ALGAE BIOMASS SUMMIT 2020

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September 15, 2020 - Carbon as Pollutant and Critical Feedstock

Microalgae Biomass Production for Utilization of CO2 and Mitigation of Greenhouse Gas Emissions

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global thermostat (a carbon negative solution) — *Hans Kistenmacher, Ron Chance*

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U.S. DEPARTMENT OF ENERGY

- Research and Development
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- Facility Designs
- Algae Equipment Sales
- Techno-Economic Analyses / Life Cycle Assessments
- Wastewater treatment/ nutrients recovery
- Biofuels production and

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Wastewater treatment technology for:

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- Nutrients, N and P, recovery
- Co-production of biofuels, biofertilizers, bioproducts

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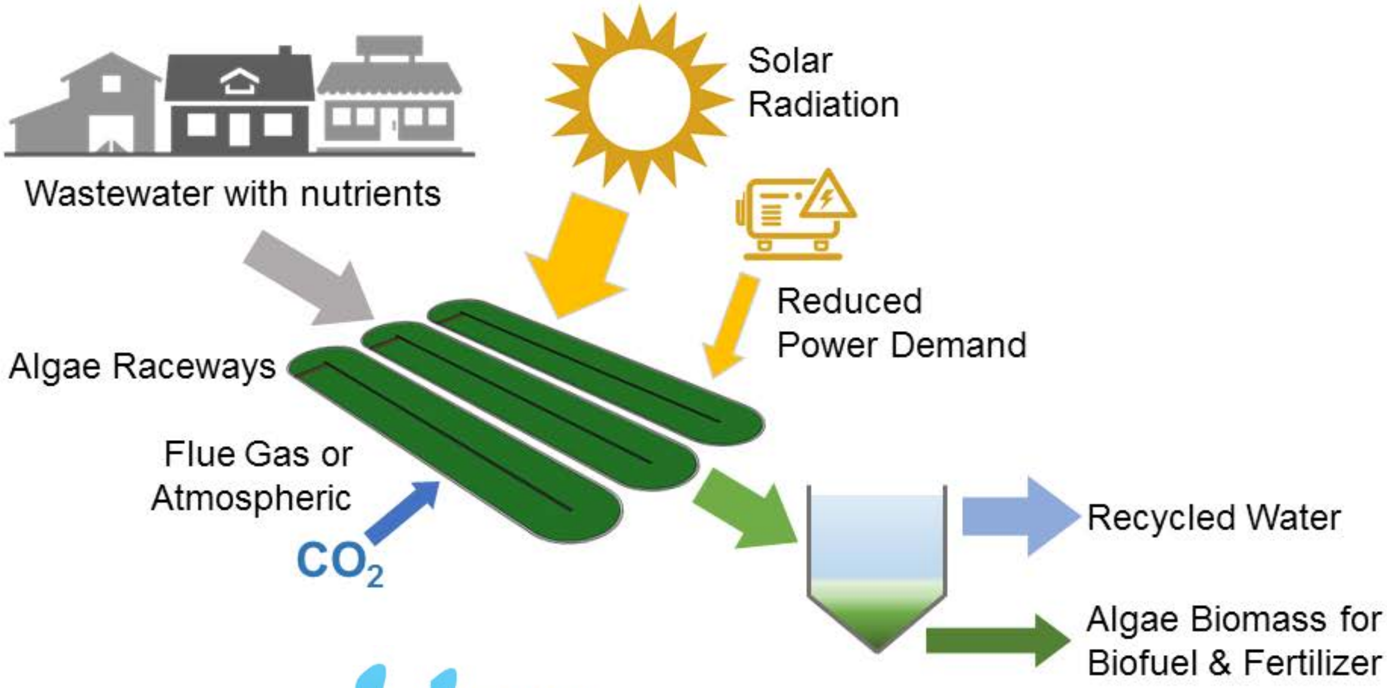

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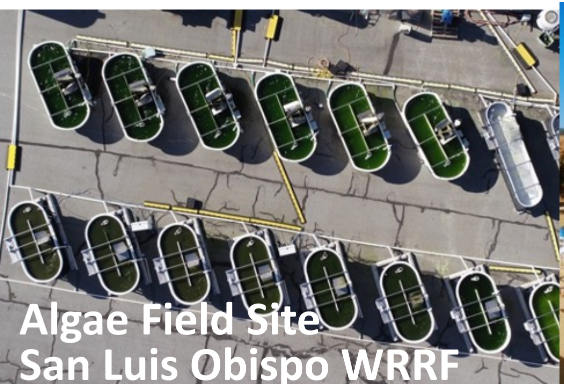
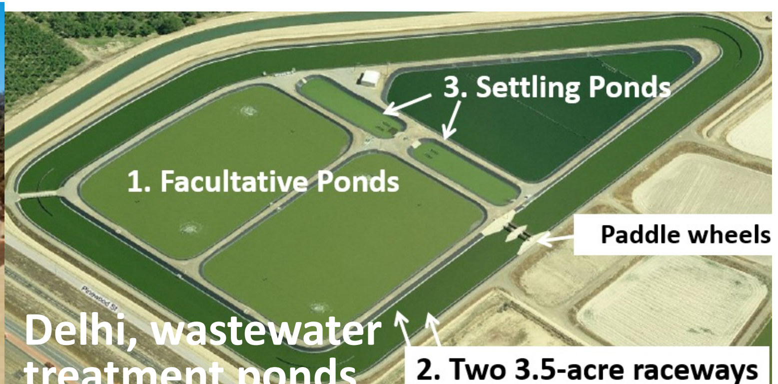
Recent and Current U.S. DOE Supported R&D Projects

- 2013 - 2016 US DOE Water & Nutrient Recycling (BETO - ASAP)*
- 2016 - 2017 Culture of Filamentous Algae on Wastewater (BETO, SBIR)*
- 2015 - 2021 CO_2 Use at Coal-Fired Power Plant (NETL **(R. Spierling presentation)**
- 2015 - 2018 Algae Harvesting by Bioflocculation (BETO, SBIR/STTR 1, 2)*
- 2014 - 2021 Algae Biomass Yield (BETO, ABY1,2) **(See A. Davis Presentation, 9/22)***
- 2020 - 2021 Biorecovery of Nutrients from Municipal Wastewaters (SBIR)*
- **2015 - 2022 Algae Culture on air-level CO_2 (BETO 'AirFix')****

***in collaborations with Cal Poly, others ** Collaboration with PNNL, Qualitas Health, Global Thermostat**





INTRODUCTION

Microalgal cultivation for production of fuels, feeds, bioproducts generally and wastewater treatment could help reduce CO_2 and other greenhouse gas emissions

CO_2 reductions would be relative to current biofuels, feed, or wastewater treatment.

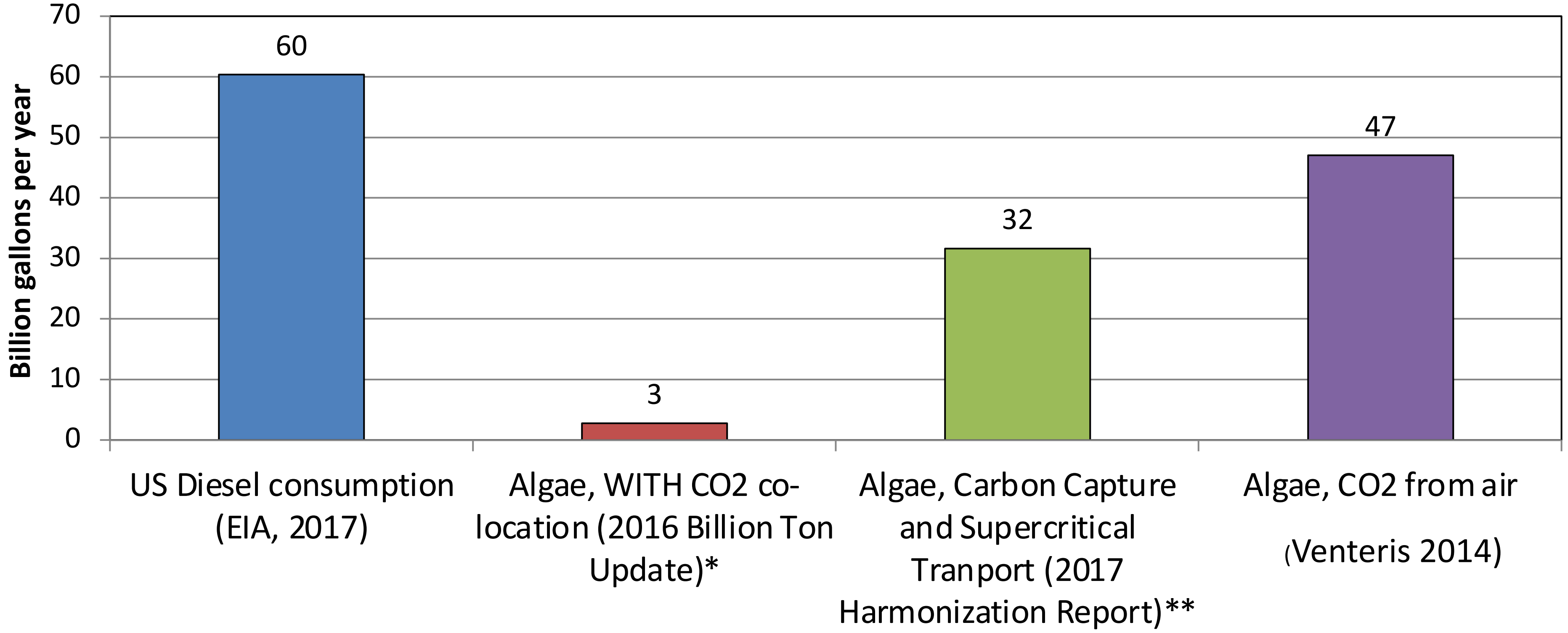
Unlike higher plants, microalgae currently require concentrated sources of CO_2.

Flue gas (~3 - 12 % CO_2) transport greatly reduces the microalgae biomass potential.

For maximum potential direct capture and utilization of CO_2 from air will be required.

This might be accomplished by the algal cultivation process itself, using large open-raceway ponds, through chemical and/or biological enhancements of CO_2 transfer.

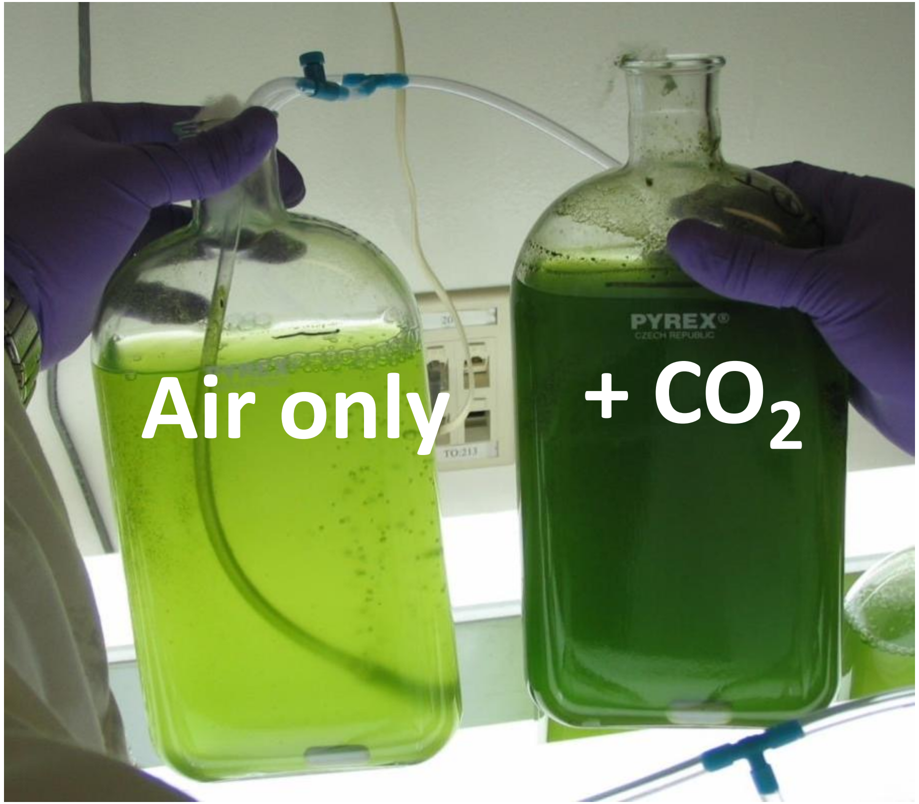
WHY PRODUCE ALGAE BIOMASS ON CO_2 FROM AIR? By decoupling algae cultivation from CO_2 point-sources, resource potential increases > 10-fold. (Alternative is flue gas carbon capture & long-distance supercritical transport)



*freshwater and saltwater scenario, present productivity. Assume 0.35 g diesel/gas per g of biomass.

**Assume 0.35 g diesel/gas per g of biomass (for comparison to the 2016 BTU case)

Growing algae on air vs. enriched CO2 sources



Growing algae on higher CO_2 (>10x) than air levels maximizes growth rates and productivity, while allowing for complete nutrients (N, P) assimilation in wastewater treatment.

Algae can be cultivated on air-CO_2 but that reduces biomass productivity by ~25% <u>and also</u> requires energy for sparging with large volumes of air.

Q?: can we grow algae on air-CO2 without sparging with air?

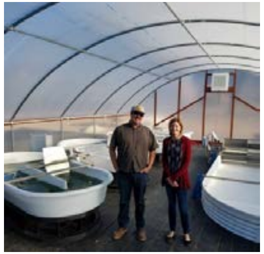
Increasing CO_2 Mass Transfer Rates from Air into Ponds

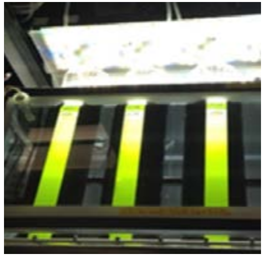
- **<u>Physical:</u> Increased mixing (turbulence) results in a smaller boundary layer. Challenge**: Energy intensive to transfer air-CO2 at sufficient rate into large algal ponds.

- **<u>Biological:</u> Addition of carbonic anhydrase could sufficiently increase CO_2 mass transfer. Challenge:** Must be present and active in the boundary layer at the air-water interface.

- **<u>Chemical:</u> High pH increases 'chemical-enhanced' CO_2 mass-transfer. Challenge:** Requires strains with high growth rate-productivity at high pH (>11). **THIS PRESENTATION**

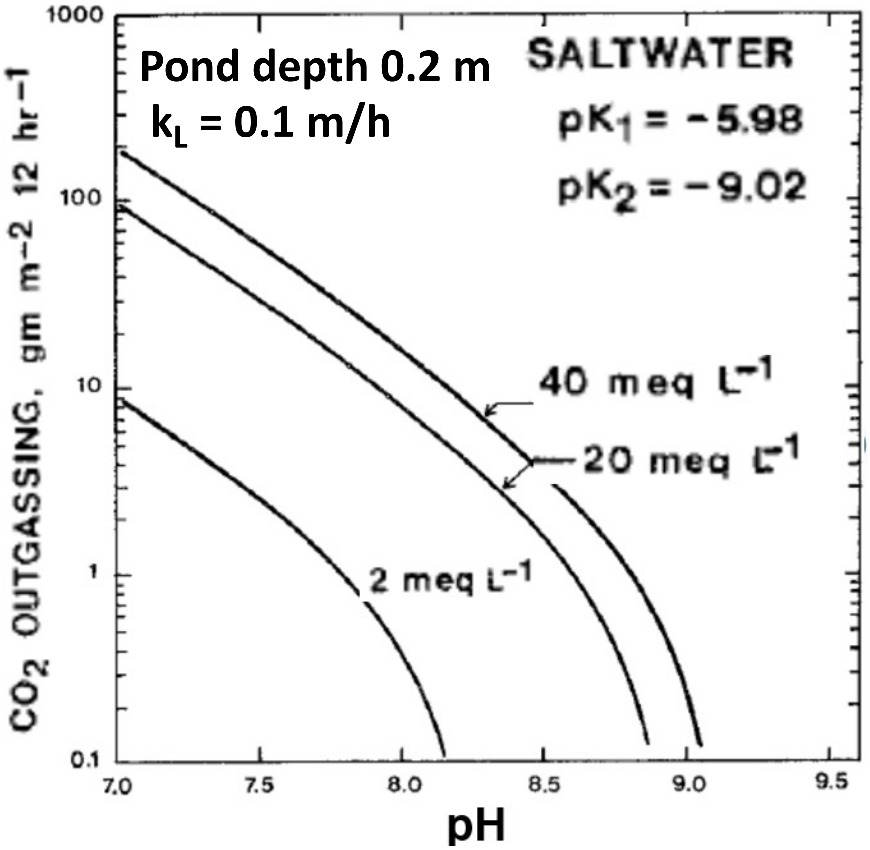
Objectives: Increase air-CO_2 mass transfer rates by chemical enhancement (high pH) with high biomass productivity with only air levels of CO_2





- Identify the extent to which chemical enhancement (high pH, alkalinity) would be able to support algae biomass production in small and large ponds.
- Select microalgae able to grow with air-CO_2 at the high pH required to achieve sufficiently high transfer rates
- Estimate air CO_2 mass transfer rates achievable in large production ponds (~10-acres), and their effects on production costs and the environment (TEA/LCA study)

CO_2 Flux to Atmosphere out of Algal Ponds



Weissman, Goebel, and Benemann, 1987.

CO_2 outgassing wastes CO_2. It is a function of pH and alkalinity and can be minimized, allowing for overall near 90% CO_2 utilization efficiency.

When pH is high enough, CO_2 will cease outgassing and start ingassing from air into the algal ponds. How high a pH? What alkalinity? What transfer rates? What is the effect of mixing?

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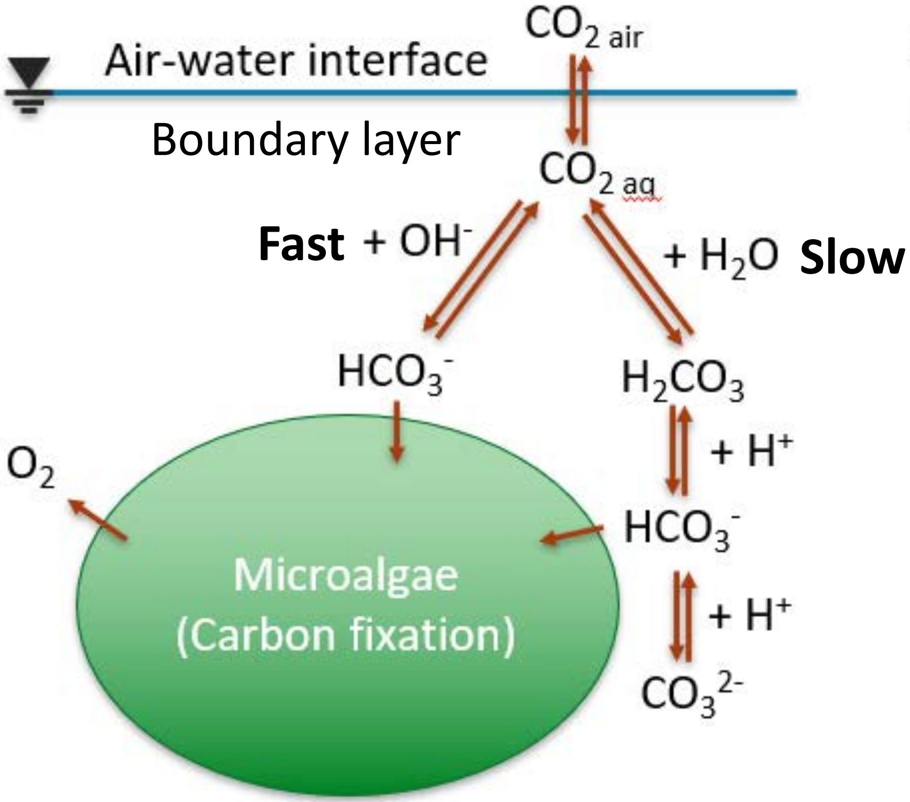
Air- CO_2 mass transfer into ponds can be accelerated by high hydroxide ion concentrations (high pH)



Air-CO_2 flux (J_{CO_2}) can be described by Fick's law:

$$J_{CO_2} = k_L^0 * (P_{CO2}^{air} * H - C_{CO2}^*(x = \delta))$$

"Piston velocity" (k_L^0); "Driving force" ($P_{CO2}^{air} * H - C_{CO2}^*(x = \delta)$); "Back pressure" ($C_{CO2}^*(x = \delta)$)

Where:

k_L^0= mass transfer coefficient, m/hr, a function of pond hydraulics

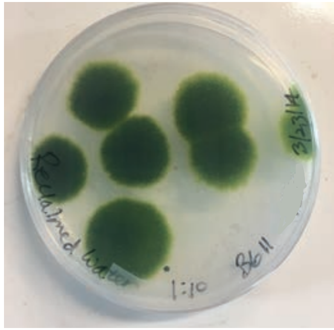
$P_{CO2}^{air} * H$= Dissolved CO_2 concentration in equilibrium with air

$C_{CO2}^*(x = \delta)$ = Dissolved CO_2 concentration some distance from the air-water interface

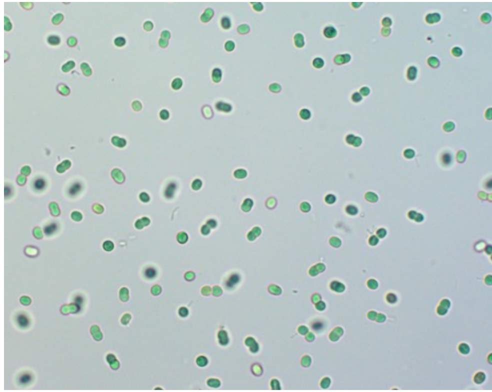
Bioprospecting for alkaliphilic strains

- Obtain inoculum from high pH environments (possible locations: Soap Lake, Soda Lake, Mono Lake, Searles Lake, Walker Lake, Owen’s Lake)

Left: Soap Lake, WA.   Right: Searles Lake, CA

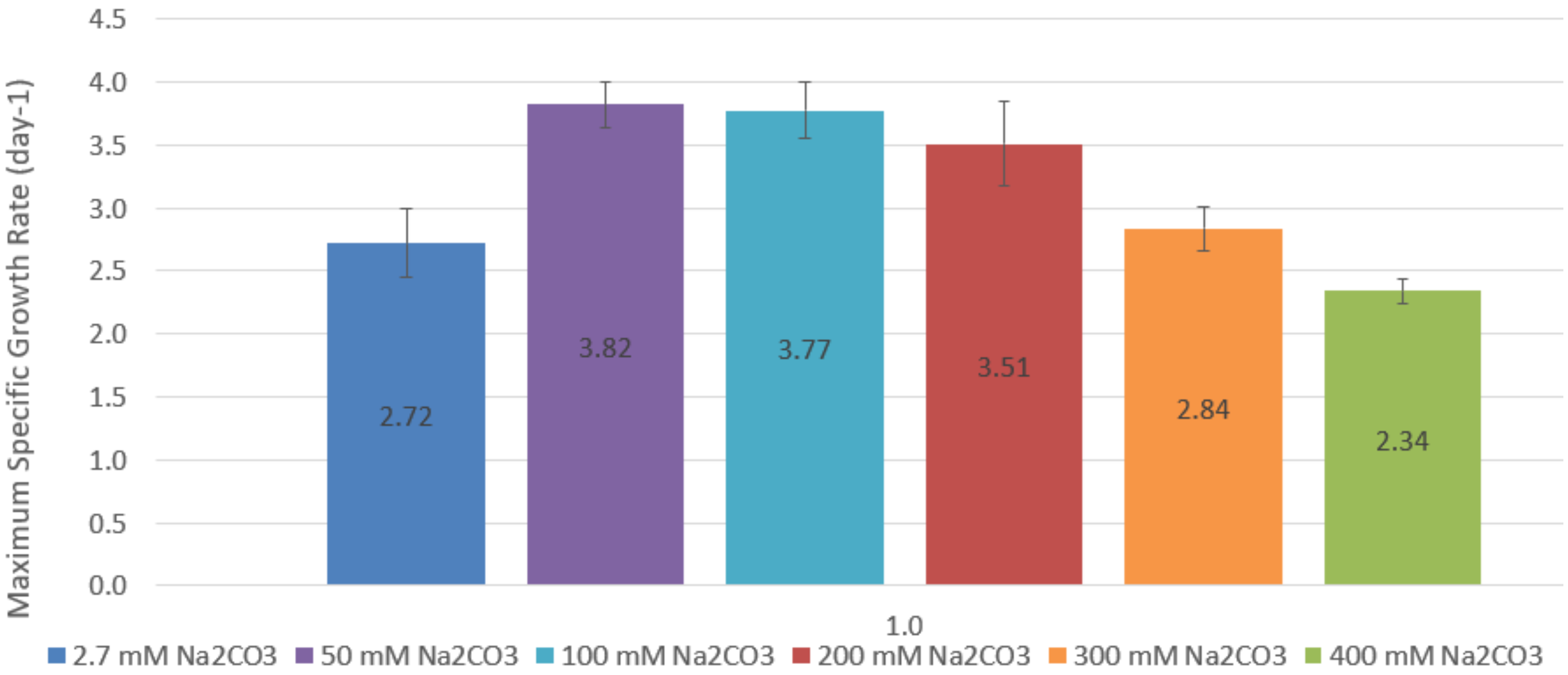


***Cyanobacterium* sp. SSL1 (isolated by PNNL)**



- Obtain isolates using plating
- or FACS sorting

Objective: select alkaliphilic strains with high productivity at high pH: Maximum specific growth rate as function of alkalinity, pH 11



CO_2 ingassing from air: being studied at large ponds at Qualitas Health, Imperial, TX.

Carbon balances both calculated from known pH and alkalinity, and directly measured as DIC

By Calculation (known pH, alkalinity):

$$A_C = A_T - ([B(OH)_4^-] + [OH^-] + [HPO_4^{2-}] + 2[PO_4^{3-}] + [SiO(OH)_3^-] + [NH_3] + [HS^-] + \ldots - [H^+]_F - [HSO_4^-] - [HF] - [H_3PO_4] - \ldots)$$

$$[CO_3^{2-}] = \frac{A_C K_2}{[H^+] + 2K_2} \quad [HCO_3^-] = \frac{A_C[H^+]}{[H^+] + 2K_2} \quad [CO_2^*] = \frac{A_C[H^+]^2}{K_1([H^+] + 2K_2)},$$

DIC = Carbonate + Bicarbonate + Carbon dioxide

DIC is a function of K1, K2, and KW.

Water-source and temperature specific equilibrium coefficients must be used

Direct measurement of DIC:

MBE, Qualitas Health, and PNNL all use in-house TOC, DIC analyzers. **Analytical round robin completed**.


Abiotic ingassing-outgassing experiments
now underway at the Imperial, Texas,
facility of Qualitas Health.

Bicarbonate Evaporation Pond Near Mexico City - Site of first Spirulina production facility (1974 -1995): CO_2 was provided by a combination of air and bicarbonate. NOTE: Chinese Spirulina producers still use this process. But productivity is low and bicarbonate addition expensive.

Conclusions

- Point-source CO_2 co-location limits resource potential
- 2nd generation carbon capture technologies combined with compressed CO_2 transport are expensive.
- CO_2 transfer from air requires very high pH (>11) for sufficient C transfer, which reduces productivity.
- Strains are required able to grow well at high pH.
- Abiotic & biotic studies required to establish feasibility.
- Feasibility requires low energy and chemical inputs.
- Small scale pond results must be verified, and at scale.

Acknowledgement:

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NEXT PROJECT: Microalgae Commodities Production with a Direct Air Capture Process

Topic Area 3: Algae Bioproducts and CO2 Direct-Air-Capture Efficiency (ABCDE)
DE-FOA-0002203 Control Number: 2203-1728. Award Number: DE-EE0009276

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Charley O' Kelley, Gerry Cysewski – Cyanotech Inc.

Ron Chance, Eric Ping, Hans Kistenmacher – Global Thermostat Inc.

Michael Huesemann, Scott Edmundson, Song Gao – PNNL

Period of Performance: October 2020 to December 2022.

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Cyanotech nutrex HAWAII
Fulfilling the Promise of Whole Health Through Hawaiian Microalgae

global thermostat
a carbon negative solution

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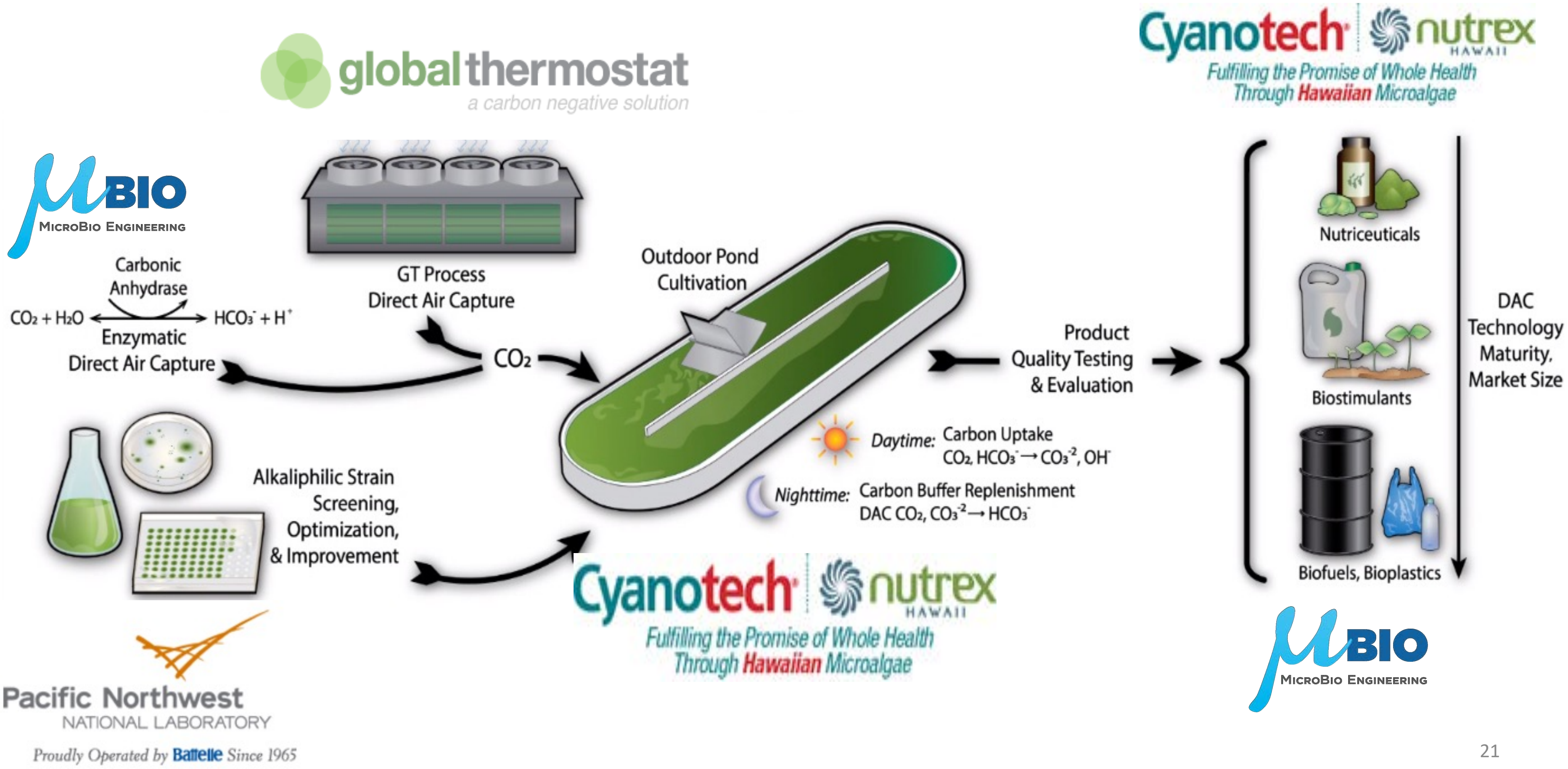
Project Overview




Paddle wheels→
Cyanotech

THANK YOU!

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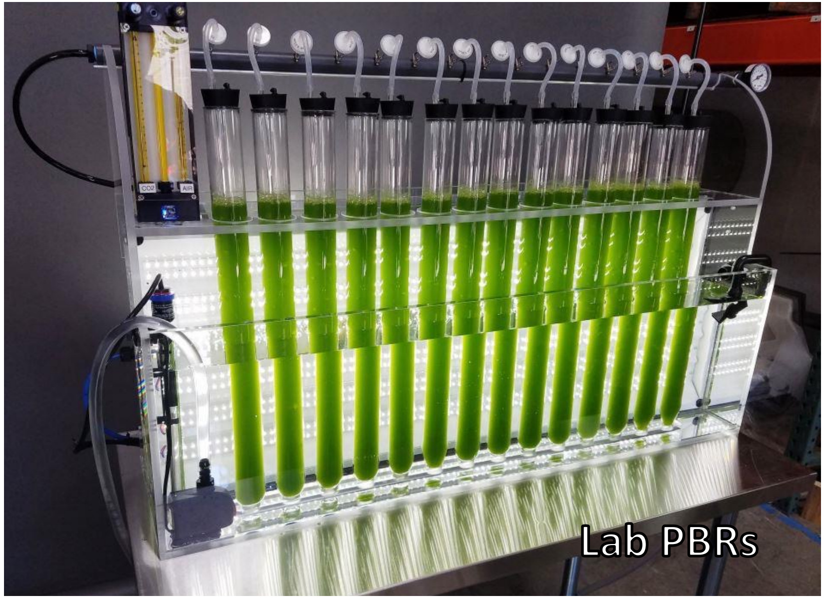

Acknowledgment

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