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Institute for Decarbonization and Energy Advancement at PPL R&D Center

Ammonium Looping with Membrane Absorber and Distributed Stripper for Enhanced Algae Growth

DE-FE0031921

Bradley Irvin, Len Goodpaster, Otto Hoffman, Julia Parker, Robert Pace, Heather Nikolic, Mark Crocker and Kunlei Liu

Institute for Decarbonization and Energy Advancement
University of Kentucky
Lexington, KY

http://uknow.uky.edu/research/unique-public-private-research-consortium-established-caer-co2-capture-pioneers

Project Overview

Overall Project Performance Dates

Task		Status	Deadline
	Budget Period 1	Complete	
	Budget Period 2	In progress	12-30-2024
Tasks 8 and 9	Integrated process assembly	Complete	
Task 10	Parametric Campaign	Complete	
Task 11	Long-term Campaign	Complete	
Task 12	TEA	In progress	12-30-2024

Funding (DOE and Cost Share)

Budget Details (June 2023)	Federal Share	Cost Share (Cooperative Agreements)
Total Project (Award Value)	$2,999,564	$751,764
Total Budget Period 2 (planned)	$1,800,234	$421,211
Monthly Expenditures (planned)	$140,397	$42,776
Total Project (cumulative)	$1,473,397	$538,086
Total BP 2 (cumulative)	$613,661	$217,544

Project Participants

University of Kentucky

- Project management
- Project execution and communication
- Risk identification and mitigation
- Process integration and data analysis and reporting
- Development and operation of proposed technology and derived facility

Vanderbilt University (Vanderbilt)

Optimization of the membrane capital and operation cost for scale-up

Colorado State University (CSU)

Perform the TEA/LCA and provide H&MB tables and equipment sizing for the algae production process

Trimeric Corporation

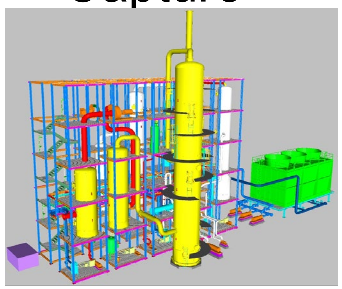
Conduct the TEA and LCA analyses

Technology Background

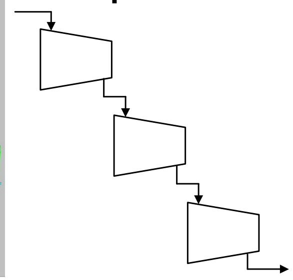
Capture then Utilization

Sources

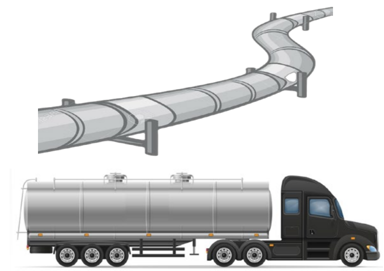
Capture



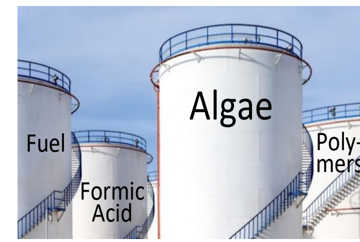
Compression



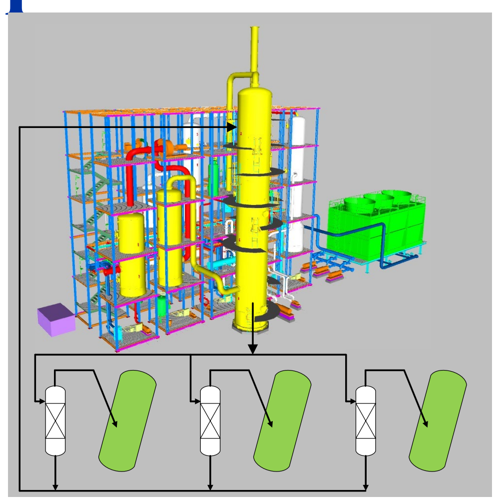
Transportation



Utilization



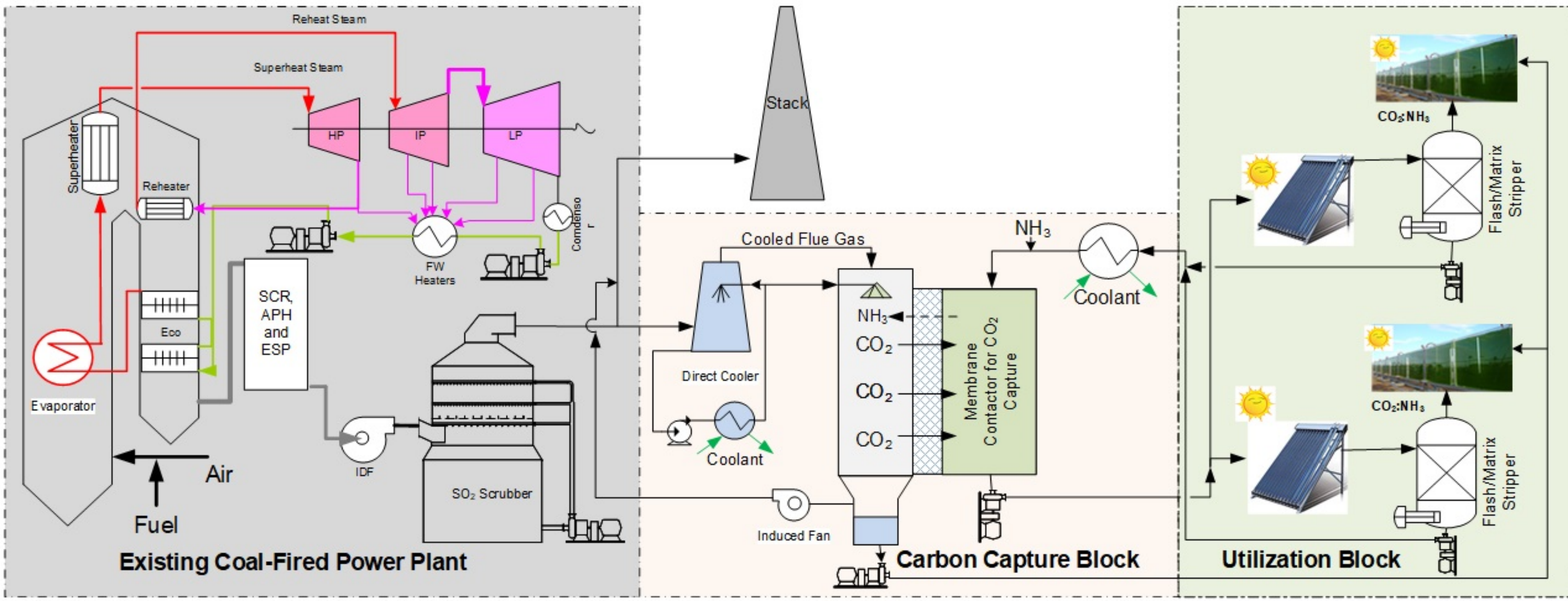
OR Capture and Utilization



Process Overview

Unique, integrated CO_2 capture and utilization technology that:

- **Reduces the cost of CO_2 capture**
- **Boosts algae production**

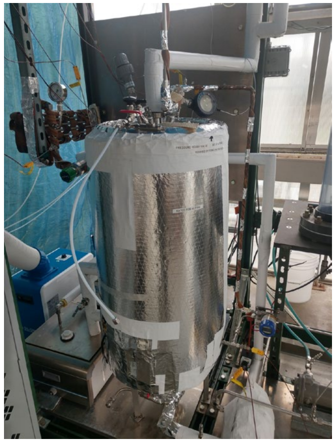


Direct to utilization CO_2 capture

Pilot-scale Integrated Process

LF Boiler

Stripping Loop



Solar Water Heater

Completed Assembly

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Gas sampling for product CO_2/NH_3 ratio

Alkalinity: 0.5 mol/kg

Run	Hot Oil Setpoint (° C)	Stripper bottom temperature (° C)	Stripper top temperature (° C)	Rich feed temperature (° C)	Lean loading (mol C/mol N)	$CO_2:NH_3$ (exp mol/mol)
1	140	93	90	89	0.424	2.53
2	0	31	63	90	0.536	13.41
3	0	84	78	79	0.512	11.47
4	90	79	78	98	0.622	21.75

Alkalinity: 1.8 mol/kg

Run	Hot Oil Setpoint (° C)	Stripper bottom temperature (° C)	Stripper top temperature (° C)	Rich feed temperature (° C)	Lean loading (mol C/mol N)	$CO_2:NH_3$ (exp mol/mol)
5	0	36	45	68	0.548	13.8
6	0	51	68	91	0.491	4.78
7	0	52	98	92	0.454	4.21
8	0	32	64	91	0.511	7.09
9	0	54	64	92	0.504	5.84
10	100	85	81	95	0.514	1.8

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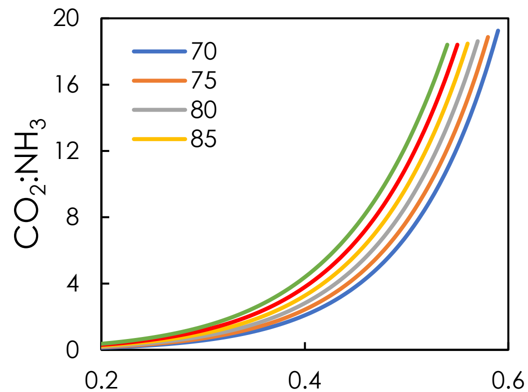
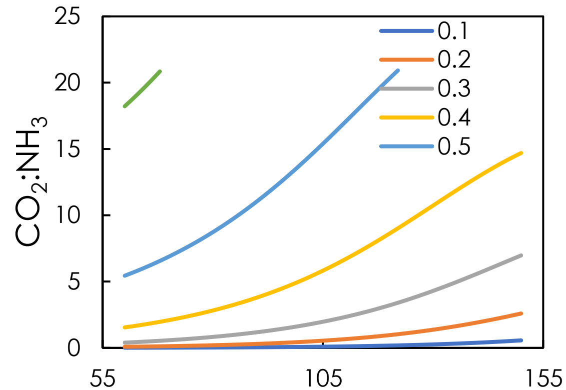
Determining Nutrient Ratio (CO_2/NH_4)

Aspen simulation → Guideline for operation conditions optimization



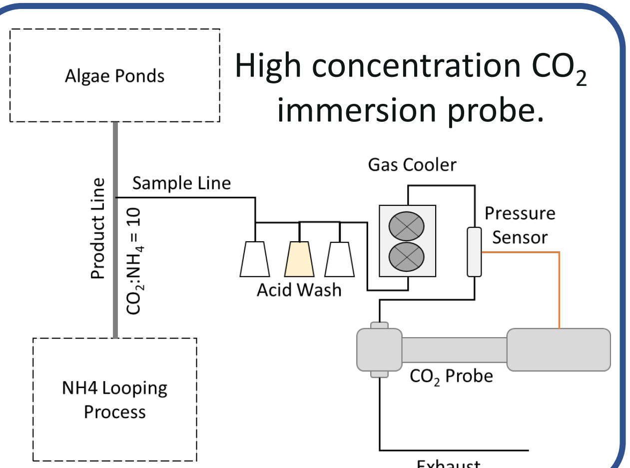
Correlation of pH measurements with NH_4 concentration



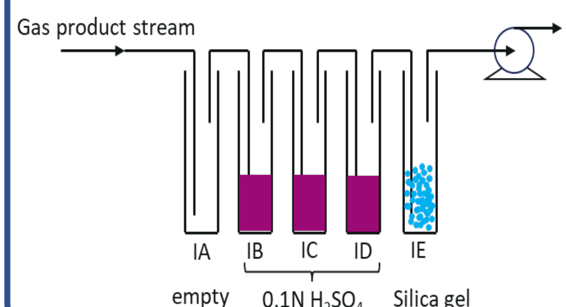
Simple and fast NH_4 concentration estimation

Gas phase sampling

High concentration CO_2 immersion probe.



IC analysis for NH_3 quantification



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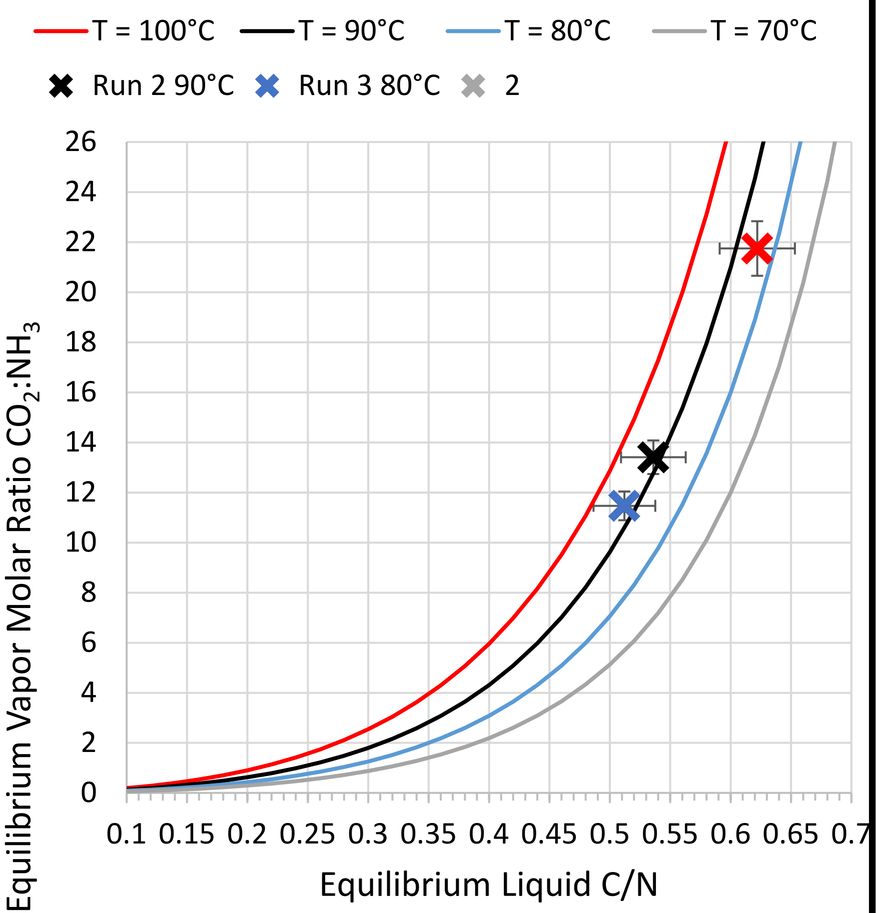
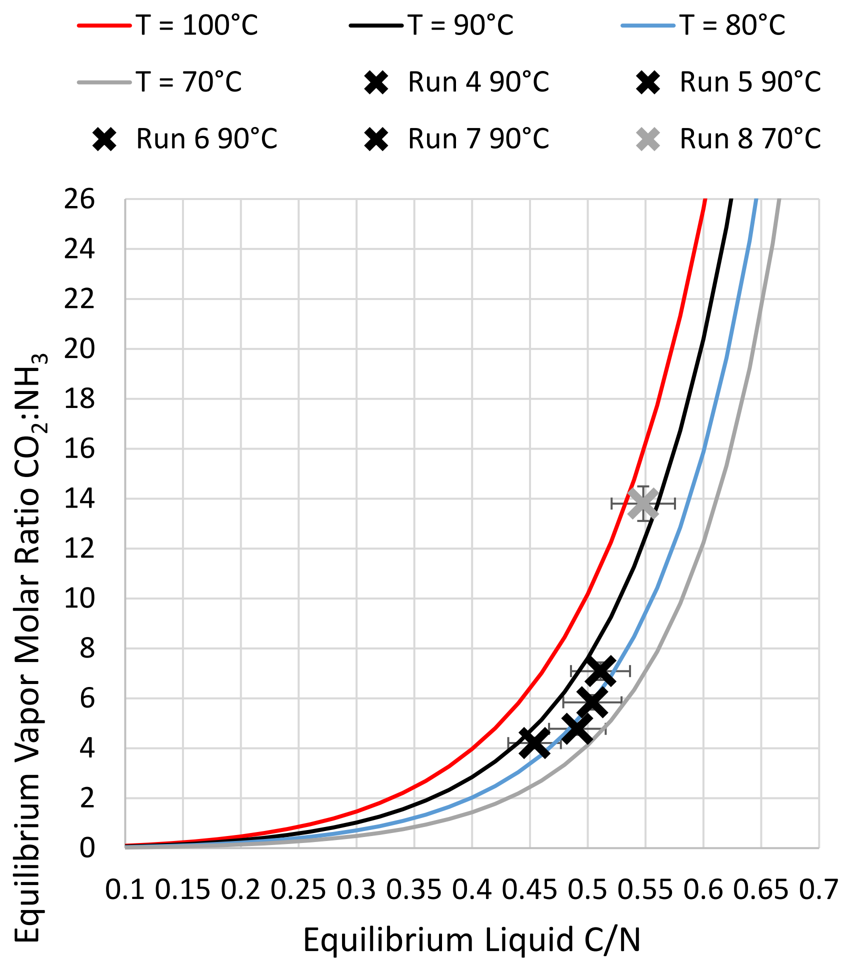
Product Ratio: Experimental vs. Model

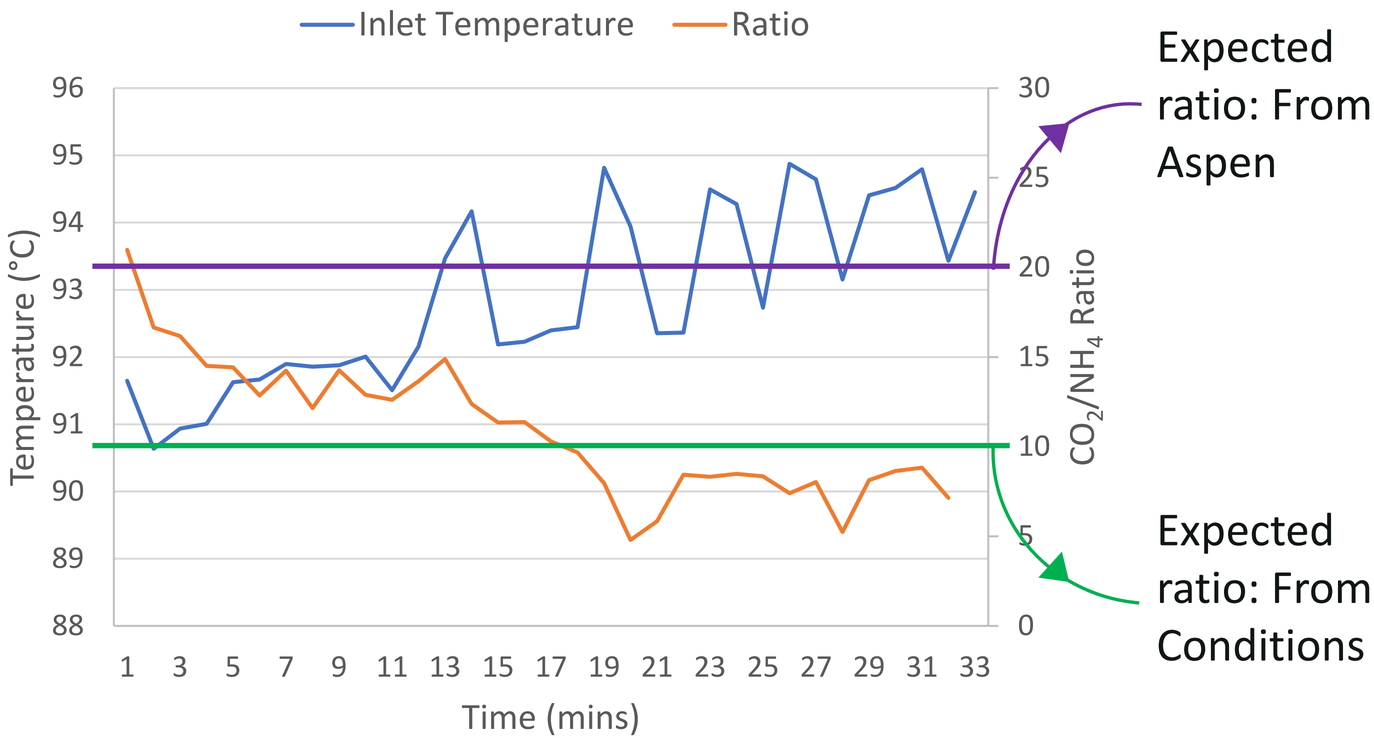
0.5 Mol/kg



2.0 Mol/kg



Product Ratio: Determined from High concentration CO_2 immersion probe.



- Expected ratio is about 20, per ASPEN model.
- Ratio is stable around 10, as desired.
- Ratio decreases with increasing solvent inlet temperature. This is controllable by adjusting the cold rich flow to the stripper.

Summary: Capture

- The ammonia looping process can function and produce desired product ratios at varying solvent alkalinities, even as low as 0.5 mol/kg.
- Product ratios of 10 or more are easily achievable with higher rich carbon loadings. Preferable greater than 0.45 mol/kg.
- Can capture CO_2 at any inlet concentration. However, if the desired product ratio of CO_2:NH_4 is 10 or more, then the minimum inlet CO_2 concentration needs to be 2% or more.

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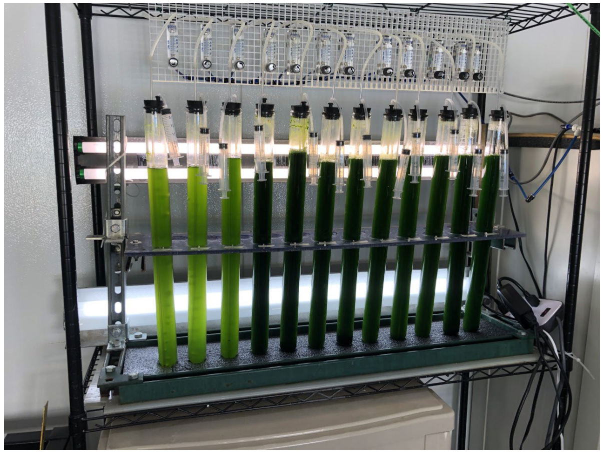
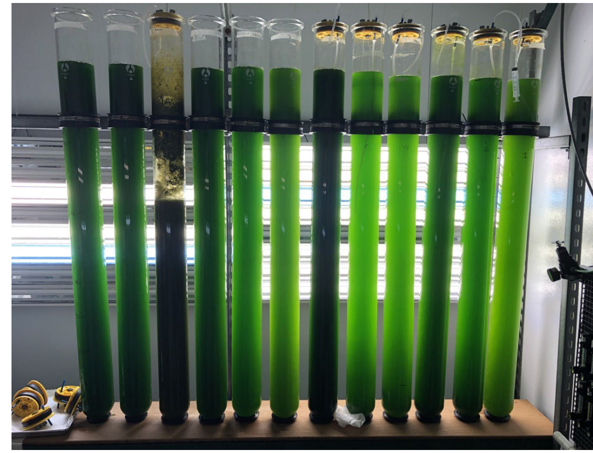
Algae Culturing

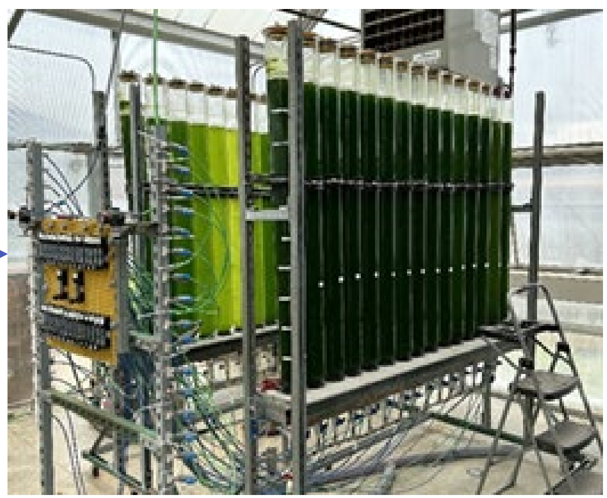
Start



12 x 800 mL tubes



11 x 10 L tubes



30 x 10 L tubes

2 x 900 L ORPs

End

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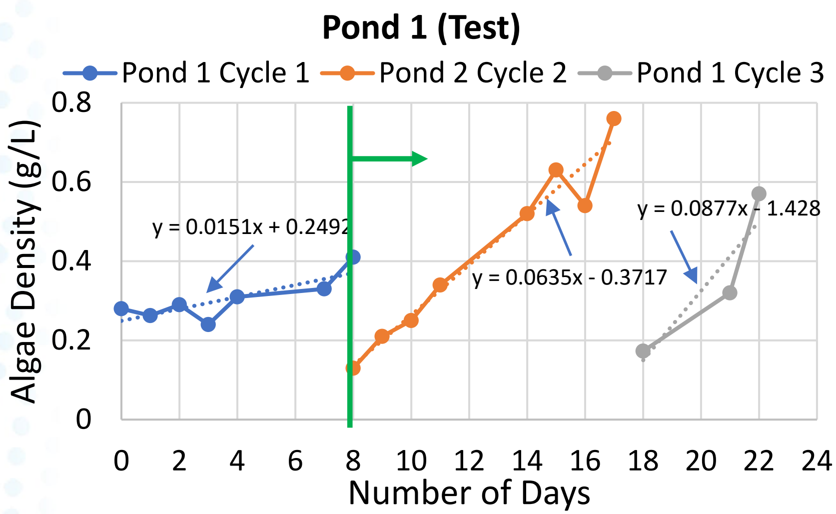
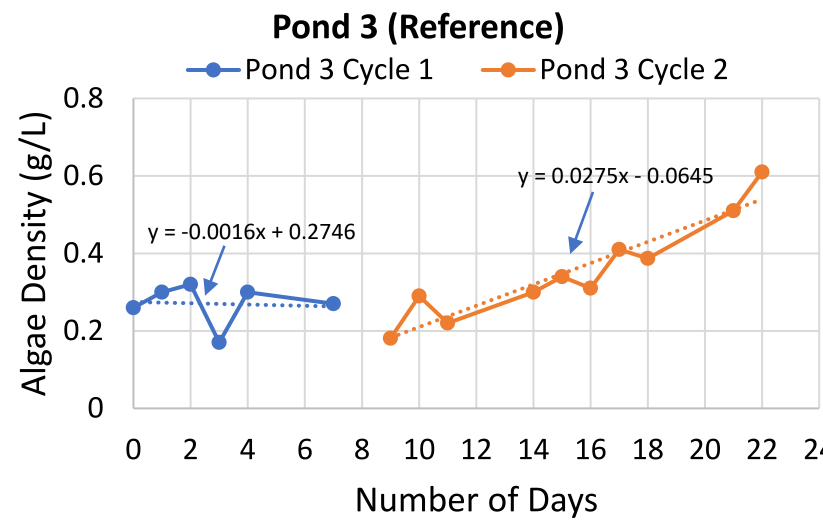
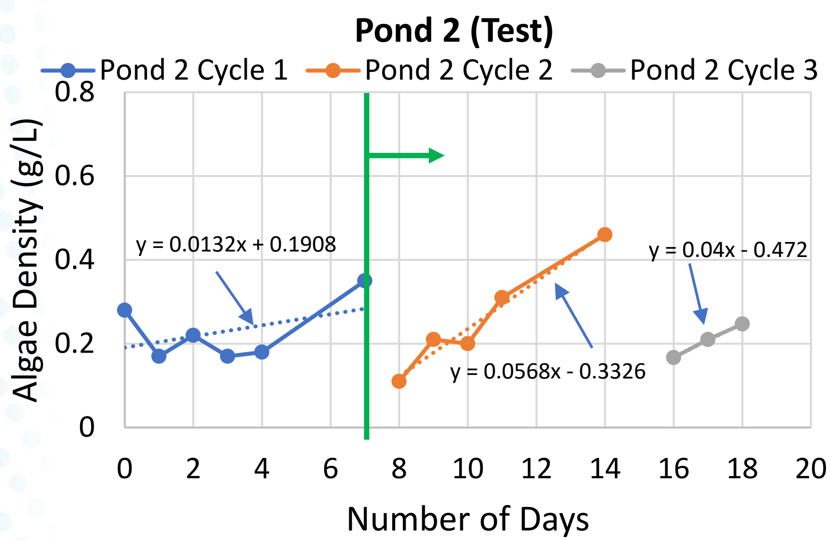
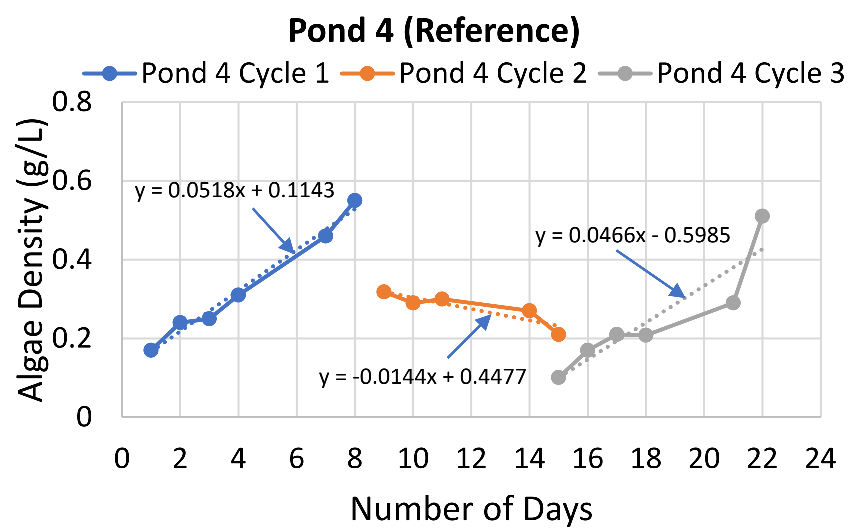
Initial Algae and ORP Data









Test		Reference
0.062 ± 0.014 g/L per day	**3X increase** ←	0.021 ± 0.007 g/L per day

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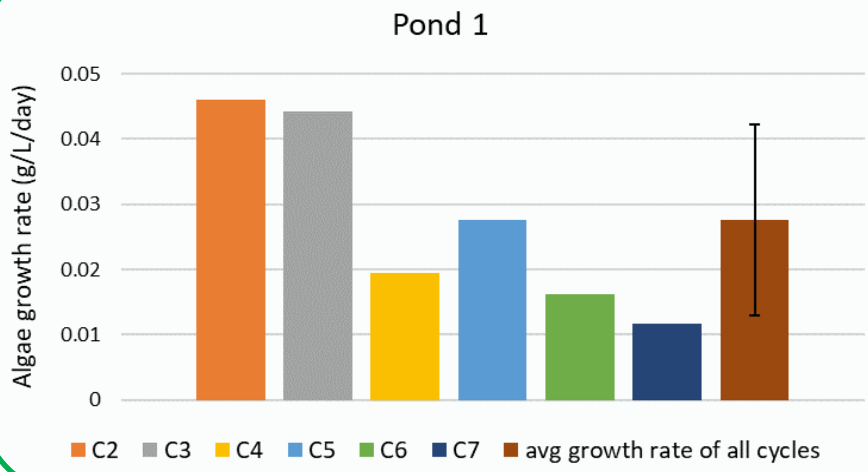
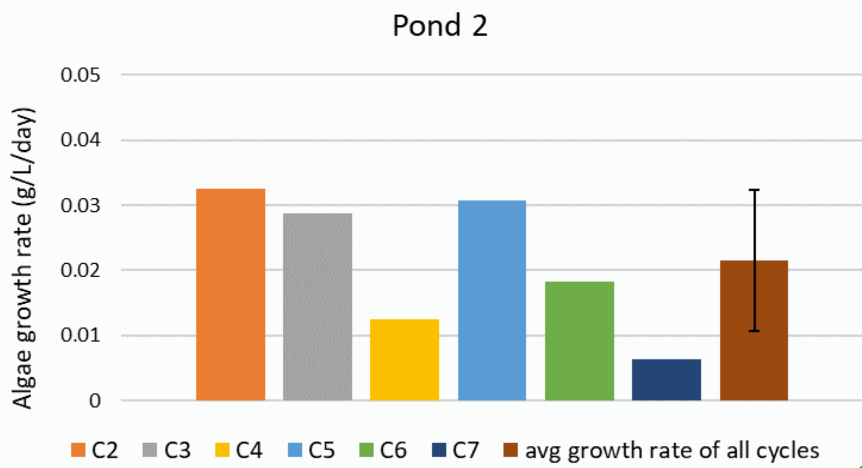
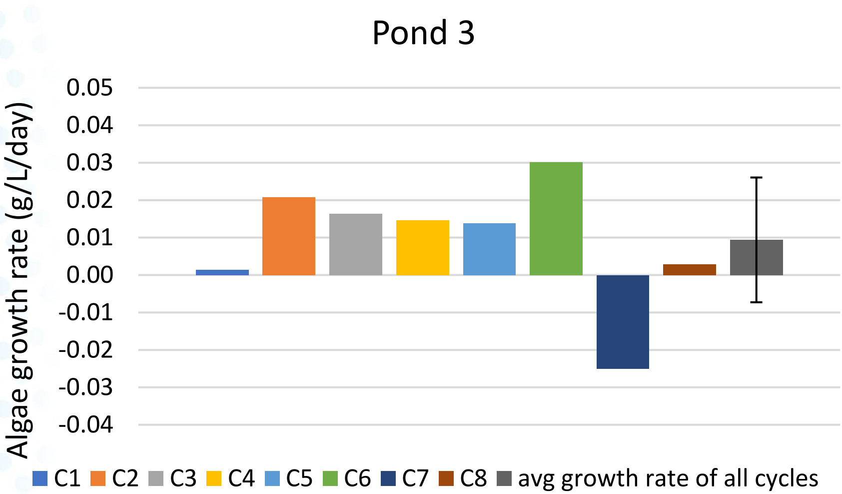
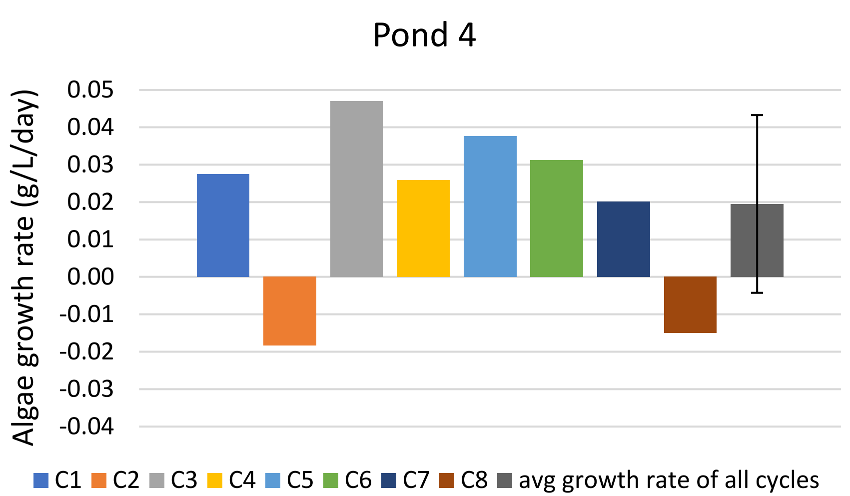
Algae Culturing: Comparison of Algae Productivity (Volumetric)

Test Ponds

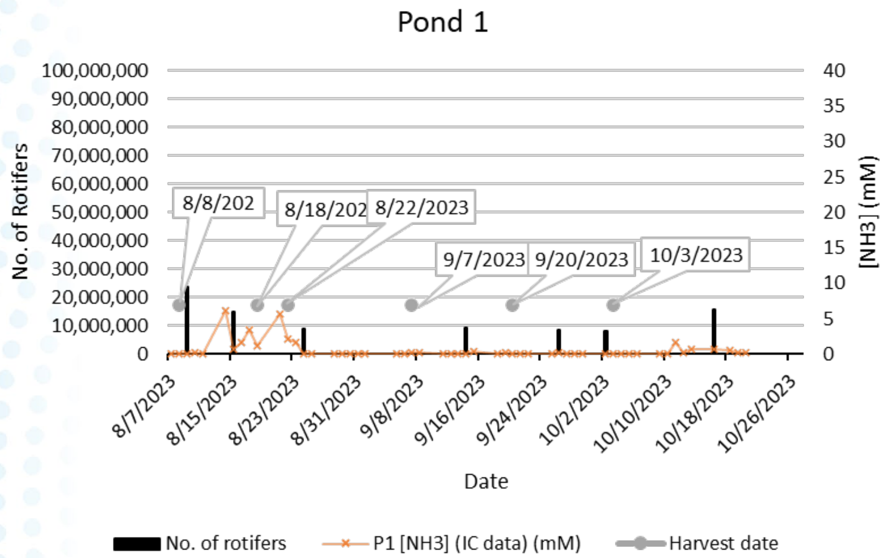


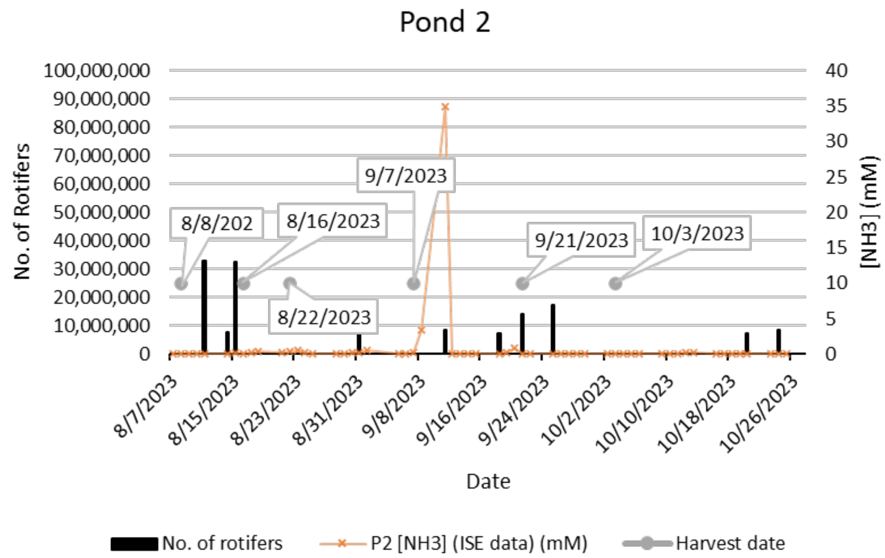


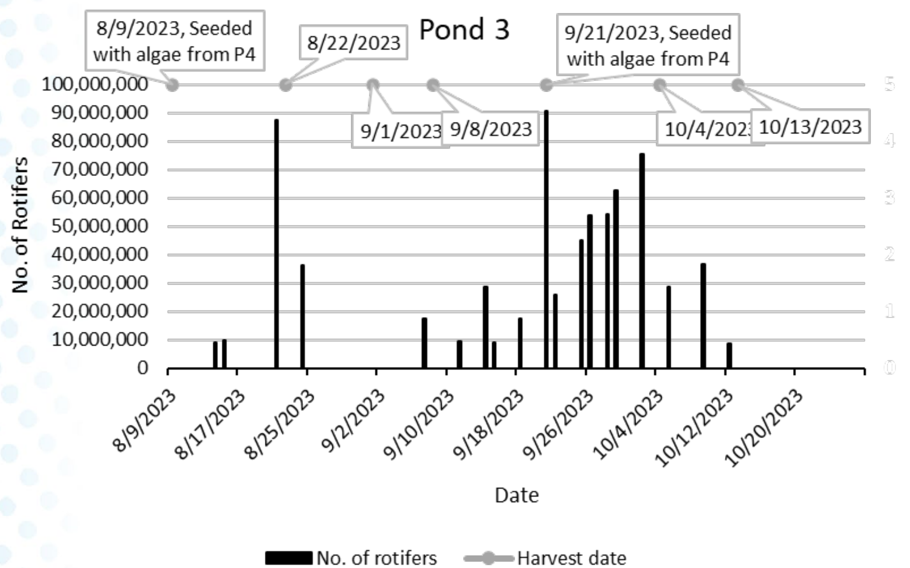


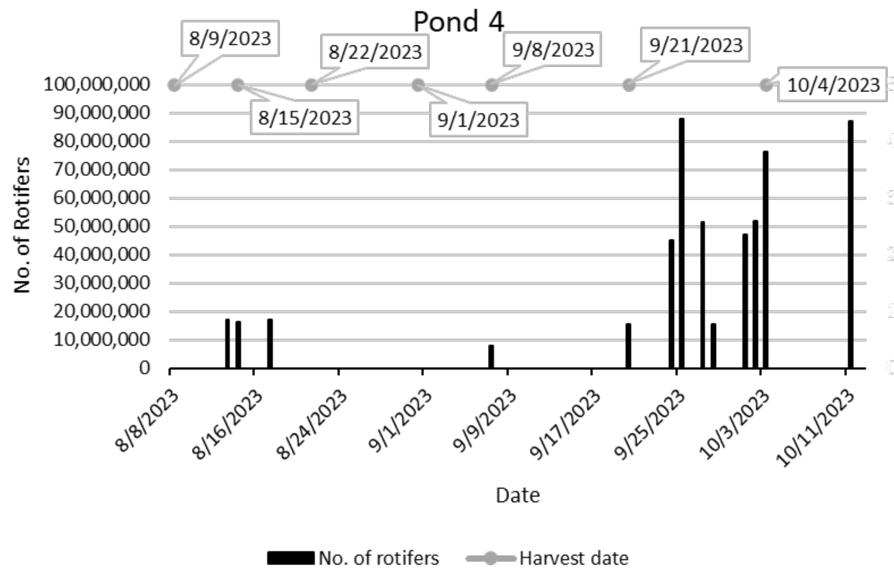


Algae Culturing: Rotifer Population Data









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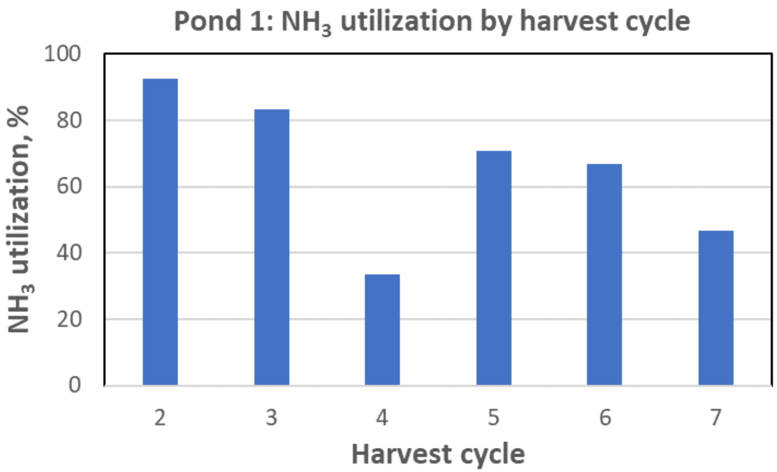
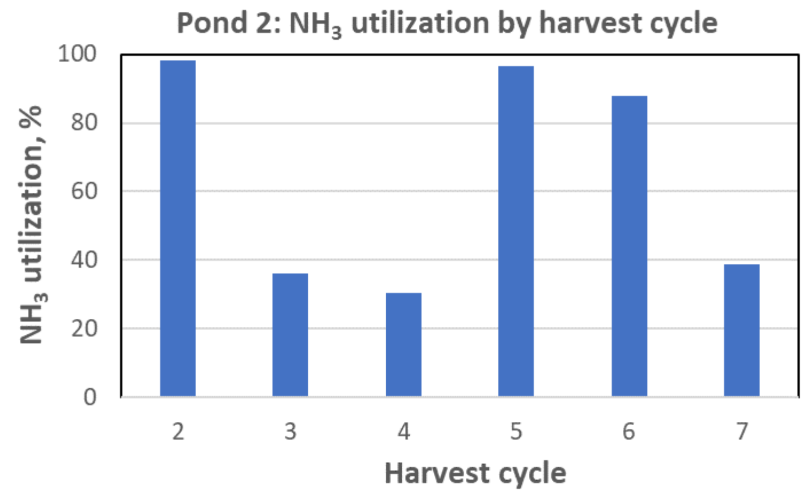
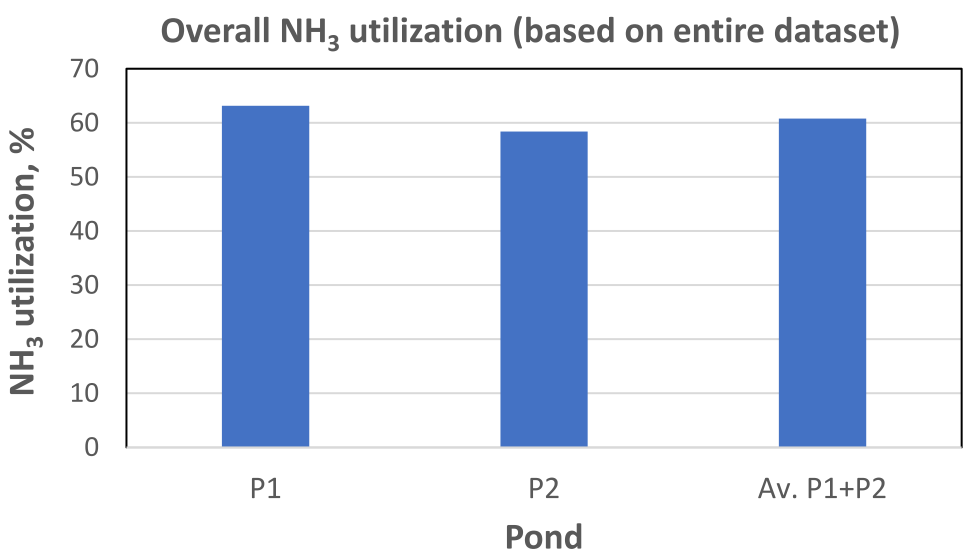
Algae Culturing: NH_3 Utilization (η_{NH3})





NH_3 utilization ranged from 30% - 98% by harvest cycle

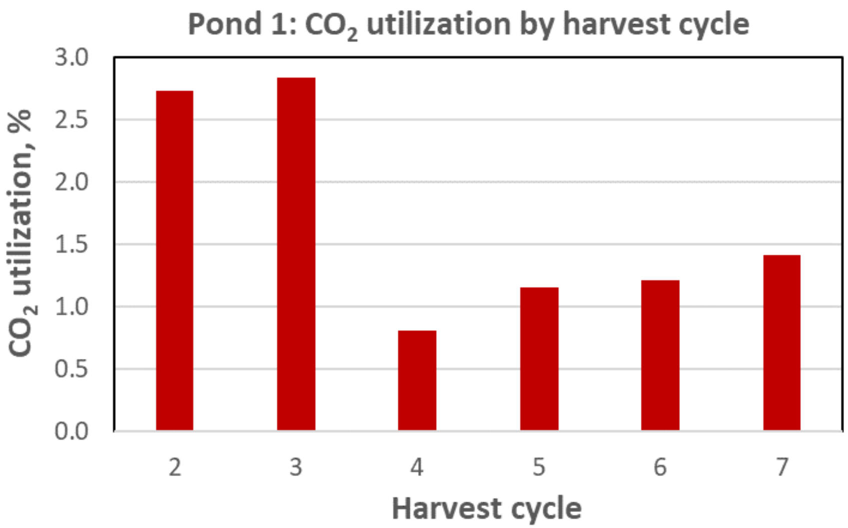
Periods of high NH_3 utilization correspond to harvest cycles when algae growth was strongest

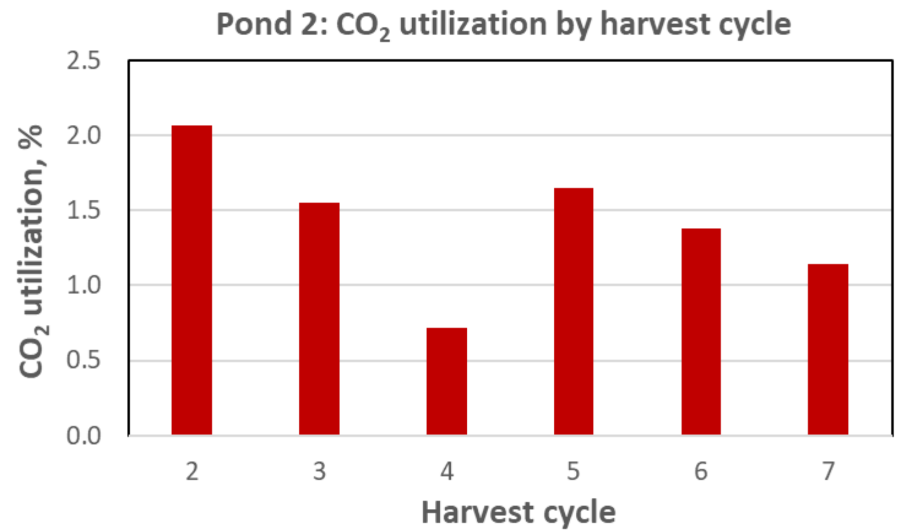


$$\eta_{NH3} = \frac{100 * m_{SA} * X_N}{m_{NH3}}$$

m_{SA} = mass of algae produced
X_N = N fraction in the algae (from elemental analysis)
m_{NH3} = mass of NH_3 fed

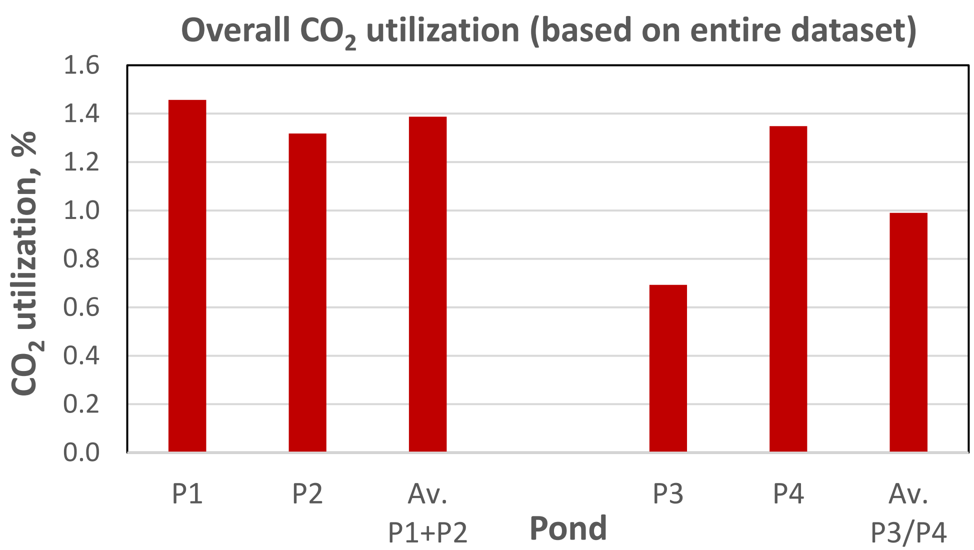
Algae Culturing: CO_2 Utilization (η_{CO2})





Low CO_2 utilization efficiencies due to high supplemental CO_2 flow and discontinuous nature of membrane absorber operation (i.e., algae productivity was nitrogen-limited during weekends)

Highest CO_2 utilization corresponds to periods of strong algae growth



$$\eta_{CO2} = \frac{100 * m_{SA} * X_C}{m_{CO2}}$$

m_{SA} = mass of algae produced
X_C = C fraction in the algae (from elemental analysis)
m_{CO2} = mass of CO_2 fed

Algae Culturing: Compositional Analysis

	C (%)	N (%)	Ash (%)	Protein (%)
2nd harvest cycle				
ORP 2	48.1 ± 0.4	9.5 ± 0.1	6.0 ± 0.1	45.2 ± 0.1
ORP 4	48.6 ± 0.6	8.5 ± 0.1	n.d.	40.7 ± 0.1
3rd harvest cycle				
ORP 1	50.2 ± 0.5	9.7 ± 0.1	5.9 ± 0.1	46.6 ± 0.1
ORP 2	48.4 ± 0.5	9.2 ± 0.1	7.1 ± 0.2	43.9 ± 0.1
ORP 3	50.9 ± 0.4	8.6 ± 0.2	5.5 ± 0.1	41.1 ± 0.2
4th harvest cycle				
ORP 1	50.5 ± 0.1	9.2 ± 0.0	5.0 ± 0.1	43.9 ± 0.0
ORP 2	47.9 ± 0.2	9.0 ± 0.1	6.3 ± 0.1	42.9 ± 0.1
ORP 4	51.8 ± 0.1	9.1 ± 0.0	6.0 ± 0.1	43.6 ± 0.0
5th harvest cycle				
ORP 1	50.2 ± 0.3	9.5 ± 0.0	6.5 ± 0.1	45.2 ± 0.0
ORP 2	50.4 ± 0.3	9.9 ± 0.2	6.9 ± 0.1	47.3 ± 0.2

- Ash content low in all cases (albeit higher than for indoor experiments)
- No significant differences in protein or ash content between test and reference ponds

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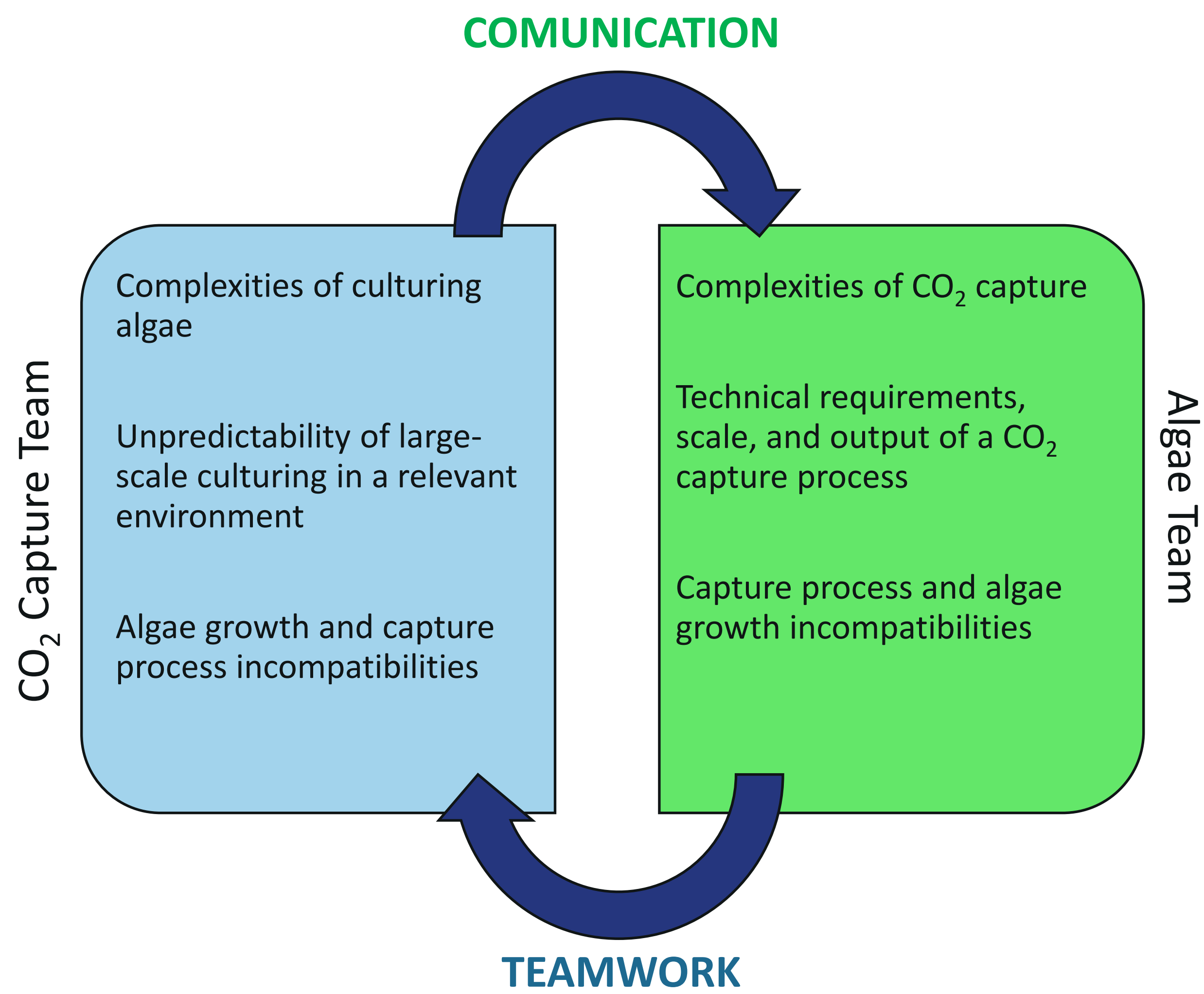
Lessons Learned



Plans for Future Testing & Development

Future testing

Scale up algae growth: Currently we are only using 1% of the total capacity of the capture unit, feeding 1800L of algae

X 100 → Total capacity, 180,000L
(which about the size of a large swimming pool)

Development

- Streamline the process, experimental → commercial
- Could be used as a polishing step for point source capture to achieve net negative emissions.
- Direct air capture

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- **Trimeric Corporation:** Andrew Sexton