U.S. Department of Energy (DOE) Bioenergy Technologies Office (BETO) 2017 Project Peer Review

Algae Production CO_2 Absorber with Immobilized Carbonic Anhydrase

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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
21% Complete
(on track to complete 12/17)

Budget

	FY16 ($000)	Total Planned FY 17 + ($000)
DOE Funded	**256**	**743**
Cost Share TSD	**64** 17	**185** 31

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.

Partners

- TSD Management Associates

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

1 - Project Overview Goals

Objective	Start of Project	Current Status	Project Goal
Single pass carbon capture efficiency	10%	10%	80%
Carbon Utilization Efficiency	60%	84%	90%
Integrated operation	Yes[a]	Yes[a]	Yes[b]
Cost of CO_2 capture & delivery ($/mt CO_2 in algae biomass)	$47	$33	$21

[a] With baseline absorber
[b] With high efficiency absorber

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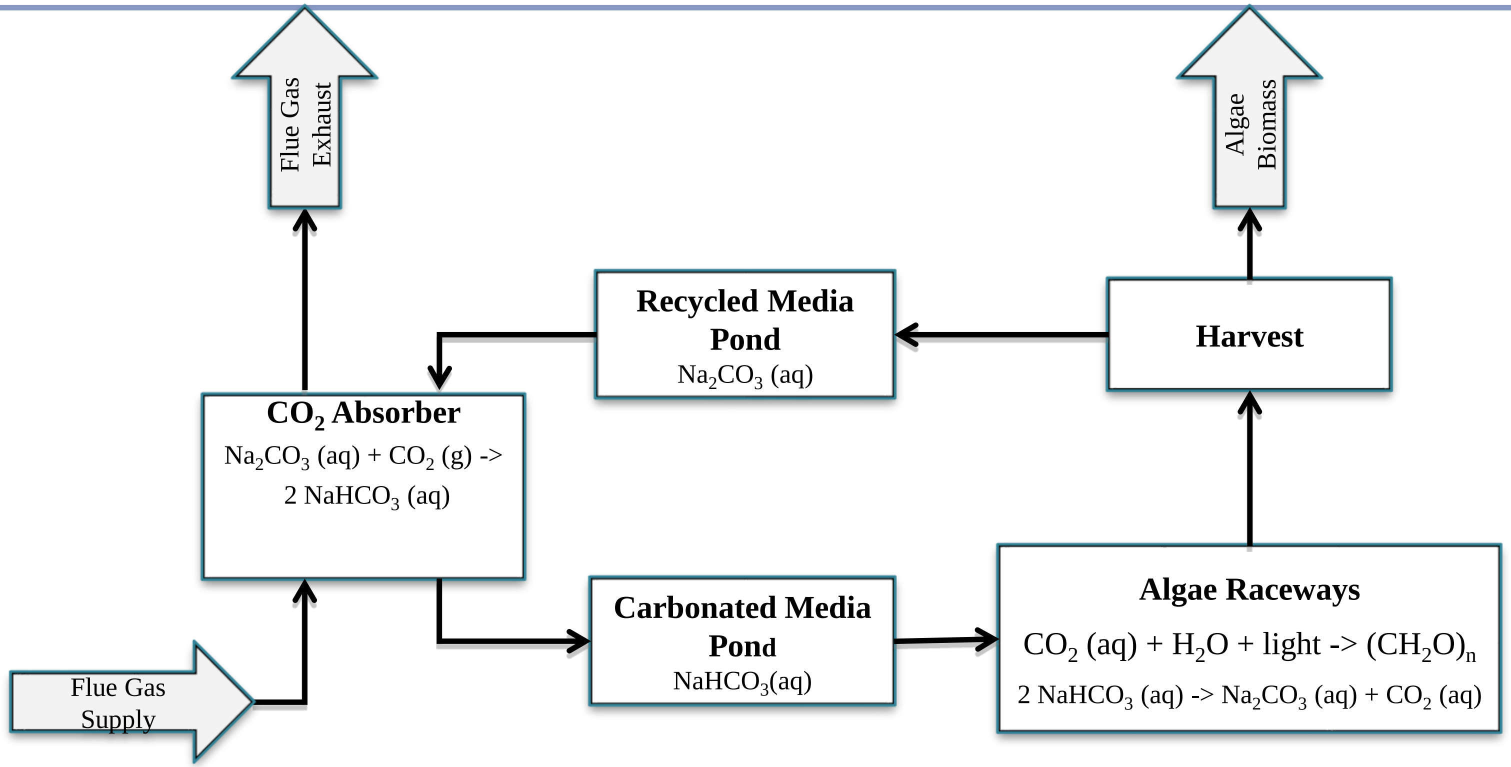
2 – Approach (Management)

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

Area	Target	Month	Status (Month 7)
Utilization Efficiency	70%	9	Complete
	80%	13	Complete
	90%	16	Achieved with high growth rate
Absorber test system	Design	4	Complete
	Fab & Shakedown	10	Complete
	Operate w/catalyst	13	Catalyst on-order
Capture Efficiency	80% neat solutions	16	
	70% integrated	19	
	80% integrated	22	
	80%, 10 cycles	30	
Management	Risk Plan	3	Complete
	Commercialization	36	

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) $CO_2(\mathbf{g}) \leftrightarrow \mathbf{CO}_2(aq)$

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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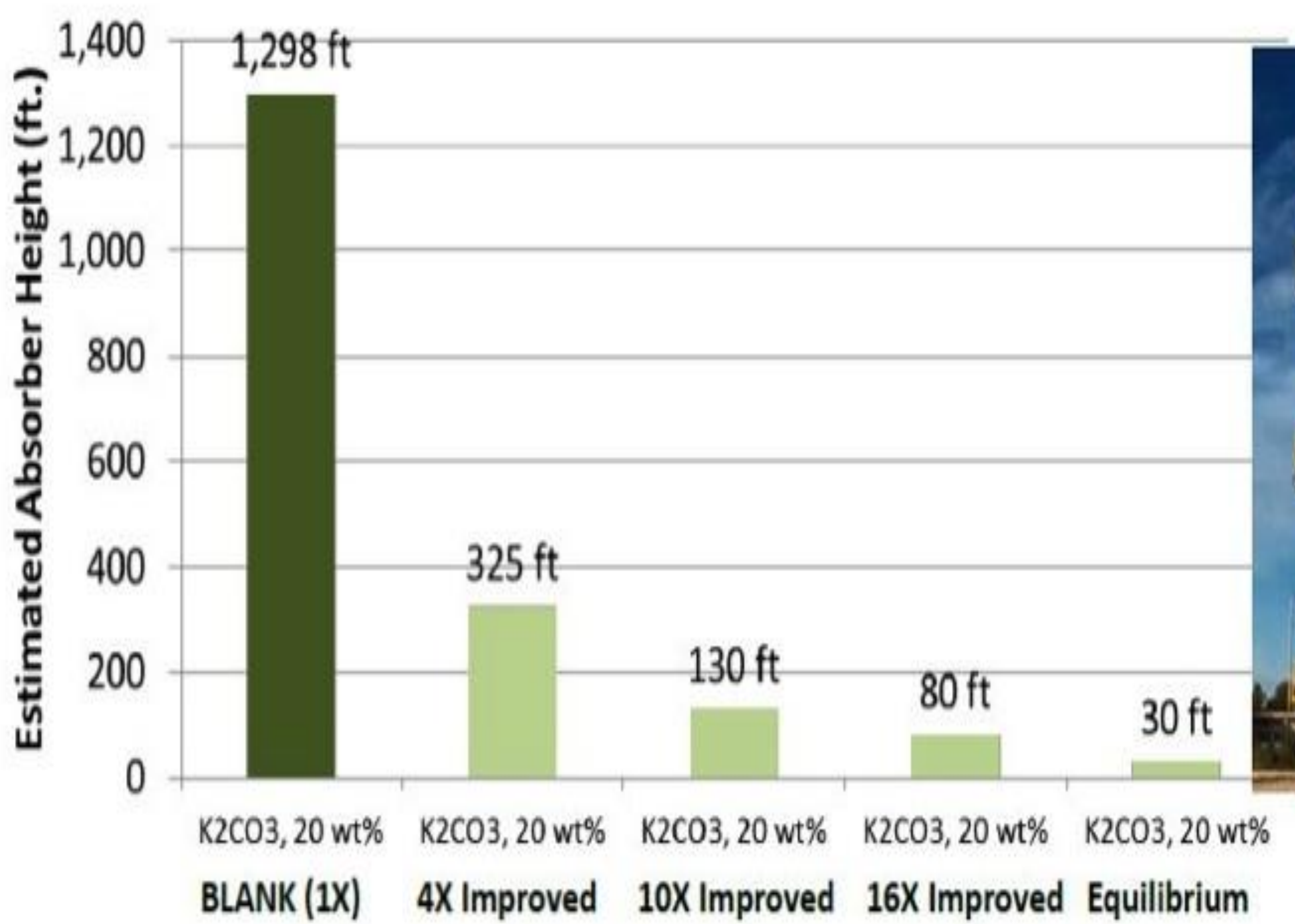
Utilize carbonic anhydrase to accelerate rate of hydration



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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

- 84% average utilization efficiency in outdoor raceways
- 99% average utilization efficiency for days when growth rate was 15-25 g/m^2d

Carbon Capture Efficiency

- Completed design, fabrication, and shakedown testing of test absorber system
- Measured the mass transfer coefficients in the test absorber system over a wide range of conditions without catalyst

Absorber test system variables

Independent Variables

- Carbonate solution strength
- Salt concentration
- Inlet liquid pH (9 to 10.5)
- Inlet CO_2 concentration (4-14 vol %)
- Operating temperature - (25-45° C)
- Liquid flow (4-20 L/min)
- Gas Flow Rate – 200-400 L/min
- Packing Height – 1-2 m
- Catalyst form and concentration

Dependent Variables

- Exhaust gas % CO2
- Outlet liquid pH
- Catalyst lifetime
- Packing pressure drop
- Liquid hold-up

5 – Future Work

Increase carbon utilization to 90%

- Refine control scheme for carbonated media addition during lower growth periods such as during rain or heavy cloud cover

Achieve CO_2 absorption rate for 80% capture efficiency in single pass absorber

- Optimize performance of the absorber through parametric testing

Demonstrate integrated operation the test absorber with open raceway cultivation

- Operate through at least 10 cultivation/harvest/carbonation cycles in integrated operation with open raceway cultivation

Summary

1. **Overview:** Improves efficiency of proven CO2 capture technology
2. **Approach:** Milestone driven
3. **Technical Accomplishments/Progress are ahead of schedule:**
   - Increased CO_2 utilization efficiency from 60% to 84%
   - Absorber test system completed and characterized
4. **Relevance**
   - Improves efficiency of only proven flue gas CO_2 supply for open systems
5. **Future Work**
   - Increase CO_2 utilization efficiency to 90%
   - Increase CO_2 capture efficiency to 80% for a single pass absorber
   - Demonstrate integrated operation with high efficiency absorber

Additional Slides