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

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

2023 Carbon Management Research Project Review Meeting
August 28 – September 1, 2023

Project Overview

Overall Project Performance Dates

Task		Status	Deadline
	Budget Period 1	Complete	6-30-2022
	Budget Period 2	In progress	9-30-2023
Tasks 8 and 9	Integrated process assembly	Complete	12-23-2022
Task 10	Parametric Campaign	Complete	2-28-2023
Task 11	Long-term Campaign	In progress	9-30-2023
Task 12	TEA	In progress	9-30-2023

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
Monthly Expenditures (actual)	$112,414	$16,839

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

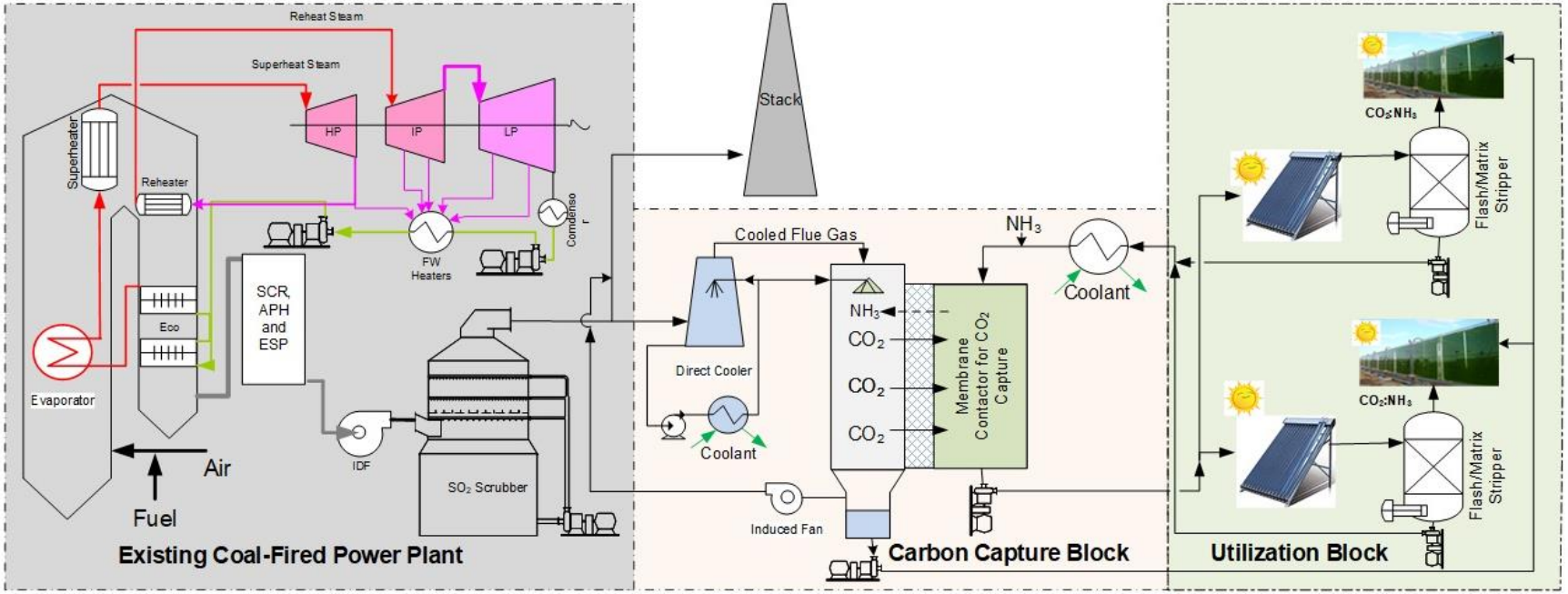
Trimeric Corporation

Conduct the TEA and LCA analyses

Process Overview

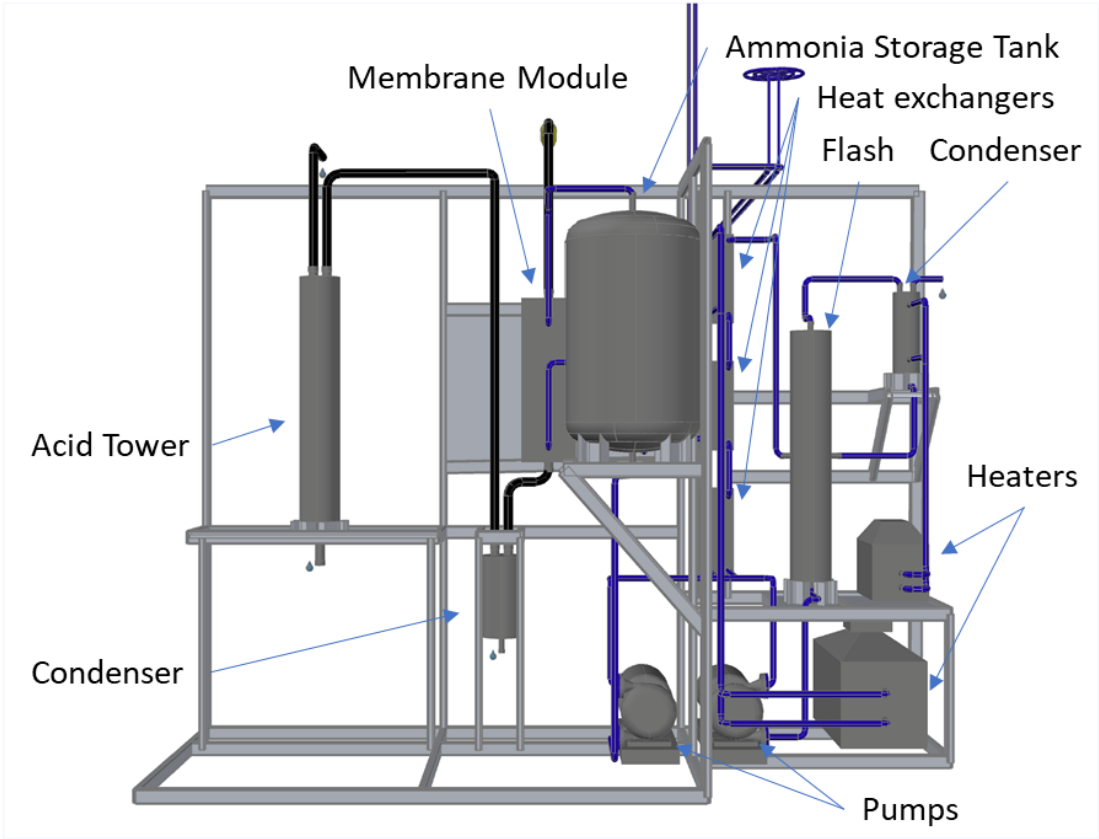
Unique, integrated CO_2 capture and utilization technology that:

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



Direct to utilization CO_2 capture

Technical Approach and Skid

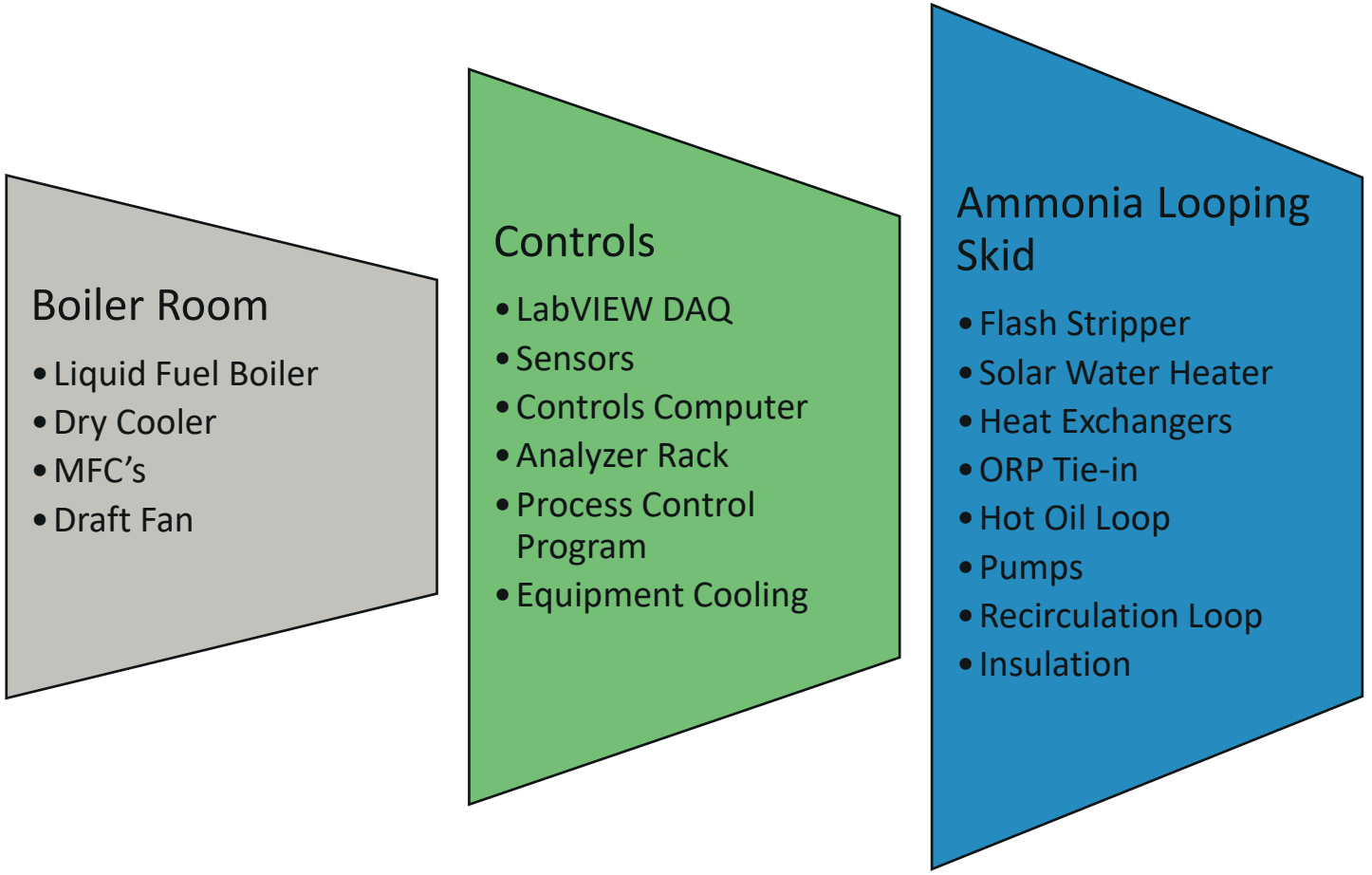


- Use 20 wt% ammonia solvent in a hollow fiber membrane to capture CO_2 from a combustion source.
- Feed regeneration products to algae in an open race pound to increase biomass production.

- The compact nature of the hallow fiber membrane allows for a small absorber column to be used.
- The HFM also reduces ammonia slip.
- The entire process fits on a small movable skid.

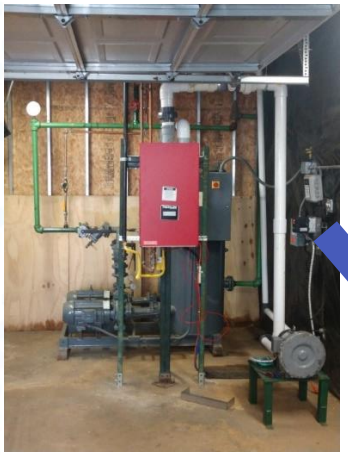
Progress and Current Status of Project

Process Equipment & Assembly

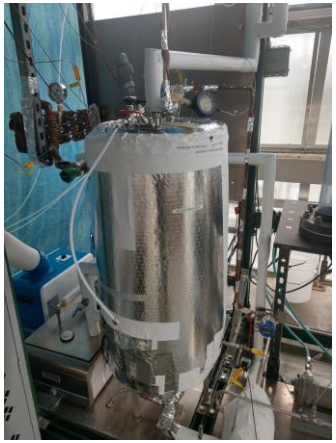


Integrated Process Assembled

LF Boiler



Stripping Loop

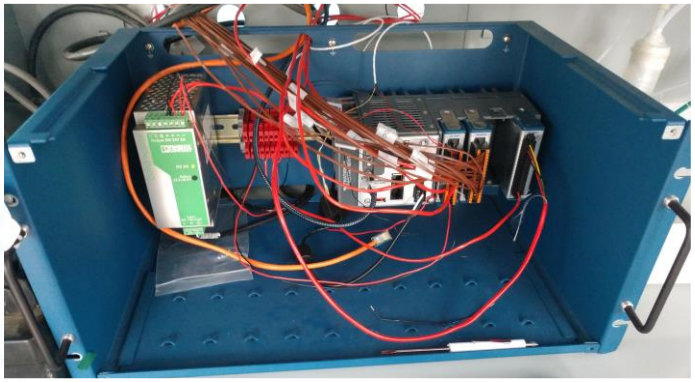


Solar Water Heater

Completed Assembly

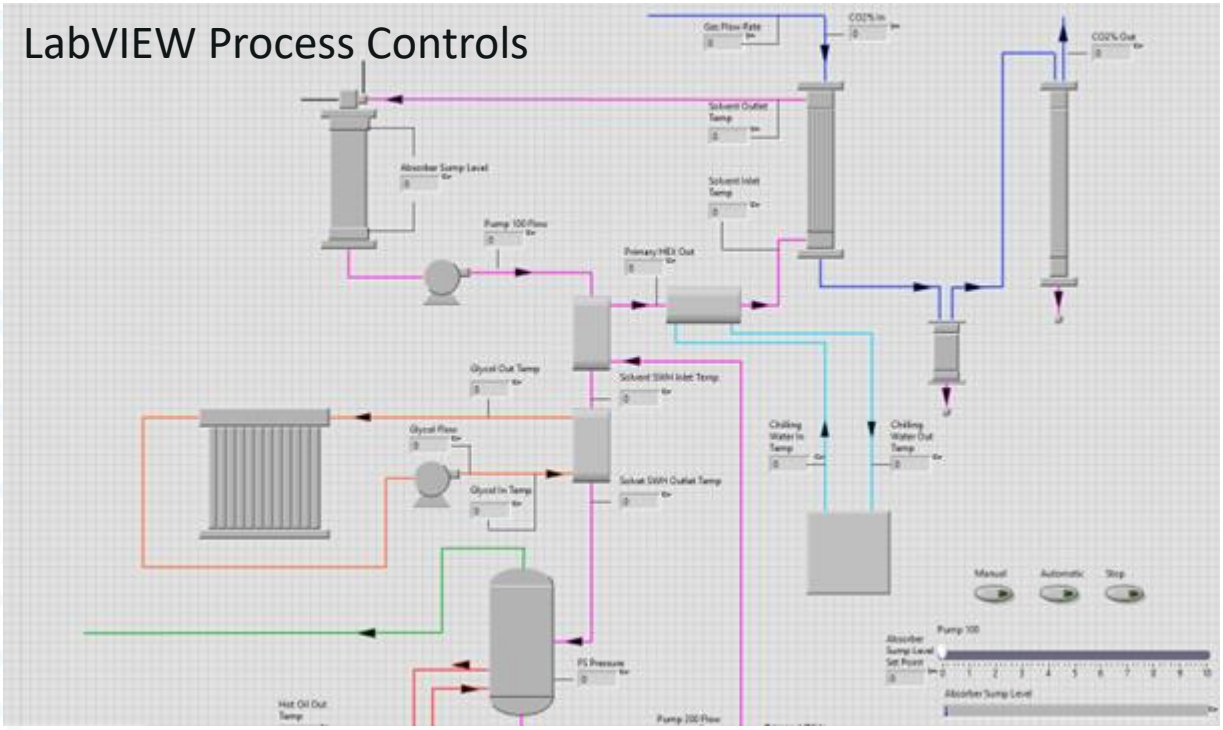
Process Controls

LabVIEW Data Aquation Rig



- All process inputs and outputs are controlled via a LabVIEW VI.
- Data is automatically logged and stored.
- Provides easy process monitoring and control.

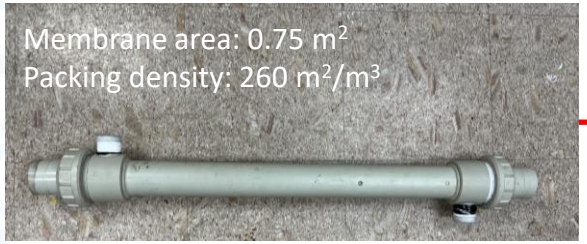
LabVIEW Process Controls



Gas Analyzer and Sensor Cabinet

Membrane Development

Hollow fiber membrane modules from Mann+Hummel (bore size=1.8 mm)



Pressure drop = 0.3 psi
CO_2 absorption flux
$=40.7 \times 10^{-4}$ mol/m^2/s

Gas sampling for product CO_2/NH_3 ratio

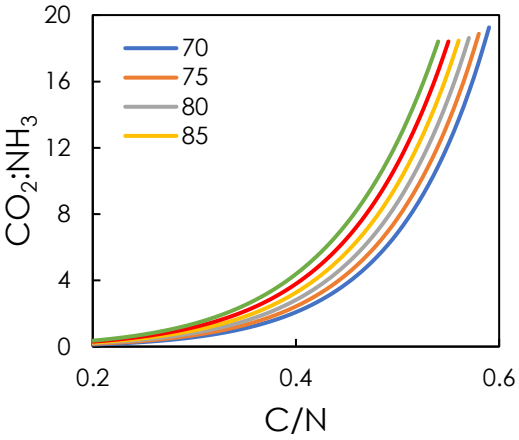
Parametric campaign result of ammonium looping tests

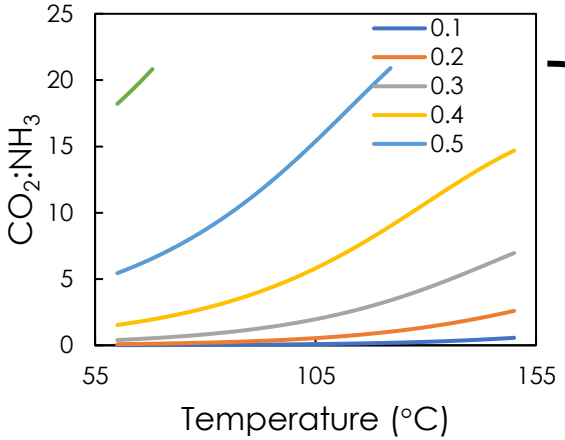
Solar water heater + heat trace + wrap-up heater + hot oil bath	Stripper pressure (psia)	Stripper bottom temperature (°C)	Stripper top temperature (°C)	Stripper inlet temperature (°C)	Rich carbon loading (mol C/mol N)	CO_2:NH_3 (mol/mol)
Different rich stripper feed carbon loading (0.2-0.5)	15.89	80.58	80.79	80.77	0.20	0.40
	14.84	81.36	81.22	73.76	0.25	0.67
	16.00	82.63	83.05	81.58	0.30	0.40
	14.93	81.44	81.32	78.32	0.35	0.52
	16.08	84.17	84.32	83.70	0.40	1.38
	16.09	83.06	84.32	82.65	0.45	2.89
	16.09	83.06	84.32	83.65	0.50	4.07

- Testing shows a direct correlation between solvent rich loading and nutrient ratio.
- This is due to VLE of the solvent and when operating at low stripping temperatures the impact of rich loading is prominent.

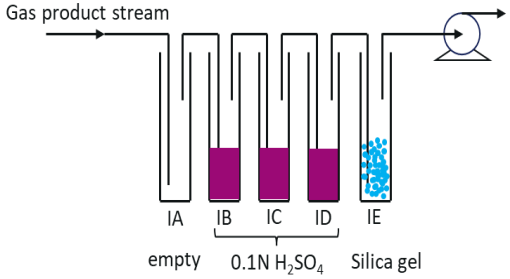
Determining Nutrient Ratio (CO_2/NH_4)

Aspen simulation → Guideline for operation conditions optimization

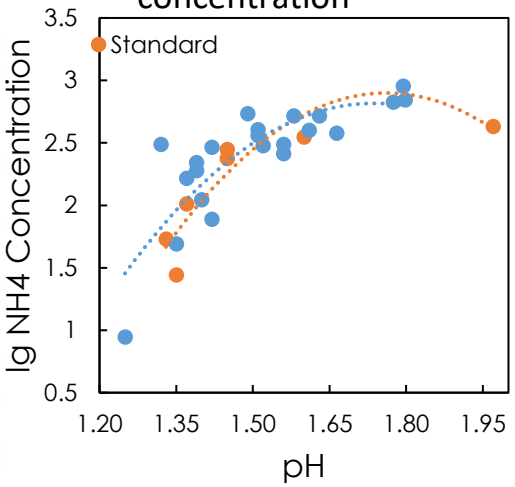


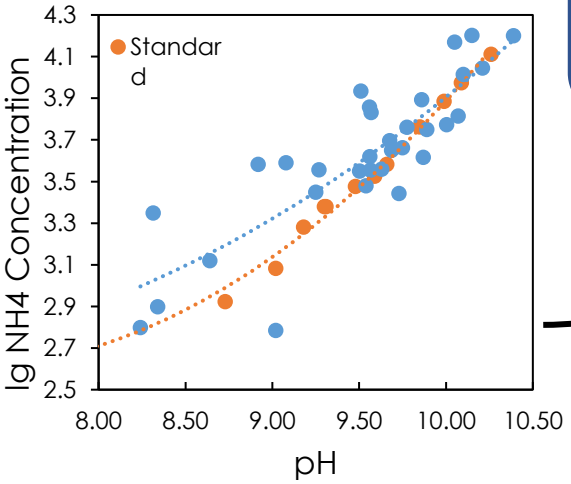


Gas phase sampling → IC analysis for NH_3 quantification



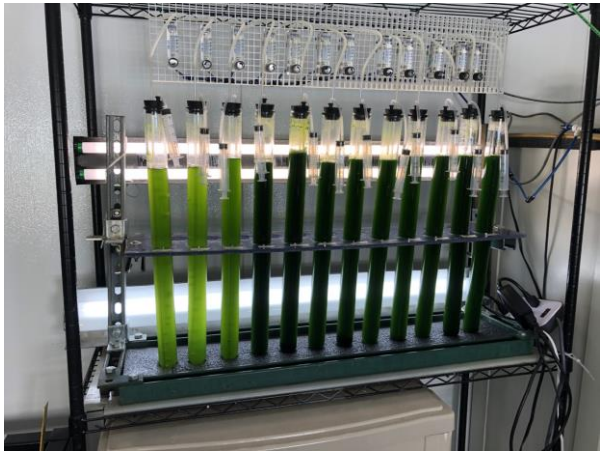
Correlation of pH measurements with NH_4 concentration → Simple and fast NH_4 concentration estimation



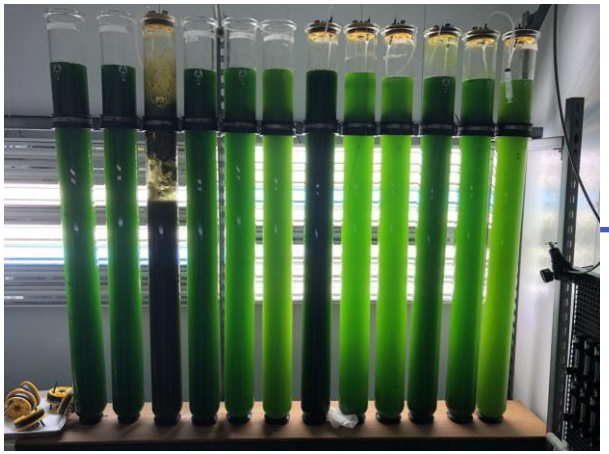


Algae Culturing

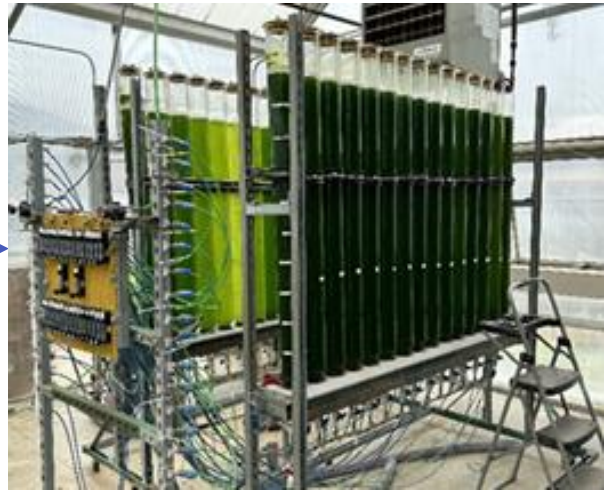
Start



12 x 800 mL tubes



11 x 10 L tubes

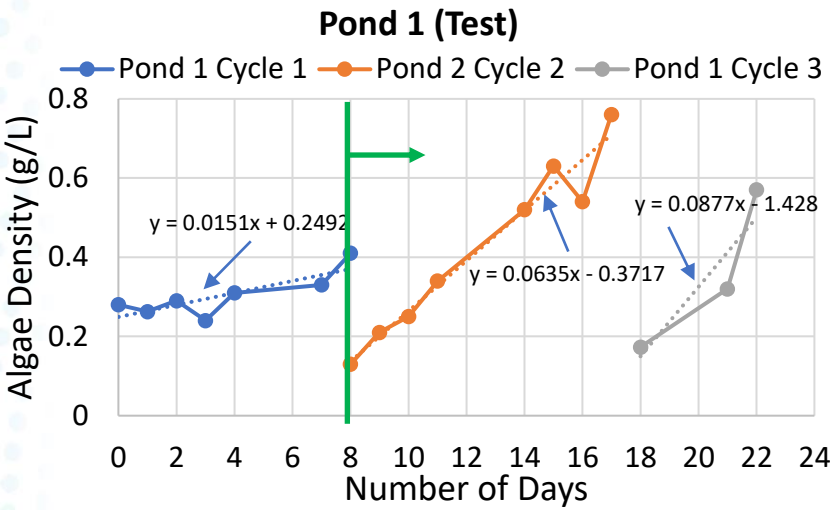


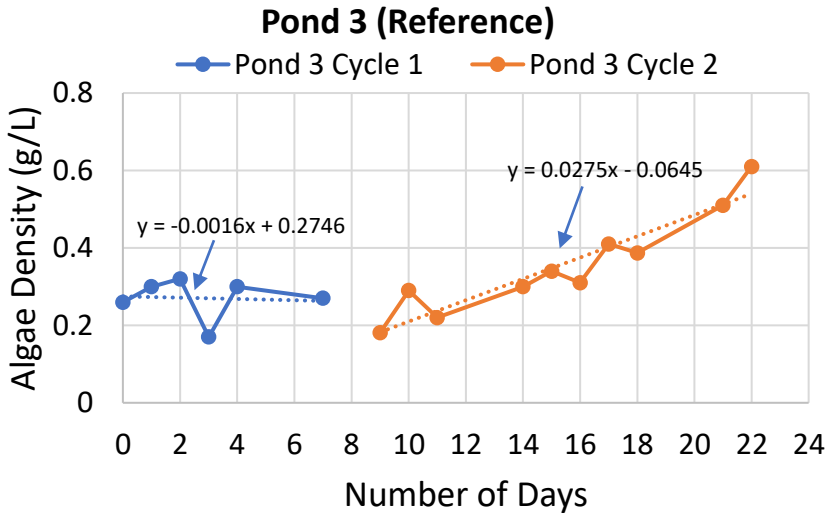
30 x 10 L tubes

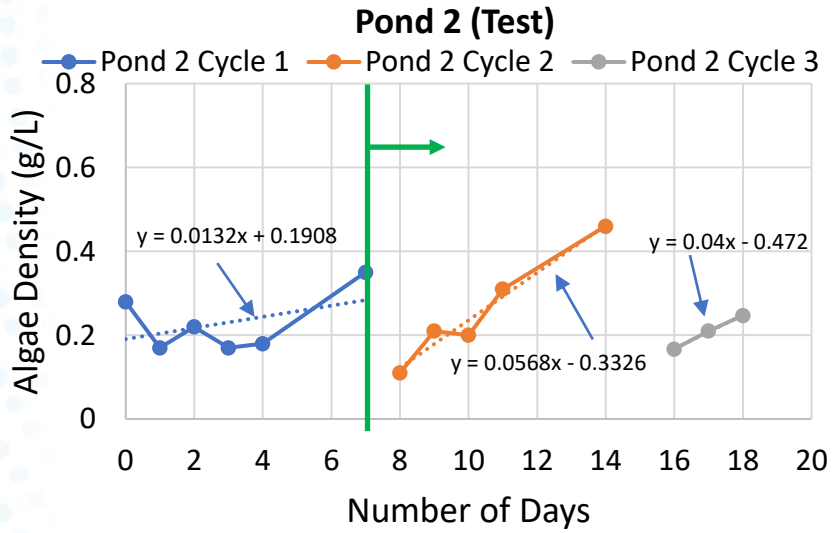
2 x 900 L ORPs

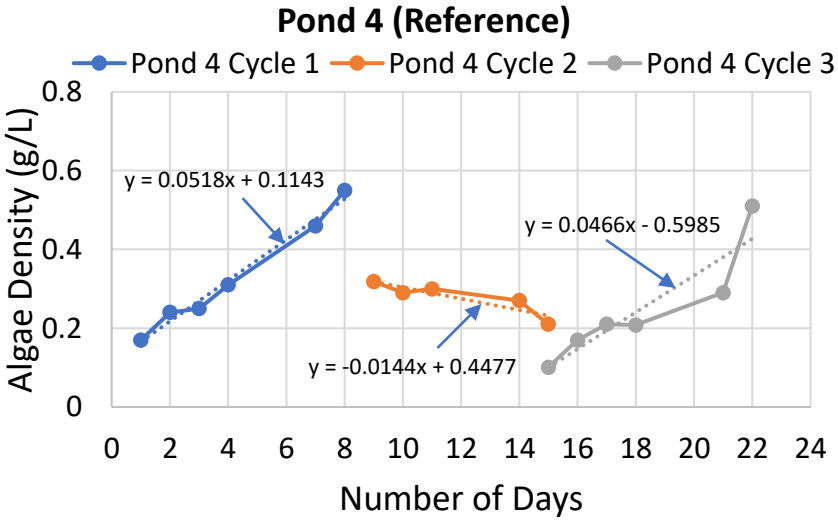
End

Initial Algae and ORP Data









Test

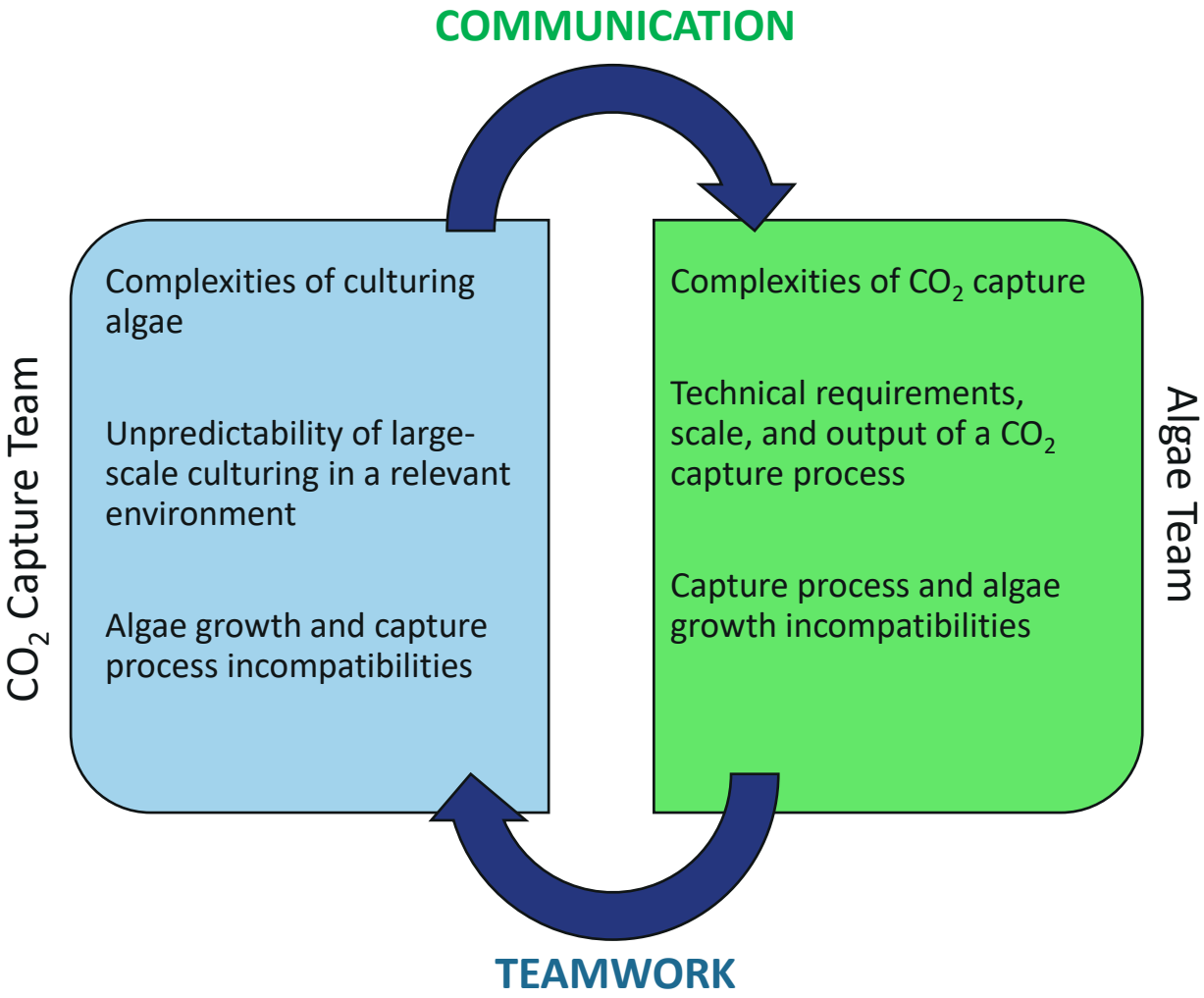
0.062 ± 0.014 g/L per day

3X increase

Reference

0.021 ± 0.007 g/L per day

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

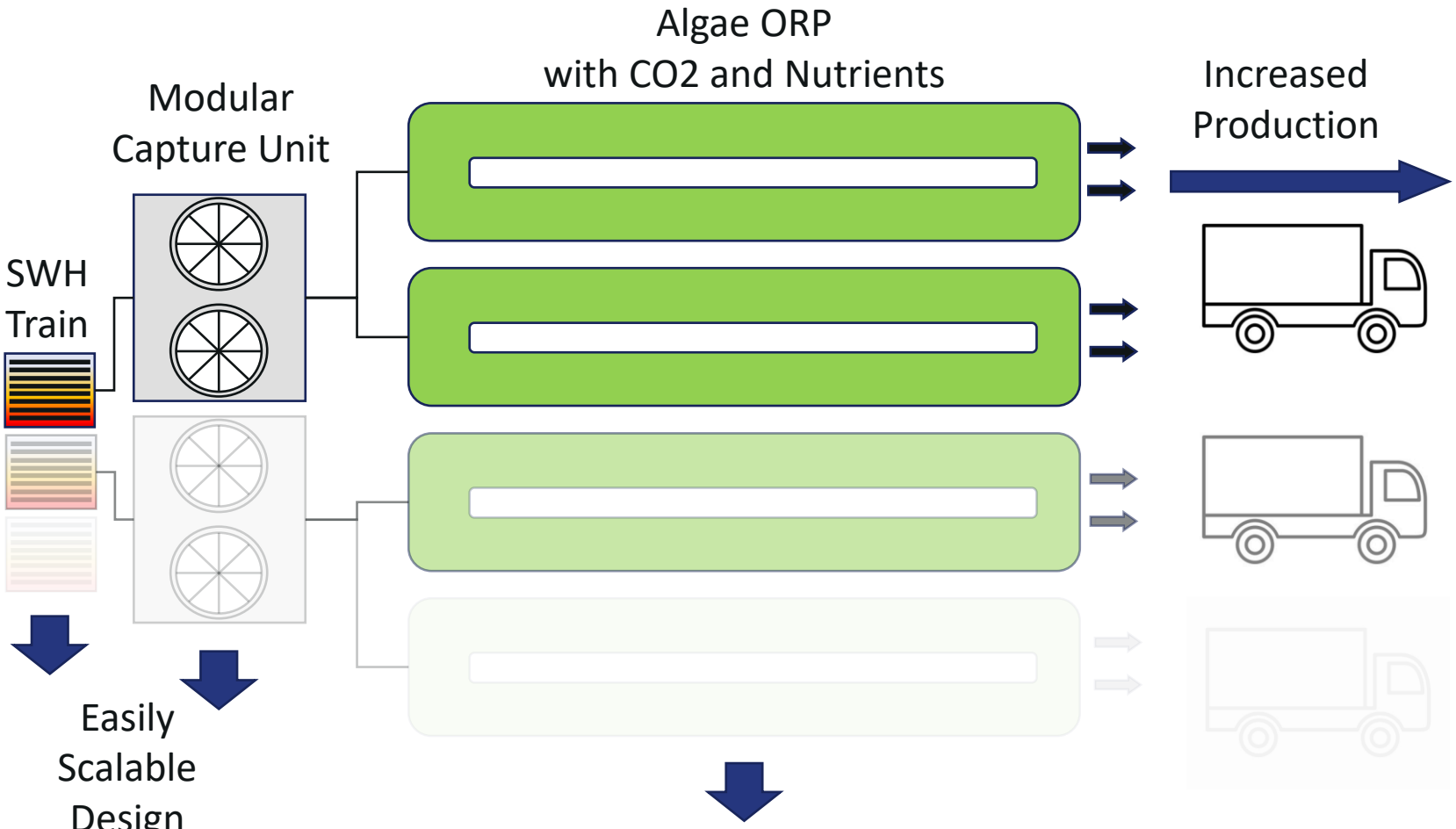
X 100 → Total capacity, 180,000L
(which about the size of a large swimming pool)

Development

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

Plans for Future Commercialization

Modular direct air capture and nutrient supply system for off-source algae cultivation.



Takeaway Summary

Completed

Integrated process assembly, Membrane Development

Parametric Campaign, Sampling and Estimation Method

Up Next

Long-term Campaign, TEA, Algae Growth Results

"With the full integrated process in operation, feeding nutrients to ORPs, we are eagerly awaiting continued positive results. It will be exciting to see where this project ends up going in the future, the concept is versatile and can be altered to fit a variety of different situation. We would like to thank the DOE for their continued support and interest in this unique project."

Acknowledgements

- **DOE-NETL**: Isaac Aurelio, Patricia Rawls, Joseph Stoffa
- **UKy:** Lisa Richburg, Xiaoshuai Yuan, Fritz Vorisek, Yaying Ji, Steve Summers, and Reynolds Frimpong
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