Advanced Manufactured Carbonate Materials for Algal Biomass Production: Joint LLNL-SNL Program

NETL CO_2 Capture Technology Project Review Meeting

August 30, 2019

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Lawrence Livermore National Laboratory

Project Overview

Project: FWP-FEW0223

Project Period: 10/01/2017-12/31/2019

Funding:

	Government Share FY18	Government Share FY19
Lawrence Livermore National Laboratory	$390,000	$375,000
Sandia National Laboratory	$360,000	$350,000
Total	**$750,000**	**$725,000**

Objective: Develop and evaluate advanced manufactured carbonate materials for carbon capture, storage, and algal biomass production.

Project Tasks

FY18	Task 1	Project planning and management
	Task 2	Select the most promising material and geometry
	Task 3	Demonstrate CO_2 storage and delivery to support algal culture
	Task 4	Evaluate the economics and gate-to-gate GHG emissions
FY19	Task 5	Refine the material formulation
	Task 6	Scale-up synthesis, CO_2 loading, and delivery processes
	Task 7	Demonstrate scalability of material to sustain algal growth
	Task 8	Refine TEA and LCA of the system

Success Criteria FY19

July 1, 2019

Achieve a material loading capacity of at least 10 wt% CO_2

Sept. 30, 2019

Carbonate materials can be reloaded with CO_2 after use in algal cultures with less than 10% loss of CO_2 capacity over 10 cycles

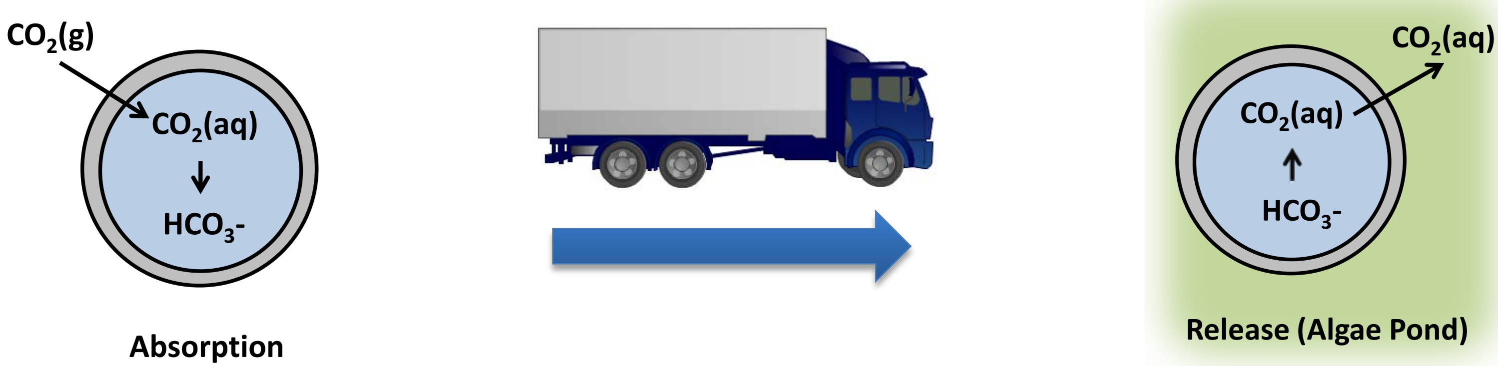
Oct. 31, 2019

Carbonate materials can support algal growth in indoor and outdoor conditions up to 20L scale for >24 hr

Dec. 31, 2019

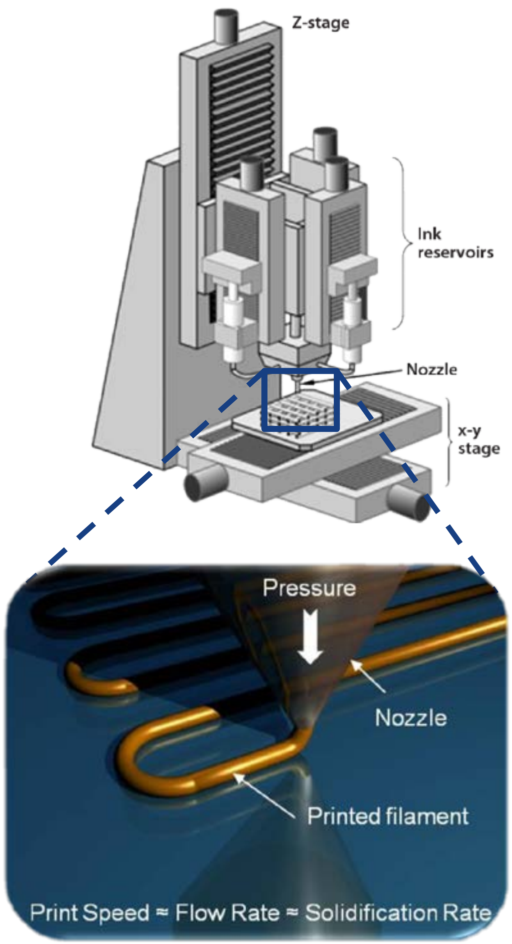
At 100-1000 L scale, carbonate materials can support the growth of algae at 80% productivity for one day-night cycle (24 hours)

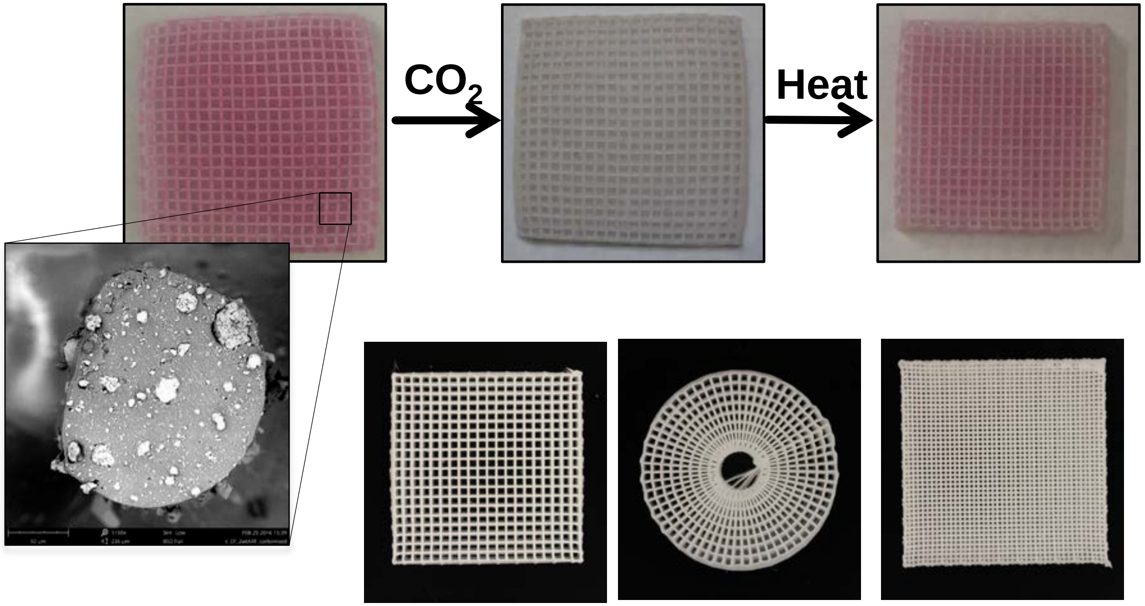
CO_2-loaded materials can be used for algae production



1) Provide tunable transport, storage, and delivery
2) Eliminate need to co-localize
3) Reduce capture costs up to 75%

Sorbent-polymer composites printed with Direct Ink Write (DIW)

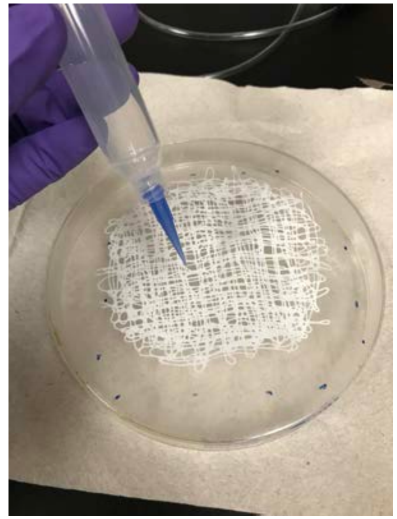




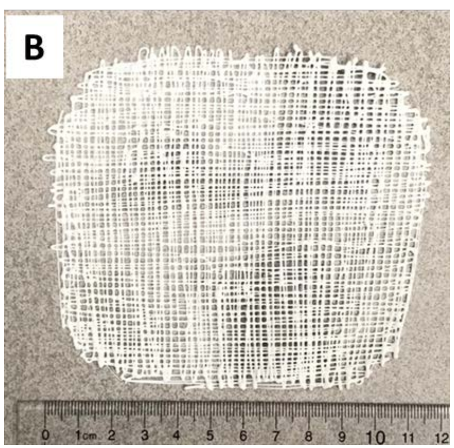
- Ink can be loaded with as much as ~60 wt% carbonate
- Particulate sizes sieved as small as possible for best performing ink

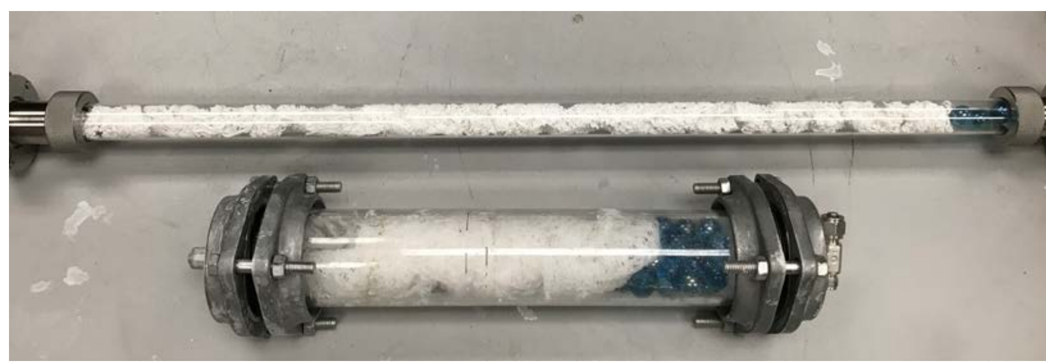
Scale up materials synthesis from grams

Hand extrusion
~10s grams

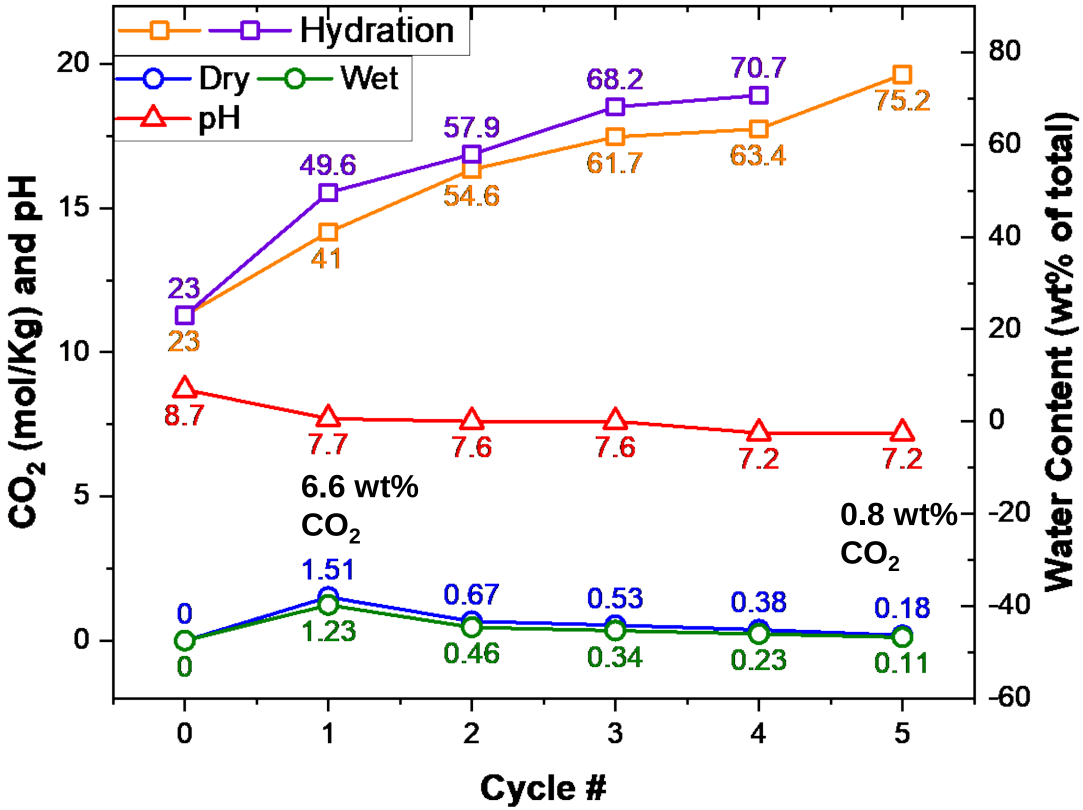


Power extrusion
kilograms



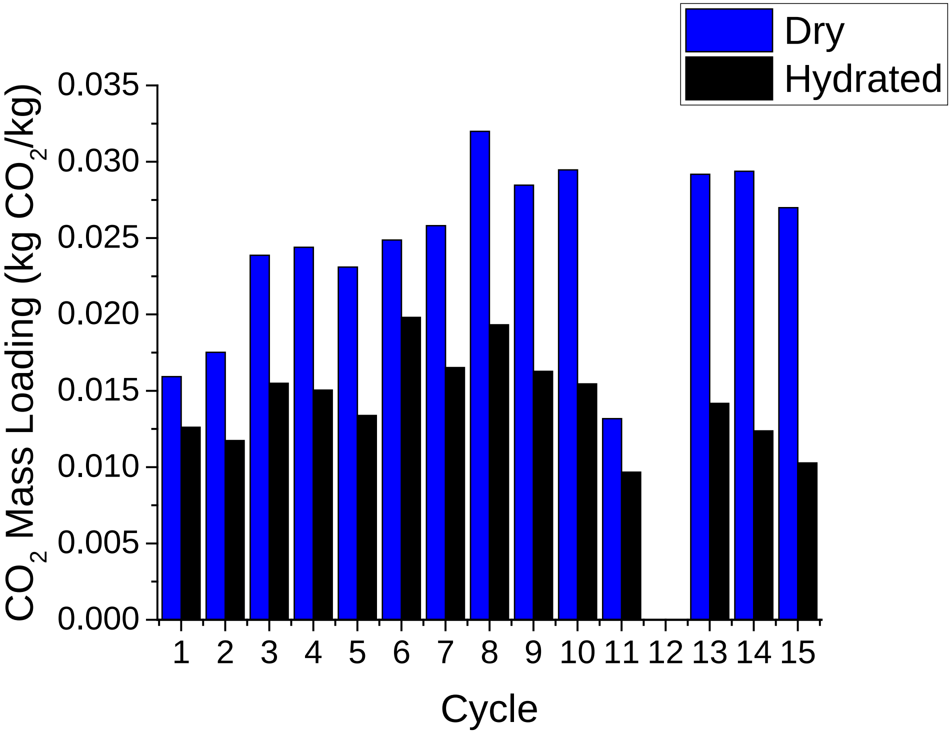


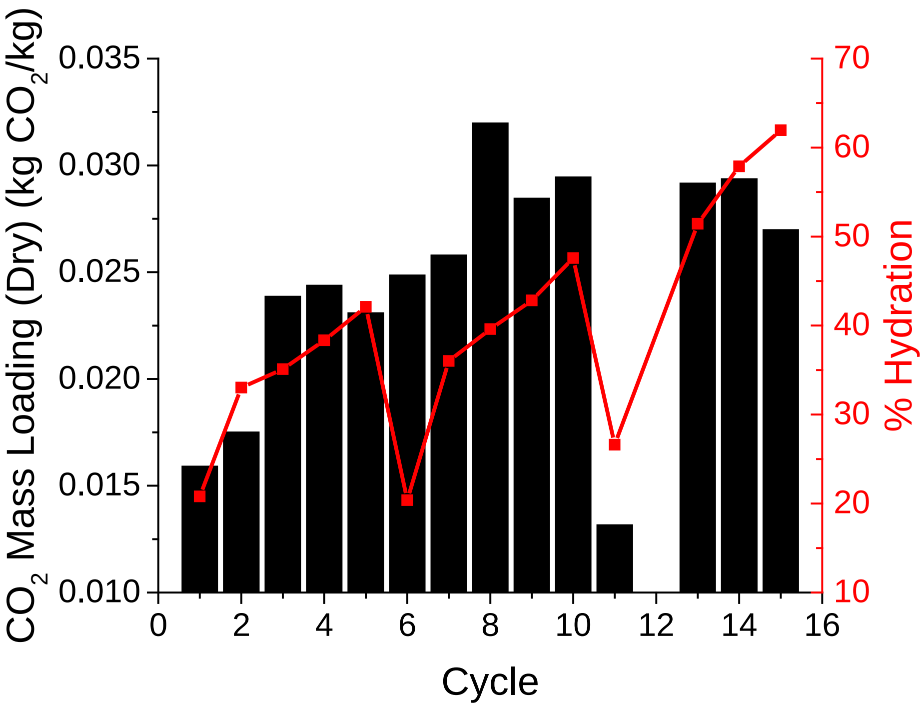
CO_2 capacity decreases across 5 cycles *without* algae



- 25% sodium carbonate, 52% SE-1700 + 23% Sylgard formulation
- Samples loaded in 100% CO_2
- Samples “regenerated” by soaking in media **without** algae
- **Samples were not adequately regenerated**

Constant CO_2 capacity across 15 cycles *with* algae

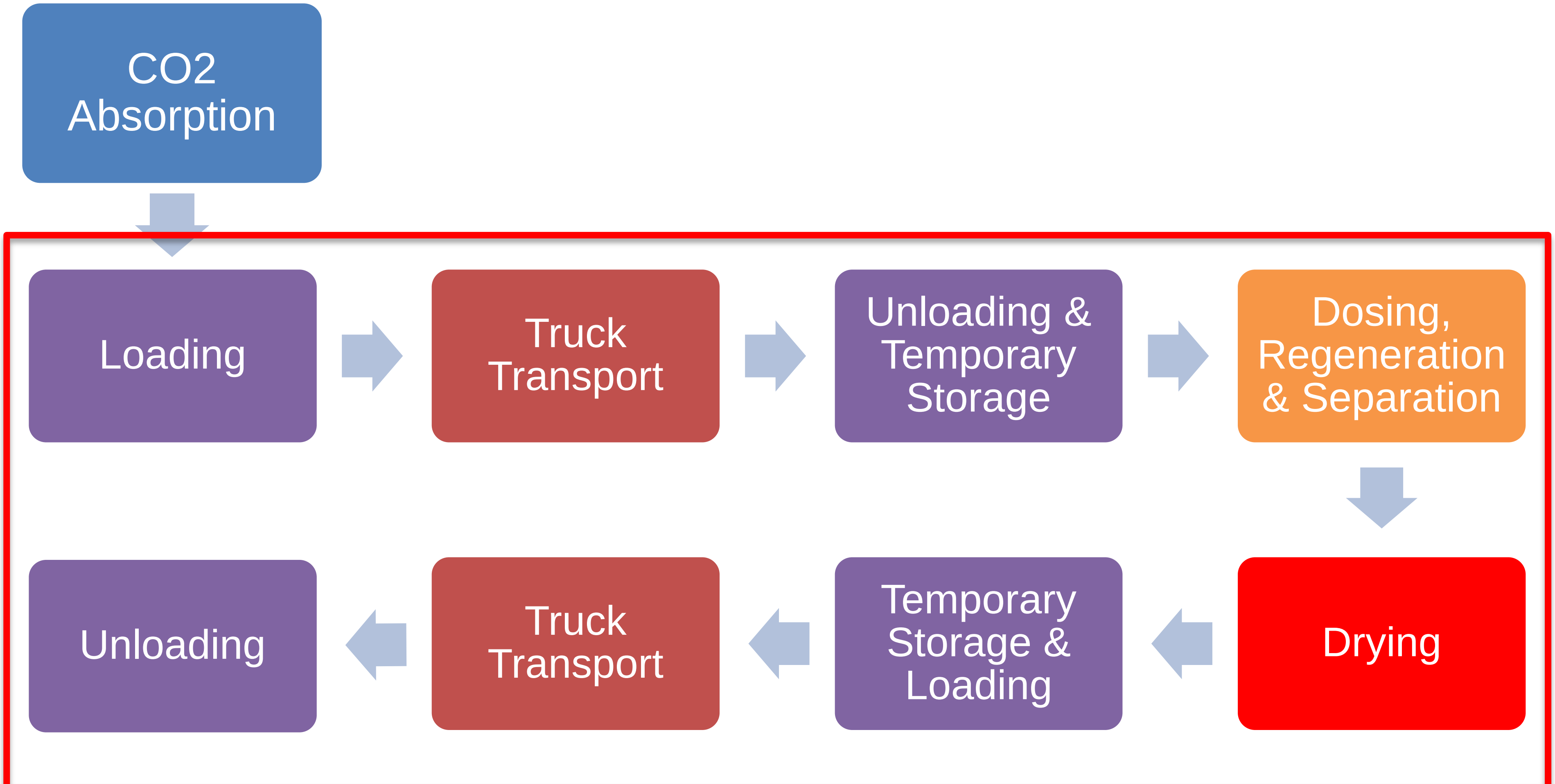




- 25% sodium carbonate, 52% SE-1700 + 23% Sylgard formulation
- Material loaded with 10% CO_2 in N2 for 1.5 hours
- Material regenerated in algal culture for 2 hours

CO_2 loading dependent on hydration and does not decrease over cycling

Process configuration for preliminary TEA of transport and delivery



Flow diagram of CO_2 delivery to algal farm

TEA model assumptions & results for transport and delivery

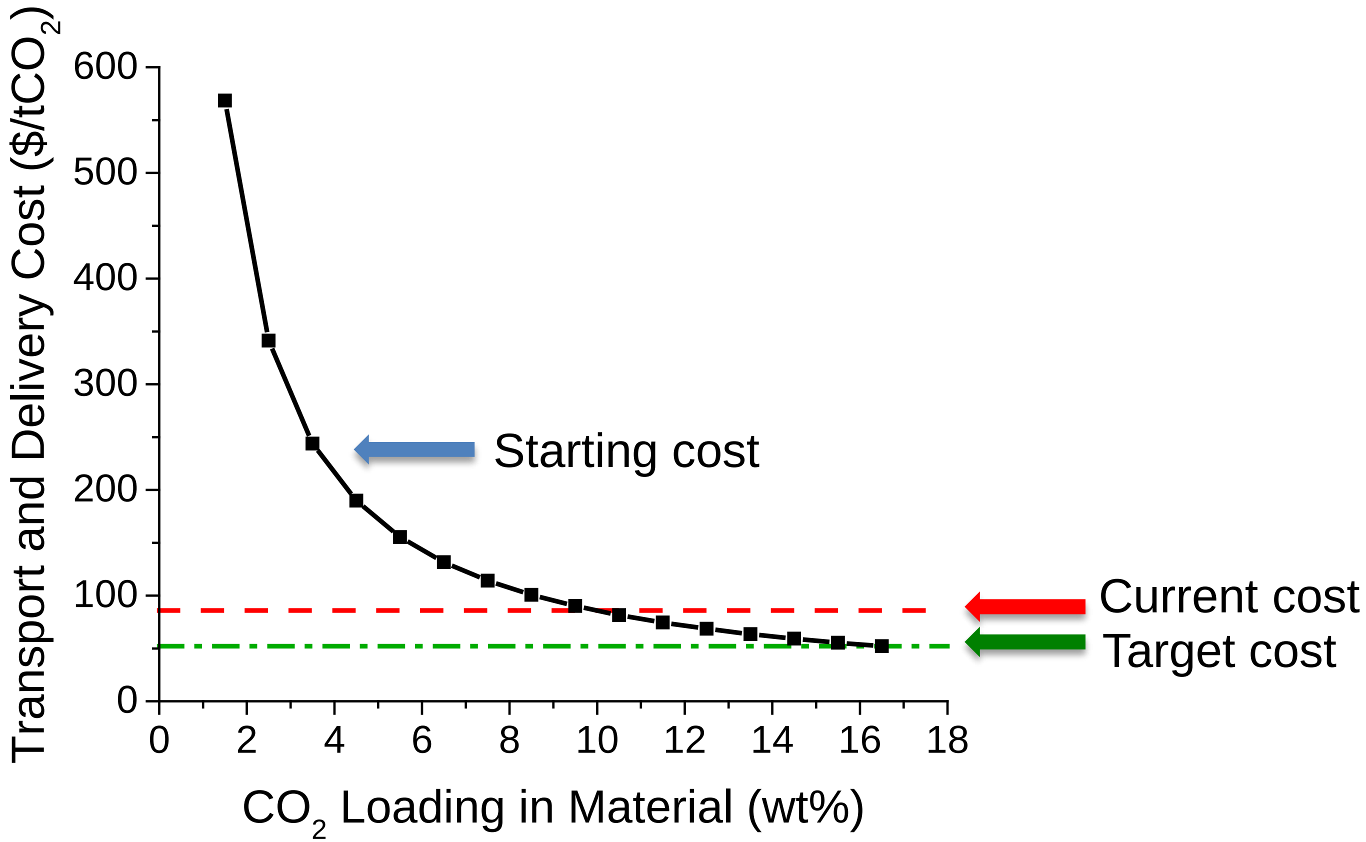
Assumptions:

- 5000 ac pond area
- 1,112 tons CO_2/daily
- **16.5 wt%** CO_2 loading in material
- Transported via motor transport 60 mi (one-way)

Stage	Cost ($/ton of CO_2 delivered)
Non-Fuel Transportation Cost	21
Fuel Transportation Cost	19
Storage Units Cost	0.19
Conveyors Cost	12
Total	$52/ton CO_2

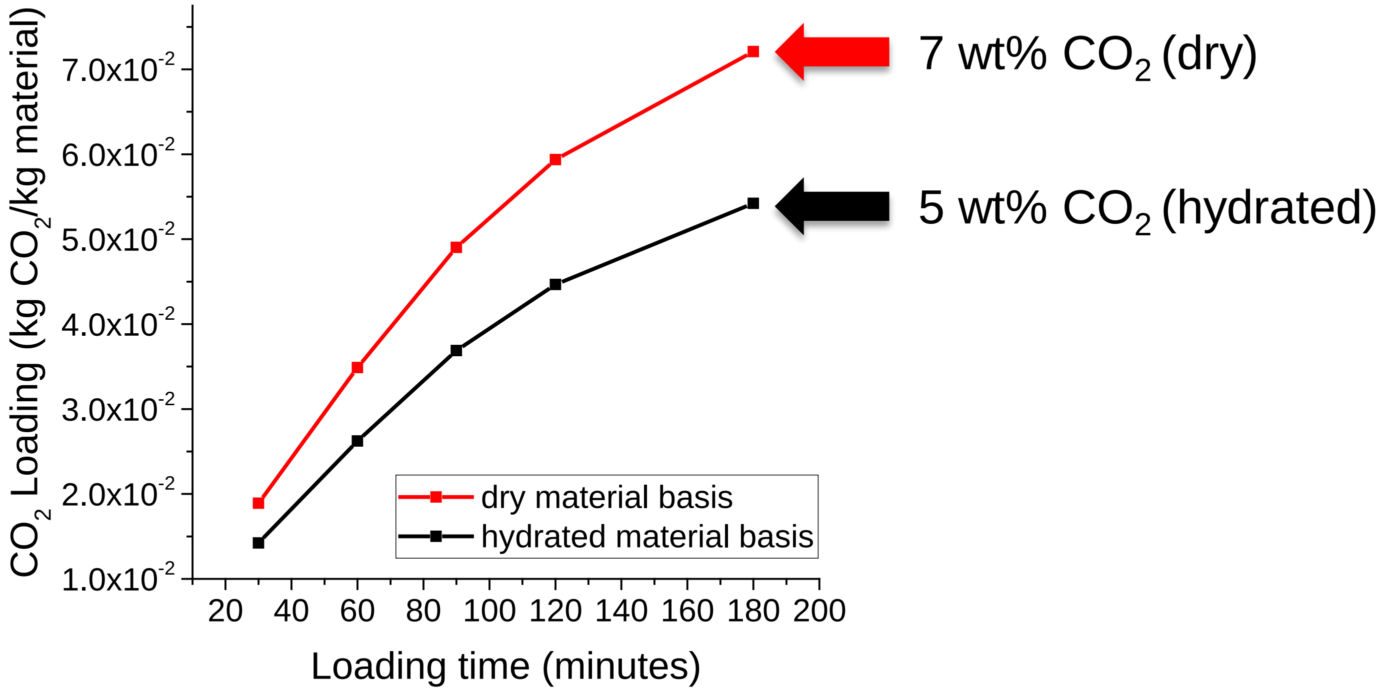
Target cost for transportation & delivery is $52/ton CO_2

Target cost of transport and delivery based on TEA



Transportation cost & delivery has been reduced by 60%

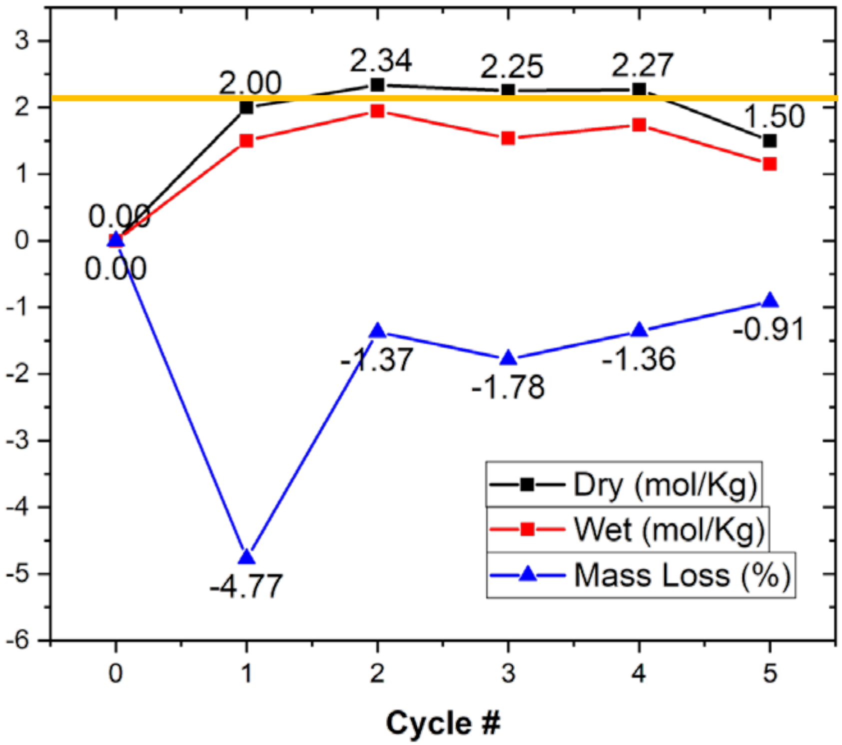
CO_2 loading in process-relevant conditions



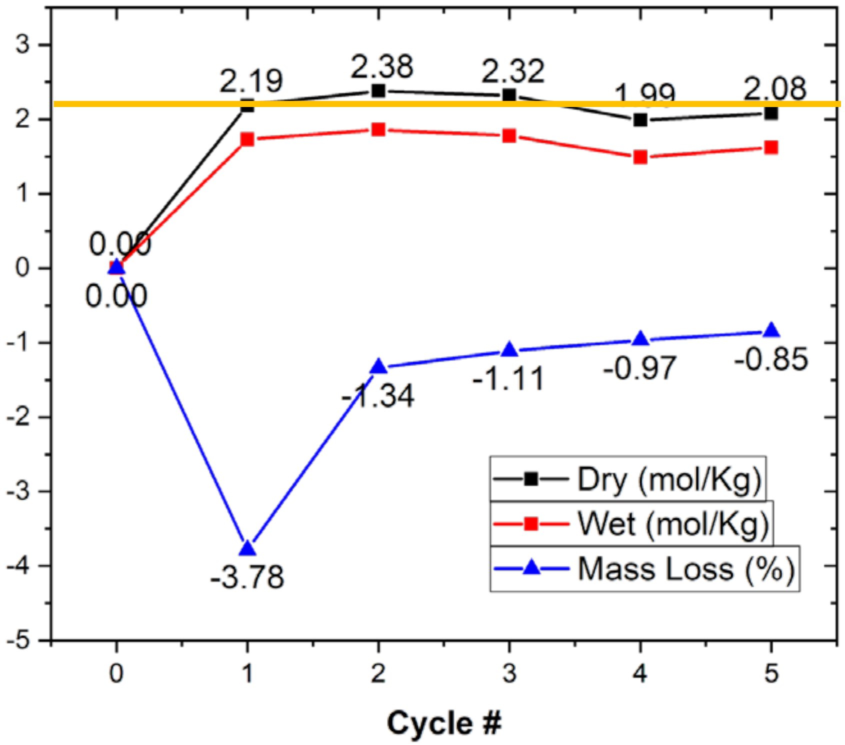
- **25% sodium carbonate**, 23% Sylgard, and 52% SE-1700
- 10% CO_2 with 87% relative humidity at 23°C

Loading rate slower than expected – can be tuned with filament size

Tune material formulation to increase CO_2 loading



40% Na2CO3 + **25% SE-1700 + 35% Sylgard**



40% Na_2CO_3 + **35% SE-1700 + 25% Sylgard**

Orange line meets 10 wt% CO2 loading

Stability of CO_2-loaded material

CO_2 loading and hydration of samples stored in **2L** containers for 20 days

Condition	% CO_2 "lost"	% Hydration after incubation
35C with media	32.72	40.13
35C with media	55.30	52.72
RT with media	12.58	31.59
RT with media	13.29	29.55
RT	6.50	11.40
RT	3.05	12.12
35C	55.90	21.59
35C	53.37	14.63

Samples stored at room temperature lost <10% of the loaded CO_2

Stability of CO_2-loaded material

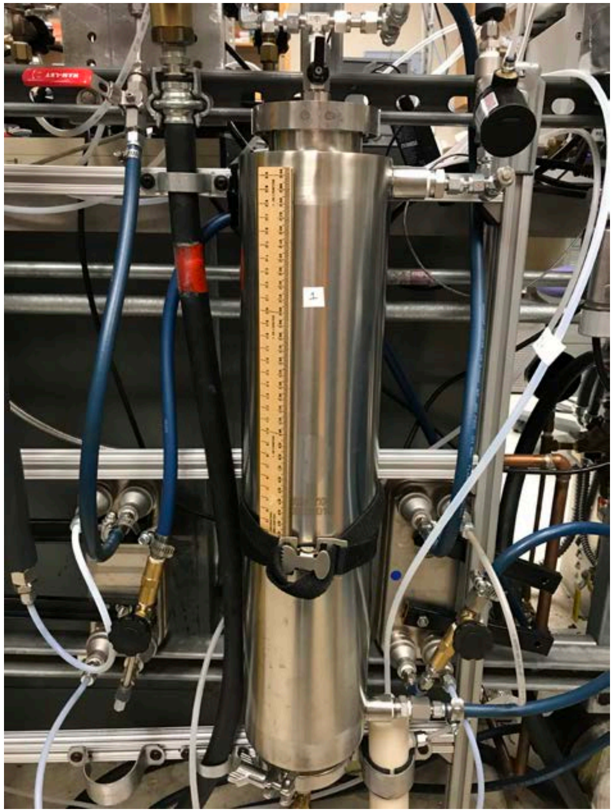
CO_2 loading and hydration of samples stored in **50 ml** containers for 14 days

Condition	% CO_2 "lost"	% Hydration after incubation
RT	8.3	15.7
RT	9.2	15.1
RT	5.3	11.9
RT	11.9	17.9
35C	10.5	24.58

Samples stored at room temperature lost <10% of the loaded CO_2

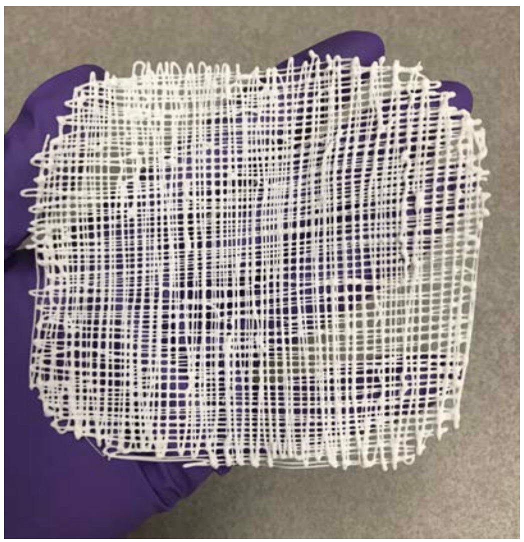
Scale up CO_2 loading from column to 2L reactor

Small absorption column
~50 g material



Larger, automated absorption column
~300 g material

Measure CO_2 delivery to algal cultures

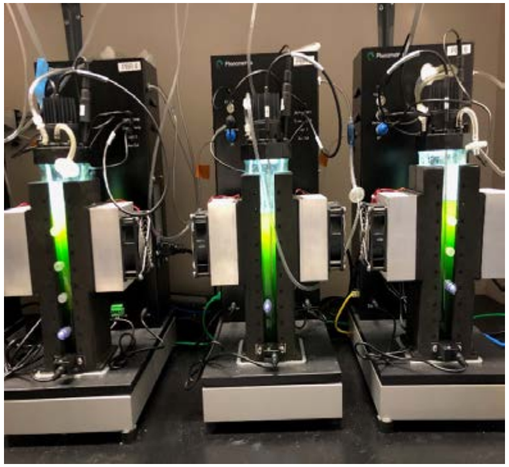


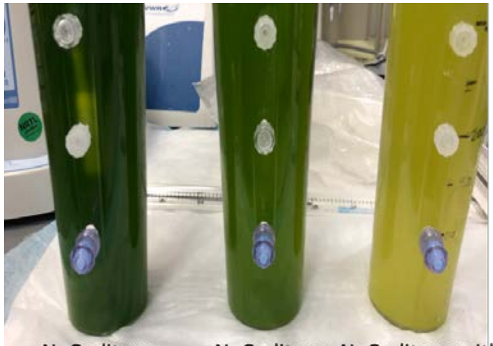
Measure pH of culture every 30 minutes

Dose the culture with CO_2 loaded material every 2 hours

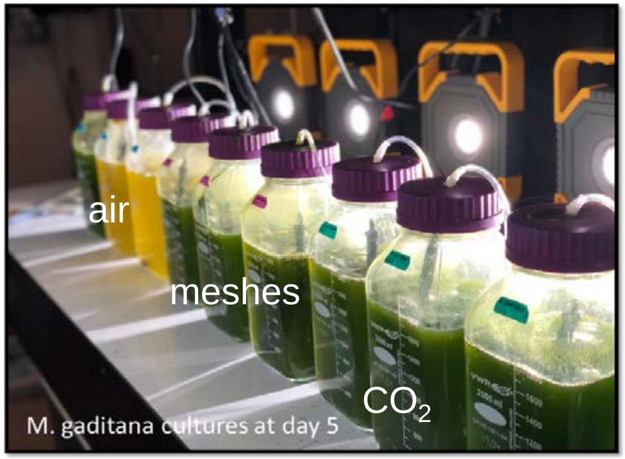
Scale up cultures from 500 mL to 4L

500 mL | **2L** | **4L**

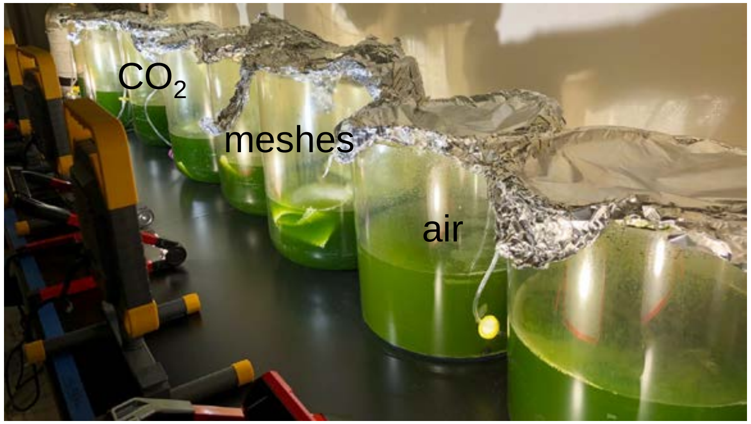


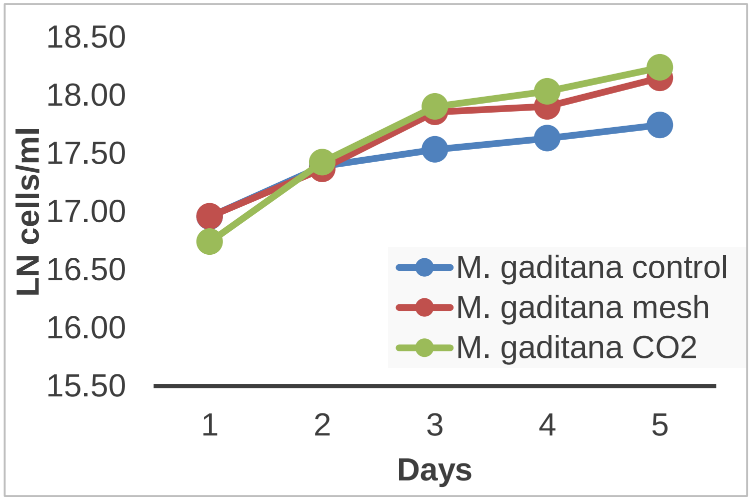


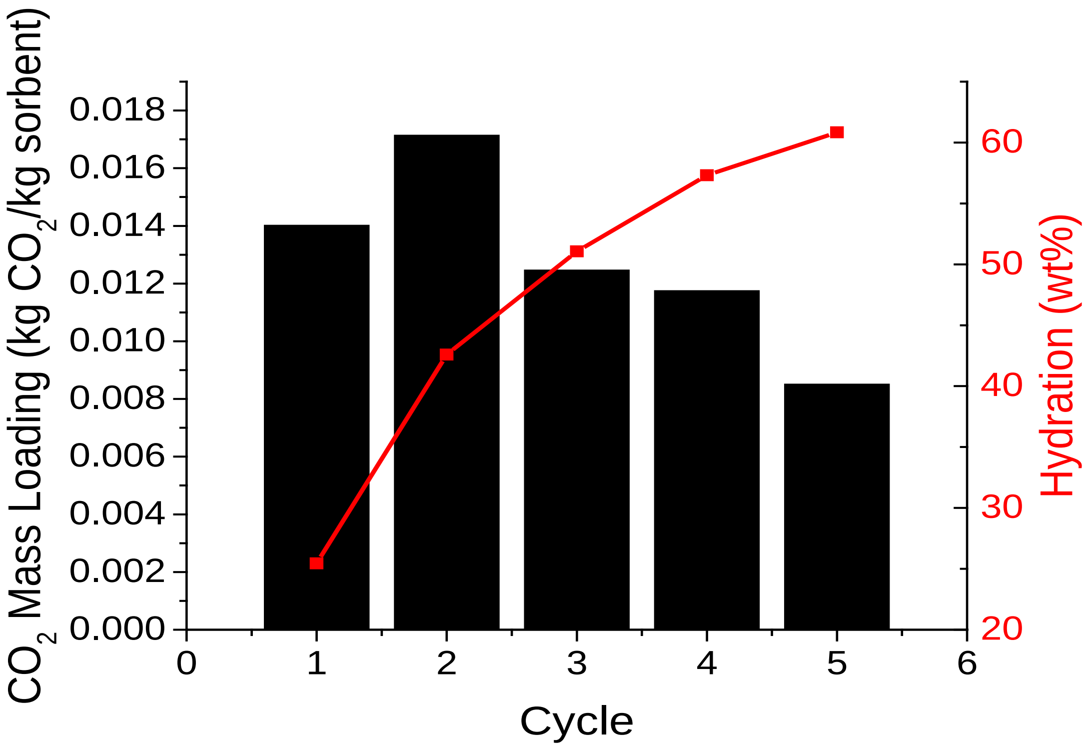
N. Gaditana with the addition of CO_2 gas | N. Gaditana with mesh addition | N. Gaditana with No CO_2 addition



8 L algal cultures



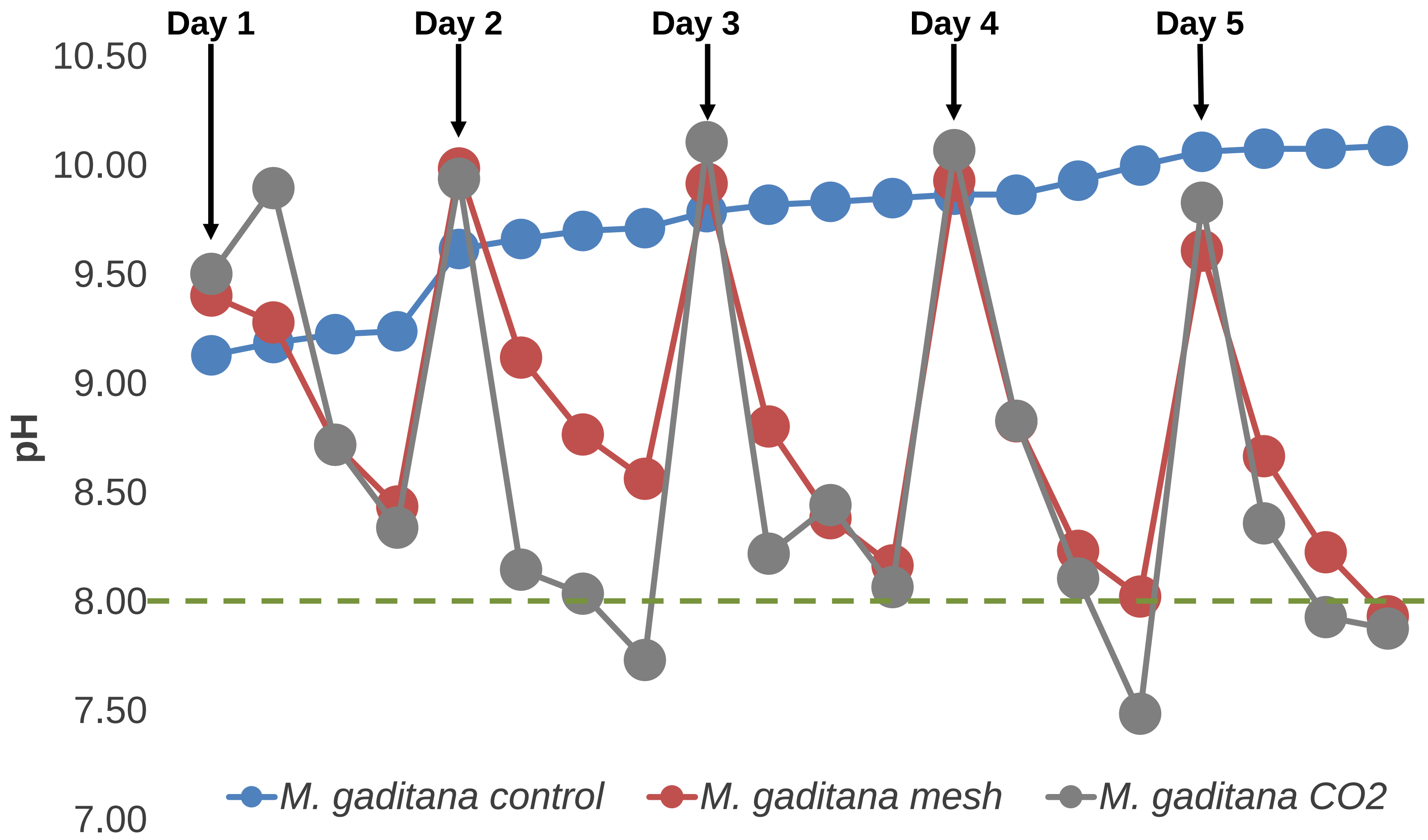




~1.2 wt% CO_2 loading, 30-60 wt% hydration

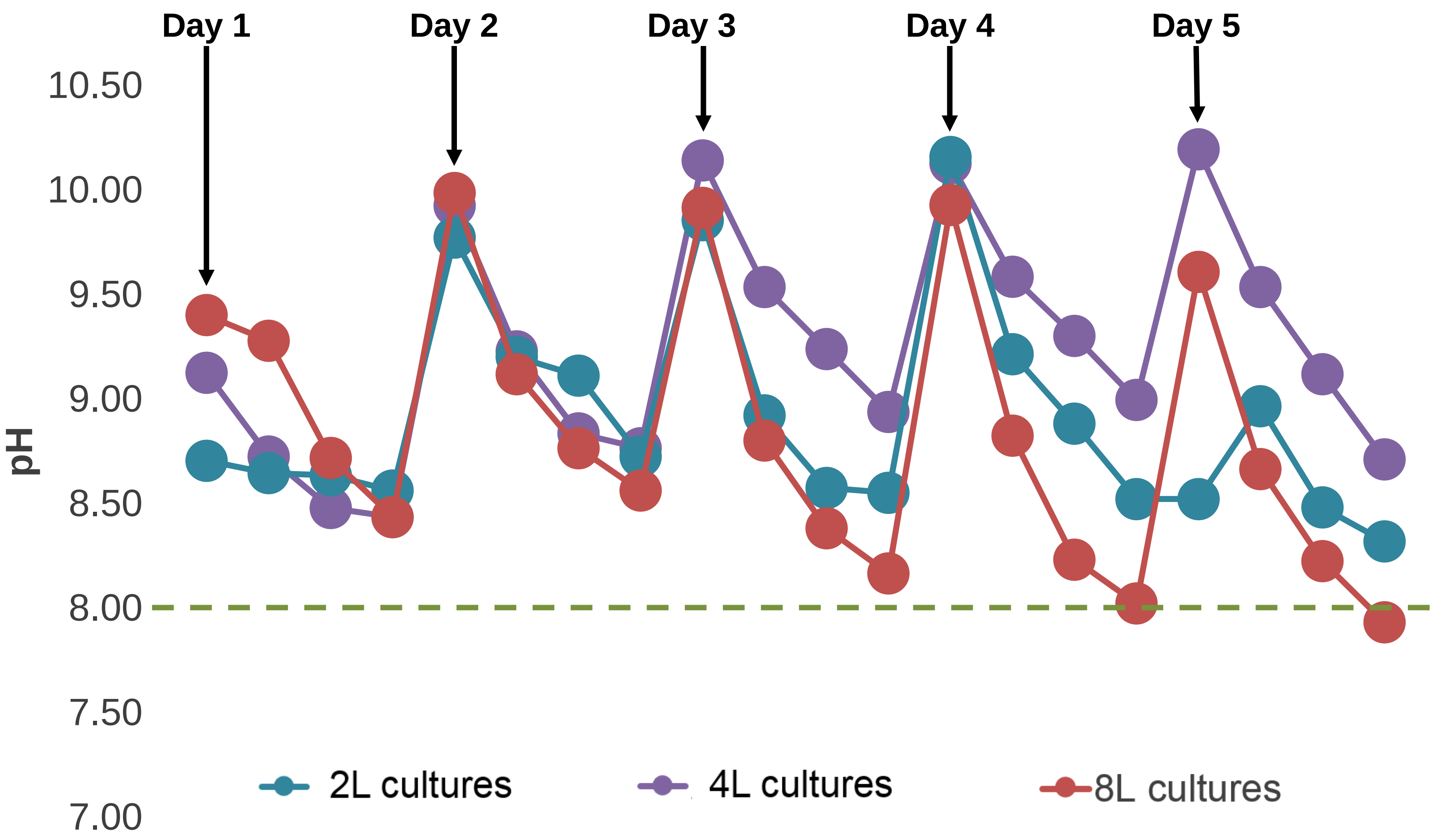
Hydration increases over 5 cycles, but mass of CO_2 loaded is constant

pH response of 8L cultures



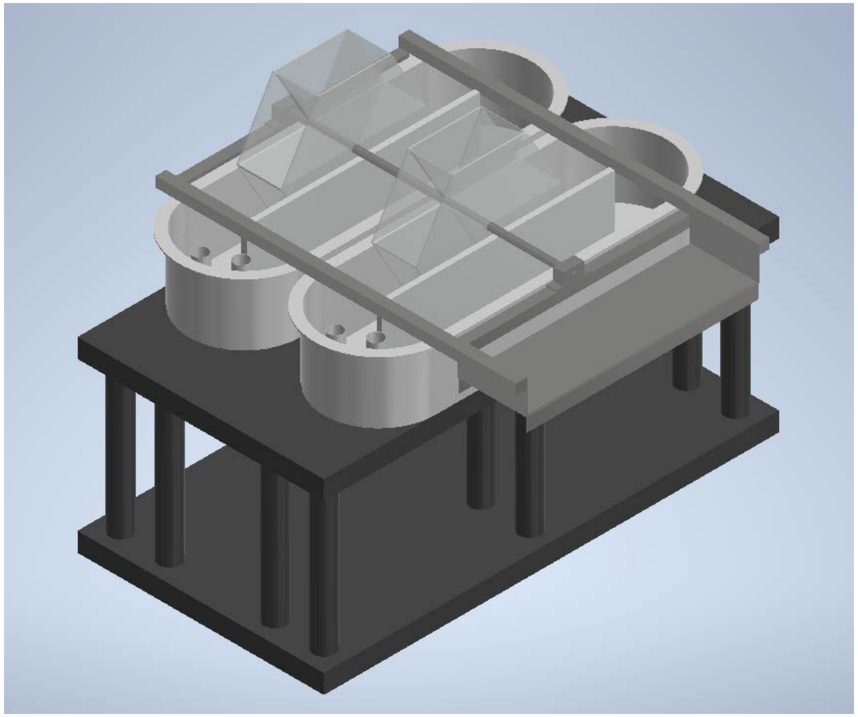
pH profile of cultures with meshes matches that of positive control

pH response from 2-8 L scale up

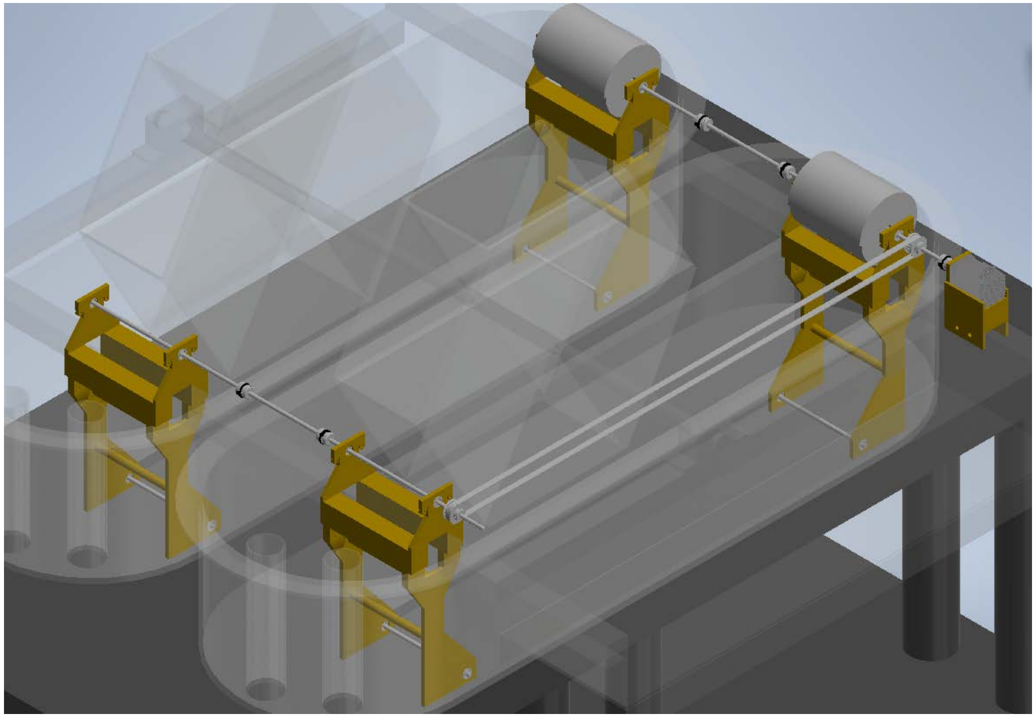


Dosing of cultures did not scale linearly with culture volume

Develop scalable delivery method to raceways



Drawing of 100L raceways



Design for roll-to-roll automated delivery system

Design for delivery system is being finalized

Remaining tasks

- Install power extruder to scale production to kilograms
- Scale algal cultures to 20L and 100L
- Build an automated material delivery system for 100L raceways
- Complete TEA/LCA based on experimental data from scale up studies

Summary

- Synthesis was scaled up to 100s of grams
- Formulation was tuned to achieve 10 wt% CO_2 loading
- CO_2-loaded material loses <10% of CO_2 over 2 weeks at room temperature
- CO_2-loaded material controls pH of algal cultures and retains loading capacity over cycling
- We have scaled our benchtop algal cultures from 0.5L to 8L and tested ability of the material to deliver CO_2 and control pH

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