ALBUS: Algae-Based Bioproducts Utilizing Sorbent-Captured CO_2

2654-1546

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Lawrence Livermore National Laboratory

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Project Overview

Objective: ALBUS are developing an integrated modular system that can continuously capture CO_2 from natural gas-fired units and deliver it to 1000 L algae growth ponds over a 30-day period.

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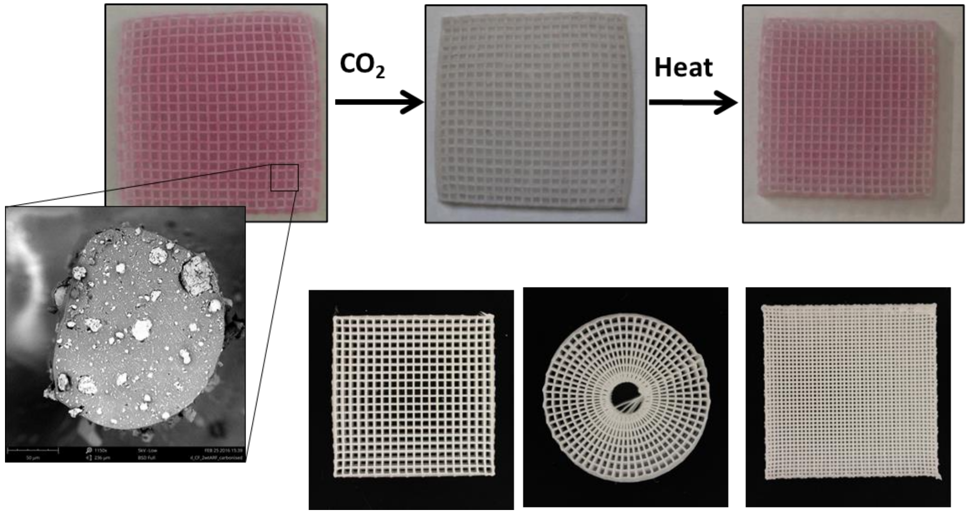
FE0032190 $2M DOE and $500k Cost Share

Project Performance Dates: 08/01/2023 – 07/31/2025

Program Manager: Michael Stanton

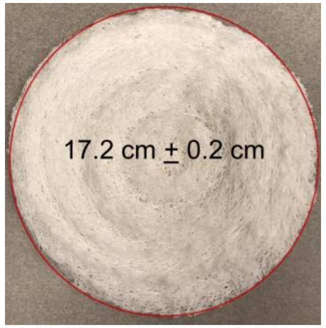
Sorbent-polymer composites developed at LLNL with CC rates one order-of magnitude faster compared to liquid counterpart

$$M_2CO_3 + H_2O + CO_2 \leftrightarrow 2MHCO_3$$



- Particulate sizes sieved as small as possible for best performing ink
- Increase surface area using 400 µm nozzle

Automated Extrusion

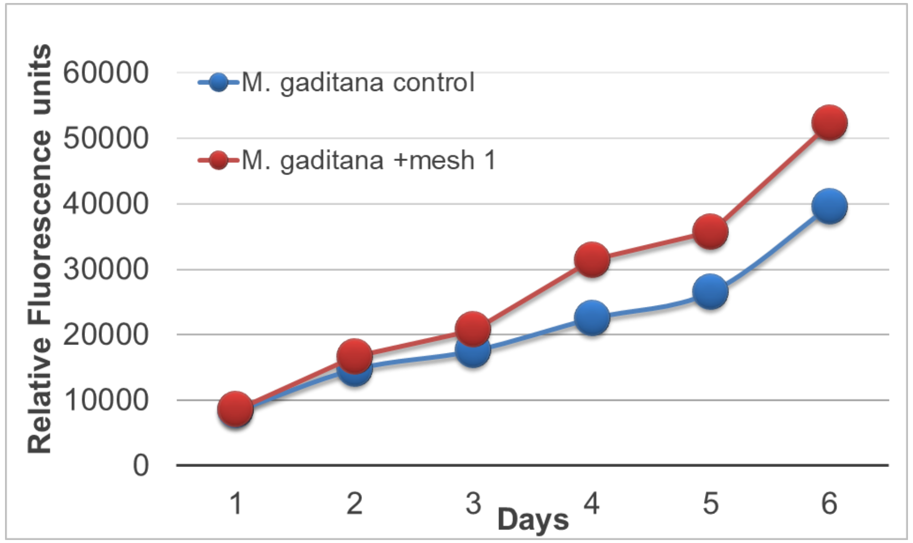


20 nozzles 400 µm

LLNL demonstrated scalability up to 10s of Kg. ***ALBUS will scale up to 100s of kg***.

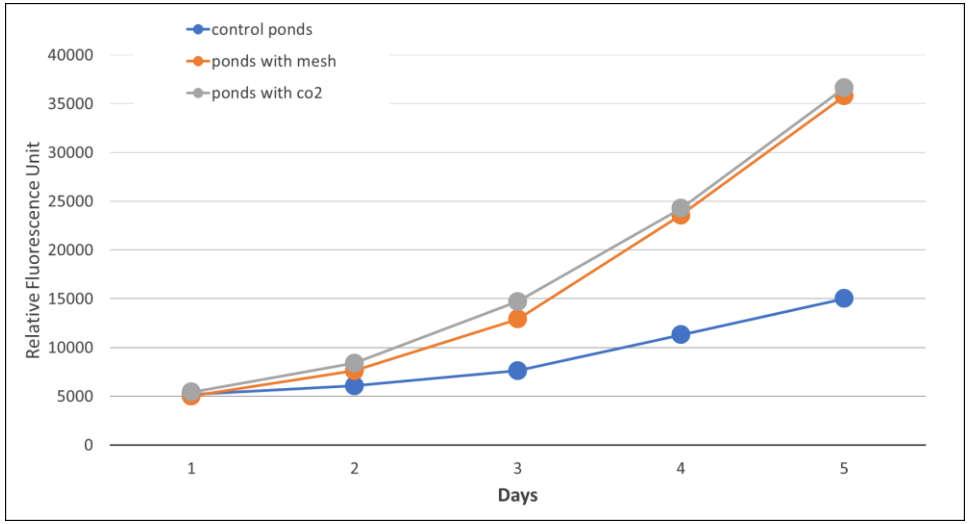
LLNL and SNL Cultivated at Bench and Lab Scale M. Gaditana with Composite Sorbent

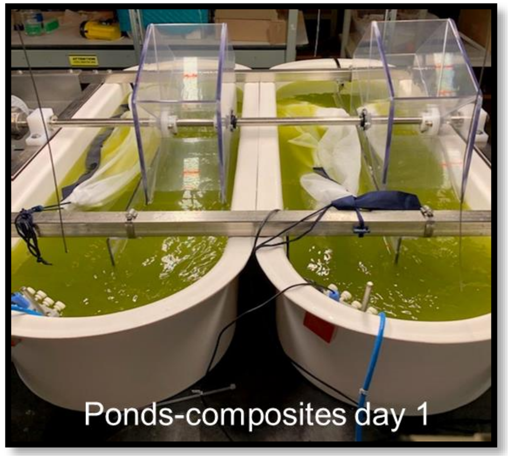
Biocompatibility (100 mL)



M. gaditana + composite

Lab Scale 100 L





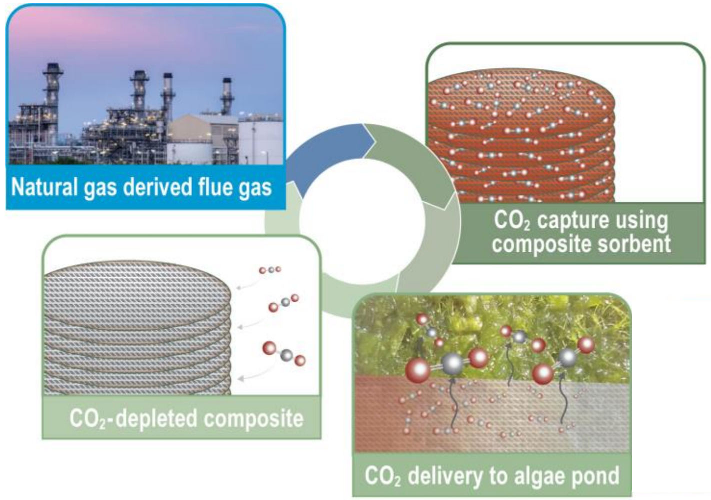
Ponds-composites day 1

Ponds-composites day 5

CO_2-loaded materials can be used for Algae cultivation

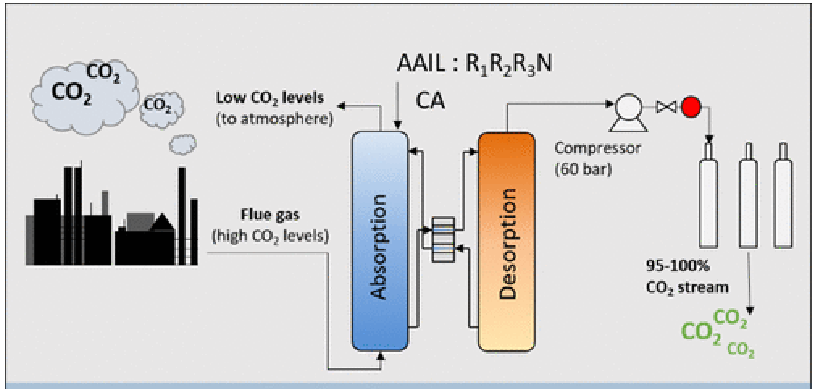
Advantages CO_2 Loaded Materials

- ✓ Selective CO_2 capture from point source
- ✓ Easy transport to algae farm
- ✓ No need of desorber and compressor
- ✓ Mass transfer enhancement
- ✓ Improve pH control



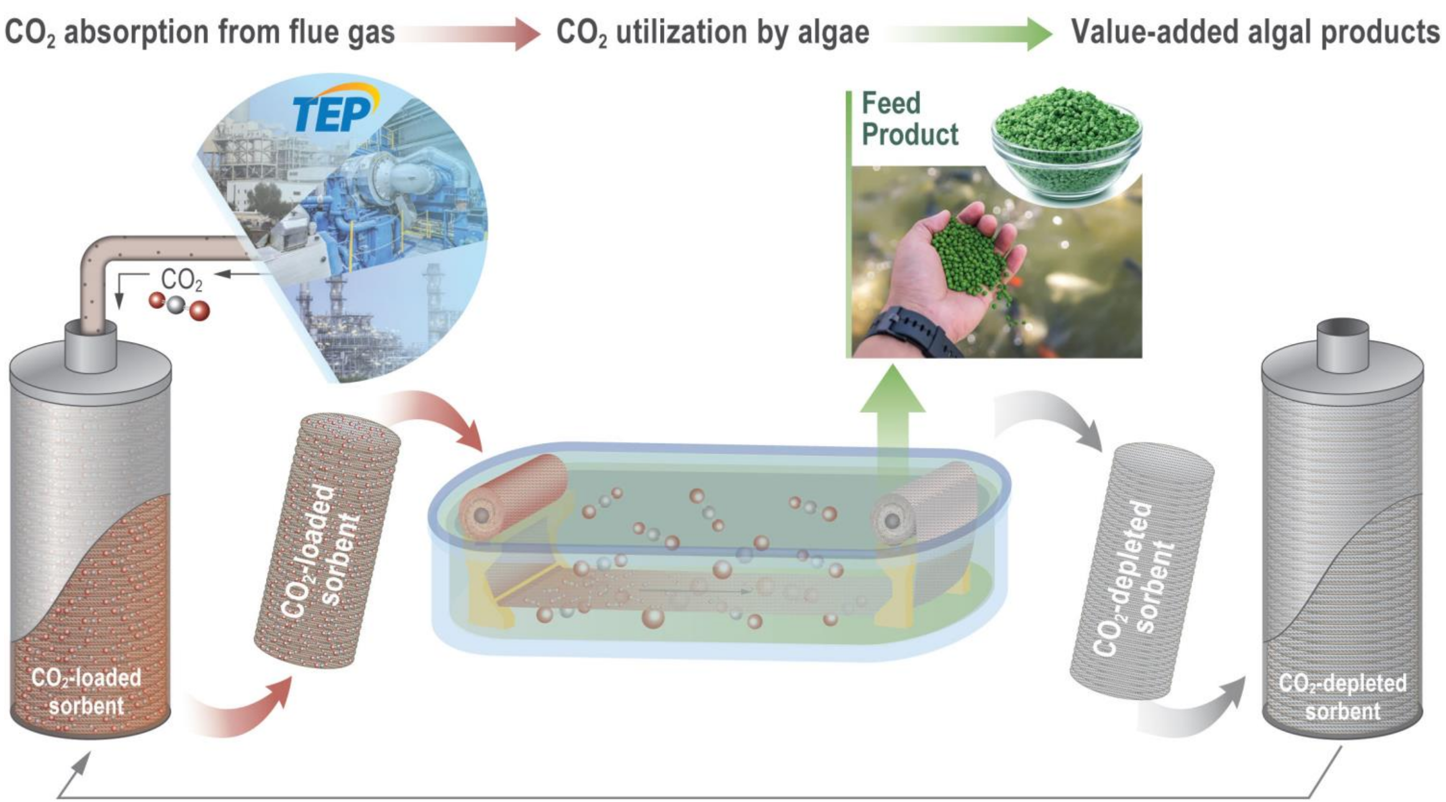
Challenges CO_2 Sparging

- ➢ Absorption, desorption column and compressor
- ➢ Co-location of algae ponds near the carbon source
- ➢ Low CO_2 solubility in water, requires high injection flow
- ➢ Loss of CO_2 from surface of pond
- ➢ Poor pH control



Sorbent-polymer composite can reduce CO_2 capture, storage and delivery cost

ALBUS: Integrated modular system using sorbent-polymer composite to cultivate algae



Advantages

- ✓ Modular system
- ✓ Affordable materials
- ✓ Eliminates co-location of algae ponds
- ✓ Inorganic carbon transport, storage, and delivery tuned to algal productivity levels

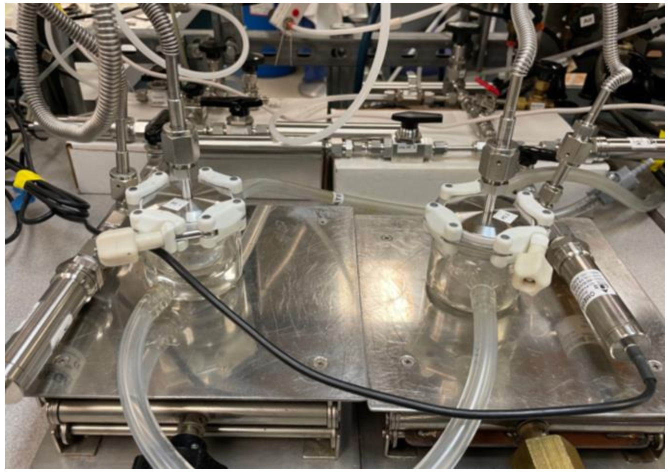
Challenges

- ➢ Lower stability with fresh water algae cultures
- ➢ Water uptake from algae ponds
- ➢ Carbonate lost with high hydration levels

ALBUS Key Milestones

2.3	• Determine algae growth using sorbent-supplied CO_2 and compare to algal growth from air and CO_2
3.2	• Demonstrate composite sorbent reusability. 30 days of absorption/desorption cycles >70% loading.
3.3	• Design and build CO_2 absorption column and desorption spool-automated system.
5.2	• ~60 kg of Sorbent material produced for pilot-scale.
6.3	• Formulate dried algal meal.
7.2	• TEA-LCA Model Integration.

Subtask 3.1: CO_2 absorption of sorbent under different conditions

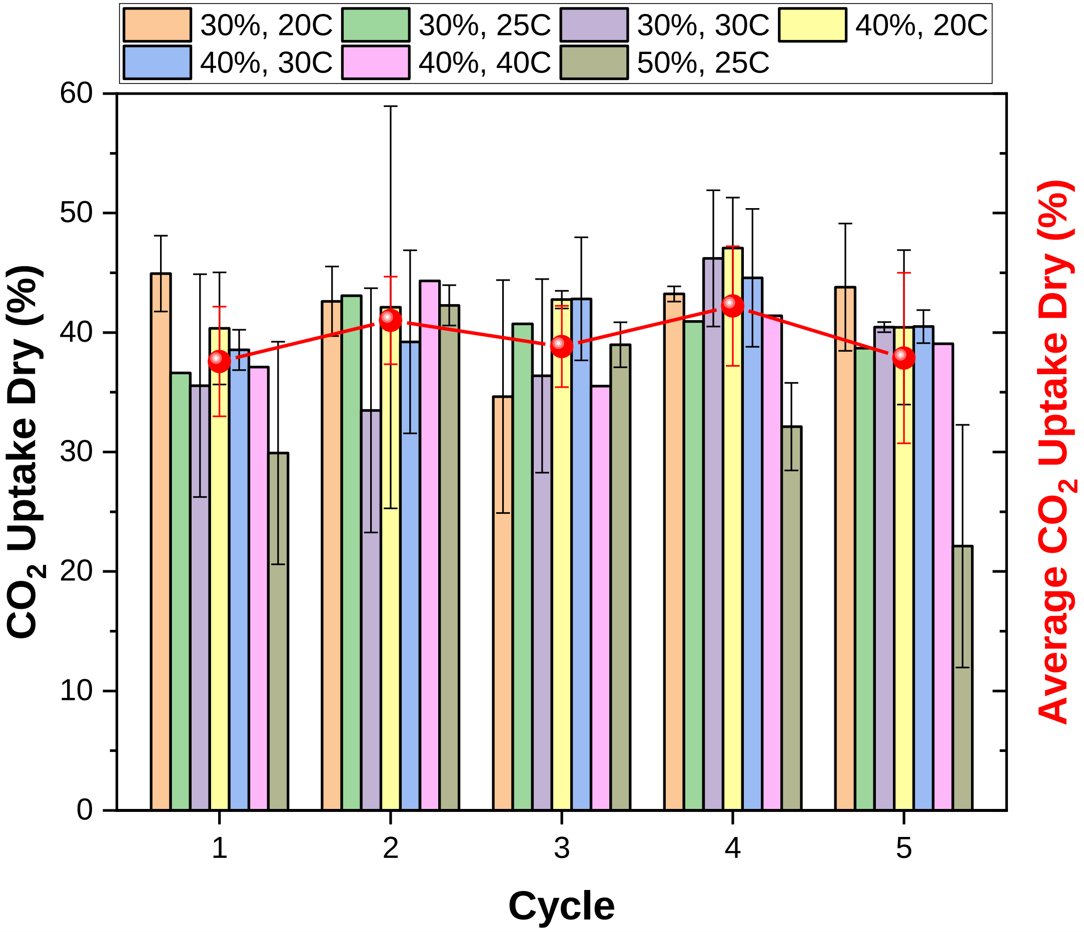


Two pressure decay systems

Bench scale absorption column

- Increasing surface area by changing strand diameter
- CO_2 absorption capacity vs hydration and loading temperature

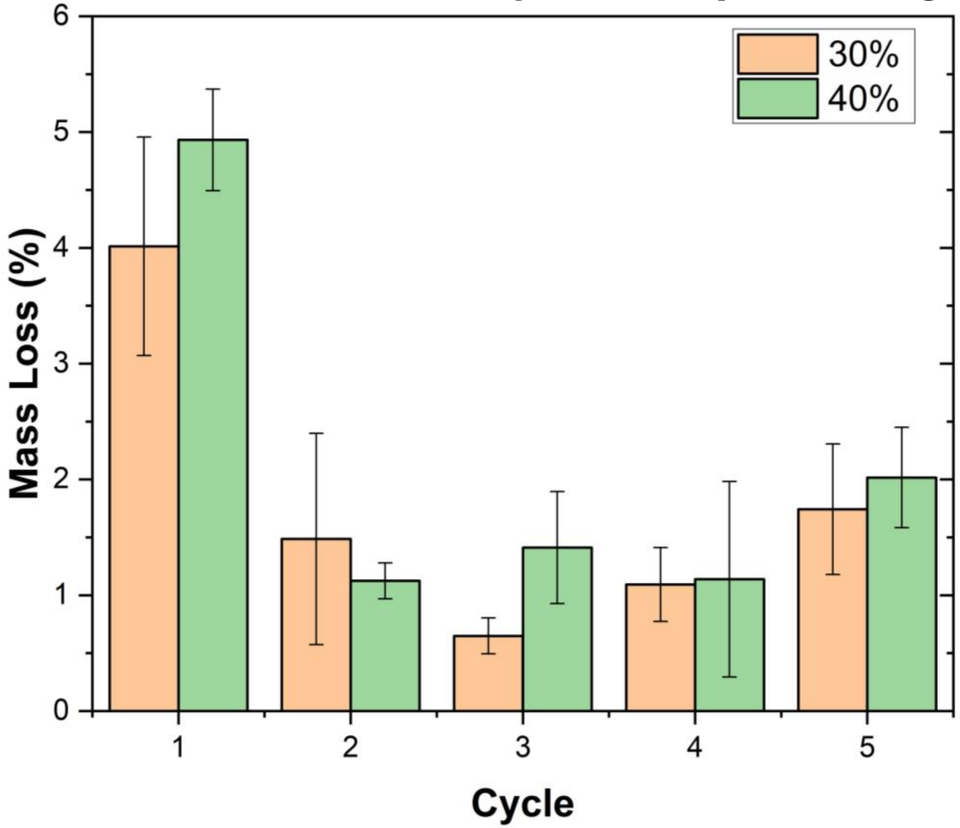
Absorption: 40 kPa CO_2 until equilibrium
Regeneration: 12h at 150C



CO_2 absorption in dry is independent of loading temperature and hydration percentage

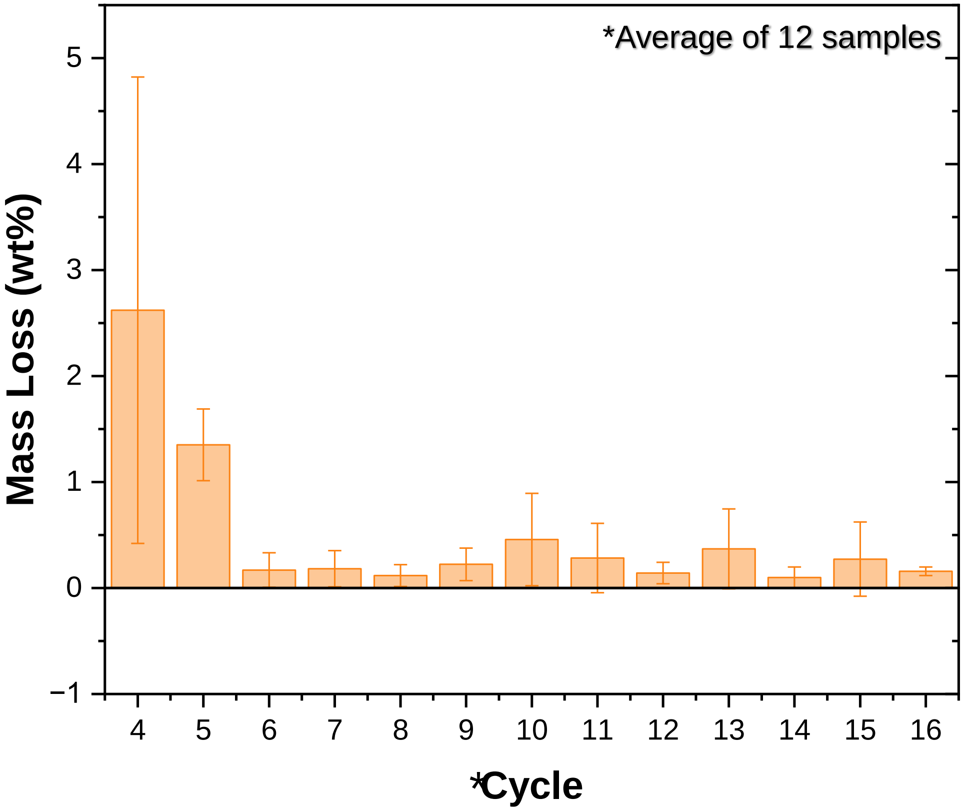
Subtask 3.2: Sorbent stability over 16 cycles without algae

Carbonate loss vs hydration percentage



High hydration percentages promotes carbonate leaching, therefore ***drying step in between cycles would be necessary***

30% Hydration/heat regeneration cycles



Carbonate mass loss significantly decreases after cycle 5

Subtask 3.3 and 3.4: Scale up composite sorbent production

LLNL Automated Extruder

20 nozzles 400 μm

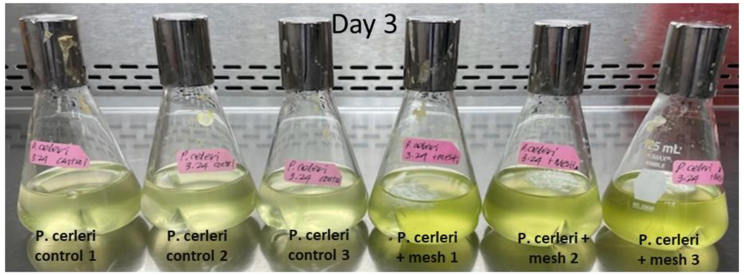
8 in diameter

SWT Mixing/Extrusion

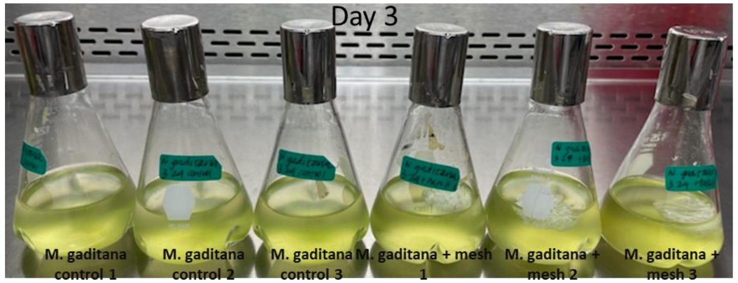
Composite roll

Subtask 2.1: Algal biocompatibility with Sorbent

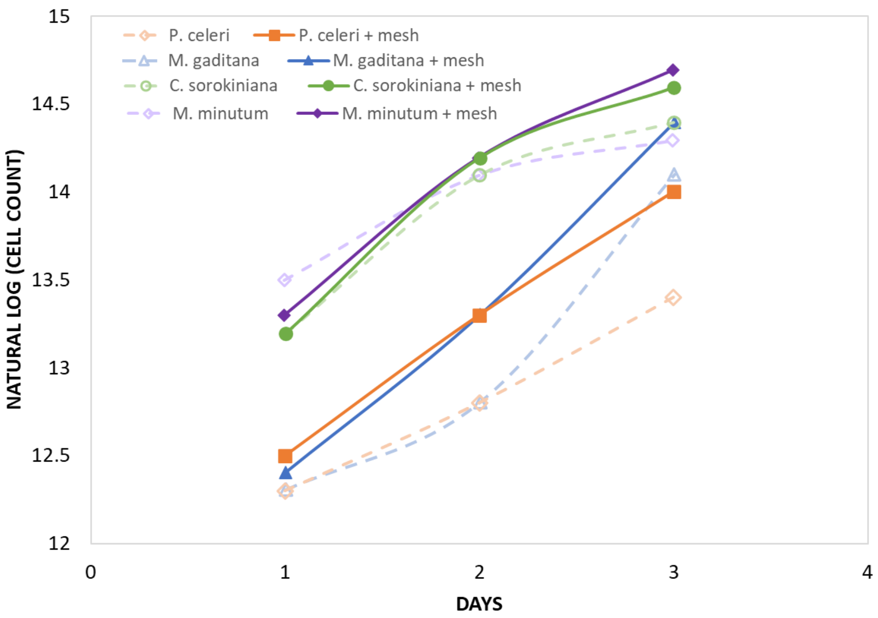
Picochlorum celeri (ESAW)



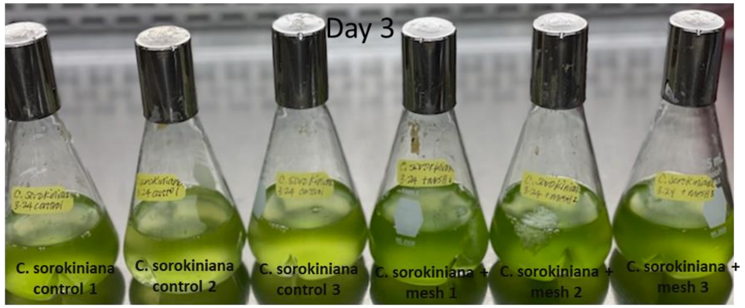
Microchloropsis gaditana (ESAW)



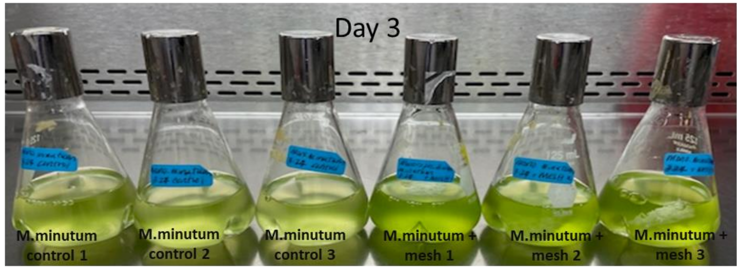
Algal strains cell count CO_2 sparging vs sorbent



Chlorella sorokiniana (fresh water, 5ppt salt)

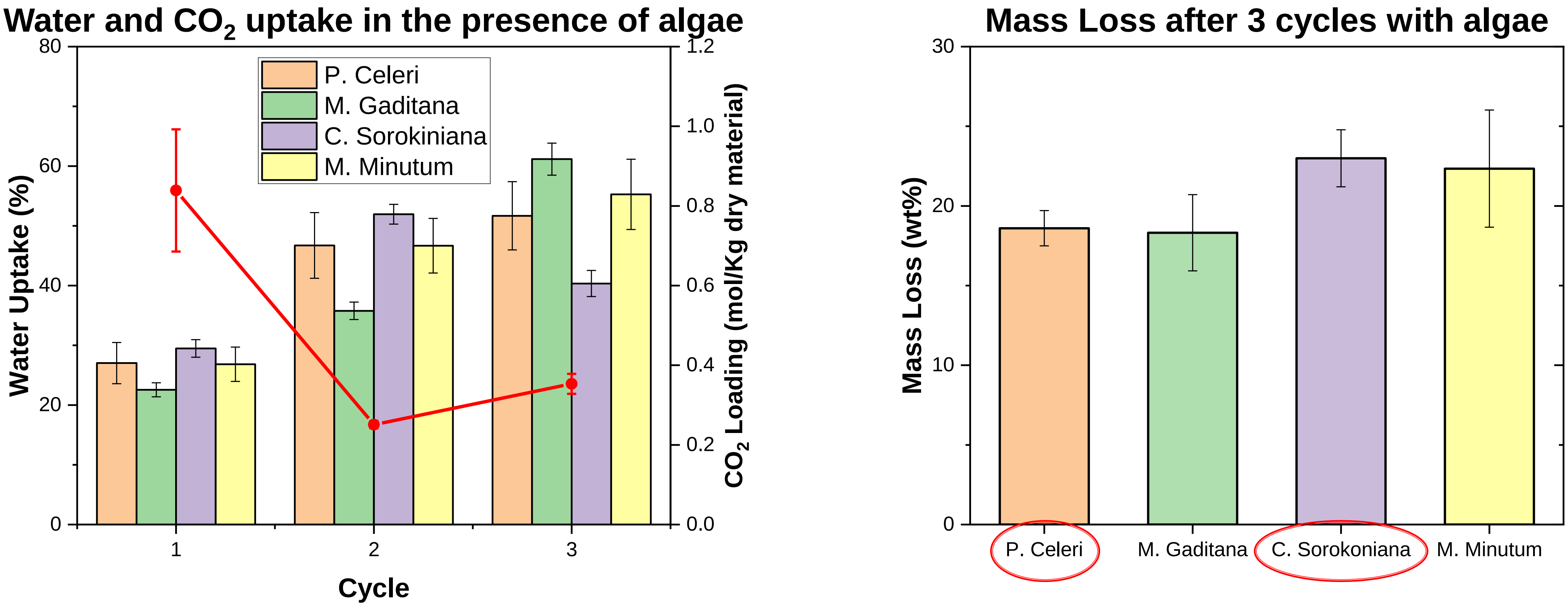


Monoraphidium minutum (fresh water, 5ppt salt)



All algal strains had higher cell count in the presence of composite sorbent compared with CO_2 sparging

Subtask 2.1: Algal biocompatibility with composite sorbent

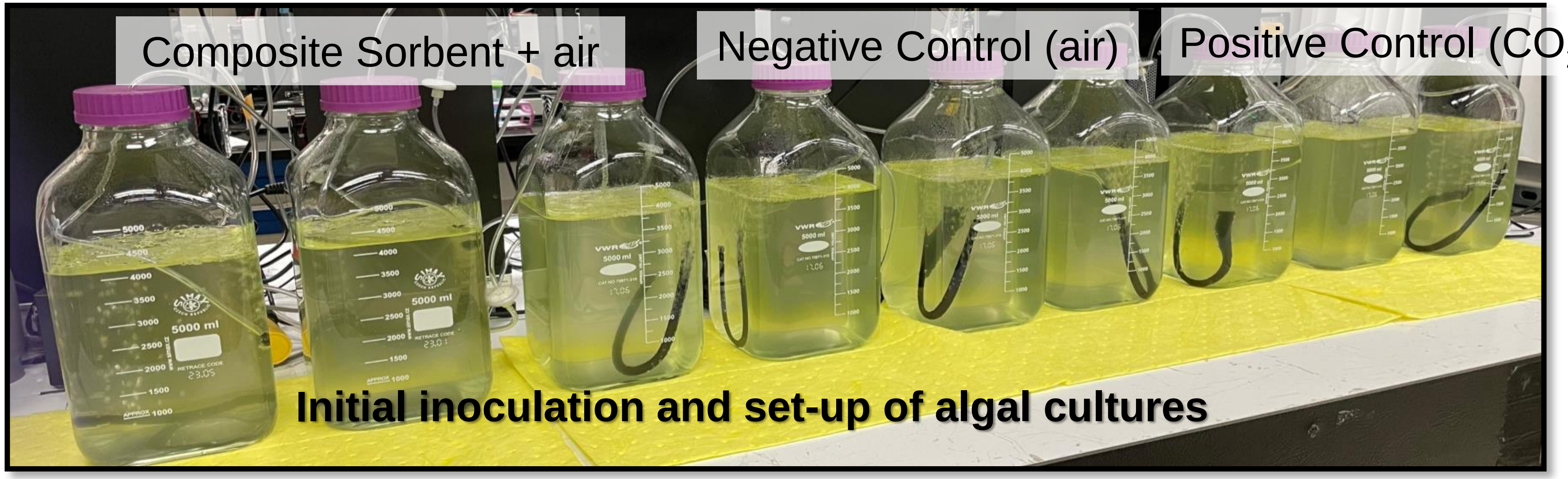


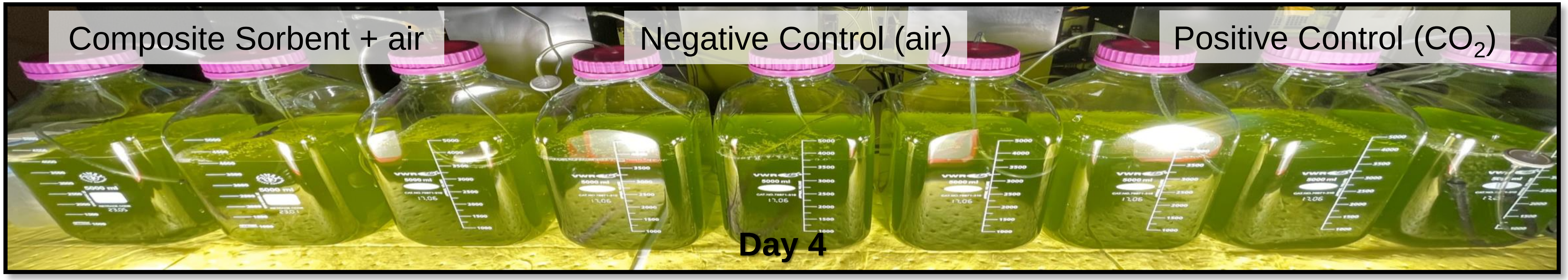
Absorption: 40 kPa CO_2 until equilibrium
Regeneration: algal culture ~7.5h rt

Cycle 1 initial CO_2 loading of the composite sorbent
Cycle 2 and 3 CO_2 loading after CO_2 desorption in algal cultures

Composite sorbent is more compatible with algal cultures grown in brackish water or higher salinity concentrations

Subtask 2.1: 4 L Picochlorum celery scale up with composite sorbent

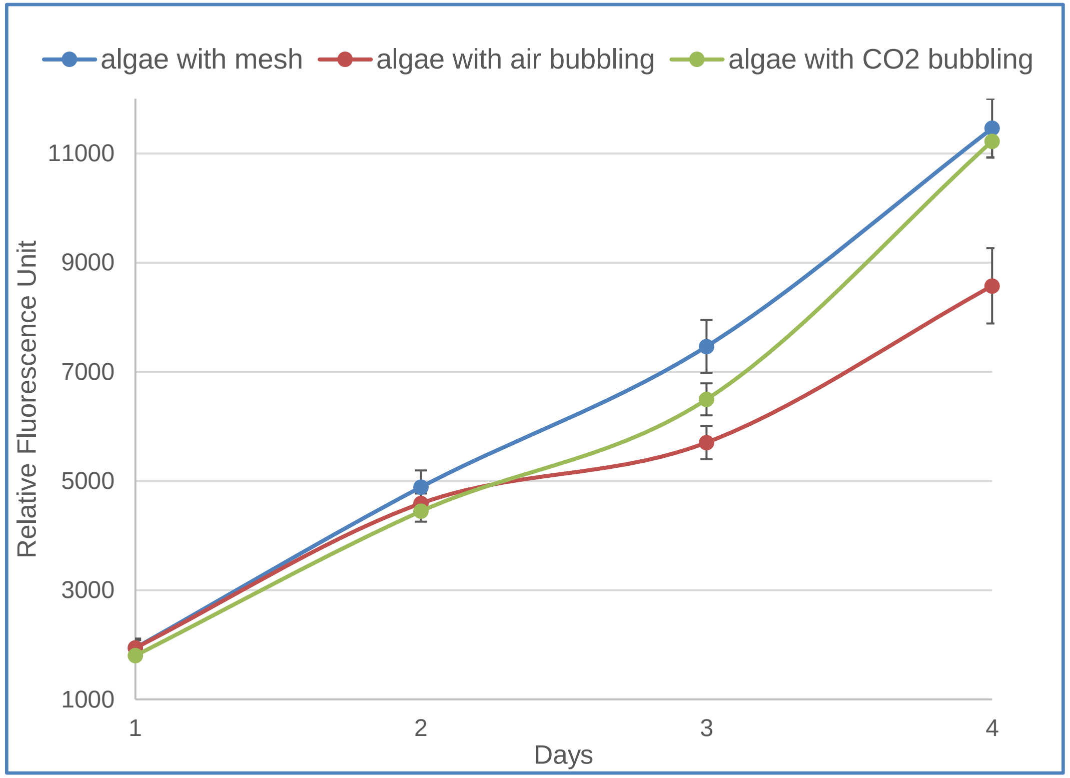




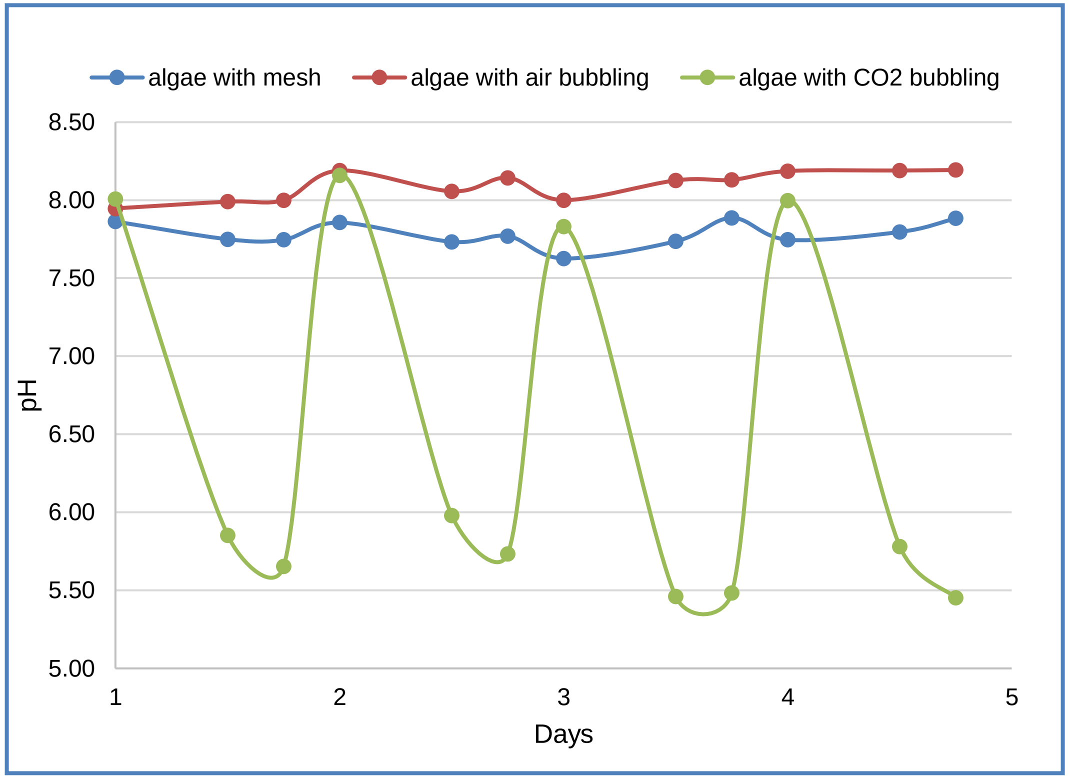
- 4 days, sampling twice a day for growth, pH, and total inorganic carbon
- **One composite in the morning and one in the afternoon** of ~2.7 g each per day

Subtask 2.1: 4 L Picochlorum celery scale up with composite sorbent

Cell Growth by Fluorescence



pH vs time



Aliquots of algal culture taken 3 times daily

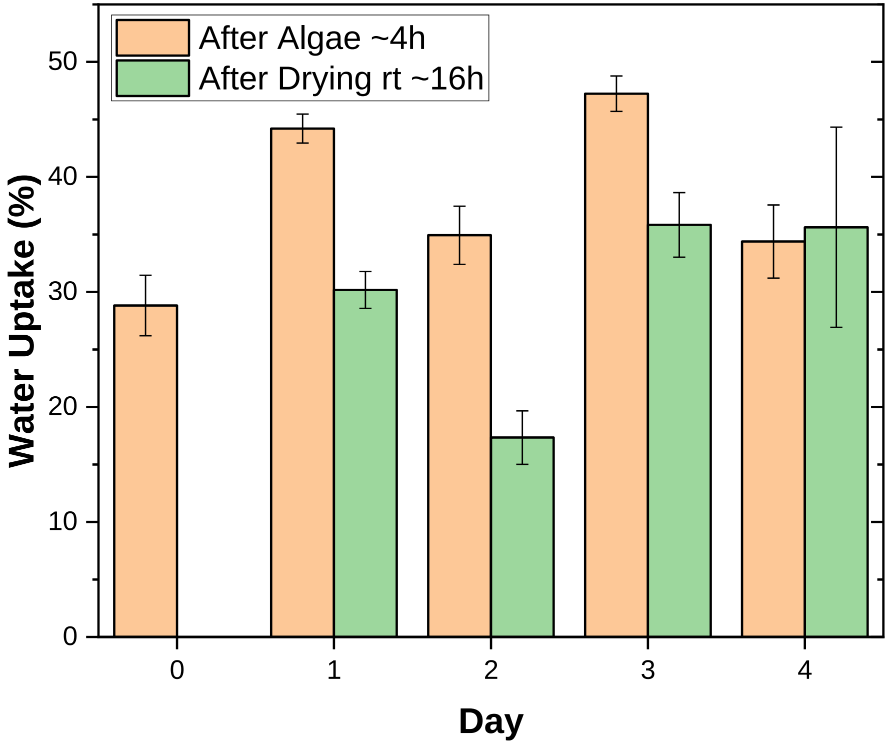
(1) Every morning after 12 hours without light. (2) After removal of first composite. (3) After removal of second composite

Algal cultures with composite and 5% CO_2 bubbling grew at similar rates, while negative control slower.

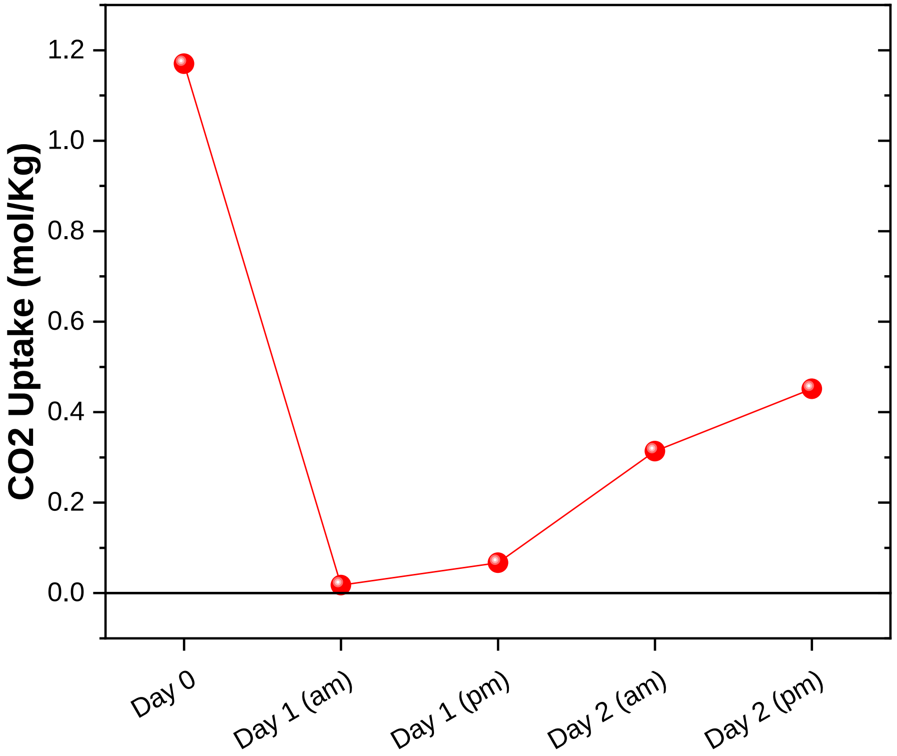
The composite maintained the pH of the algae culture ~7.78, while negative control pH ~8.1

Subtask 2.1: 4 L Picochlorum celery scale up with composite sorbent

Water uptake over time after exposure to algae and air-drying step at rt overnight



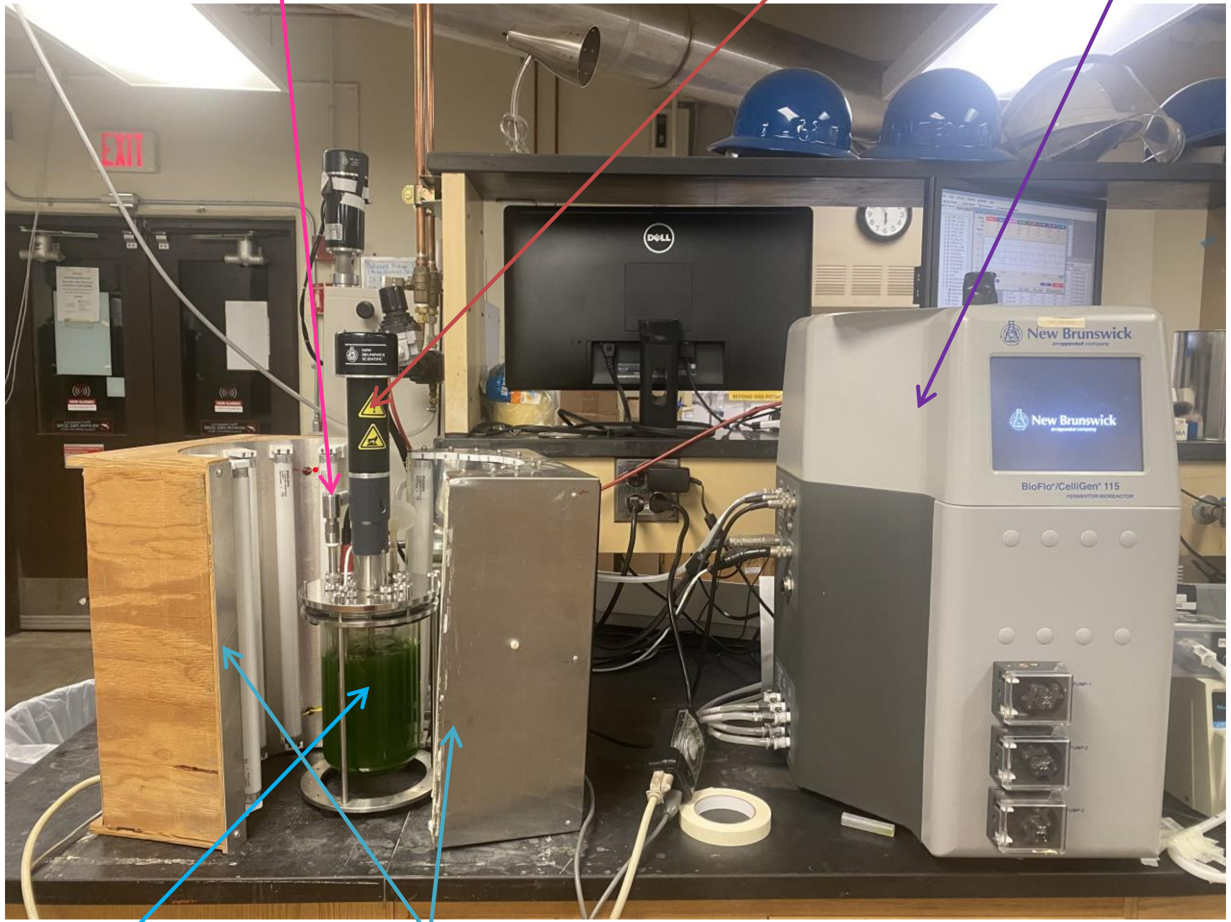
Composite sorbent CO_2 absorption after exposure to algae



Absorption: 40 kPa CO_2, 25C until equilibrium
Regeneration: 4h in algae cultures

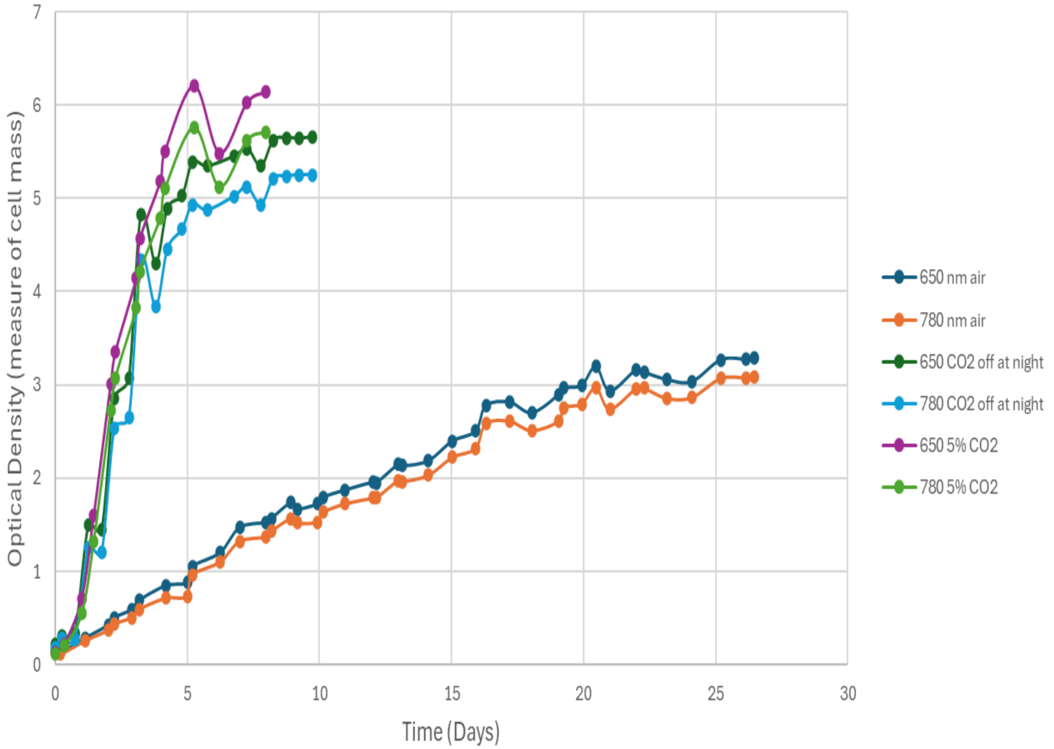
CO_2 uptake increases with cell growth, indicating successful CO_2 delivery from the composite and CO_2 consumption by the algae

Subtask 2.2: Grow Algal strain with simulated flue gas and high salt concentrations



Subtask 2.2: Chlorella Sorokiniana with simulated flue gas and high salt concentrations

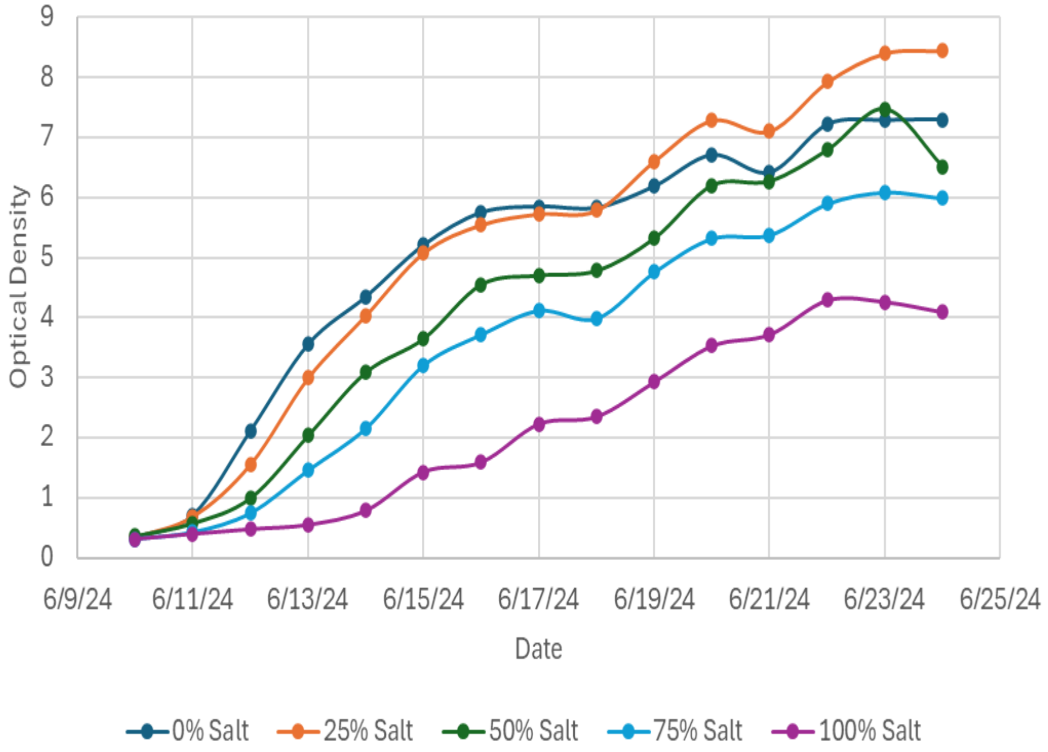
Air vs 5% CO_2 cultivation



650 nm measures the chlorophyll
780 nm is cell mass

Similar cell growth when CO_2 all day purging

Varying concentration of sea water



The 100% Salt is the same as ocean water

C. Sorokiniana similar cell growth rate up to 50% salt concentration.

Summary

- Proved cycling stability of sorbent over 16 without algae, 5 cycles with algae
- Scaled up composite sorbent to 10s of kilograms
- Scaled up algal cultures from 100 mL to 20L and tested ability of the composite sorbent to deliver CO_2 and control pH
- Successfully grow C. Sorokiniana with concentration up to 50% salt
- LLNL and SNL hosted two summer students, one from minority serving institution program (MSIIP) and from community collage intern program (CCIP)

Future Developments

- Perform 100 L algae + composite experiment
- Develop Thermodynamic, Kinetic and Mass Transfer Model
- Integrate ALBUS at TEP and scale up to 1000 L
- Produce algal biomass for diet study
- Develop TEA and LCA models

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Appendix

- Detailed team roles
- Organization Chart
- Gant Chart
- Milestone Timeline
- Success Criteria year 1
- Risk and mitigation strategy year 1

ALBUS Team

Key Personnel	Institution	Tasks	Title, Roles
T. Currin	SWT	Tasks 1,2,3,4,5,6,7	CEO, PI
M. Ceron Hernandez	LLNL	Tasks 2,3,7	Research Staff Scientist, LLNL PI
C. Santoyo	LLNL	Tasks 2,3	Staff Scientist, Composite Characterization
E. Johnson	LLNL	Task 3	MSIIP Summer Student, Composite scale up
T. Lane	SNL	Tasks 2,3	Research Staff Scientist, SNL PI
M. Tran-Gyamfi	SNL	Tasks 2,3	Technical Staff, Algae cultivation
S. Mengel	SNL	Task 2	CCIP Summer Student, 20L Algae + Composite experiments
K. Ogden	UA	Tasks 2,4,5,6	Professor, UA PI
E. Saez	UA	Tasks 4	Professor, thermodynamic, kinetic and mass transfer model
A. Martin	UA	Task 2	PhD Student, Piccolorium scale up.
Nik Gruber	UA	Task 2	MS Student, varying CO_2 concentrations to grow algae
Armeen Pajouyan	UA	Task 4	MS Student, initial modeling
Zoe Johnson	UA	Task 2	BS Student, varying salt concentrations and TIC analysis

ALBUS Organization Chart

Principal Investigator
Thomas Currin
SOUTHWEST Technologies, llc

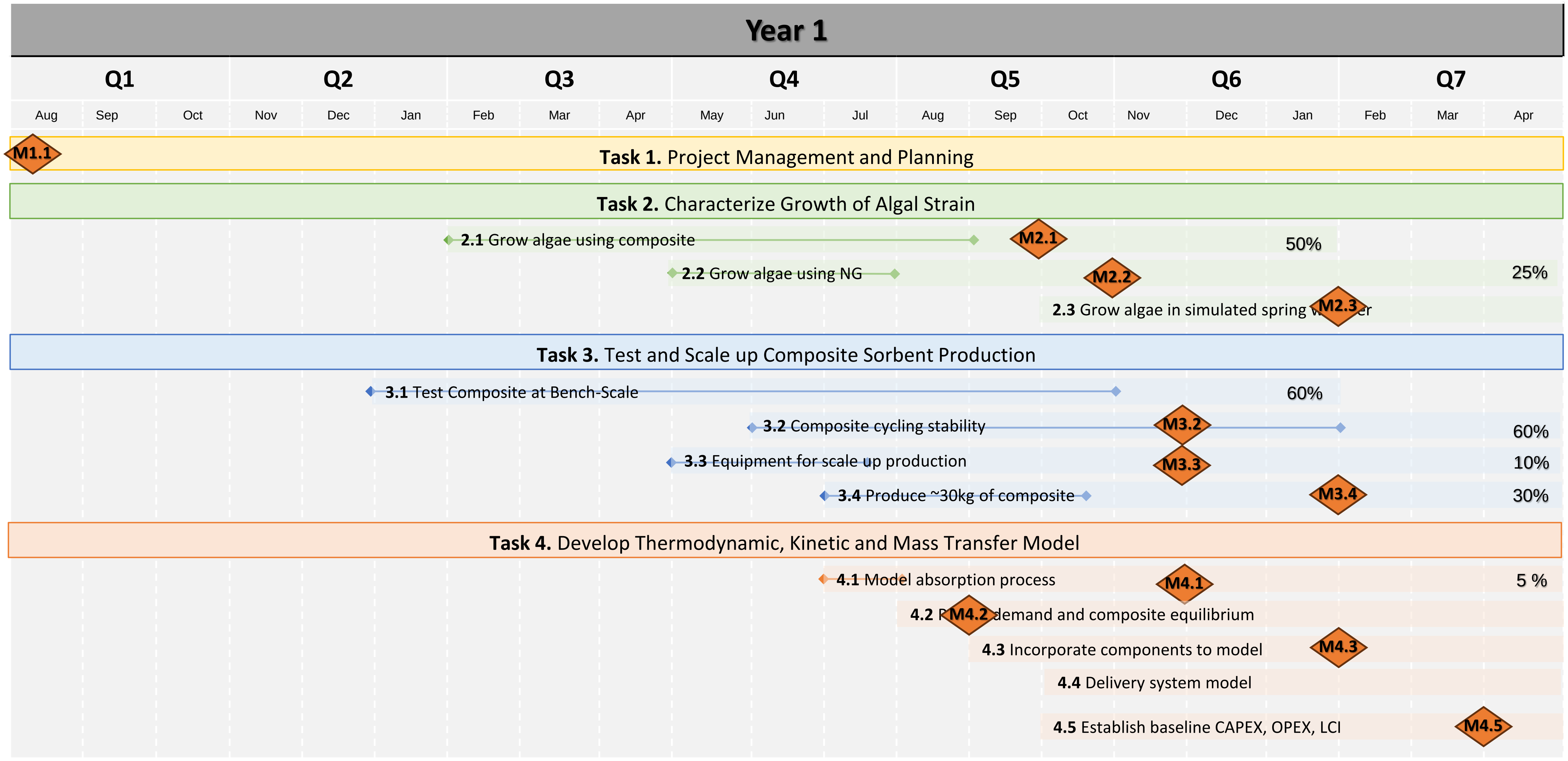
Task 1: Project Management and Planning
Task 2: Characterize and Growth of Algal Strain
Task 3: Test and Scale up Composite Sorbent Production
Task 4: Develop Thermodynamic, Kinetic and Mass Transfer Model
Task 5: Integrating ALBUS at TEP
Task 6: Production of Animal Feed Supplements
Task 7: Develop TEA and LCA models

K. Ogden
Task 2, 4, 5 & 6
The University of Arizona

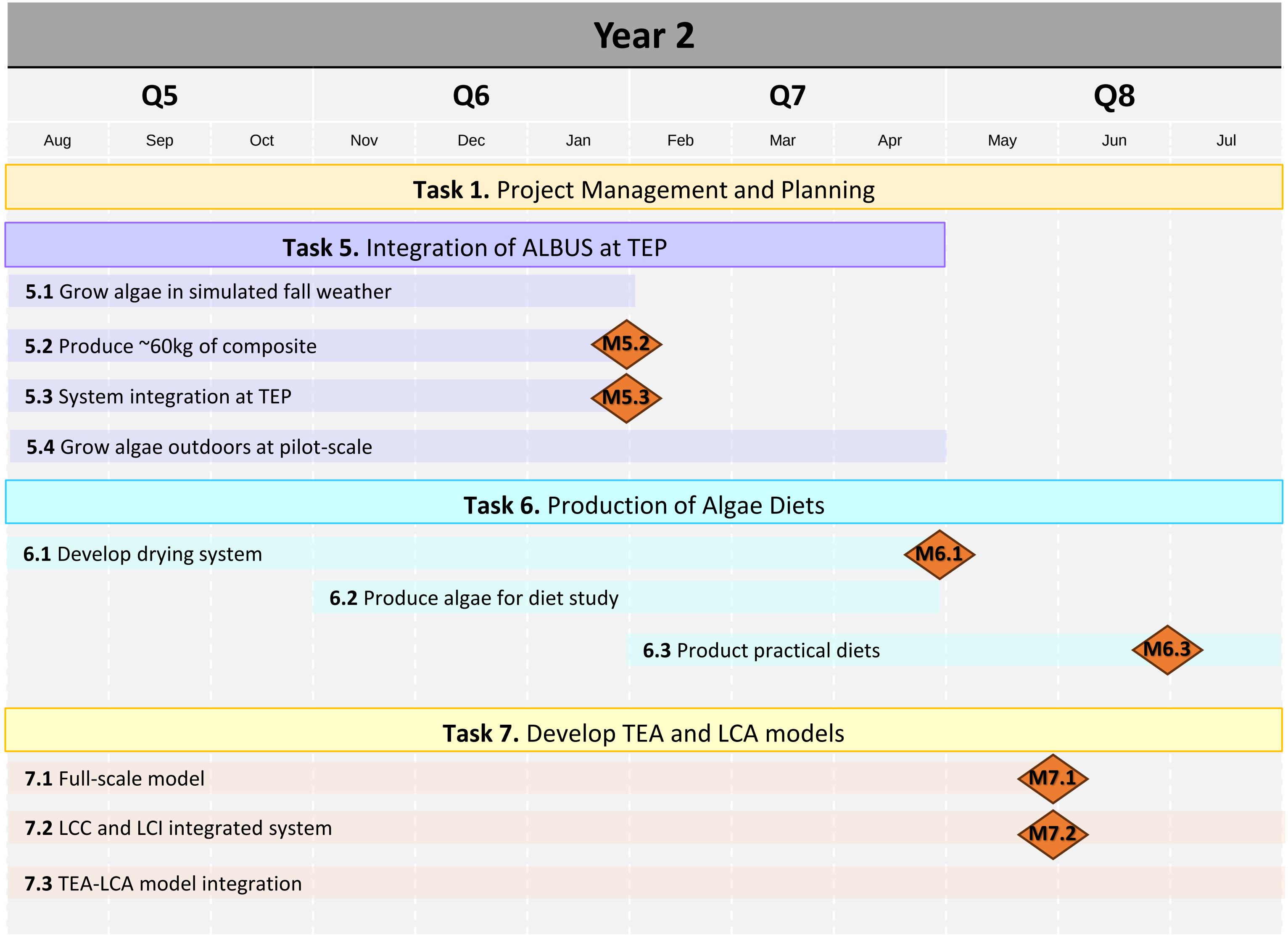
M. Ceron Hernandez
Task 2, 3 & 7
Lawrence Livermore National Laboratory

T. Lane
Task 2 & 3
Sandia National Laboratories

ALBUS Gant Chart Year 1



ALBUS Gant Chart Year 2



ALBUS Milestones Timeline

Tasks Name	Year 1												Year 2											
	Q1			Q2			Q3			Q4			Q5			Q6			Q7			Q8		
	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
Task 1. Project Management and Planning																								
M1.1 Project management plan (PMP)	■																							
Task 2. Characterize Growth of Algal Strain																								
M2.1 (SMART): Select one algae strain and their optimal media conditions														■										
M2.2: Determine baseline algal growth, and mass balances of N and S species.															■									
M2.3: Determine algae growth using sorbent-supplied CO_2.																		■						
Task 3. Test and Scale up Composite Sorbent Production																								
M3.2 (SMART): Demonstrate loading capacity of >70% over 30 days testing																■								
M3.3: Desing and build CO_2 absorption column and desorption spool-automated system.																■								
M3.4 (SMART): Produce ~ 30 kg of composite sorbent for indoor experiments.																		■						
Task 4. Develop Thermodynamic, Kinetic and Mass Transfer Model																								
M4.1: Define operating conditions and process design for sorbent loading																■								
M4.2: Determine effects of pH and CO_2 speciation on algae growth													■											
M4.3: Mass transfer model validated with experimental data.																		■						
M4.5: System mass transfer model validated with experimental data																				■				
Task 5. Integration of ALBUS at TEP																								
M5.2 (SMART): Produce ~ 60 kg of composite sorbent																		■						
M5.3: Integrate composite sorbent CO_2 absorption column/spool-automated delivery system at TEP																		■						
Task 6. Production of Shrimp Diets																								
M6.1 (SMART): Dry algae cultivated during the 30 days outdoor pilot-scale.																					■			
M6.3: Formulate dried algal meal.																								■
Task 7. Develop TEA and LCA models																								
M7.1: Develop models of integrated carbon capture/algal cultivation systems																							■	
M7.2: Validate cost and GHG models with data from fully integrated system																							■	

Success Criteria. Risk and Mitigation Strategies Year 1

- Demonstrate 10% increase in algae growth using CO_2 from composite sorbent vs CO_2 sparged cultures.
- Produce ~30 Kg of composite sorbent
- Implementation of sorbent spool-automated delivery system with 1000 L Testbed.

Risk	Mitigation Strategy
Building and installing CO_2 capture system at TEP power plant	Multiple sources of flue gas available to reroute slip streams
Scalability of composite sorbent	Leverage SWT and LLNL experience on material scale-up
Algal growth inhibition of trace contaminants in flue gas	Testing multiple strains at bench and slip stream scale.
Weather – Culture crashes	Maintain backup cultures, perform outdoor experiments during spring