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

NETL CO_2 Capture Technology Project Review Meeting

August 16, 2018

LLNL: Jennifer Knipe, Sarah Baker, Maira Ceron-Hernandez, Matthew Worthington, Sean McCoy, William Bourcier

SNL: Todd Lane, Mary Tran-Gyamfi

DOE NETL Project Manager: Andrew Jones

LLNL-PRES-756481

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

Budget - 1 year FWP 10/1/17-9/30/18

	Government Share
Lawrence Livermore National Laboratory	$390,000
Sandia National Laboratory	$360,000
Total	**$750,000**

	Lawrence Livermore National Laboratory - Fiscal Year 1							
	10/01/2017 - 12/31/2017		1/1/2018 – 3/31/2018		4/1/2018 – 6/30/2018		7/1/2018 – 9/30/2018	
	Q1	Total Project	Q2	Total Project	Q3	Total Project	Q4	Total Project
Federal Share	$112,500	$112,500	$92,500	$205,000	$92,500	$297,500	$92,500	$390,000
Total Planned	$112,500	$112,500	$92,500	$205,500	$92,500	$297,500	$92,500	$390,000

	Sandia National Laboratory - Fiscal Year 1							
	10/01/2017 - 12/31/2017		1/1/2018 – 3/31/2018		4/1/2018 – 6/30/2018		7/1/2018 – 9/30/2018	
	Q1	Total Project	Q2	Total Project	Q3	Total Project	Q4	Total Project
Federal Share	$90,000	$90,000	$90,000	$180,000	$90,000	$270,000	$90,000	$360,000
Total Planned	$90,000	$90,000	$90,000	$180,000	$90,000	$270,000	$90,000	$360,000

Project Objectives

Task 1

Project planned and managed by Lawrence Livermore National Laboratory

Task 2

Select the most promising material and geometry

Task 3

Demonstrate CO_2 storage in materials and delivery to support algal culture in an algal test bed at pilot scale

Task 4

Evaluate the economics and gate-to-gate GHG emissions of the coupled capture-transport

Milestone Schedule

Task	Milestone Description	Project Duration Start: October 1, 2017 End: September 30, 2018				Planned Start Date	Planned End Date
		Project Year (PY) 1					
		Q1	Q2	Q3	Q4		
1.0	Project Management and Planning					1-Oct-17	30-Sept-18
2.1	Synthesize multigram quantities of carbonate materials	x				1-Oct-17	15-Nov-17
2.2	Measurements of CO_2 release rates and quantities	x				1-Oct-17	31-Dec-17
2.3	Materials Biocompatibility Evaluation		x			1-Oct-17	30-Jan-18
2.4	Materials Selection for scale-up and TEA		x			1-Feb-18	31-Mar-18
3.1	Material delivery method determined			x		1-Apr-18	30-Jun-18
3.2	Scaleup materials synthesis to kg scale				x	1-Apr-18	30-Sep-18
3.3	Pilot scale testing				x	1-Apr-18	30-Sep-18
3.4	Measure material capacity during cycling				x	1-Aug-18	30-Sep-18
4.1	Identify Process Configurations for capture, transport, delivery		x			1-Oct-17	30-Mar-18
4.2	Refine Process Configuration and cost model				x	1-Apr-18	30-Aug-18
4.3	Finalize results of technoeconomic and lifecycle assessments				x	30-Aug-18	30-Sep-18

Success Criteria

June 30, 2018 (FY18)

Carbonate materials can support algal growth at laboratory scale.

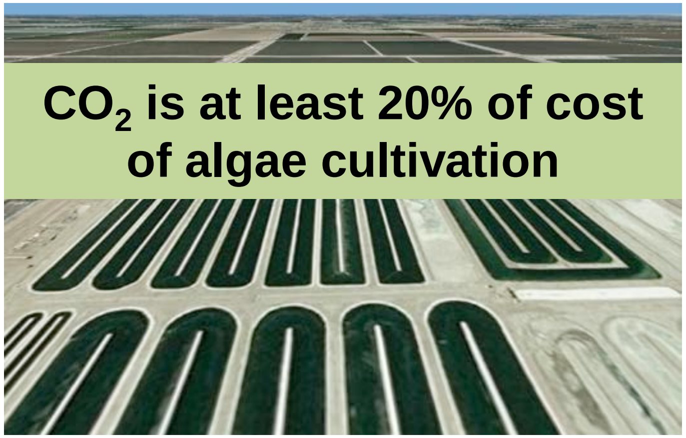
Sept. 30, 2018 (FY18)

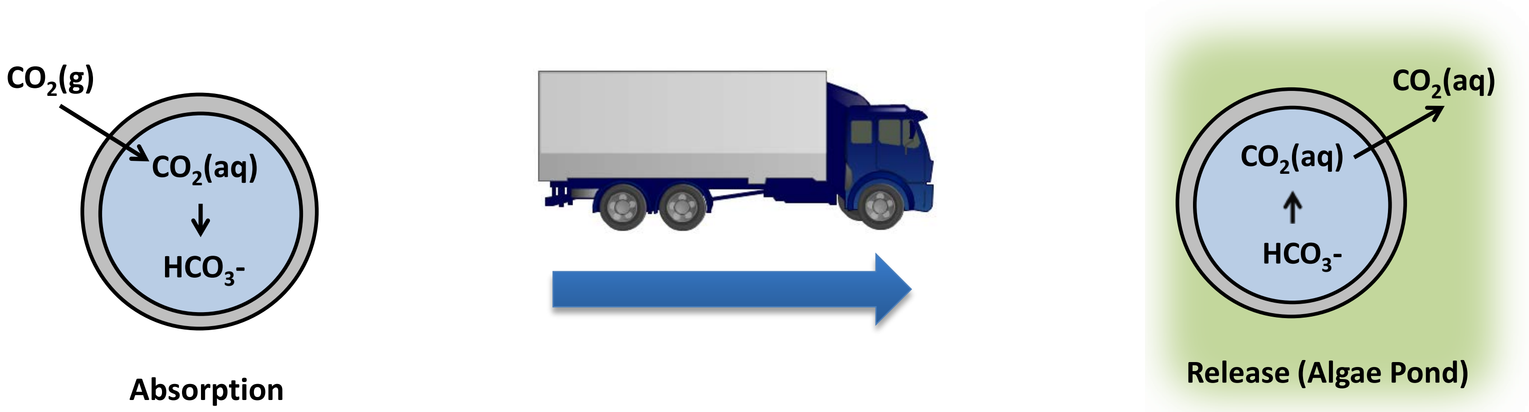
Carbonate materials can be loaded with CO_2 and unloaded in marine media with <10 % loss in capacity over 10 cycles.

Team

Key Personnel	Institution	Time	Tasks	Title, Roles
J. Knipe	LLNL	30%	Tasks 1,2,3	Post Doctoral Researcher, Task Lead 2-3, Co-PI
S. Baker	LLNL	10%	Tasks 1,2,3,4	Staff Scientist, Co-PI
M. Worthington	LLNL	30%	Tasks 2,3	Post-Collegiate Appointee, Carbonate Materials Characterization
M. Ceron-Hernandez	LLNL	30%	Tasks 2,3	Staff Scientist, Carbonate Materials Design and Scale-up
S. McCoy	LLNL	20%	Task 4	Energy analyst, Process Design and Economic Analysis
W. Bourcier	LLNL	10%	Task 2	Geochemist, Model carbonate species and pH response
T. Lane	SNL	15%	Tasks 2,3	Sandia PI, Lead Phycologist
M. Tran-Gyamfi	SNL	50 %	Tasks 2,3	Technical Staff, Algae cultivation, characterization of nutrients, biomass, and growth

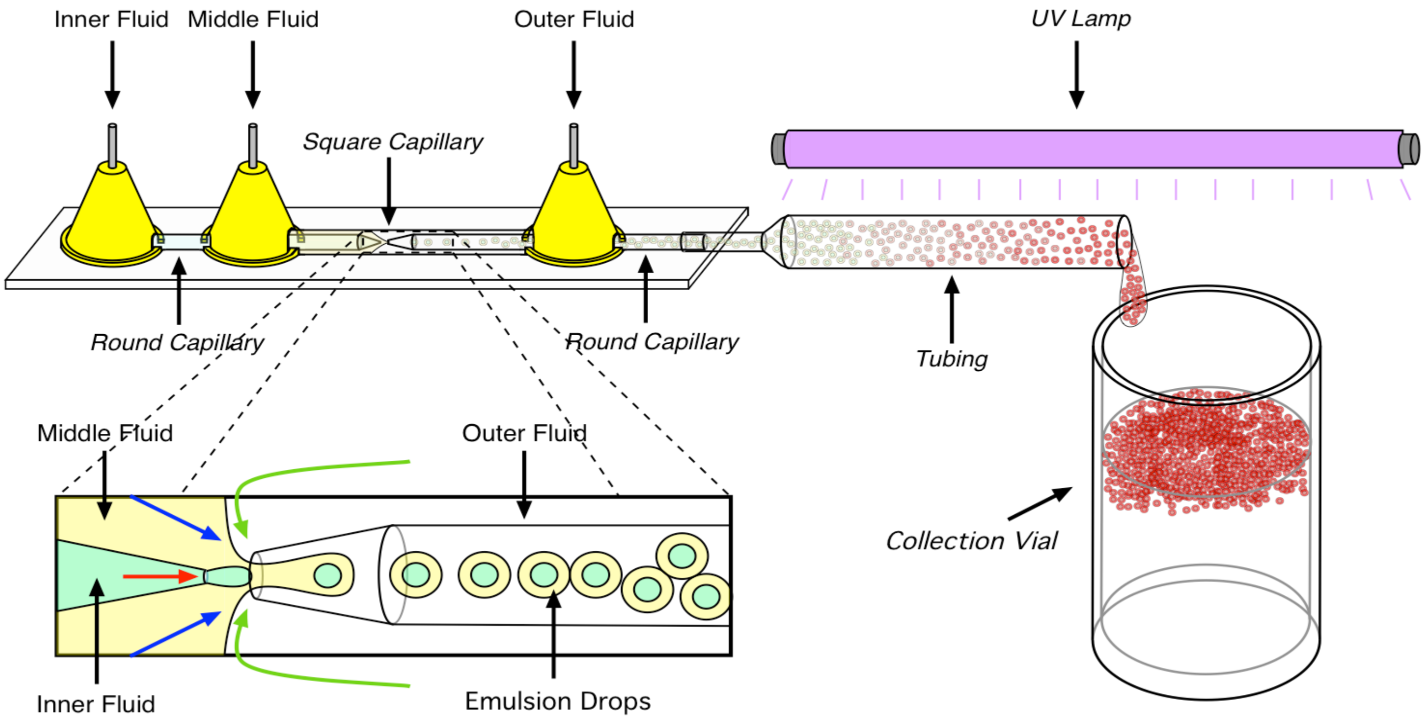
CO_2-loaded materials can be used for algae production

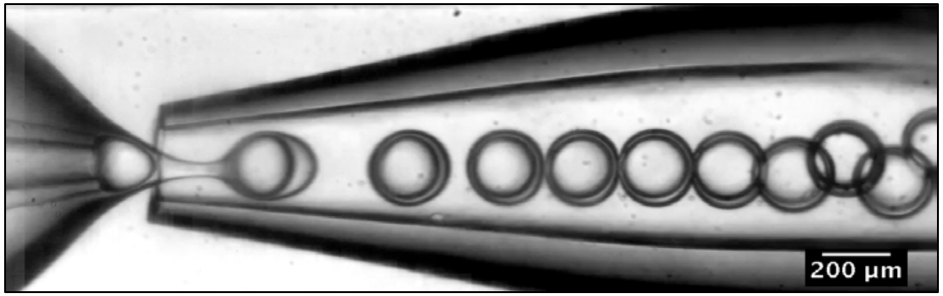




1) **Provide tunable transport, storage, and delivery**
2) **Eliminate need to co-localize**
3) **Reduce capture costs up to 75%**

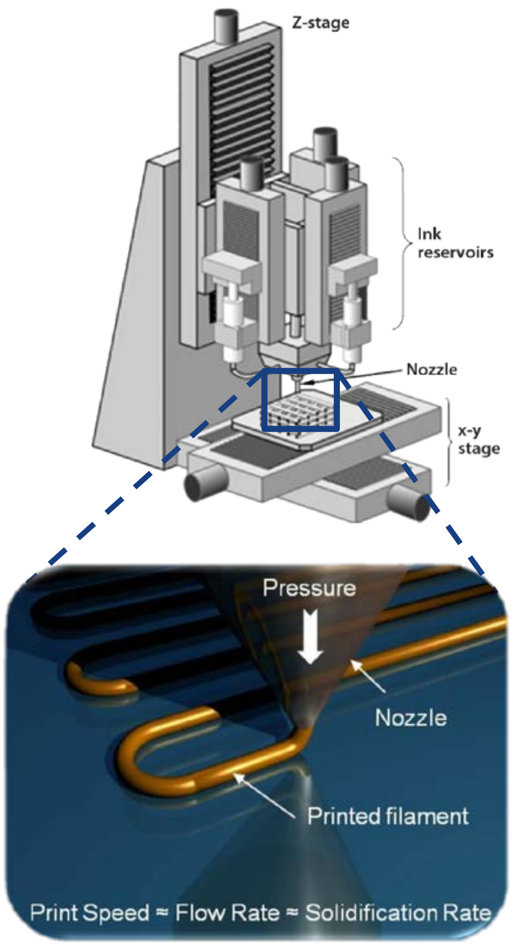
Microencapsulation: an enabling technology for CO_2 solvents

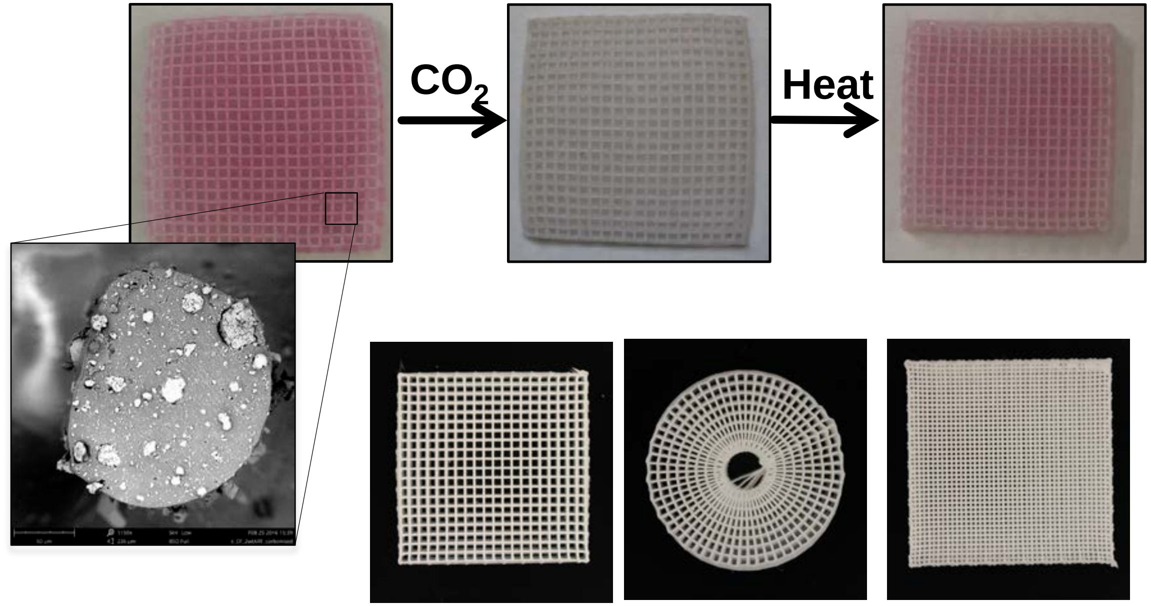




Core Solvent:
Sodium Carbonate

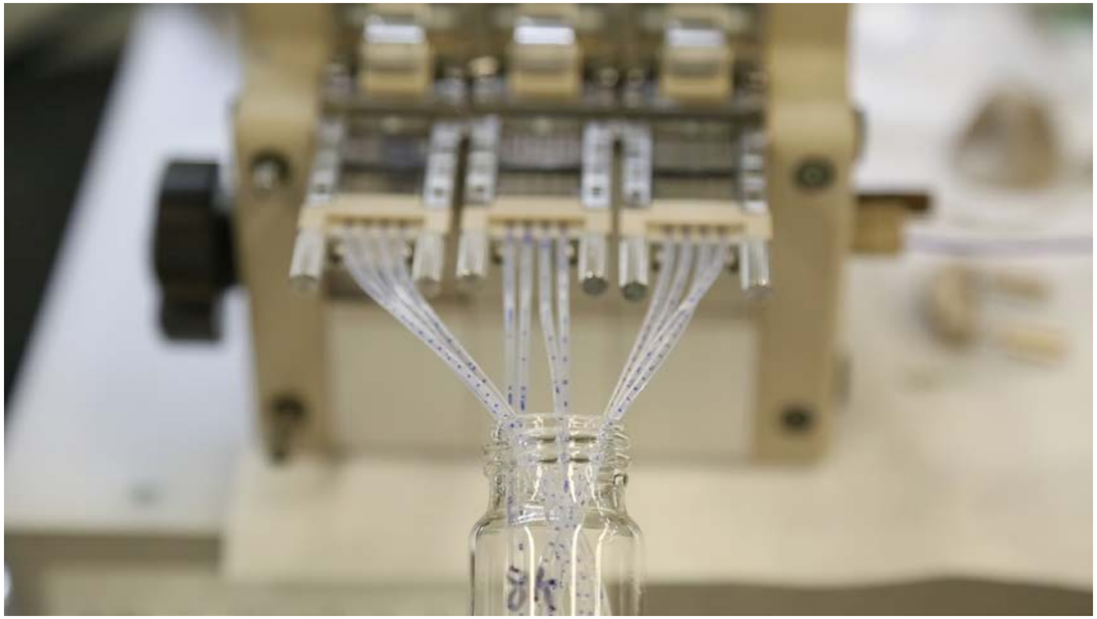
Sorbent-polymer composites printed with Direct Ink Write (DIW)

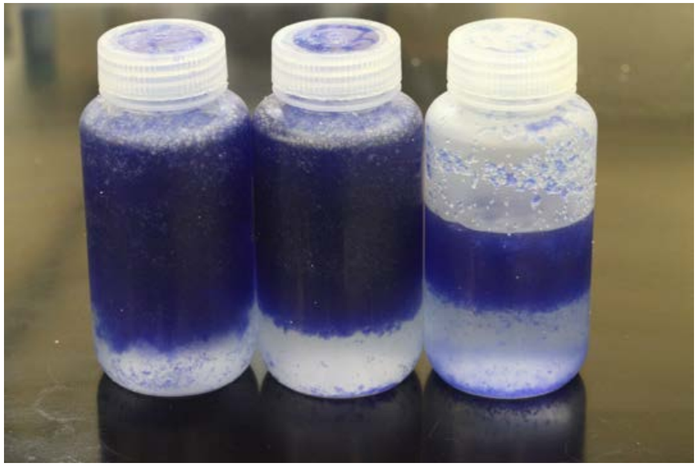




- Ink can be loaded with as much as ~60 wt% carbonate
- Particulate sizes sieved as small as possible for best performing ink

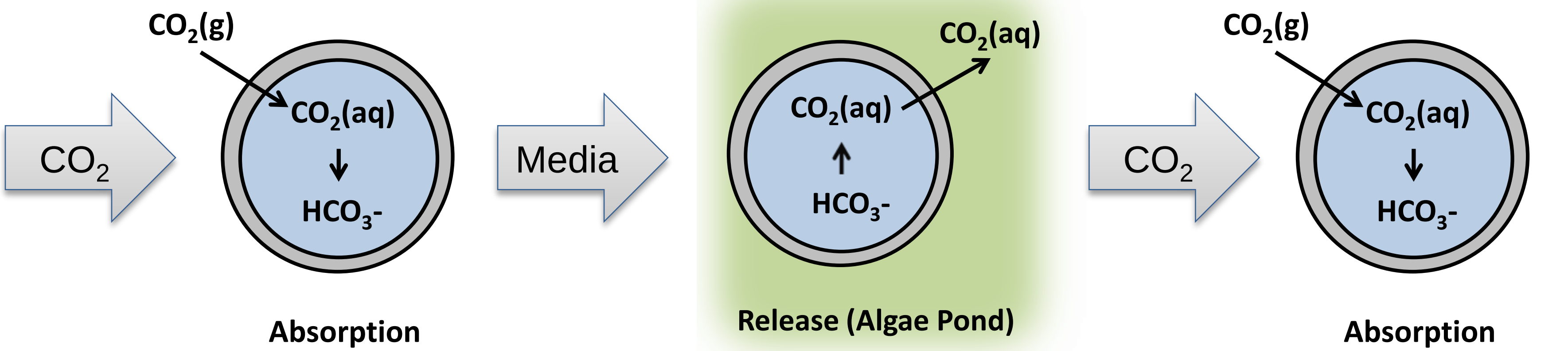
Subtask 2.1 – Scaled material synthesis to multigram quantities for testing





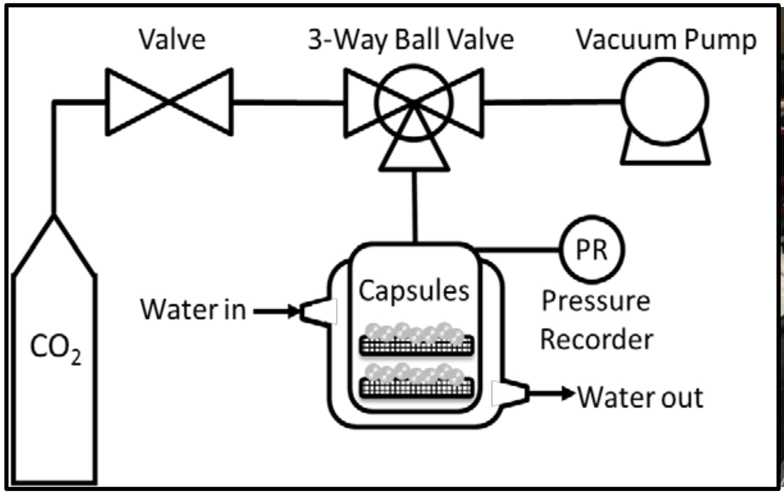
100s g/day produced

Subtask 2.2 - Measured CO_2 absorption and release rates and quantities

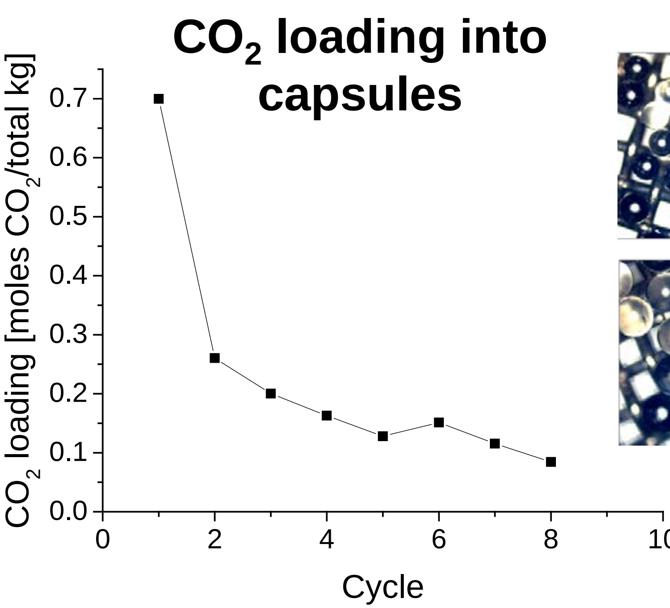


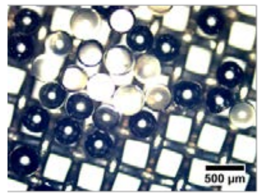
Measure pH of marine media over time to monitor rate of CO_2 release

Measure CO_2 pressure drop over time to monitor CO_2 absorption

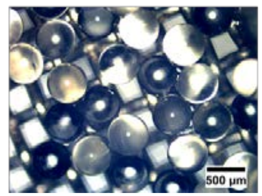


Subtask 2.2 - Measured CO_2 absorption and release rates and quantities of capsules

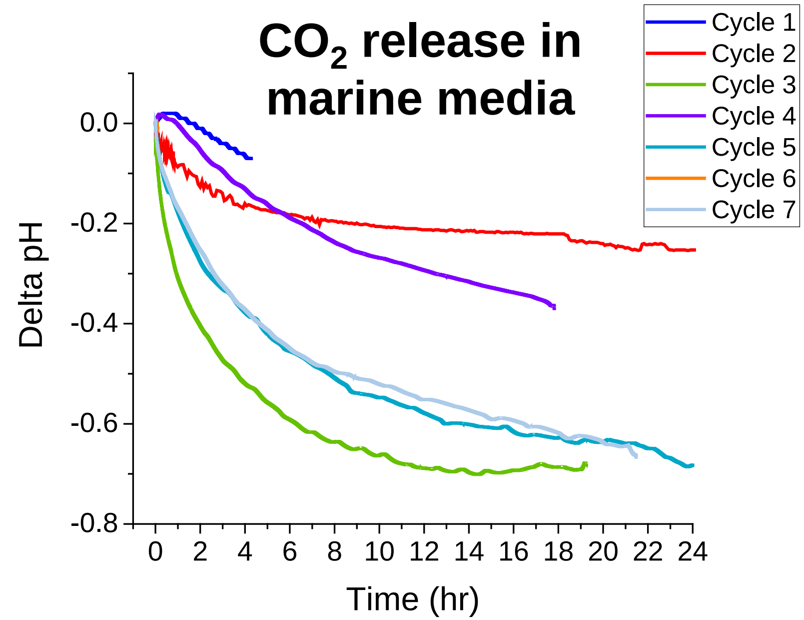




Capsules before: 370 um diameter

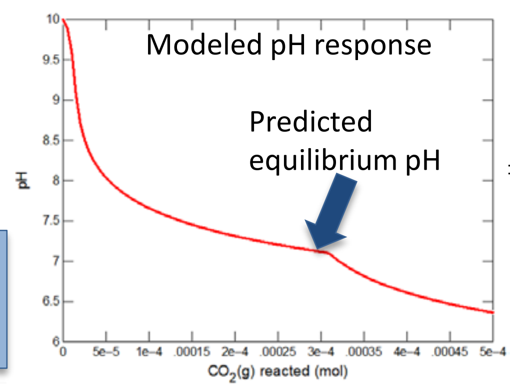


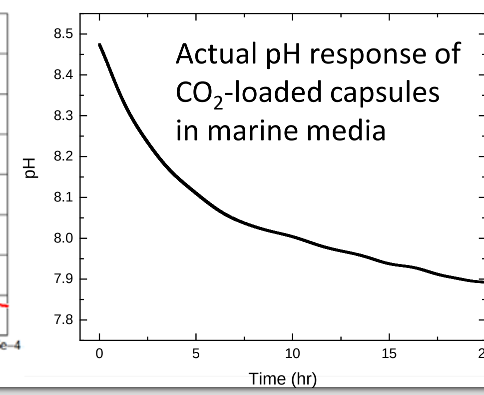
Capsules in media: 525 um diameter



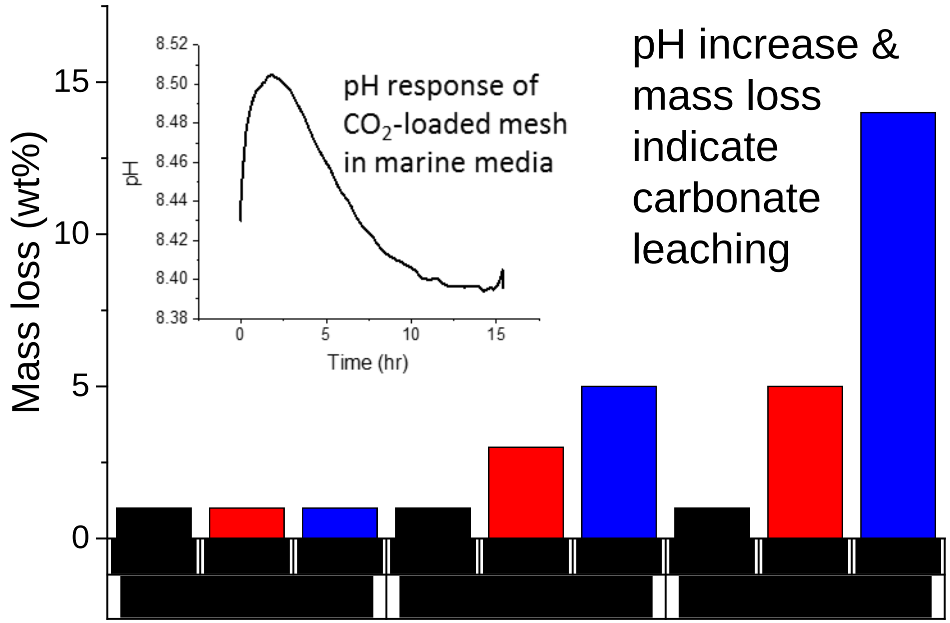
- Loading capacity decreases with cycling
- pH drop less & slower than predicted

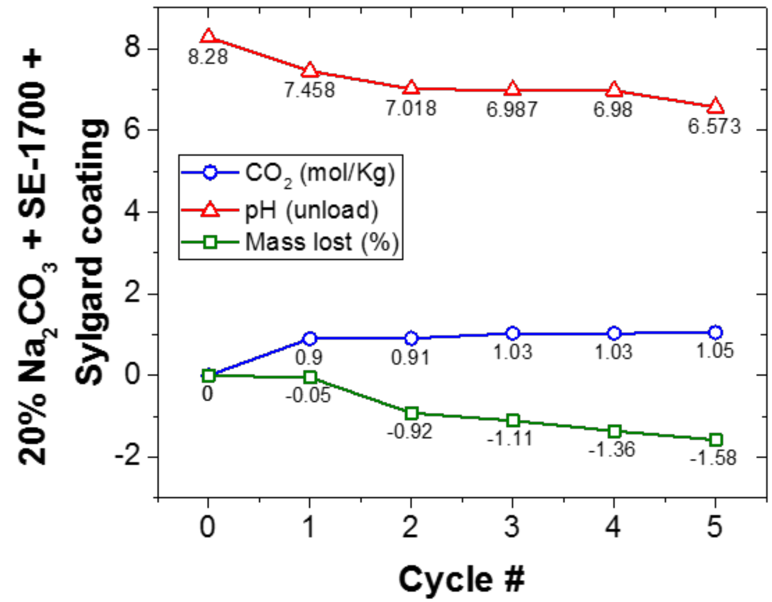
Capsules not fully releasing CO_2??



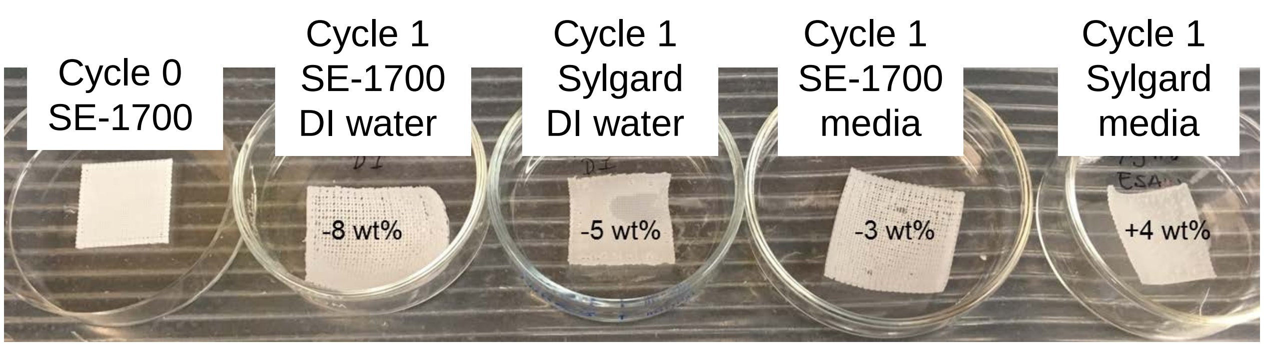


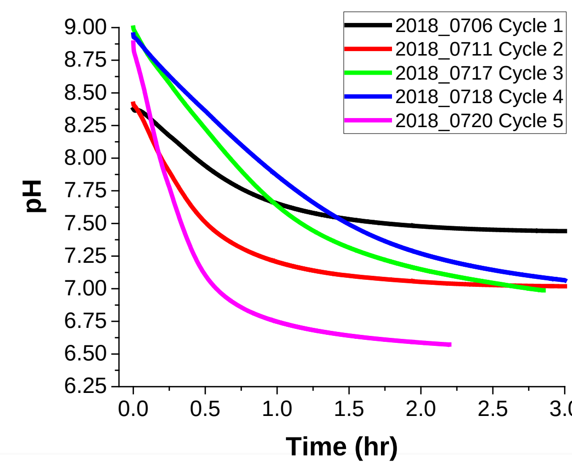
Subtask 2.2 - Measured CO_2 absorption and release rates and quantities of composite mesh



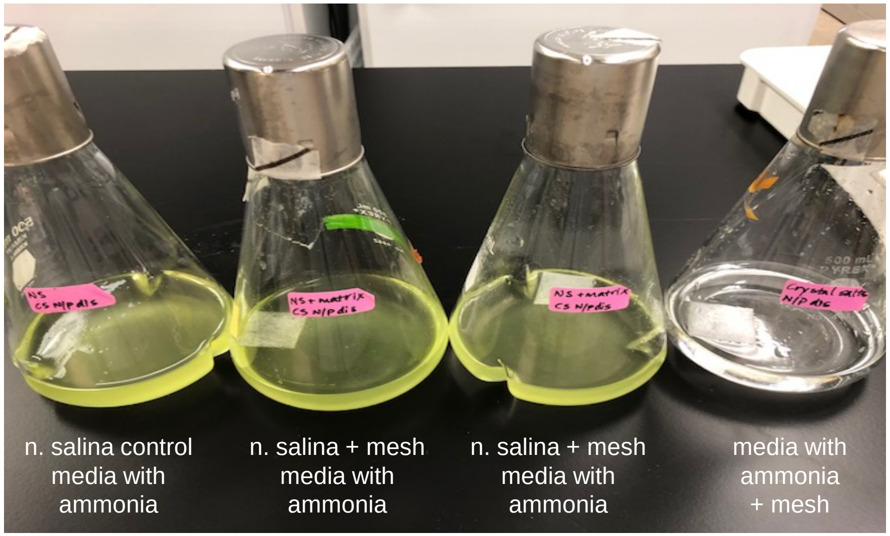


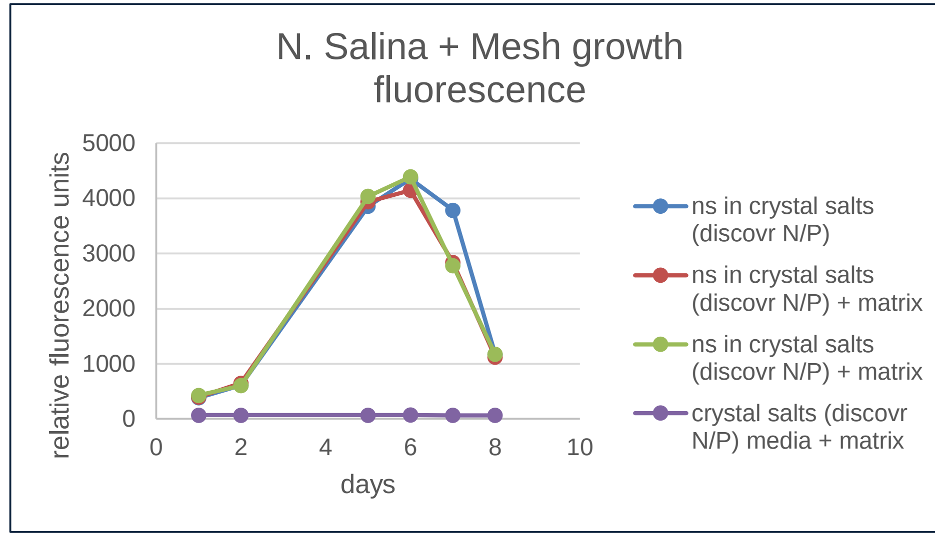
Sylgard coating prevents carbonate leaching

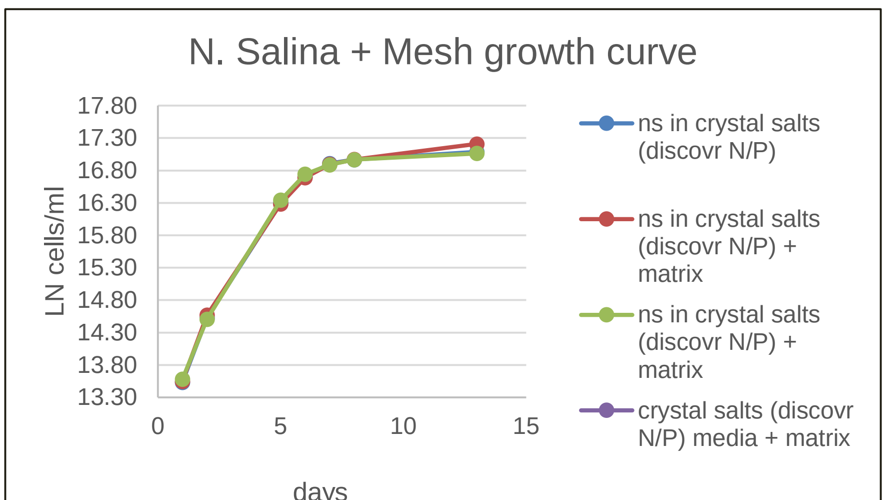


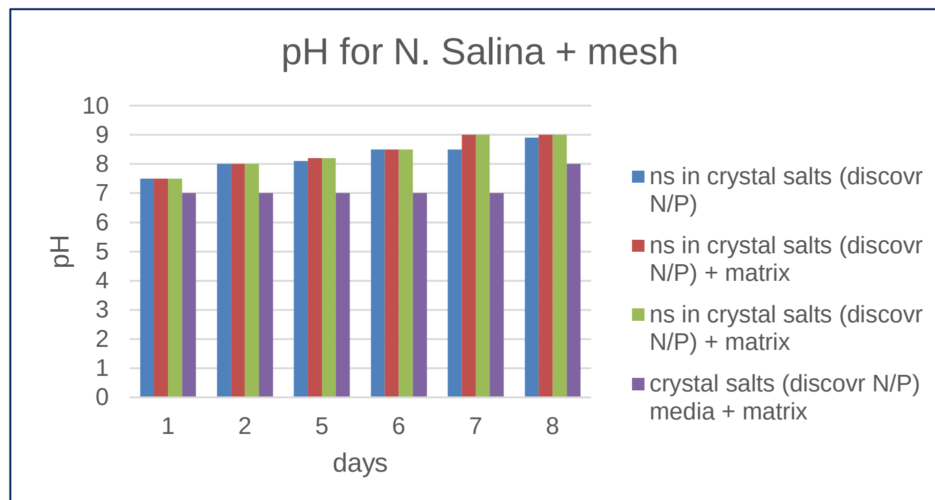


Subtask 2.3 - Materials are biocompatible

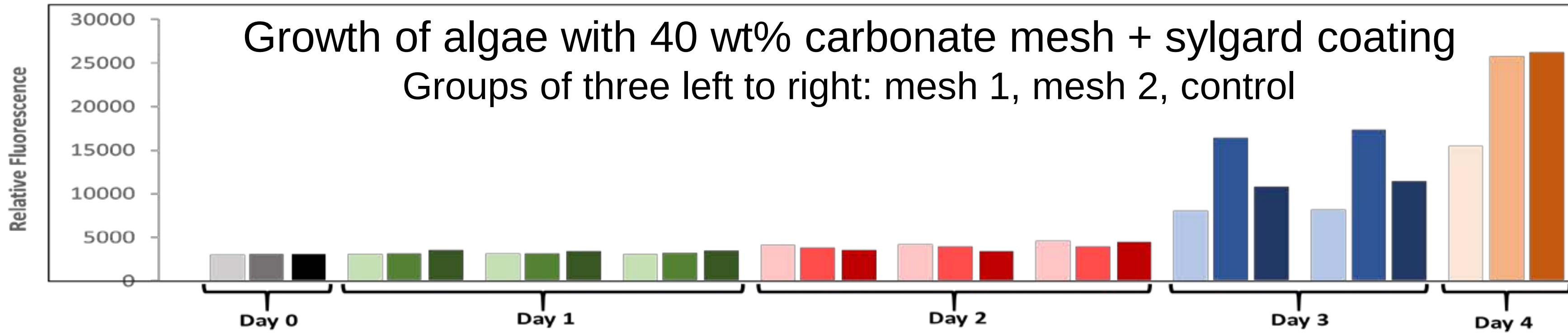


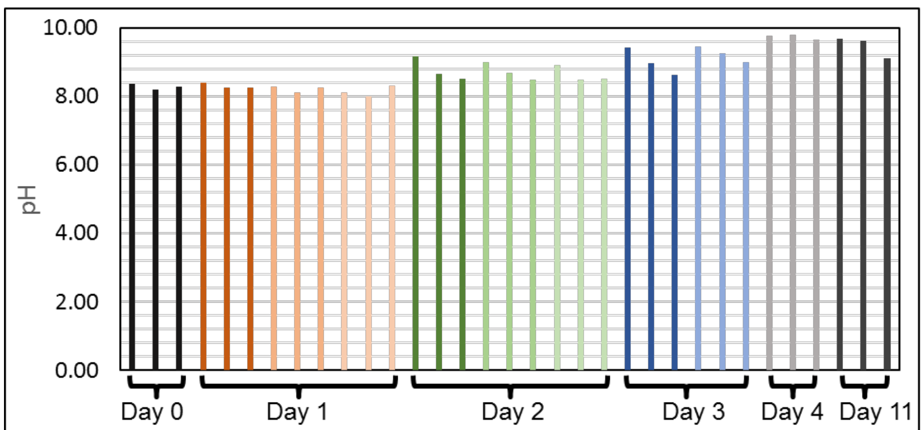




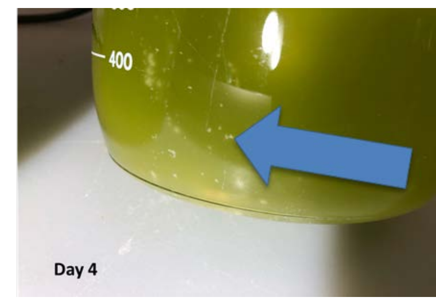


Subtask 3.1 – Material delivers CO_2 for algal growth



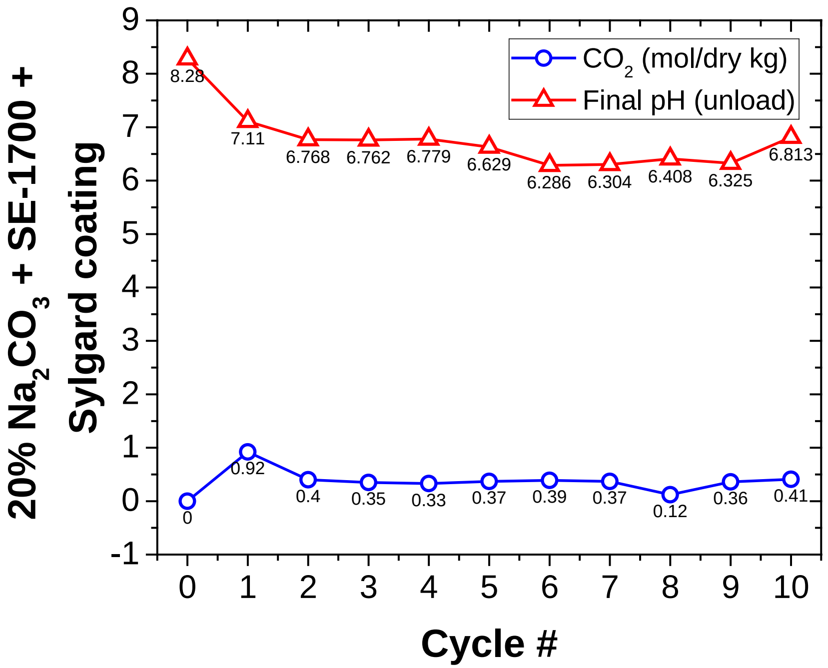


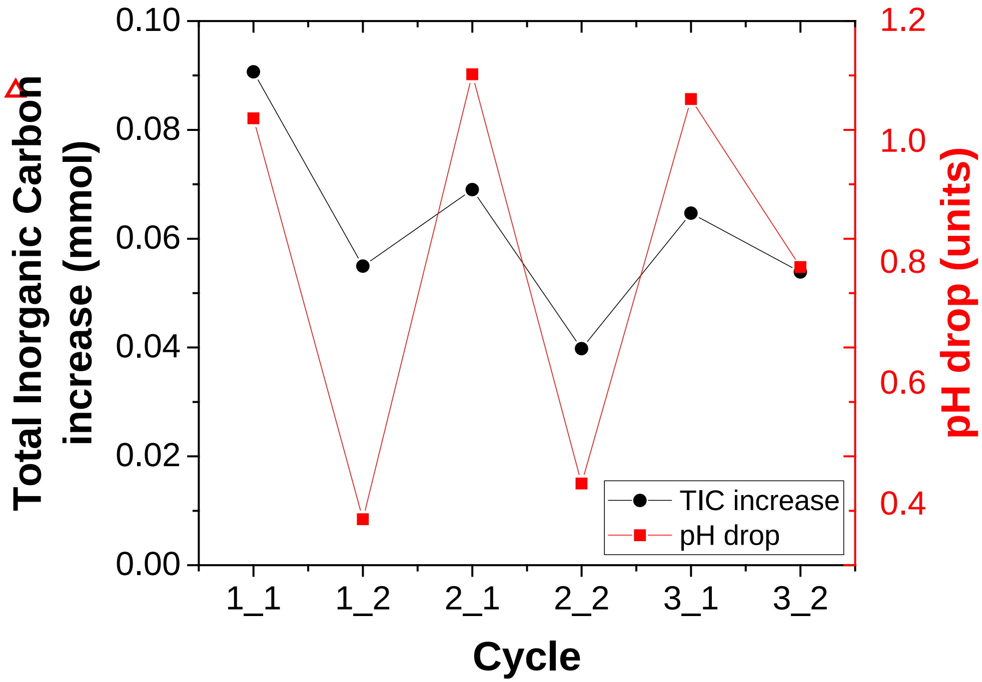
Each group of three: initial before mesh, timepoints with mesh
Groups of three left to right: mesh 1, mesh 2, control



- Increased pH and precipitant indicate leaching of carbonate
- Mesh 1 leached ~15% and Mesh 2 leached ~10%
- Drying between cycles required to prevent excessive swelling and leaching

Subtask 3.4 – Material capacity maintained over cycling



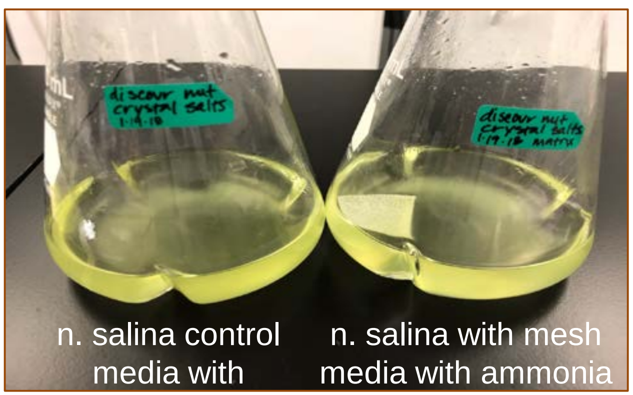


- 20 wt% carbonate with sylgard coating- not dried between cycles
- Lower carbonate loading lost <1 wt%
- Loading very reproducible but not all CO_2 is released
- pH drop tracks with TIC increase as expected

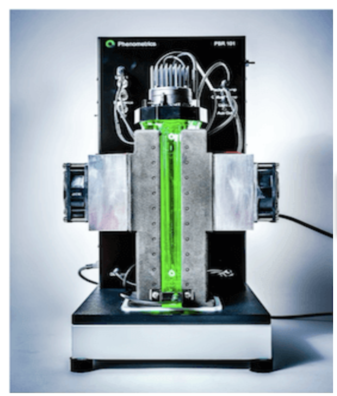
Task 3: Testing selected materials to support algal growth and CO_2 cycling

- **Subtask 3.2 – Scale up materials synthesis**
  - Synthesis of selected carbonate material(s) at kilogram scale
  - The scale-up method employed may require different manufacturing techniques such as using a vibrating coaxial tip rather than microfluidics to produce encapsulated carbonate solutions

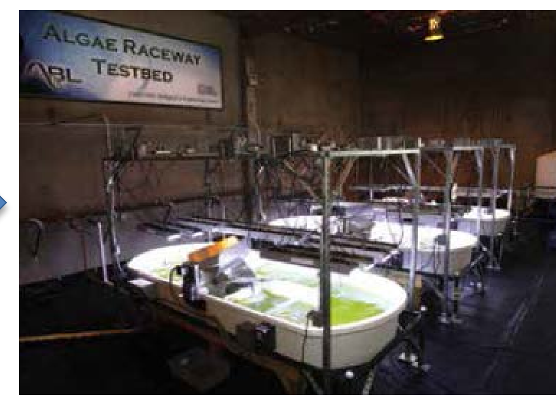
- **Subtask 3.3 – Pilot-scale testing**



100 ml



500 ml



1000 L

Task 4. Process synthesis and Techno-economic analysis

- **Subtask 4.1 - Identify process configurations for capture, transport and delivery**
  - Identify an integrated process to capture, transport, and deliver CO_2 using carbonate materials
  - Include details of transport of carbonate materials to algal farms, on-site delivery of CO_2 to algal ponds or bioreactors, and recovery and recycling of the carbonate materials
- **Subtask 4.2 - Refine process configuration and cost model**
  - Estimate the capital and operating costs of the process for several different CO_2 supply scenarios to provide a per ton estimate of the cost of CO_2 supply and profitability of the system
  - GHG emissions will also be estimated and reported
- **Subtask 4.3 - Finalize results of techno-economic and lifecycle assessments**
  - Complete an initial TEA and LCA
  - Compare the results of the TEA and gate-to-gate LCA to an equivalent system that delivers liquefied CO_2

Summary

- Measured CO_2 loading/release rates in marine media with two material formulations
- Verified biocompatibility and selected carbonate composite meshes for scale-up
- Demonstrated cyclability of material in marine media
- Continuing Task 3: Scale up & Pilot Scale and Task 4: Process Design & TEA
  - Demonstration of comparable algal growth with CO_2 delivered from material at mL to L scales
  - Obtaining data for process design & TEA

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

NETL CO_2 Capture Technology Project Review Meeting

August 16, 2018

LLNL: Jennifer Knipe, Sarah Baker, Maira Ceron-Hernandez, Matthew Worthington, Sean McCoy, William Bourcier

SNL: Todd Lane, Mary Tran-Gyamfi

DOE NETL Project Manager: Andrew Jones

LLNL-PRES-756481

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory