microalgae-based carbon sequestration system to reduce CO_2 emission from power plant flue gases

DE-FE0031914

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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management and Natural Gas & Oil Research Project Review Meeting
Virtual Meetings August 2 through August 31, 2021

Project Overview

– Funding

DOE: $3,000,000 and Cost Share: $750,000

– Overall Project Performance Dates:

Sep. 2020 to Sep. 2023

– Project Participants:

Yantao Li, Feng Chen, Russell Hill, University of Maryland Center for Environmental Science;

Robert Mroz, HY-TEK Bio, LLC;

Troy Hawkins and **Sudhanya Banerjee**, Argonne National Laboratory

University of Maryland Center for Environmental Science

HY-TEK Bio

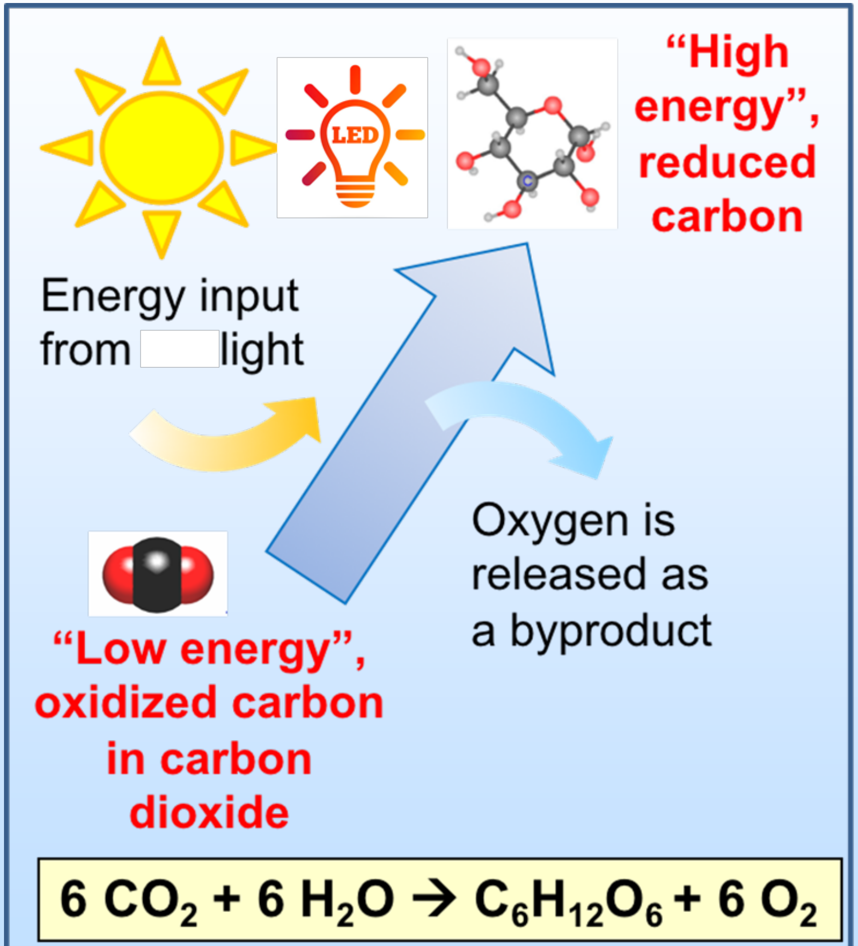
Argonne National Laboratory

Project Overview

– Overall Project Objectives

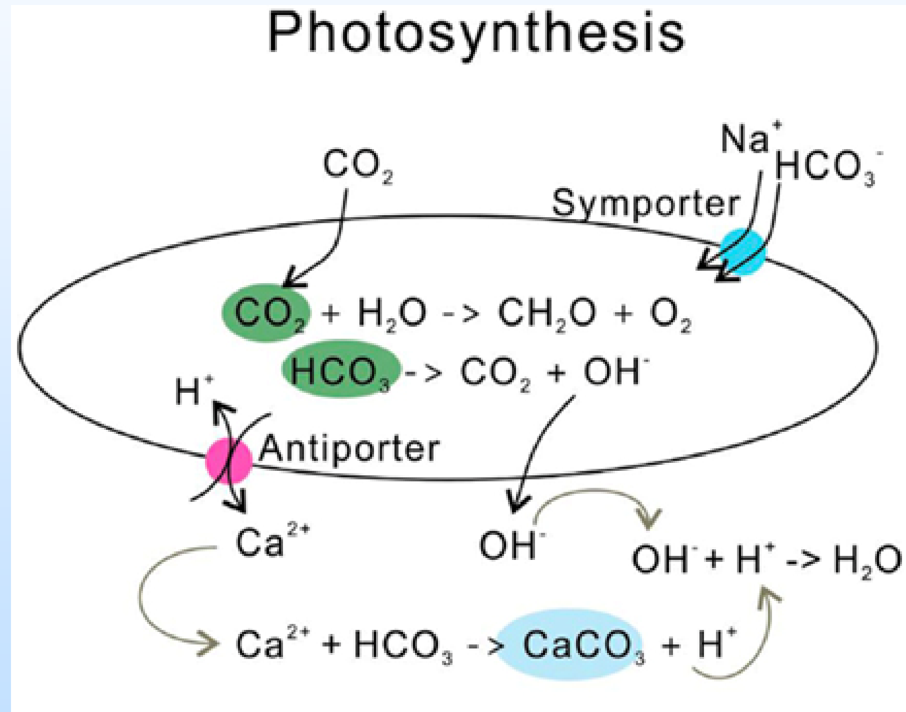
The objective of this project is to harness the power of photosynthetic microalgae to maintain a high-pH, high-alkalinity microalgal culture to create a carbon-negative system for carbon dioxide (CO_2) conversion to value-added products from power plant flue gas. The bench-scale system will be demonstrated on flue gas containing 8 to 12% CO_2.

Technology Background



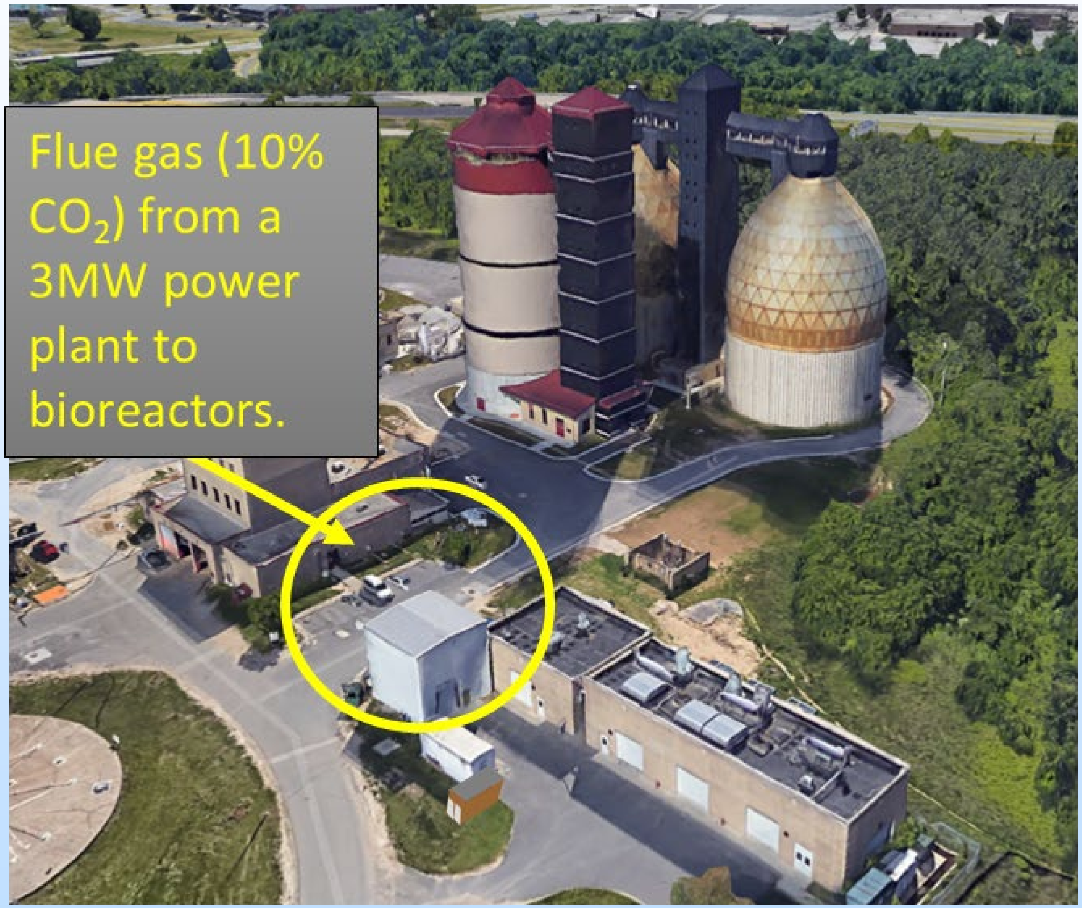
Williams, M.E. (July 31, 2016). Carbon-Fixing Reactions of Photosynthesis. The Plant Cell, doi/10.1105/tpc.116.tt0716.

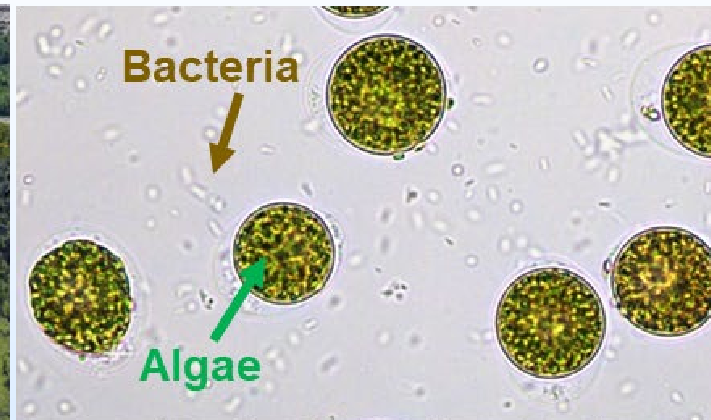
Microalgae-driven Carbon Precipitation (MadCAP)



Adapted from Zhu and Dittrich 2016 Frontiers in Bioeng and Biotech.

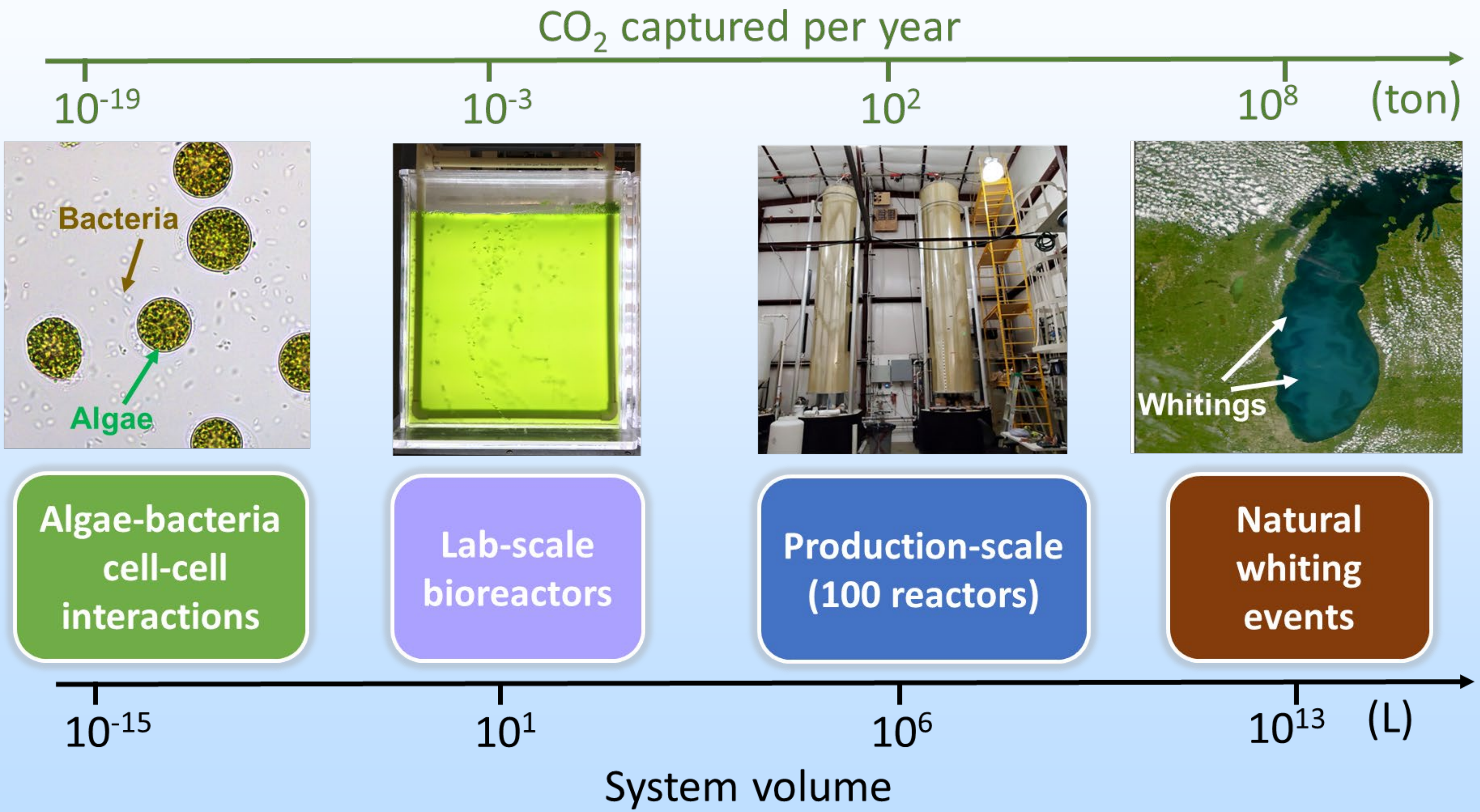
Technology Background: Microalgae Driven Carbon Capture



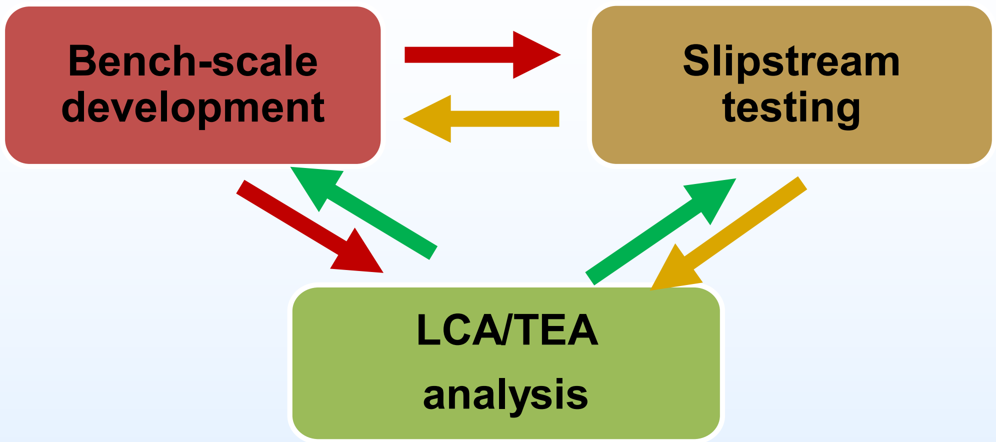


The bioreactor facility of the Back River Waste Water Treatment Plant

Technology Background: Microalgae Driven Carbon Capture



Technical Approach/Project Scope



Bench-scale development of a saltwater and a freshwater system (UMCES)

- Subtask 2.1; 3.1; 4.1: Saltwater algal carbon sequestration system **(Li and Hill)**
- Subtask 2.2; 3.1; 4.1: Freshwater algal carbon sequestration **(Chen and Hill)**

Slipstream testing of the algal carbon sequestration system (HY-TEK Bio)

- Subtask 2.3; 3.2; 4.2: Slipstream test at 500 L **(Mroz)**
- Subtask 3.3; 4.3: Slipstream test at 6,800 L **(Mroz)**

Development of TEA and LCA models to evaluate and guide (Argonne)

- Subtask 2.4; 3.4; 4.4: Perform TEA and LCA analysis **(*Hawkins and Banerjee*)**

Technical Approach/Project Scope

Efficient carbon sequestration in the lab and during slipstream testing at the Back River Wastewater Treatment Plant.

Production of algal biomass optimized for lutein/zeaxanthin production and/or biofuels.

Aggressive publication and IP protection plan to facilitate future licensing arrangements and/or partnering opportunities.

Involvement of key industrial partners to accelerate commercialization of technology.

Progress- Budget Period 1

Subtask 2.1 **- Develop a saltwater algal carbon sequestration system at lab scale**

- Grow the *Nannochloropsis oceanica* IMET1 with $NaHCO_3$ and simulated flue gas

Milestone 2.1 Achieve >90% mitigation efficiency of each algae at lab scale. M12

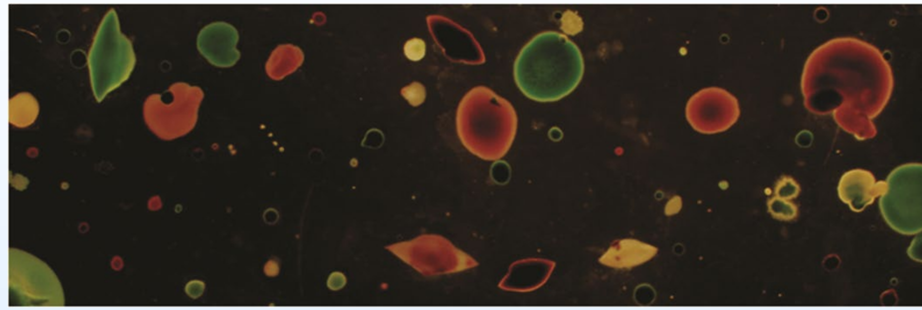
Subtask 2.2 **- Develop a freshwater algal carbon sequestration system at lab scale**

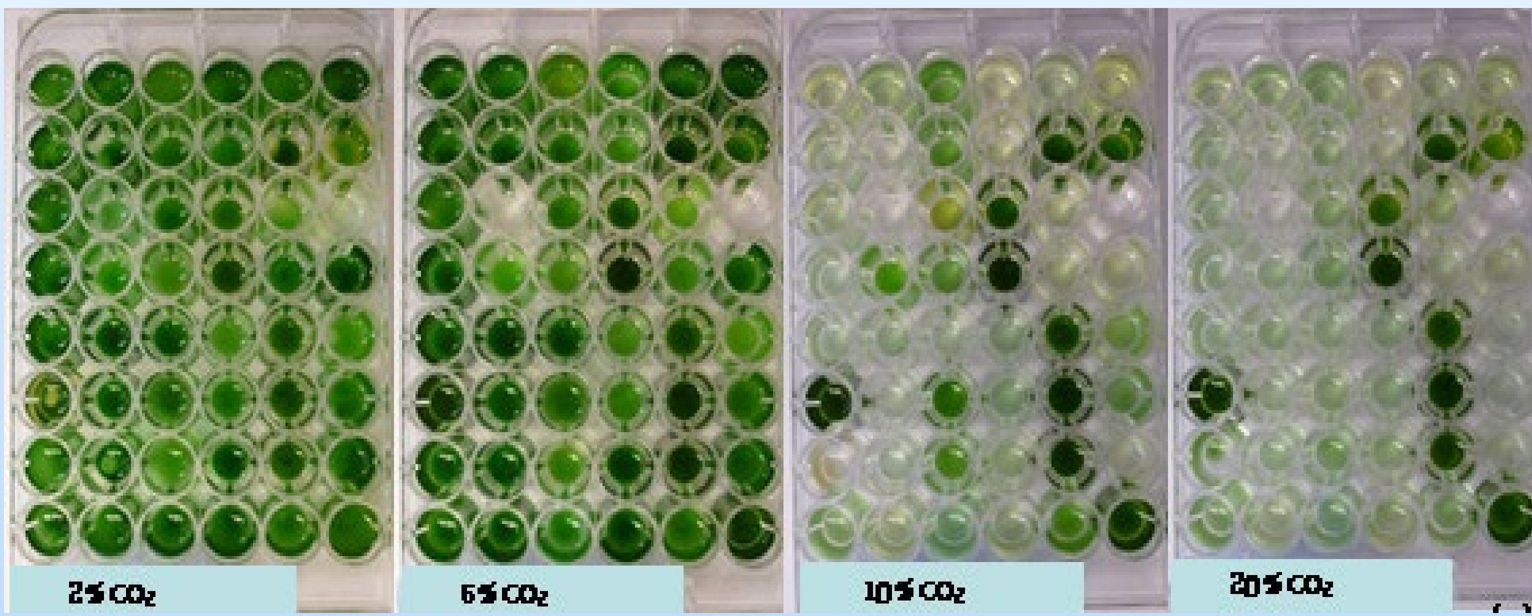
- Grow the *Scenedesmus obliquus* HTB1 with $NaHCO_3$ and simulated flue gas

Milestone 2.2 Achieve >90% mitigation efficiency of each algae at lab scale. M12

Progress- Budget Period 1 Algal Strain Selection

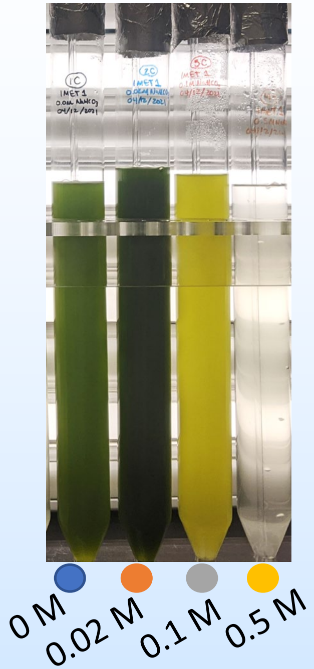
Nannochloropsis oceanica IMET1 and *Scenedesmus obliquus* HTB1 were selected

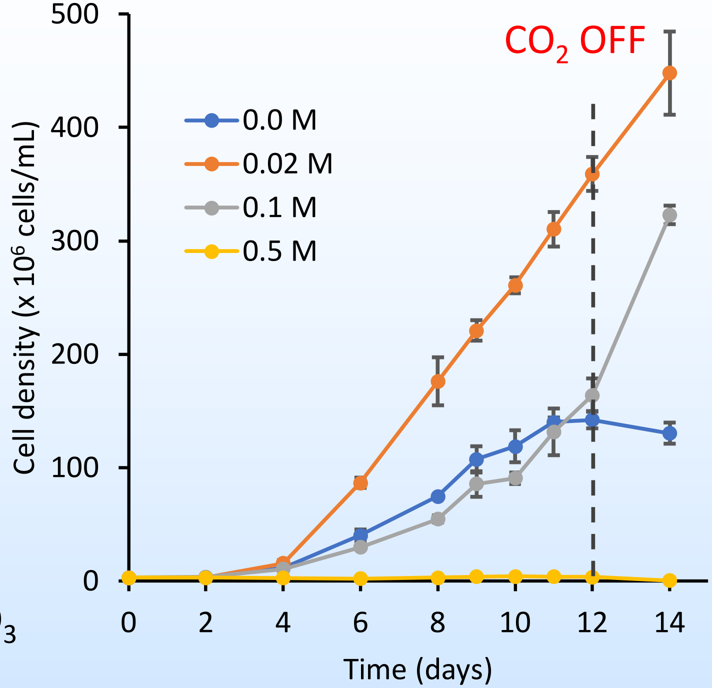


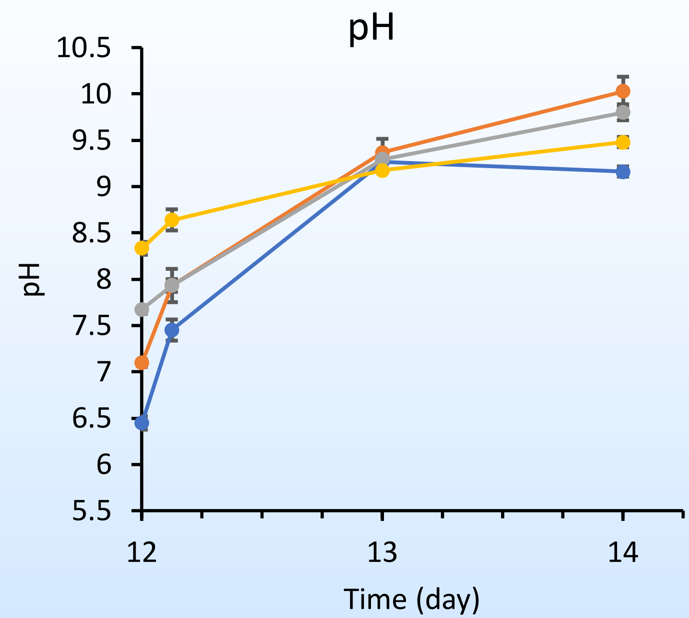


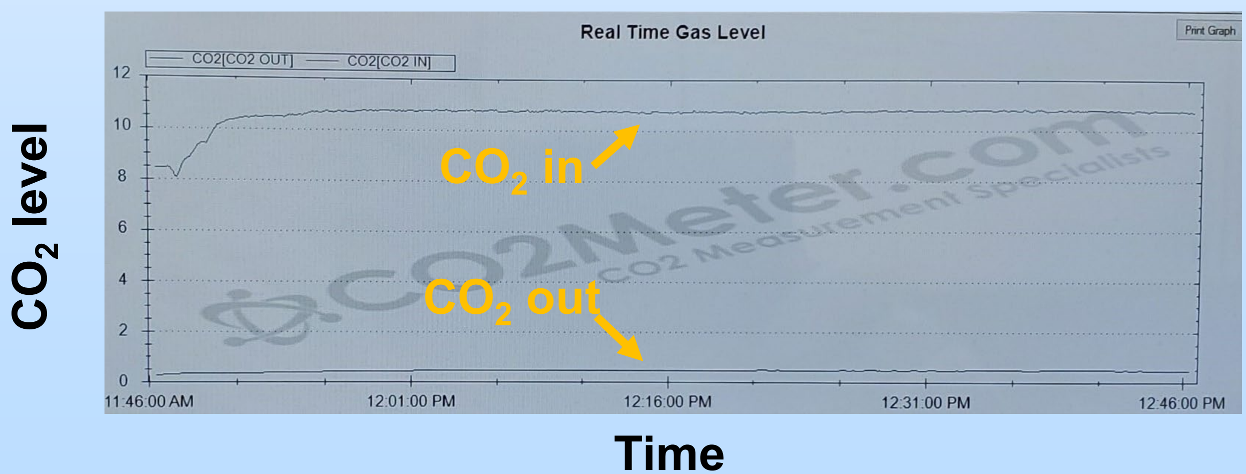
Progress- Budget Period 1 Lab culture at 10% CO_2

Lab cultures of *Nannochloropsis oceanica* IMET1

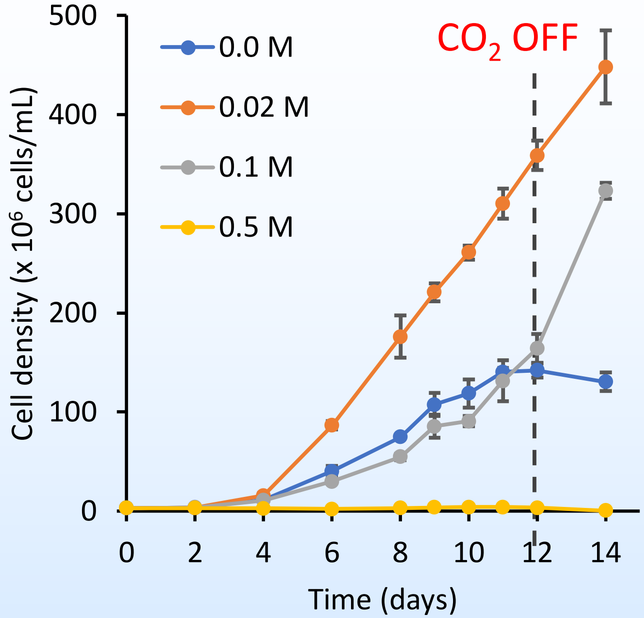


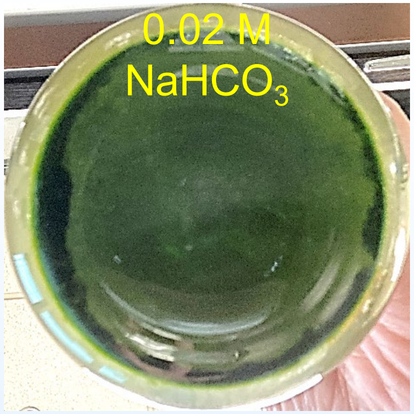


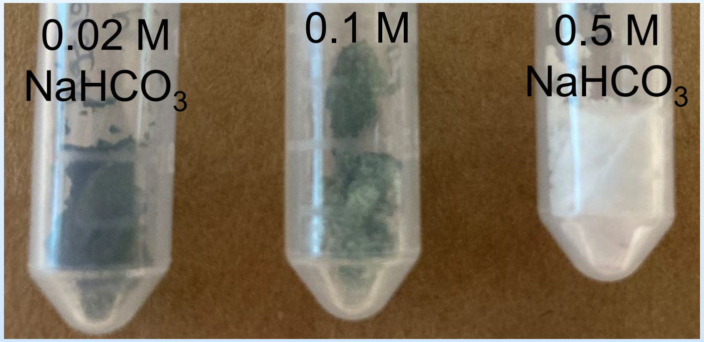




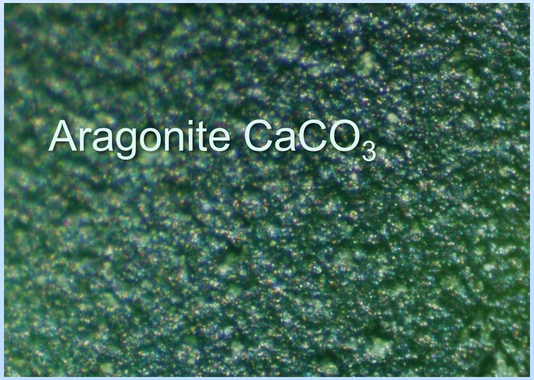
Progress- Budget Period 1 Lab culture at 10% CO_2



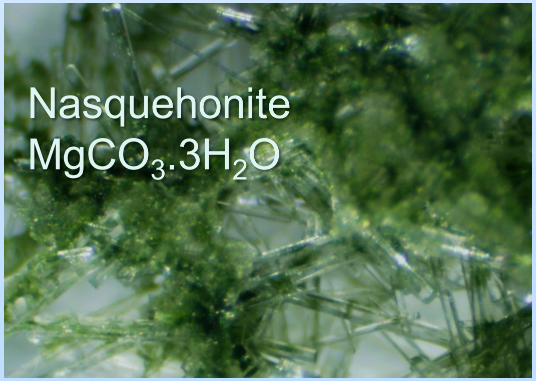


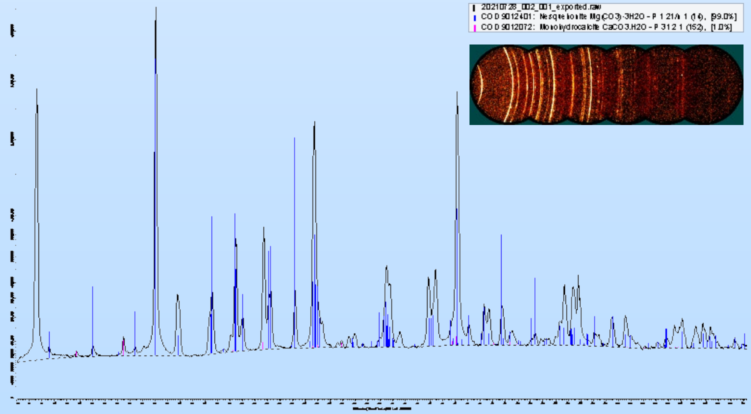


0.02 M



0.1 M





Progress- Budget Period 1

Subtask 2.3 **– Initial slipstream testing at 500-L scale**

- Grow saltwater and freshwater cultures non-axenically in 500-L bioreactors with flue gas.

Milestone 2.3 Achieve >90% mitigation efficiency at 500-L scale. M12

Subtask 2.4 **- Develop the frameworks for the TEA and LCA models**

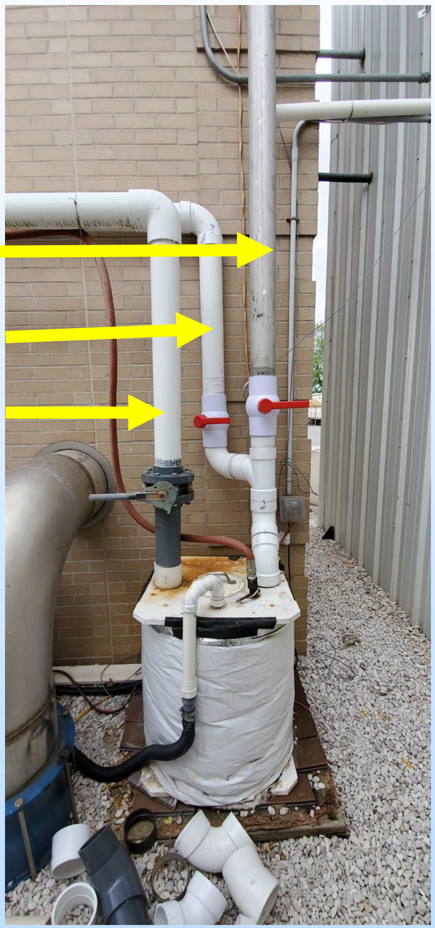
Milestone 2.4 Develop frameworks for the TEA and LCA models. M12

Progress- 500-L scale test, Flue Gas Capture Line to the Natural Gas Boiler

To Engines

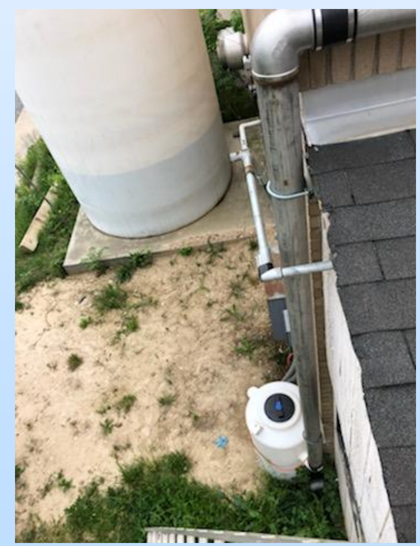
To Boilers

To Compressor



Main Flue Gas Capture Tank

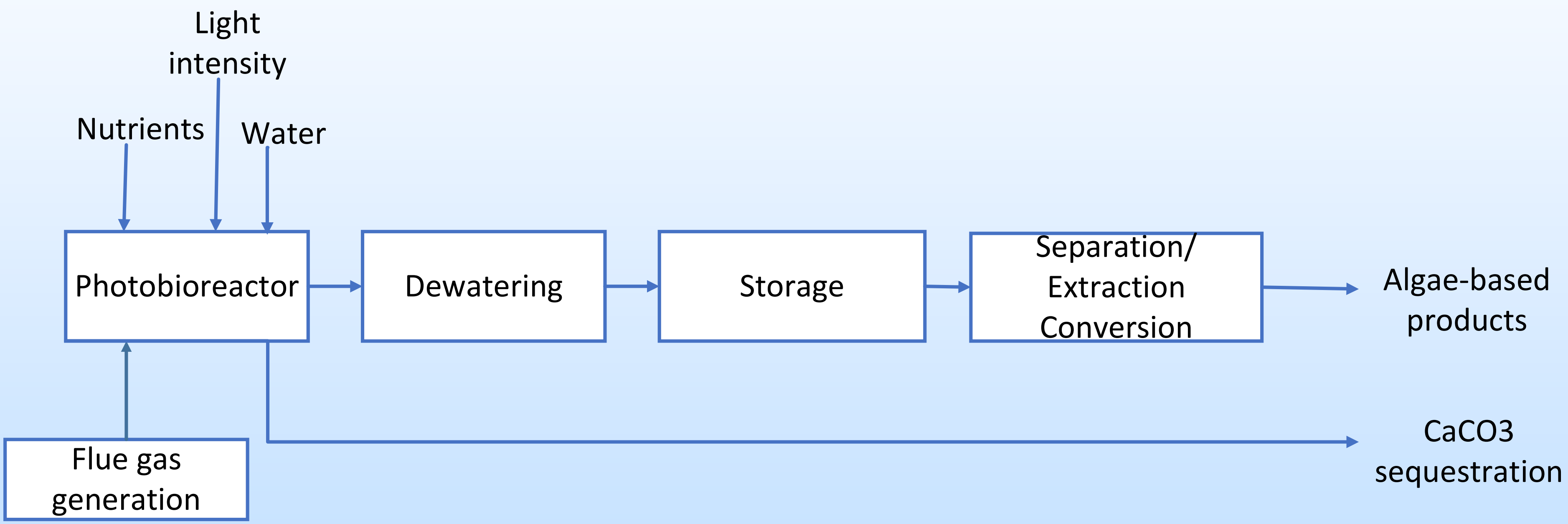
Boiler Stacks



Progress- 500-L scale test

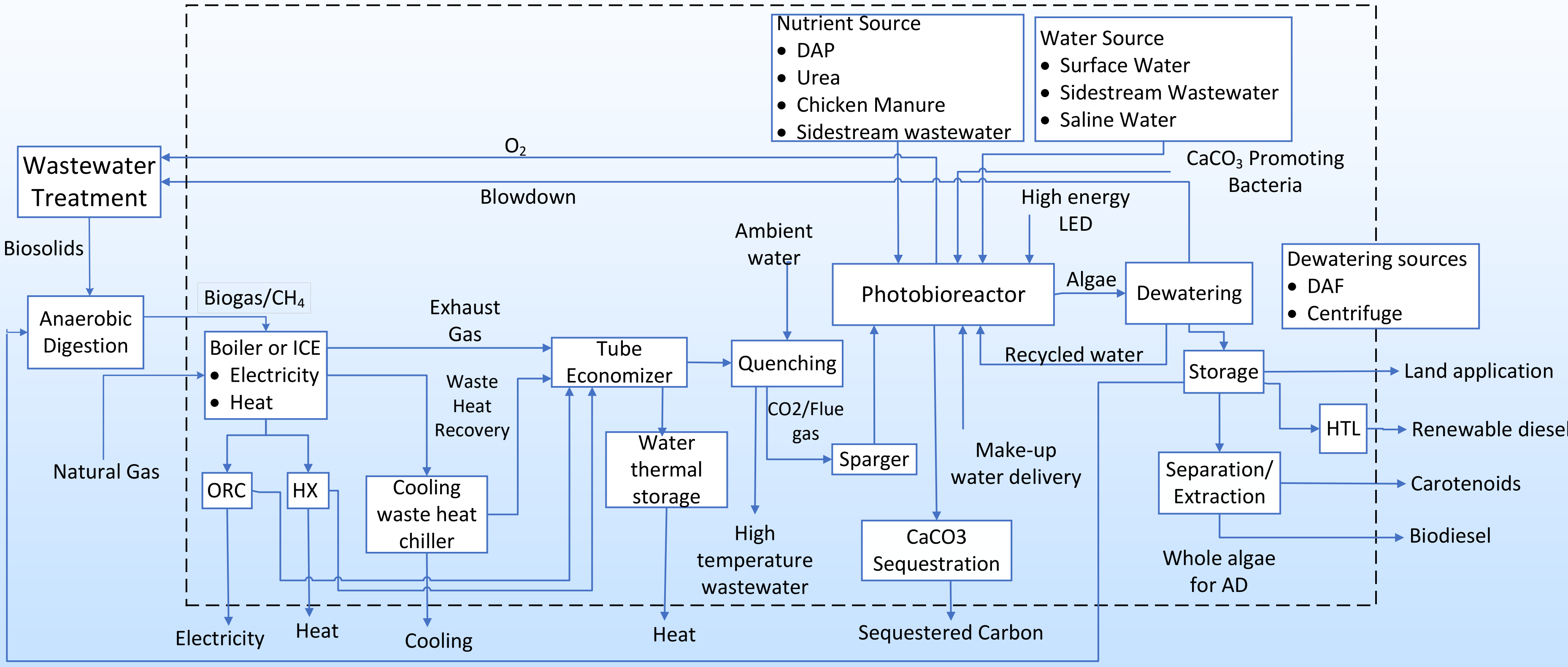
Progress- LCA/TEA

To perform LCA and TEA analysis of advanced algae-based CCS pathway



Progress- LCA/TEA

SYSTEM BOUNDARY



Plans for future work- BP2

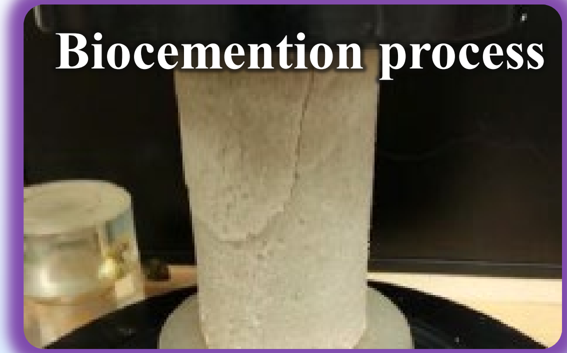
1) Bench-scale optimization of the laboratory and 500-L algal carbon sequestration system;

2) Use an iterative modification and validation process to scale up to slipstream testing of the algal carbon sequestration system at a 6,800-L scale on power plant flue gas; and

3) Describe the potential cost, energy, and environmental metrics associated with scaling the system to 500-L.

Plans for future work

Microbiome engineering; Algal photosynthesis



Process and reaction engineering

Fluid dynamics and gas-liquid-solid multiphase processes

Summary Slide

- Our freshwater *Scenedesmus* and seawater *Nannochloropsis* systems are able to capture CO_2 at >95% efficiency when grown with 10% CO_2 source
- Algae capture CO_2 in the form of algae biomass and carbonate precipitations, e.g., $CaCO_3$ or $MgCO_3$ depending on the culture conditions.
- Working on scaling up tests with boiler flue gas in case the engine flue gas shut off.

Appendix

- These slides will not be discussed during the presentation but are mandatory.

Organization Chart

No.	/Tasks	/Subtasks and PIs responsible for the task	Teams responsible
1	Project Management and Planning	• Project Management Plan ***(All PIs)*** • Technology Maturation Plan ***(All PIs)***	UMCES is the lead on this task.
2	Bench-scale development of a saltwater and a freshwater system	• Saltwater algal carbon sequestration system ***(Li and Hill, UMCES)*** • Freshwater algal carbon sequestration ***(Chen and Hill, UMCES)***	UMCES is the lead on this task.
3	Slipstream testing of the algal carbon sequestration system	• Slipstream test at 500 L scale ***(Mroz, HY-TEK Bio, LLC)*** • Slipstream test at 6,800 L scale ***(Mroz, HY-TEK Bio, LLC)***	HY-TEK Bio, LLC is the lead on this task.
4	Development of TEA and LCA models to evaluate and guide research and testing activities.	• Develop the frameworks for the TEA and LCA models ***(Hawkins and Banerjee, Argonne National Lab)*** • Perform hotspot analysis, benchmark against other carbon capture and biofuel processes, ***(Hawkins and Banerjee, Argonne National Lab)***	Argonne National lab is the lead on this task.

Gantt Chart

Task	2020-2021				2021-2022				2022-2023			
Budget period	**Budget period 1** (Month 1-12)				**Budget period 2** (Month 13-24)				**Budget period 3** (Month 25-36)			
Task 1.0 Project Management												
1.1 Project Management Plan	■											
Milestones 1.1.1												
1.2 Tech Maturation Plan	■											
Milestones 1.2.1												
Task 2.0 Bench-scale development												
2.1 Seawater system	■	■	■	■								
Milestones 2.1.1												
2.2 Freshwater system	■	■	■	■								
Milestones 2.2.1												
2.3 Initial 500-L test	■	■	■	■								
Milestones 2.3.1												
2.4 Frameworks of TEA and LCA	■	■	■	■								
Milestones 2.4.1												
Task 3.0 Optimization and slipstream test												
3.1 Lab-scale optimization					■	■	■	■				
Milestones 3.1.1												
3.2 Slipstream test at 500 L					■	■	■	■				
Milestones 3.2.1												
3.3 Initial 6,800-L test					■	■	■	■				
Milestones 3.3.1												
3.4 TEA and LCA analysis					■	■	■	■				
Milestones 3.4.1												
Milestones 3.4.2												
Task 4.0 Optimization and full-scale test												
4.1 Lab-scale optimization									■	■	■	■
Milestones 4.1.1												
Milestones 4.1.2												
4.2 Slipstream test at 500 L									■	■		
Milestones 4.2.1												
4.3 Slipstream test at 6,800-L									■	■	■	■
Milestones 4.3.1												
4.4 Frameworks of TEA and LCA									■	■	■	■
Milestones 4.4.1												

Milestone Go-No Go