DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

Algae Production CO_2 Absorber with Immobilized Carbonic Anhydrase (TABB)

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Goal Statement

The goals are to demonstrate

80% CO_2 capture efficiency can be attained in a high efficiency absorber

90% carbon utilization efficiency in an outdoor raceway

Integrated operation of the absorber with an algae raceway

Relevance to bioenergy industry

- Low-cost CO_2 supply is necessary to achieve algal biofuel cost metrics
- High CO_2 capture and utilization efficiency are necessary to achieve biofuel cost, life-cycle, and production potential metrics
- This project will improve the efficiency of a proven system for utilizing power plant flue gas to supply CO_2 for large-scale open raceway cultivation

Quad Chart Overview

Timeline

7/2016 – 7/2019
99% Complete

Budget

	Pre 2017	2017	2018	2019 +
DOE	444	525	18	11
Cost Share	111	132	4	3
Partners • TSD • CO2 Solutions			22% 3%	

Barriers

- Aft-B. Sustainable Algae Production
- Aft-H. Overall Integration and Scale-Up
- Aft-J. Resource Recapture and Recycle

MYPP milestones addressed:

- By 2017, model the sustainable supply of 1 million metric ton cultivated algal biomass
- By 2022, model the sustainable supply of 20 million metric ton cultivated algal biomass.

Objective

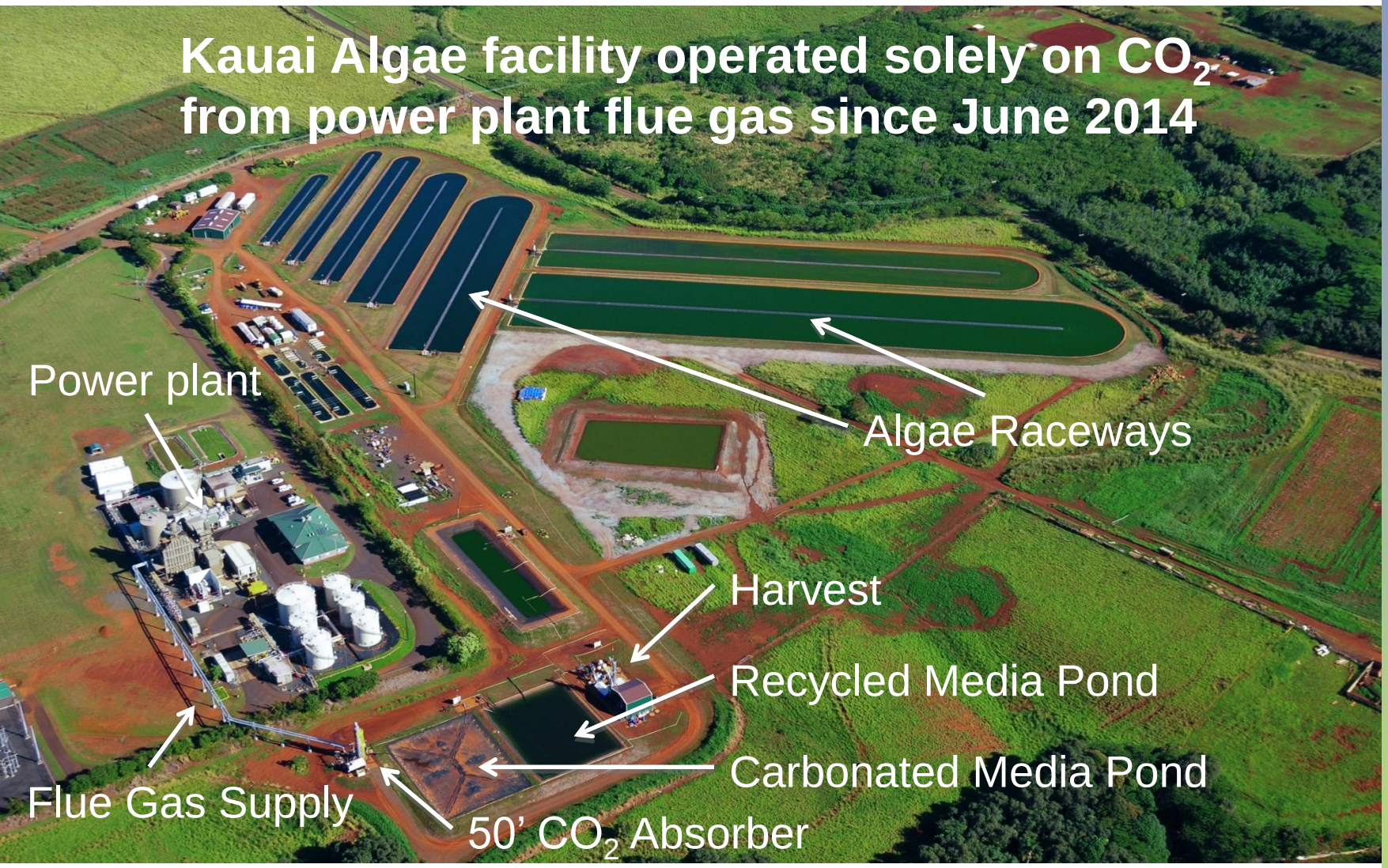
Utilize carbonic anhydrase and/or alternative absorber designs to increase CO_2 capture and utilization efficiency

End of Project Goals

Integrated cultivation and capture with

- 80% capture efficiency in single absorber
- 90% utilization efficiency

1 - Project Overview History



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Power Plant Flue Gas CO_2 Supply

- All CO_2 for growth from power plant flue gas
- 24 hour per day CO_2 recovery
- Power plant off-gas returned to stack after CO_2 recovery

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1 - Project Overview Goals

Objective	Start of Project	Current Status	Project Goal
Single pass carbon capture efficiency	10%	83%	80%
Carbon Utilization Efficiency	60%	95%	90%
Integrated operation with high efficiency absorber	No	Yes	Yes
Cost of CO_2 capture & delivery ($/mt CO_2)	$47	$21	$21

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2 – Approach (Management)

- Small team, weekly project meetings
- Milestone driven, completed well ahead of schedule

Area	Target	Schedule (Month)	Completion (Month)
Utilization Efficiency	70%	9	4
	80%	13	6
	90%	16	10
Absorber test system	Design	4	4
	Fab & Shakedown	10	7
	Operate w/catalyst	13	8
Capture Efficiency	80% neat solutions	16	8
	70% integrated	19	9
	80% integrated	22	9
	80%, 10 cycles	30	10
Management	Risk Plan	3	3
	Scale-up analyses	36	13

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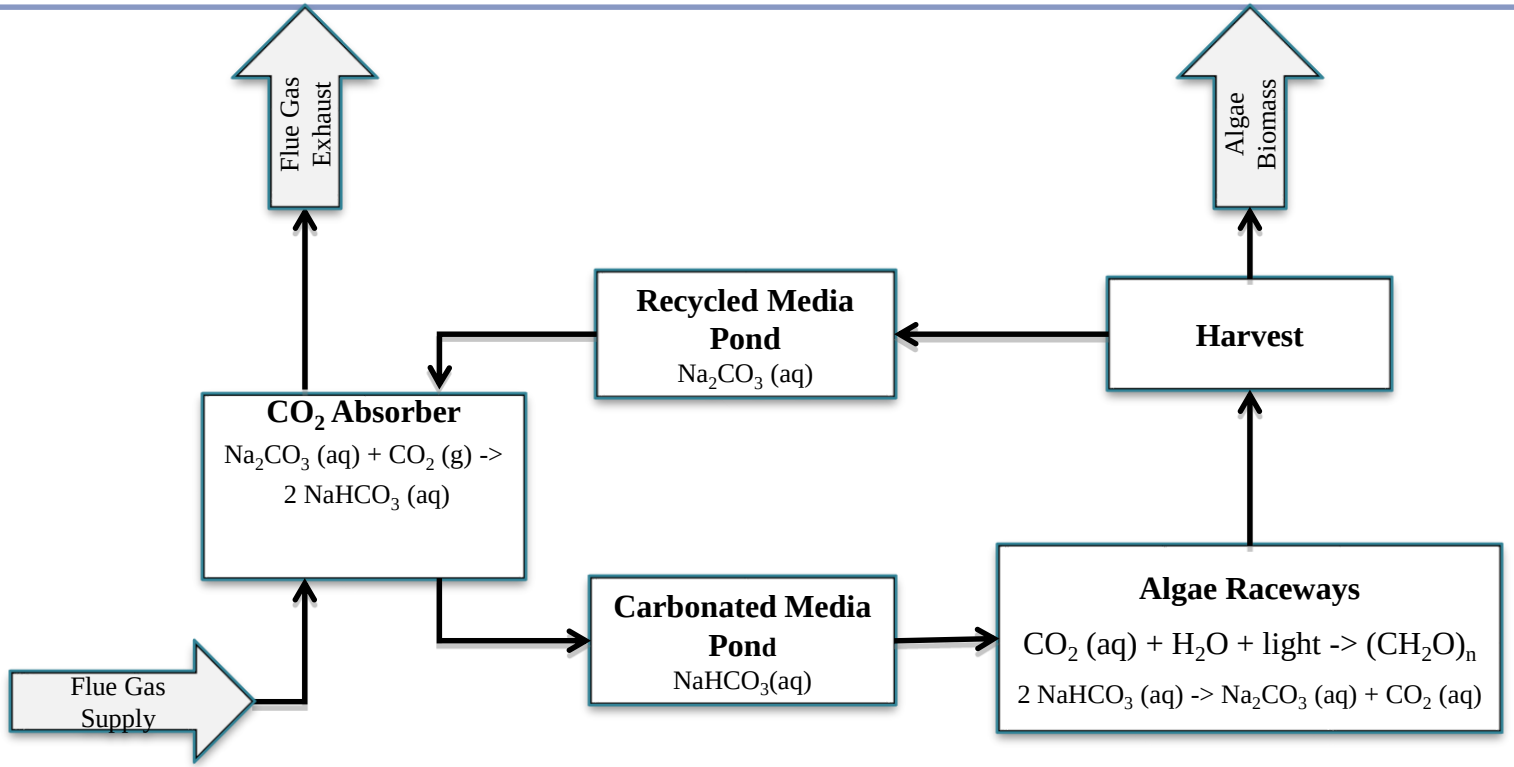
2 – Approach (Technical)



Carbonic anhydrase to increase absorber efficiency

Cultivation Methods for high utilization efficiency

Top Challenges

- Complexity of abiotic and biotic variation
- Carbonic anhydrase efficacy and lifetime in integrated operation with open raceways

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Key Attributes of CO_2 Supply Options

System Attribute	Global Algae Innovations	Bubble Flue Gas	Carbon Capture
Avoid ground level release	Yes	No	Yes
Simple distribution/controls	Yes	No	No
Low pressure drop	Yes	No	No
24 hour capture	Yes	No	Yes
Low cost capture	Yes	No	No

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Key Reactions
Hydration is the Limiting Step

1) $CO_2(g) \leftrightarrow CO_2(aq)$

2) $CO_2(aq) + H_2O \leftrightarrow H_2CO_3$ *(Limiting)*

3) $CO_2(aq) + OH^- \leftrightarrow HCO_3^-$ *(Limiting)*

4) $H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

5) $H^+ + CO_3^{2-} \leftrightarrow HCO_3^-$

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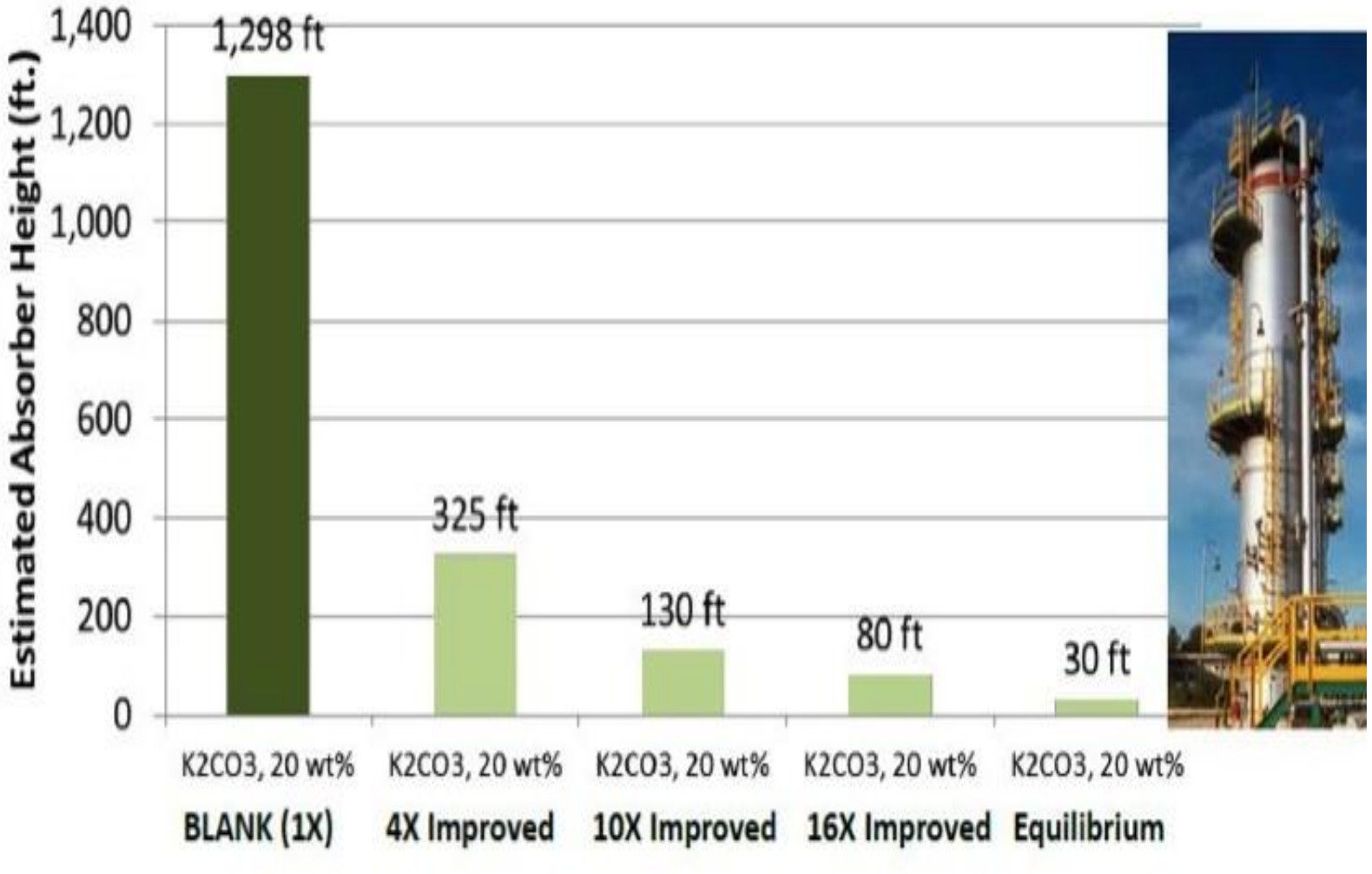
Utilize carbonic anhydrase to accelerate rate of hydration



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3 - Technical Progress

Carbonate/bicarbonate system characterization

- Data and empirical correlation for carbonate/bicarbonate ratio as function temperature, pH, and conductivity measurements

Carbon Utilization Efficiency

- 95% average utilization efficiency in outdoor raceways
- 99% average utilization efficiency when growth rate was 15-25 g/m^2d

Carbon Capture Efficiency

- 83% capture efficiency in a single pass column
- Mass-transfer data collected for scale-up
- Scale-up analyses show that 80-90% capture efficiency is reasonable for commercial-scale and cost is ~$13/mt for capture of CO_2 and ~$8/mt for storage and distribution to the raceways
- No change in efficiency during integrated operation

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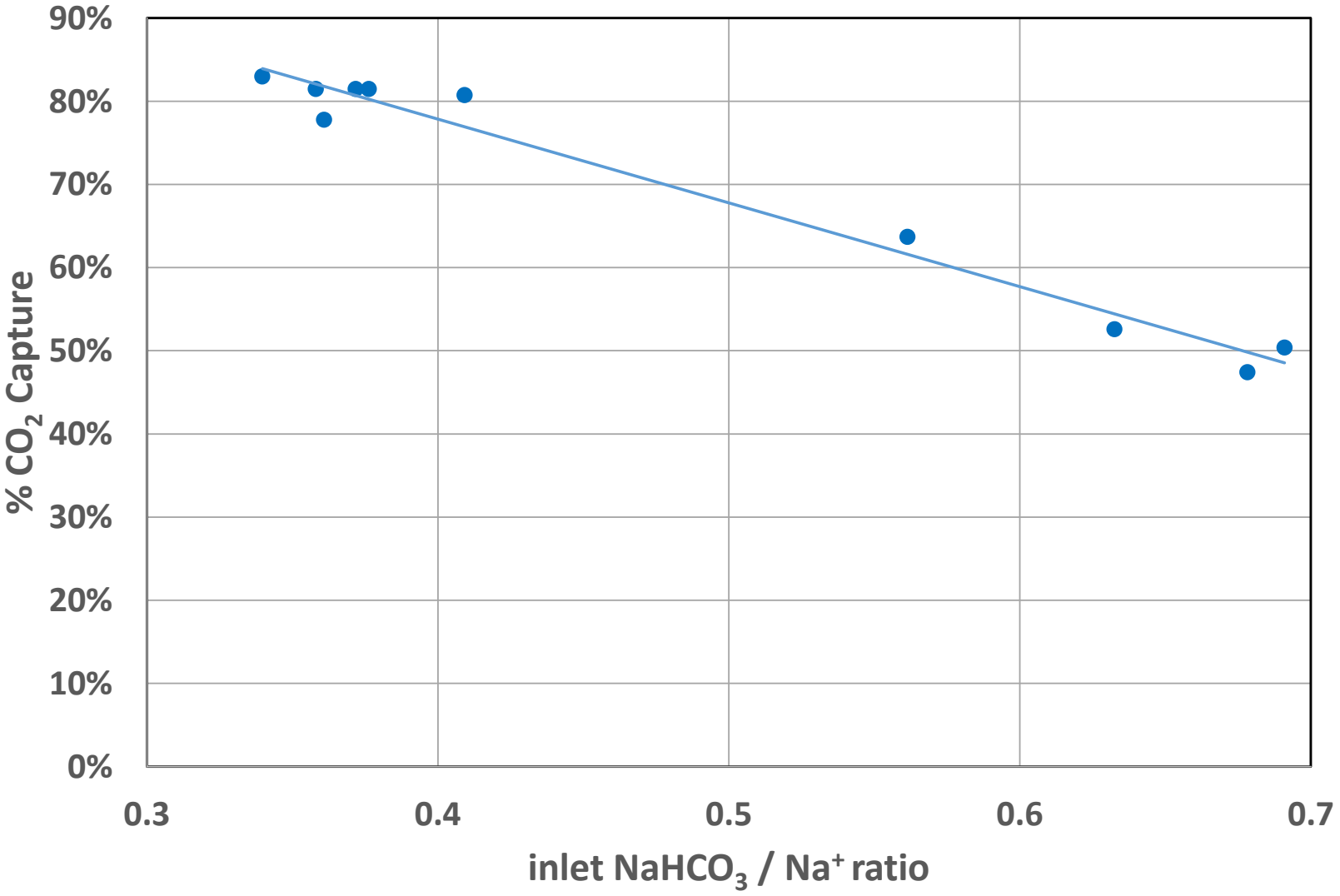
Single absorber capture efficiency results



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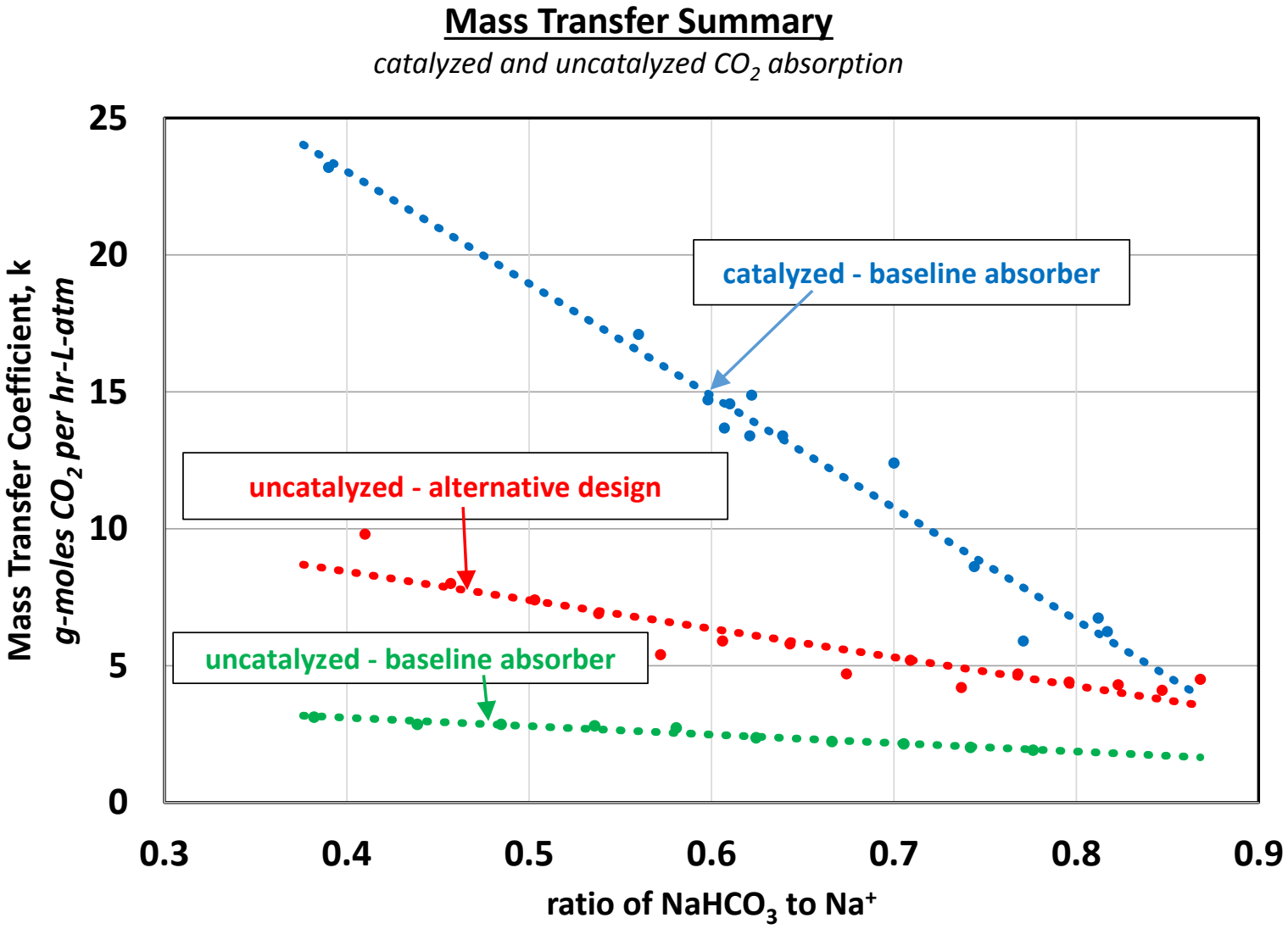
Mass transfer is improved by packing and/or catalysis



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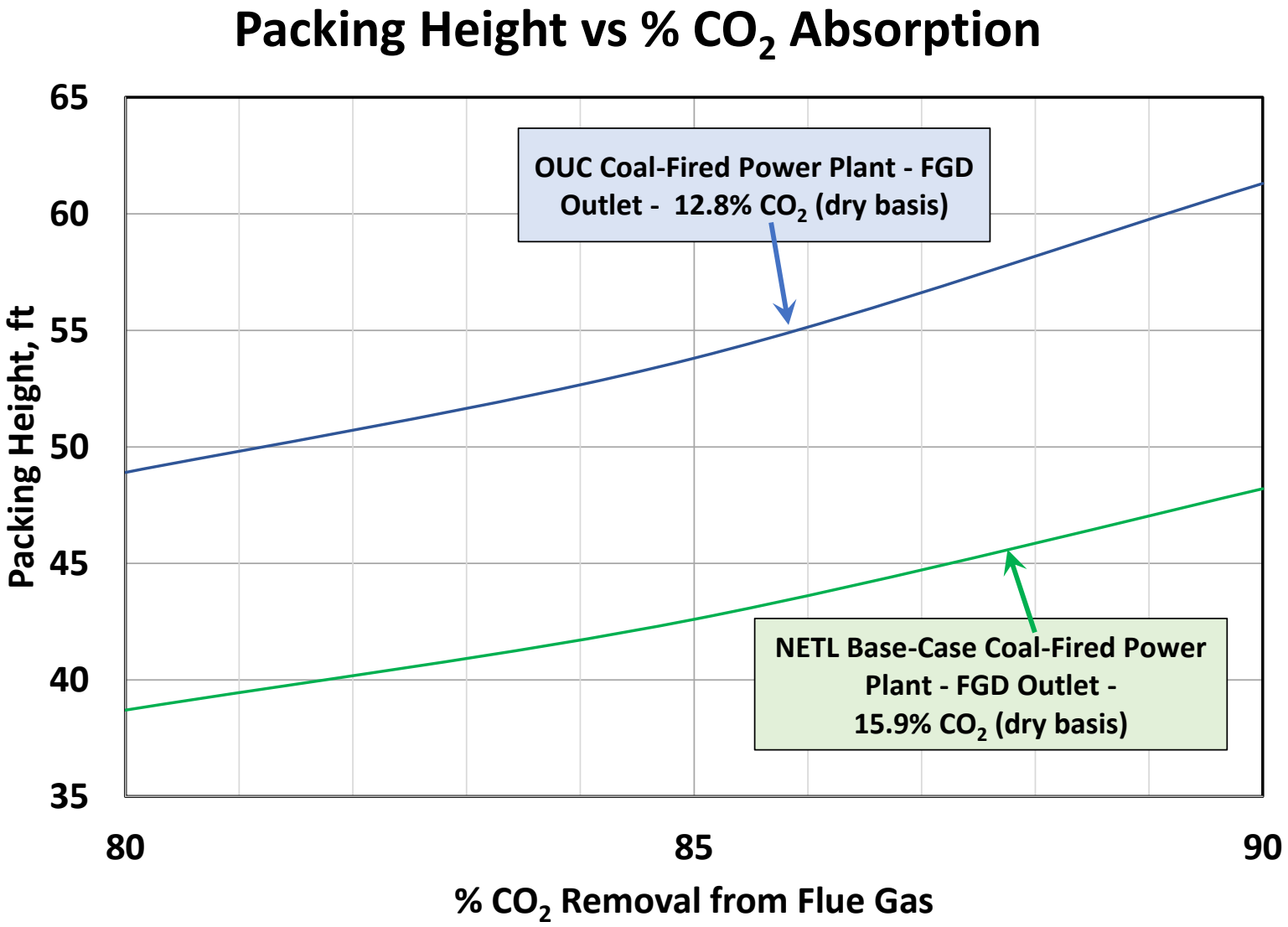
CO_2 Absorption Efficiency is improved with packing height and/or flue gas % CO_2



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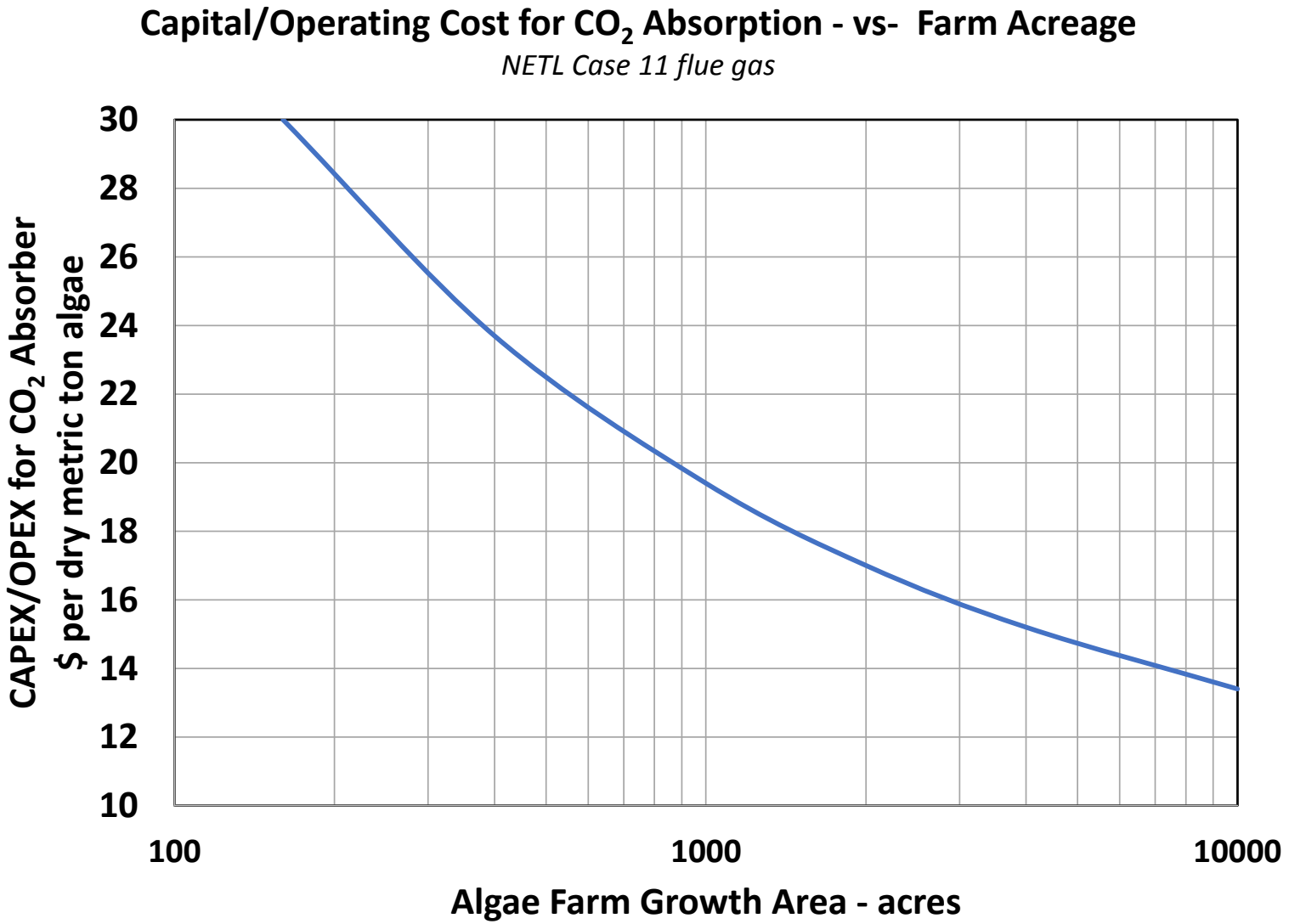
TABB Projections for Absorption Costs vs Farm Acreage



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Summary of utilization testing

Test	Average utilization efficiency
pH 9.1 to 9.6	70%
pH 9.1 to 9.3	47%
pH 9.4 to 9.5	77%
pH 9.5 to 9.6	95%
pH 9.5 to 9.6, Productivity <15 g/m^{2}d	80%
pH 9.5 to 9.6, Productivity 15 to 25 g/m^{2}d	99%
Automated control to 9.4	87%

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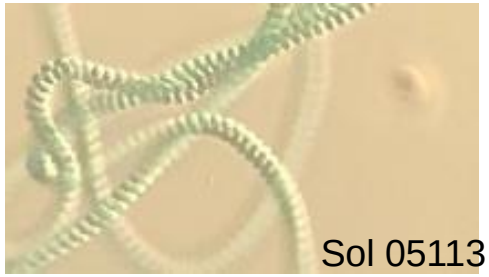
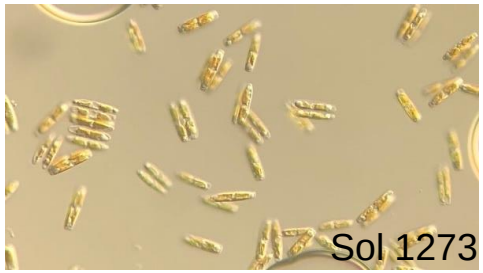
Soap Lake and surrounding area microalgae isolates





Strain	Class	Species	pH
Sol 1273	Diatom	*Nitzschia communis*	9.92
Sol 0671	Diatom	*Nitzschia communis*	9.92
Sol 04124	Diatom	*Nitzschia communis*	9.94
Sol 0458	Chlorophyte	*Chlorella vulgaris*	10.02
Sol 02103	Chlorophyte	*Nannochloris sp.*	10.20
Sol 15101	Chlorophyte	*Monoraphidium sp.*	10.40
Sol 08107	Cyanobacteria	Undetermined – potential Synechocystis	10.07
Sol 05113	Cyanobacteria	*Spirulina subsalsa*	9.86
Sol 0982	Cyanobacteria	*Synechocystis*	9.92

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4- Relevance

Supports the BETO mission to "Develop and demonstrate transformative and revolutionary bioenergy technologies for a sustainable nation."

Economical, scalable CO_2 capture required for large-scale commercialization

- Only practical, scalable, proven approach for open systems (operation on actual flue gas since 2014)
- Capture cost is lower than any other proposed method for flue gas
- Higher efficiency & lower costs directly support economical, sustainable algal biofuels and biofproducts

Goals aligned with BETO CO_2 capture and use:

- Higher capture efficiency
- Higher utilization efficiency
- Lower cost for CO_2 capture and use

Tech Transfer/marketability

- Strains for included in two BETO ECUAS projects
- Design incorporated into a BETO integrated biorefinery project
- Approach incorporated into 6 other BETO projects
- Strong interest from utilities

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5 – Future Work

Submit final report

Transfer data and results

- Global Algae techno-economic model for all projects
- ECUAS project absorber design and CO_2 utilization methods
- Integrated biorefinery project scale-up of absorber and utilization
- Commercial projects design and costing
- Discussions with utilities on integration with their power plants

Transfer newly isolated strains

- ECUAS project 1 – improved capture and utilization
- ECUAS project 2 – direct air capture

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Summary

1. **Overview:** Improves efficiency and reduces cost of proven, scalable CO_2 capture and utilization technology
2. **Approach:** Milestone driven, accelerated, focused effort
3. **Technical Accomplishments/Progress are ahead of schedule:**
   - Increased CO_2 capture efficiency from 10% to 83%
   - Increased CO_2 utilization efficiency from 60% to 95%
   - Reduced CO_2 costs from $47/mt to $21/mt (~$13 CO2, ~$8 distribution)
   - Demonstrated integrated operation with harvest and recycle of media
   - Developed improved absorber design that results in lower costs and reasonable absorber heights for 80-90% capture efficiency
   - Isolated nine high pH algal strains for future improvements
4. **Relevance**
   - Improved the efficiency of the only proven flue gas CO_2 supply for open systems
   - Strains available for improving efficiency or direct air capture of CO_2
   - Design incorporated into an integrated biorefinery project and other DOE projects