A highly efficient microalgae-based carbon sequestration system to reduce CO_2 emission from power plant flue gas

DE-FE0031914

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Troy Hawkins, Argonne National Laboratory

U.S. Department of Energy

National Energy Technology Laboratory

Aug. 11, 2024

Project Overview

- Funding

  DOE: $3,000,000 and Cost Share: $750,000
- Overall Project Performance Dates:

  Sep. 2020 to Sep. 2023 (NCTE to Dec. 2024)
- Project Participants:

  Yantao Li, Feng Chen, Russell Hill, University of Maryland Center for Environmental Science;

  Robert Mroz, HY-TEK Bio, LLC;

  Troy Hawkins, Argonne National Lab

  DOE NETL Program Manager: **Lei Hong** (From Jan. 2022), **Kyle Smith** (May- Dec. 2021), **Katharina Daniels** Sep. 2020 to Apr. 2021)

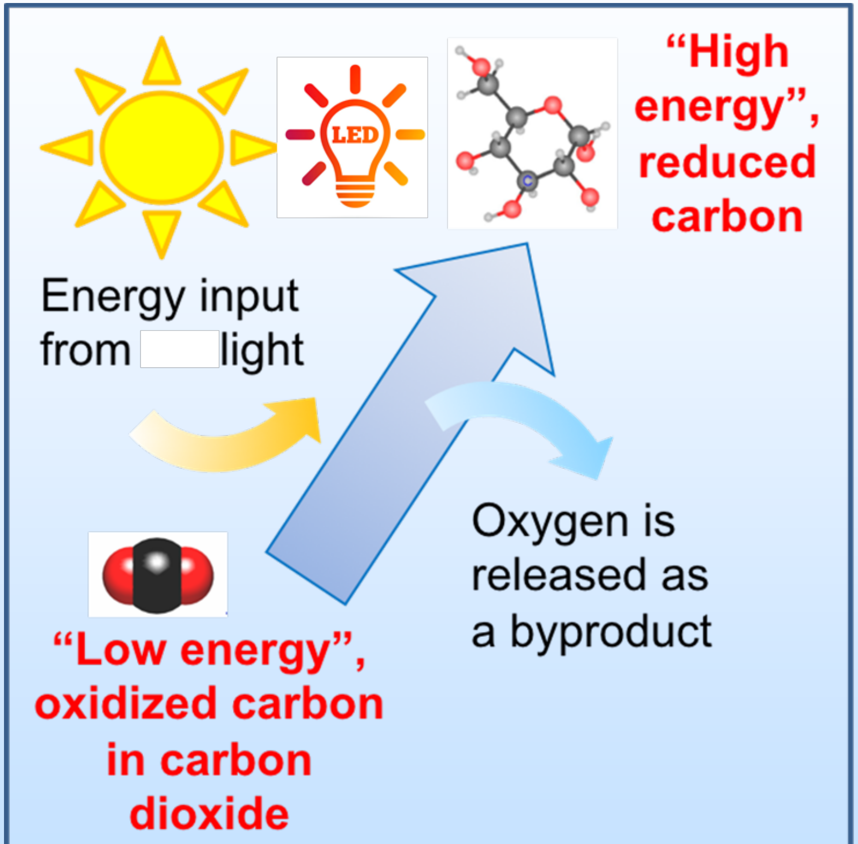
University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE
HY-TEK Bio
Argonne NATIONAL LABORATORY

Project Overview

– Overall Project Objectives

The objective of this project is to harness the power of photosynthetic microalgae to maintain a high-pH, high-alkalinity microalgal culture to create a carbon-negative system for carbon dioxide (CO_2) conversion to value-added products from power plant flue gas.

Technology Background



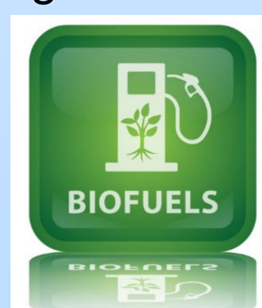
$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$$

Williams, M.E. (July 31, 2016). Carbon-Fixing Reactions of Photosynthesis. The Plant Cell, doi/10.1105/tpc.116.tt0716.

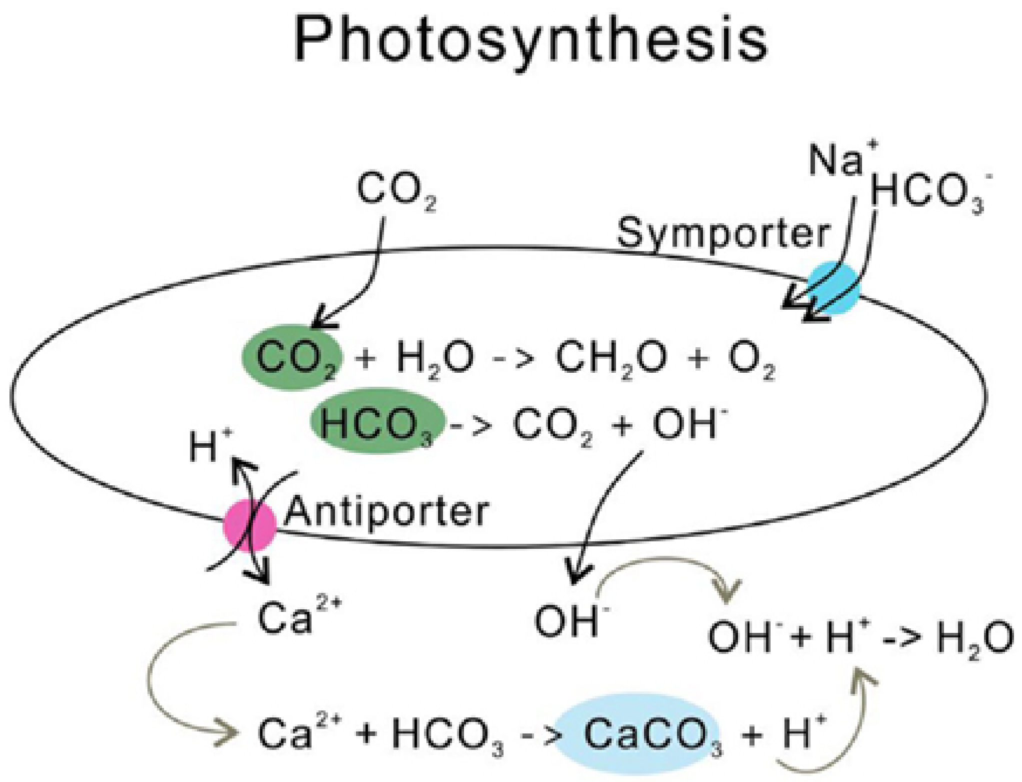

Byrne 2017

100 g algal biomass produced will use 183 g CO_2.

Algal biomass for feed/biofuels.



Microalgal Carbon Capture and Biomass Production: Microalgae-driven carbonate precipitation (MadCAP)

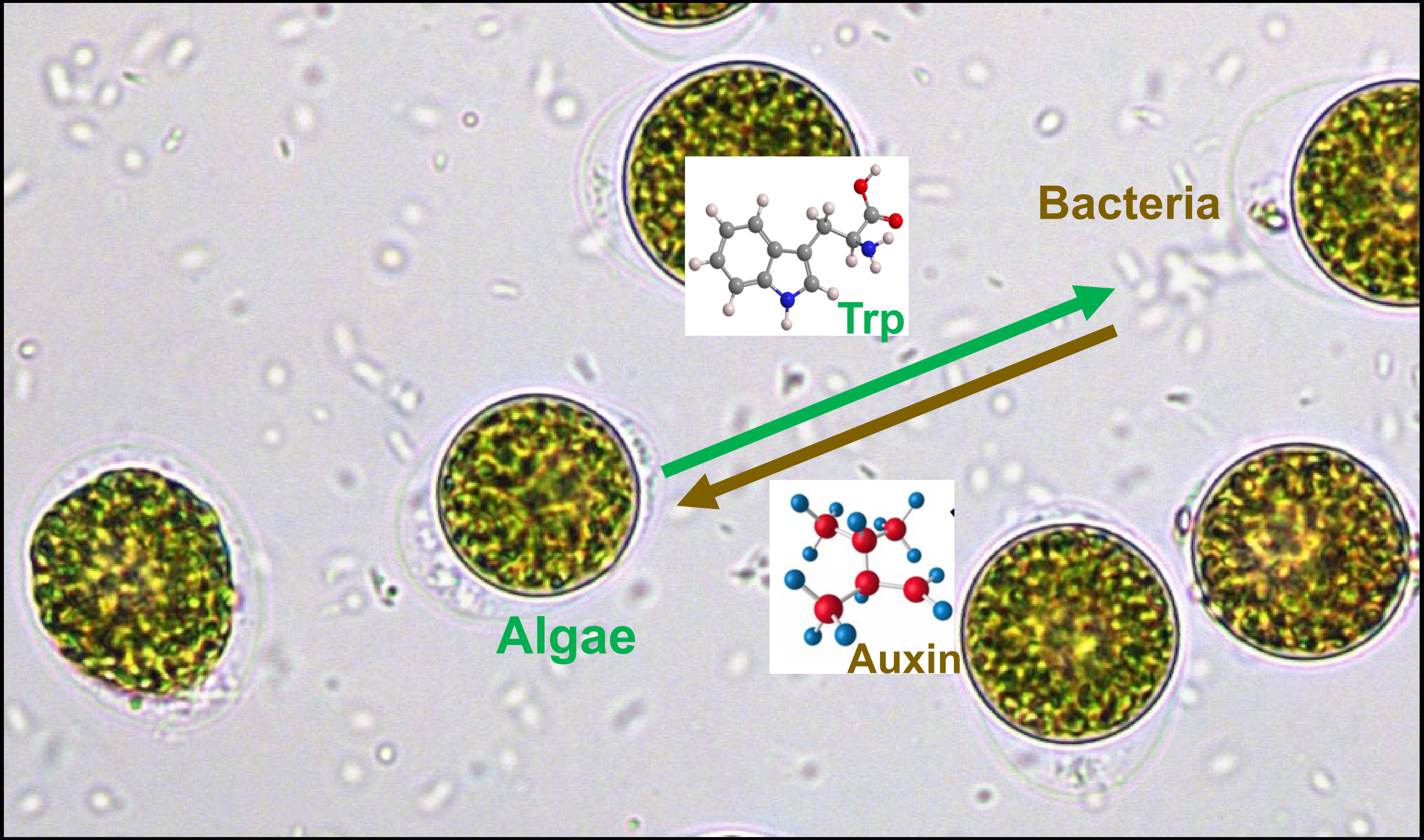


$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^{2-}$$

$$Ca^{2+} + CO_3^{2-} \rightleftharpoons CaCO_3$$

Adapted from Zhu and Dittrich 2016 Frontiers in Bioeng and Biotech.
Mazzone et al., 2002 MARSci.2002.01.020105; DE-FC26-00NT40934; http://thanhphatchem.com/;

Microbial interactions in non-axenic microalgal cultures



Lin, Li and Hill. Current Opinion in Biotechnology 2021, 73:300–307

Technology Background: Proposed Technology Readiness Level

Baseline | *End goal*

Basic principle
TRL 1

→

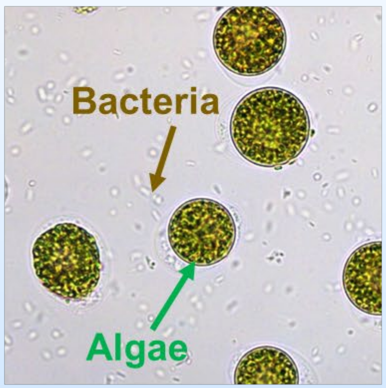
Lab scale
TRL 4

→

Pilot scale
TRL 6

→

Full scale
TRL 7



Algae-bacteria cell-cell interactions

Lab-scale Reactors (1-10 L)

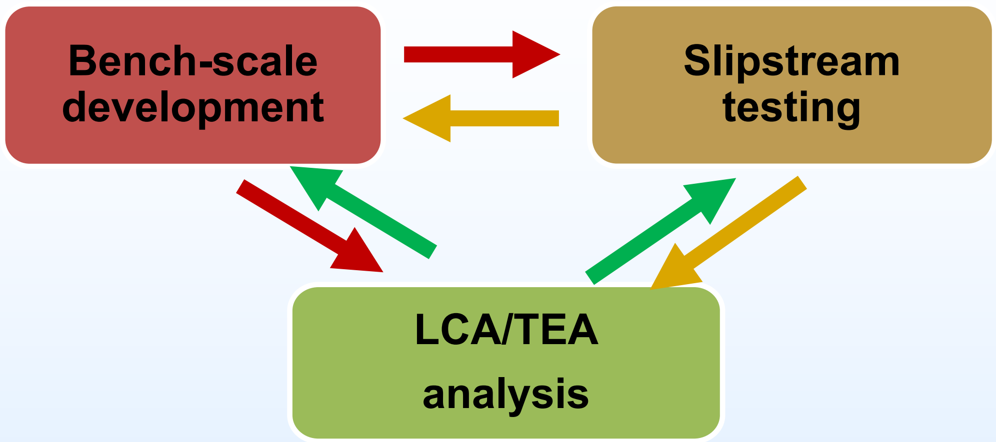
Pilot-scale reactors (500 L each)

Full-scale reactors (6,800 L each)

10^{-15} 10^{1} 10^{3} 10^{4} (L)

System volume

Technical Approach/Project Scope



Bench-scale development of a saltwater and a freshwater algal system (UMCES)

- Subtask 2.1; 3.1; 4.1: Saltwater algal carbon sequestration system **(Li and Hill)**
- Subtask 2.2; 3.1; 4.1: Freshwater algal carbon sequestration **(Chen and Hill)**

Slipstream testing of the algal carbon sequestration system (HY-TEK Bio)

- Subtask 2.3; 3.2; 4.2: Slipstream test on strains IMET1 and HTB1 at 500 L **(Mroz)**
- Subtask 3.3; 4.3: Slipstream test on algal strains IMET1 and HTB1 at 6,800 L **(Mroz)**

Development of TEA and LCA models to evaluate and guide (Argonne)

- Subtask 2.4; 3.4; 4.4: Perform TEA and LCA analysis **(*Hawkins and Banerjee*)**

Milestones

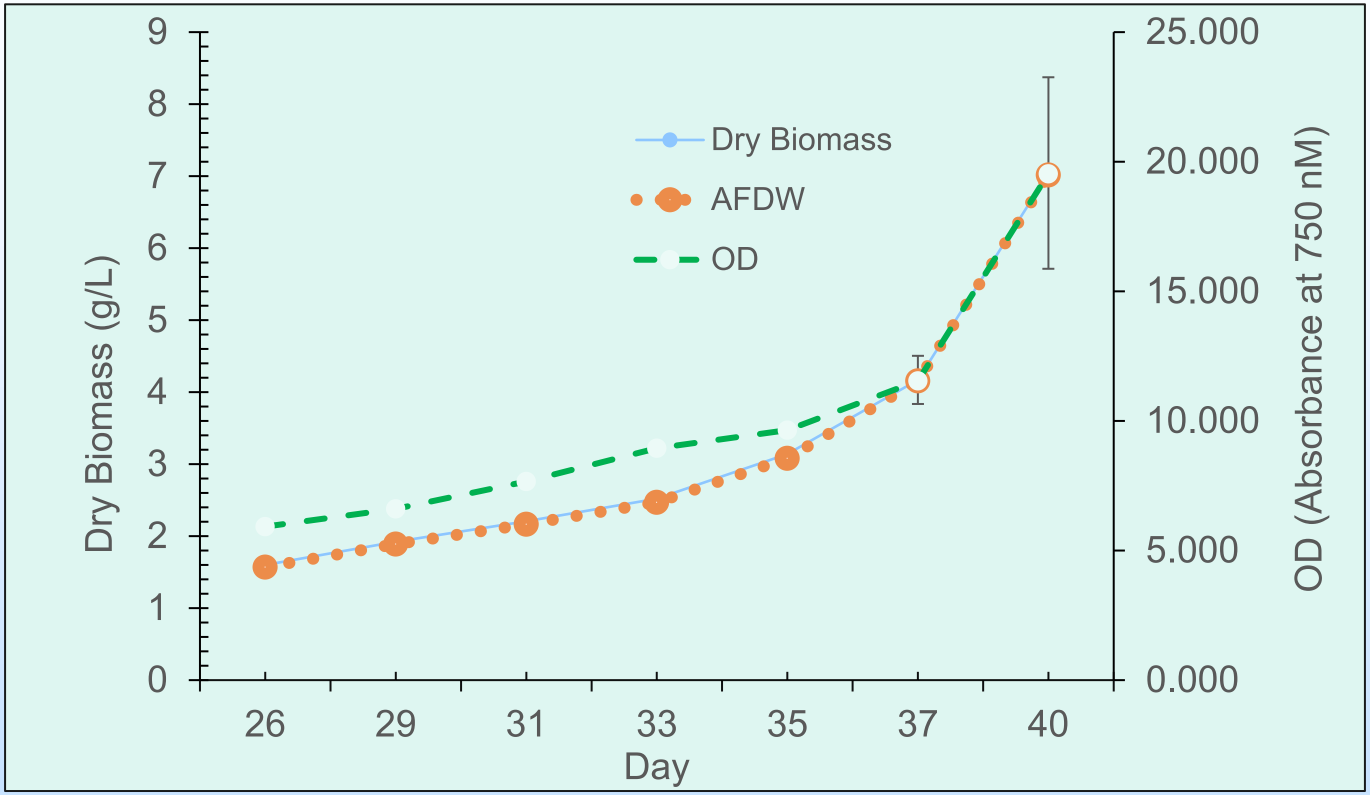
Milestone 4.1: Achieve 3 g/L biomass concentration and extra 50% carbon capture in lab cultures

Milestone 4.2: Achieve 20 $g/m^2/day$ biomass productivity and extra 50% carbon capture at 500 L

Milestone 4.3: Achieve 20 $g/m^2/day$ biomass productivity and extra 50% carbon capture at 6,800 L

Milestone 4.4: Report on updated findings of the TEA and LCA

Progress- *Scenedesmus* HTB1 Lab culture with 10% CO_2

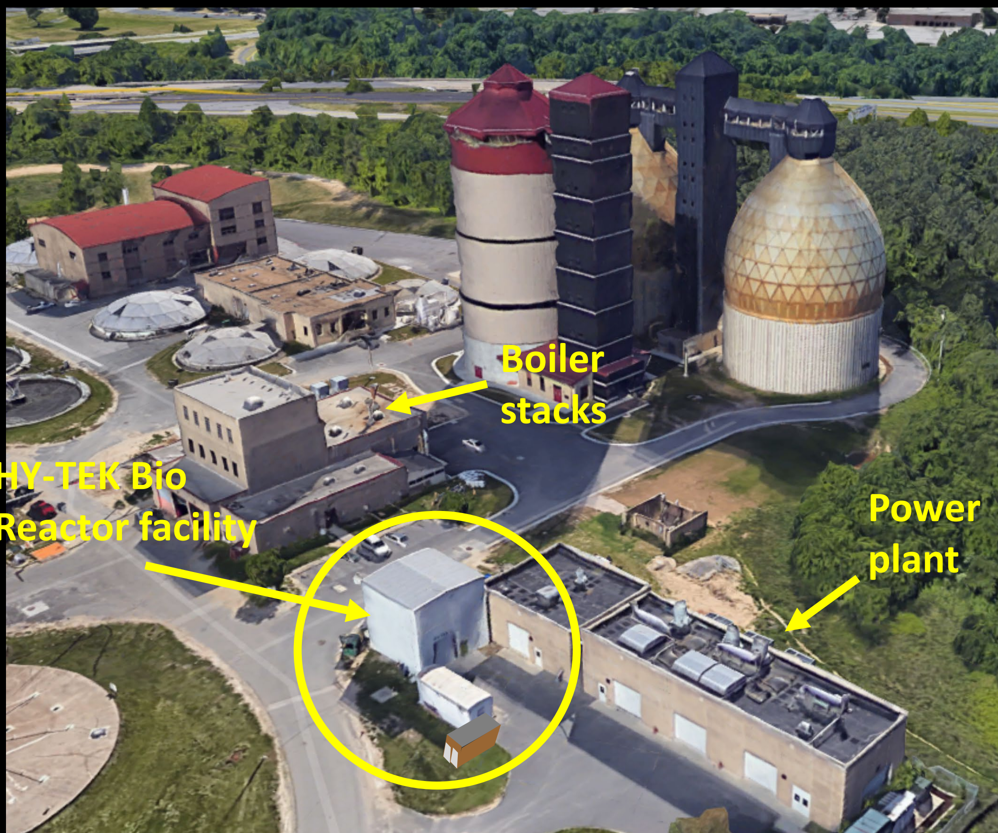


We can achieve high biomass yield (> 7g/L) and exceed our goal (Milestone 4.1).

Milestone 4.1: Achieve 3 g/L biomass concentration and extra 50% carbon capture in lab cultures

Feng Chen and Chen Lab

HY-TEK Bio’s slipstream testing site at the Back River Waste Water Treatment Plant



Current HTB site in operation for more than 8yrs

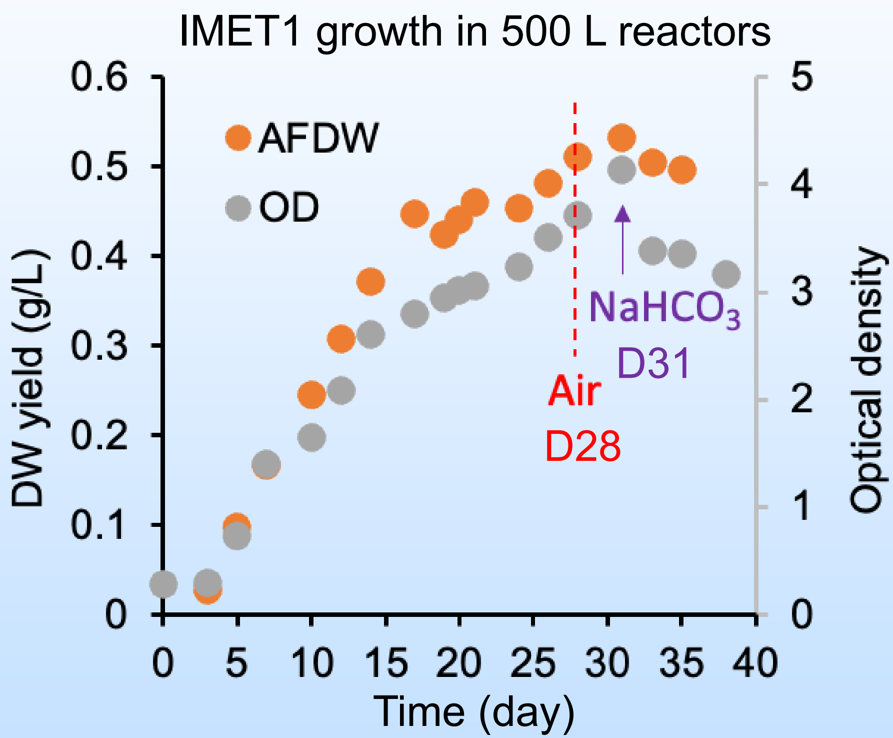
Robert Mroz and HY-TEK Bio Team

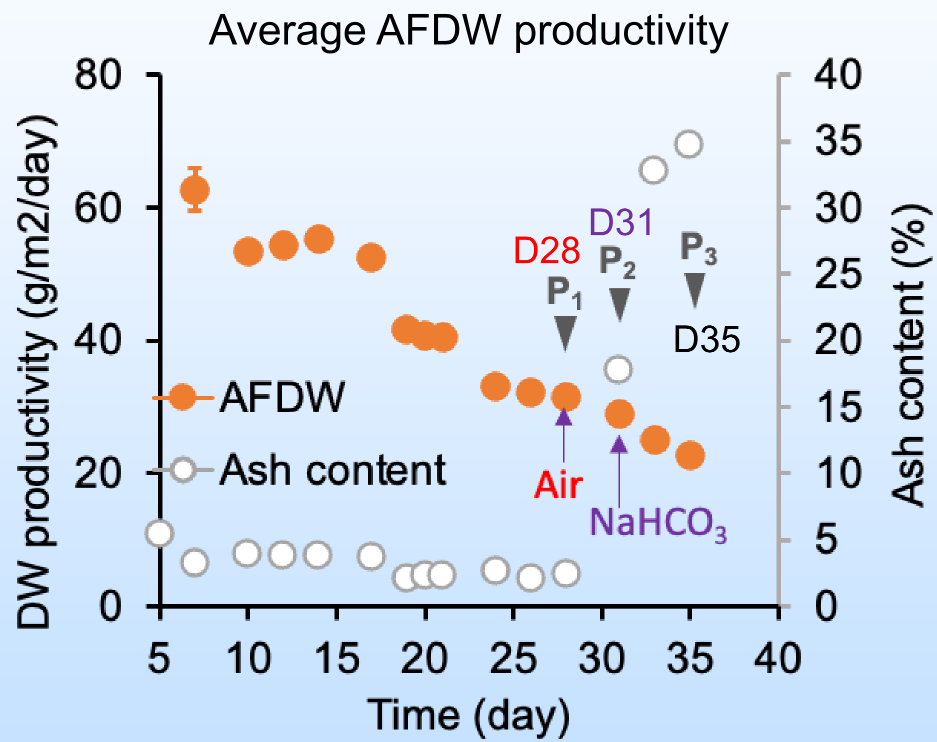
Progress- HY-TEK Bio 500L bioreactors

Milestone 3.2 Achieve 10-15 g/m²/day biomass productivity concentration and extra 20% carbon capture at 500 L. M30

Justin Shaw, Al Dawson, Kent Nicholson, Ed Weinberg, Carolyn Mroz etc.

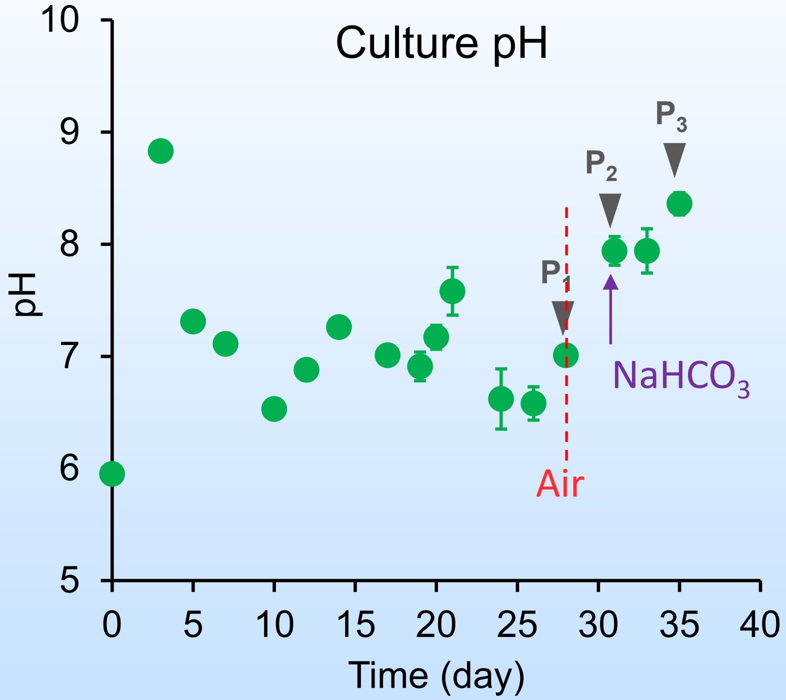
Progress- Growth of *N. oceanica* IMET1 in the 500L bioreactor

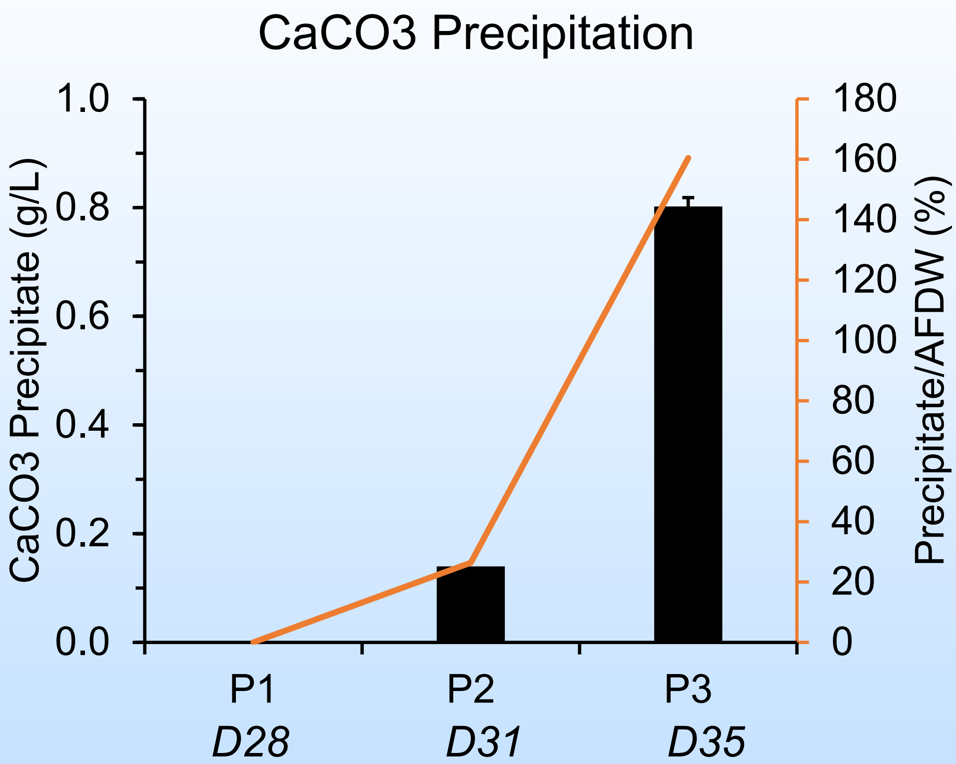




Yantao Li, Yi-Ying Lee and Li group

Progress- Growth of *N. oceanica* IMET1 in the 500L bioreactor

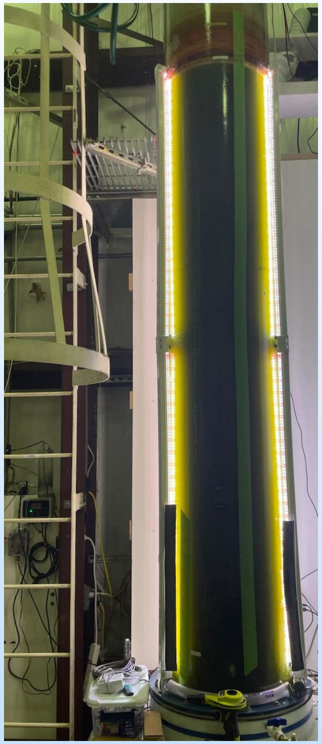


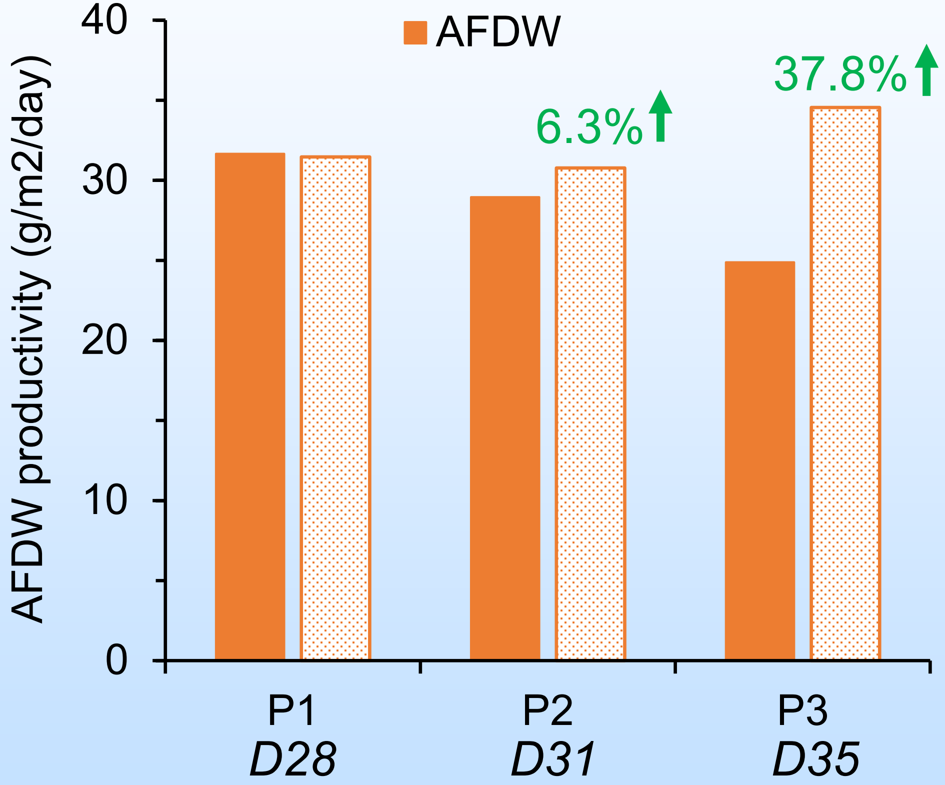


Yantao Li, Yi-Ying Lee and Li group

Progress- Growth of *N. oceanica* IMET1 in the 500L bioreactor

CO_2 capture equivalent based on AFDW biomass productivity and CaCO3 precipitation

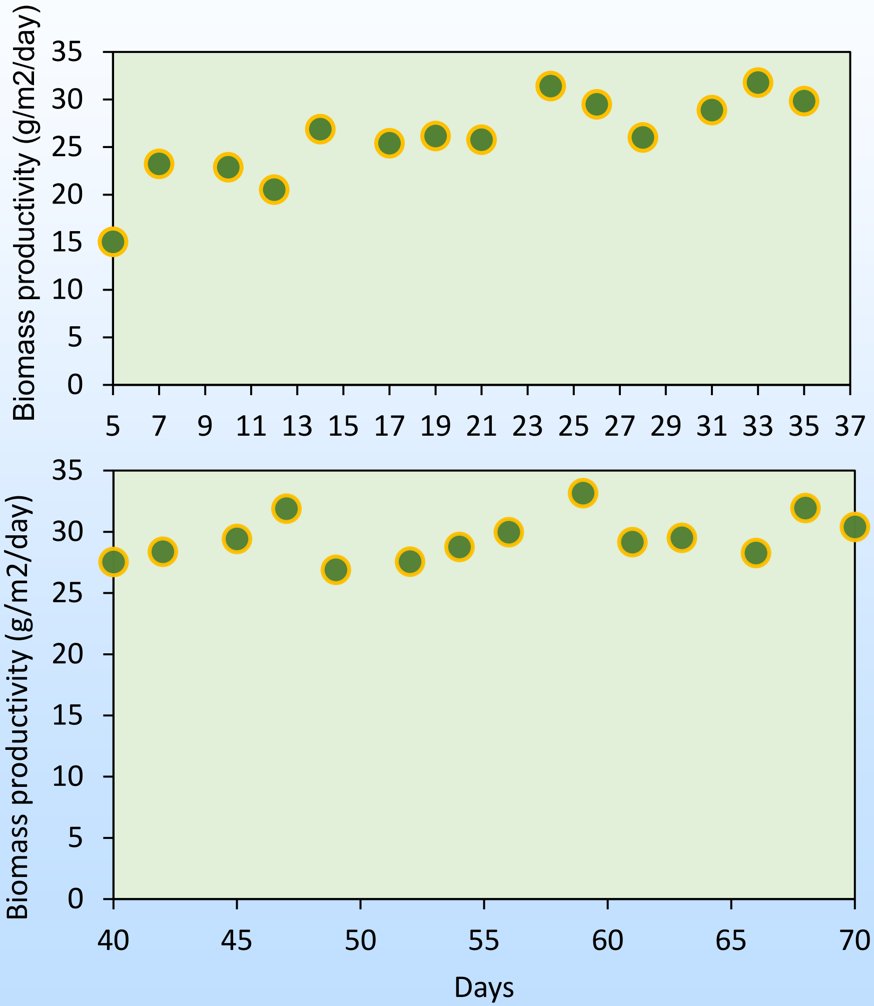




Assumption: To produce 100 g algae, 183 g CO_2 is needed; To produce 100 g $CaCO_3$, 44g CO_2 is needed; Therefore, CO_2 consumption to produce 416 g $CaCO_3$ is equal to that to produce 100 g algae.

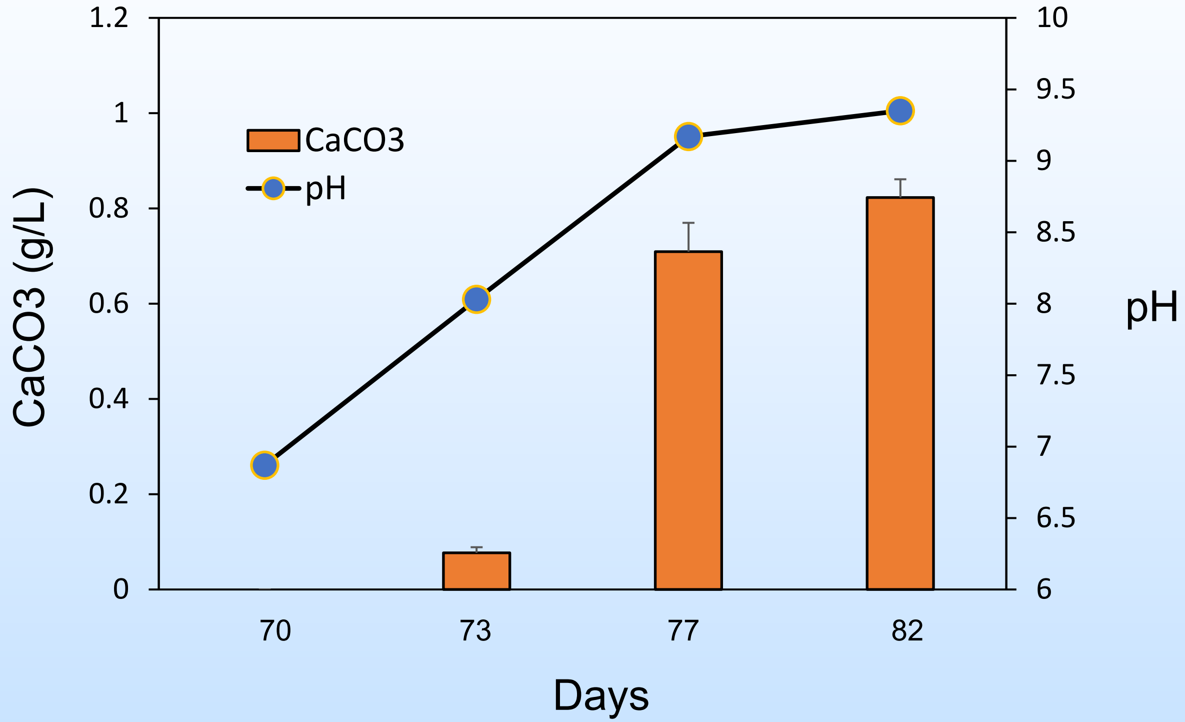
Yantao Li, Yi-Ying Lee and Li group

Progress- Growth of *S. obliquus* HTB1 in the 500L bioreactor



Feng Chen, Nick Gallagher, Chen group

Progress- Growth of *S. obliquus* HTB1 in the 500L bioreactor

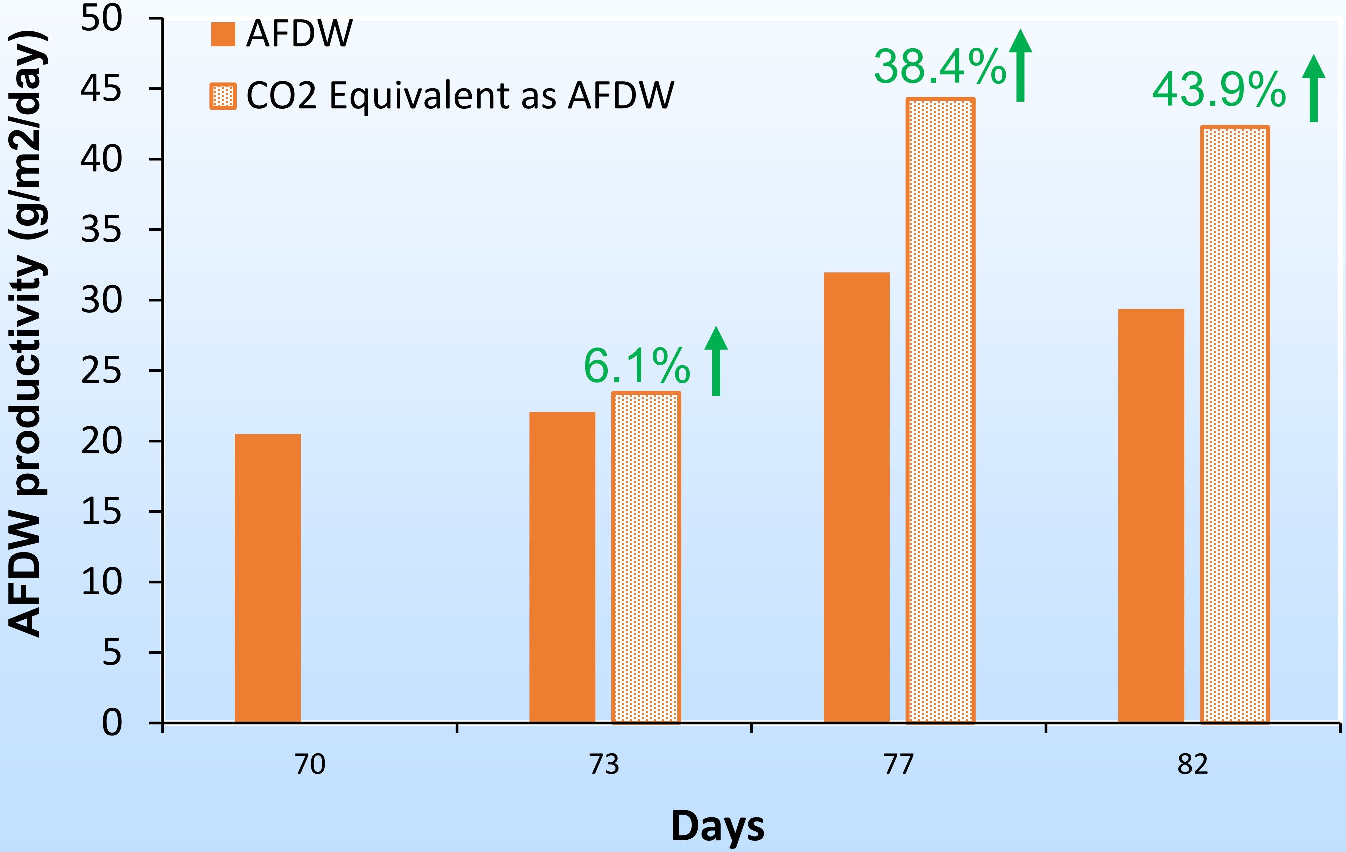


Increased pH resulted in the precipitation of CaCO3

Feng Chen, Nick Gallagher, Chen group

Progress- Growth of *S. obliquus* HTB1 in the 500L bioreactor

CO_2 capture equivalent based on AFDW biomass productivity
(Converting CO_2 captured as $CaCO_3$ into algae productivity)



Milestone 4.2: Achieve 20 g/m²/day biomass productivity and extra 50% carbon capture at 500 L

Feng Chen, Nick Gallagher, Chen group

Progress- Lab Microbial Analysis

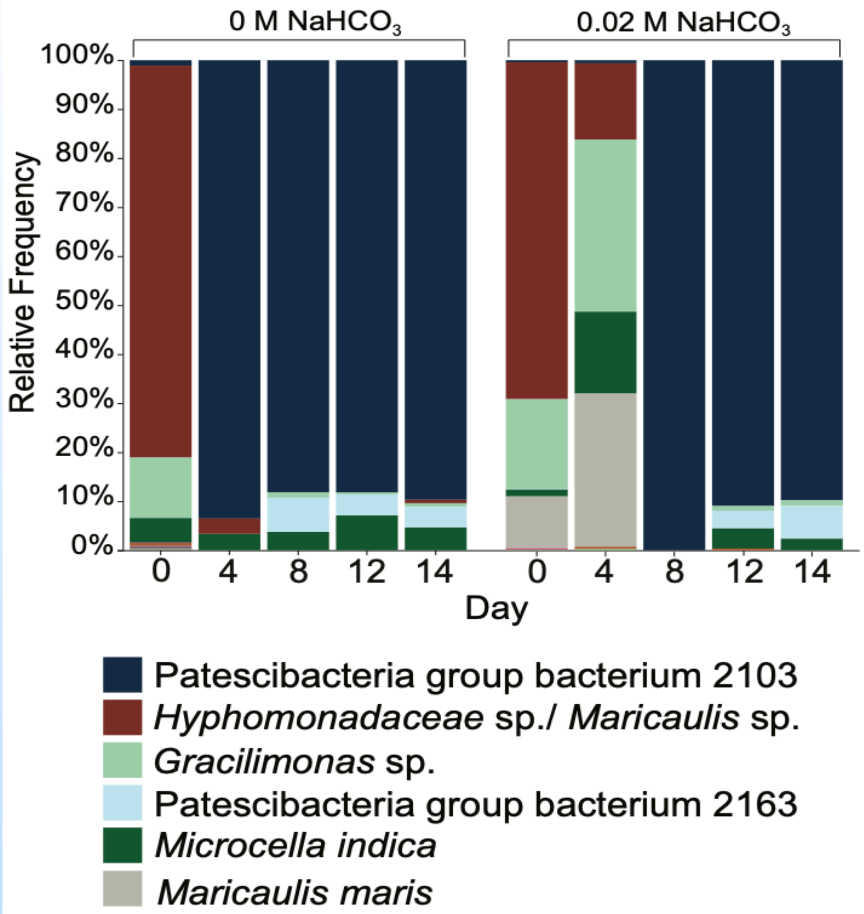
Identification of Patescibacteria

V3/V4 region of the 16S rRNA gene sequenced on Illumina Miseq Platform and analyzed with qiime2

Bacterial communities of *Nannochloropsis oceanica* bubbled with 10% CO2 at **1 liter scale**.

Microalgal 16S removed bioinformatically.

Russell Hill, Lauren Jonas and Hill Group



0.45 µm fraction (0.22 µm fraction looks similar)

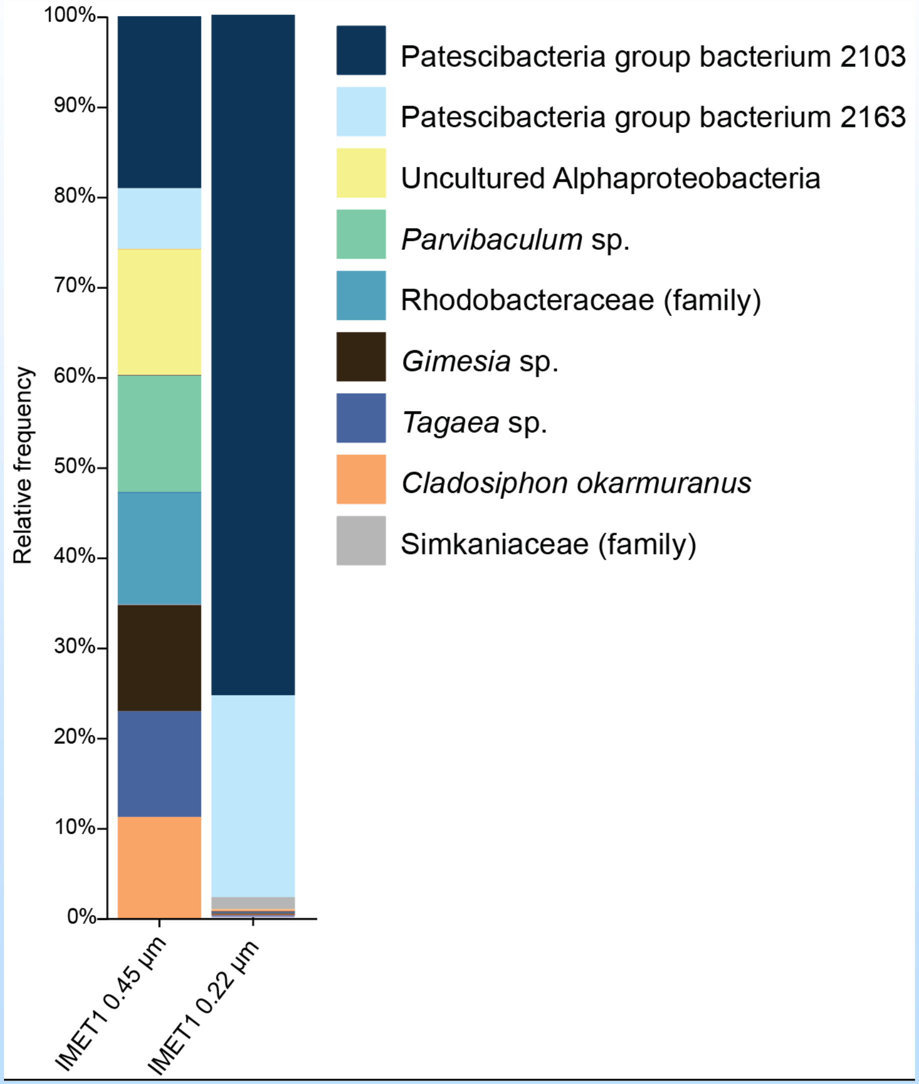
Progress- Lab Microbial Analysis

Identification of Patescibacteria

V3/V4 region of the 16S rRNA gene sequenced on Illumina Miseq Platform and analyzed with qiime2

Bacterial communities of *Nannochloropsis oceanica* grown at HY-TEK **500 L Bioreactor**

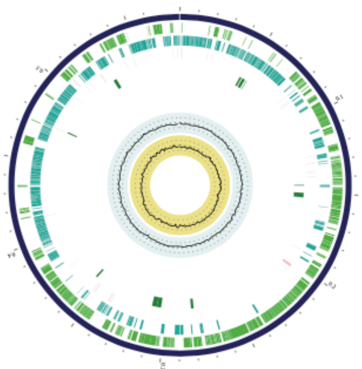
Russell Hill, Lauren Jonas and Hill Group



Progress- Lab Microbial Analysis

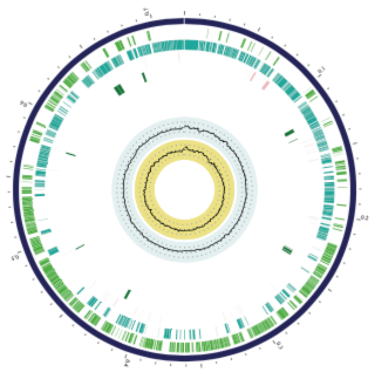
Identification of Patescibacteria

Patescibacteria group bacterium 2103



Size: 578,798 bp
Contig #: 1
GC content: 43%

Patescibacteria group bacterium 2163



Size: 721,362 bp
Contig #: 1
GC content: 44%

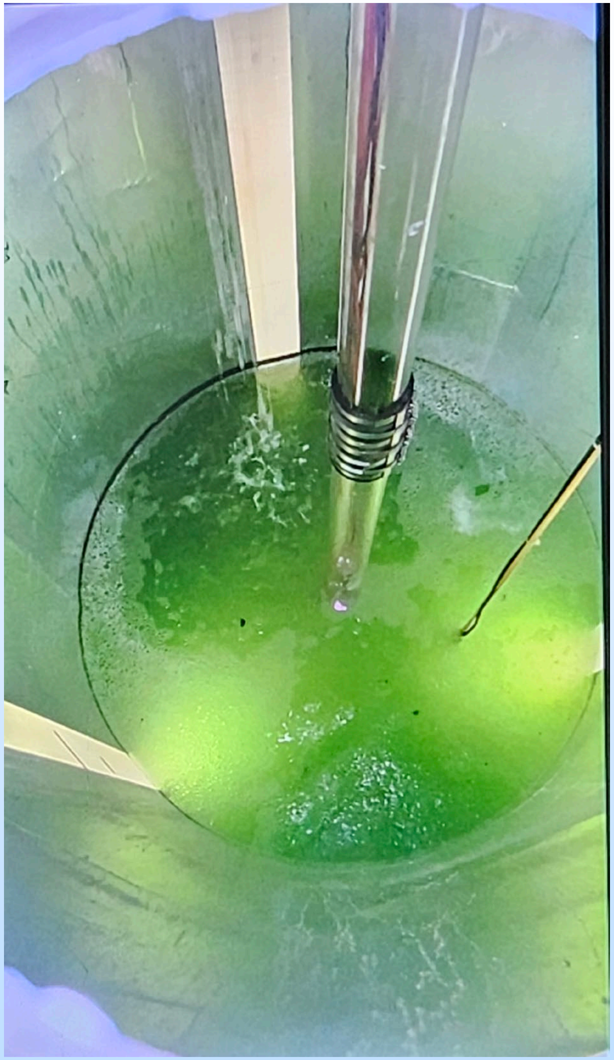
— Position Label (Mbp)	Non-CDS Features
Contigs	AMR Genes
CDS- Forward	GC Content
CDS-Reverse	GC Skew

Genome Quality Good

Metagenomic sequencing on Nanopore GridION platform

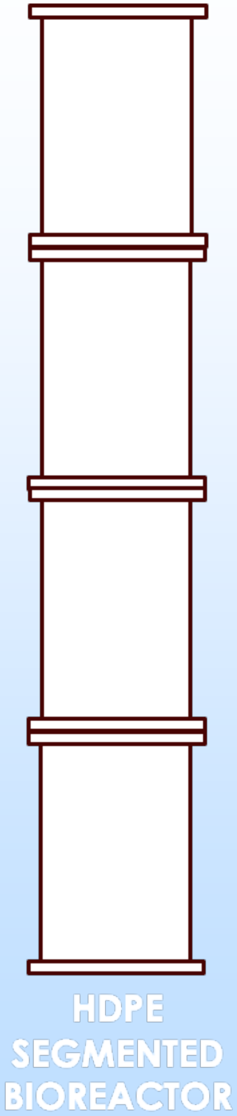
Russell Hill, Lauren Jonas and Hill Group

Progress- HY-TEK Bio 6,800L bioreactors



Robert Mroz and HY-TEK Bio Team

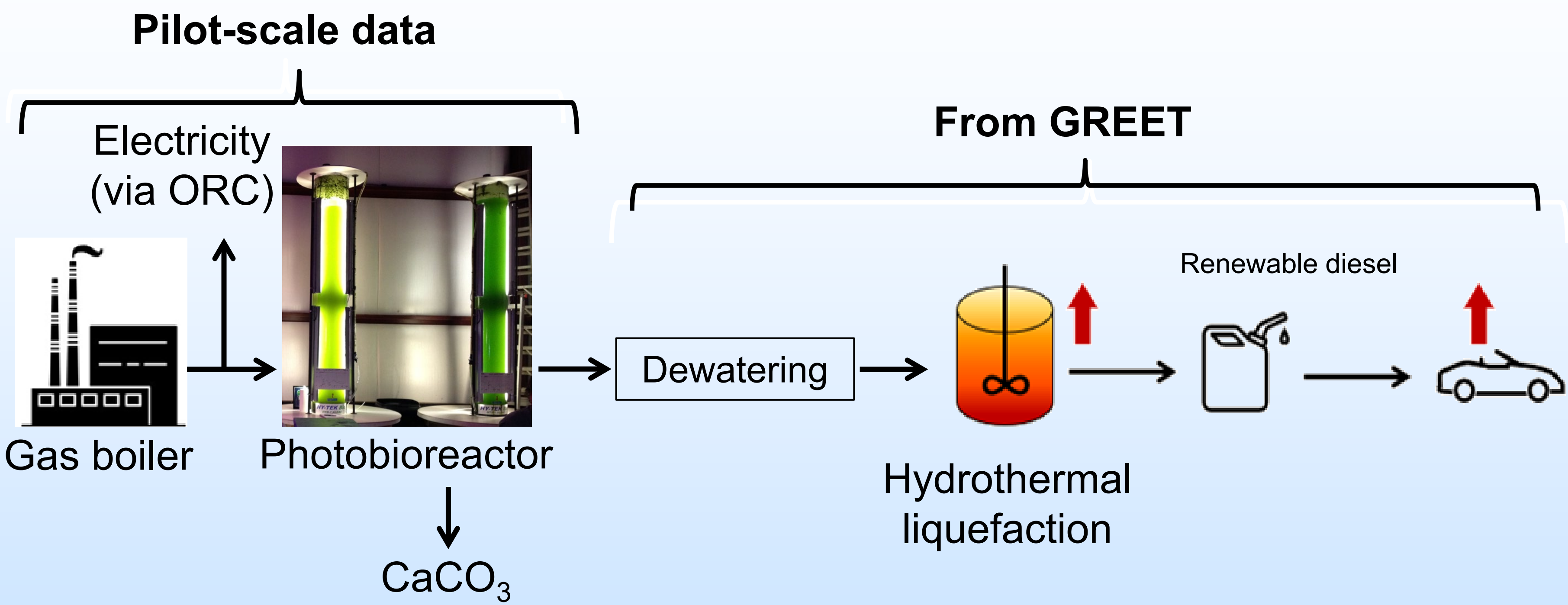
Progress- HY-TEK Bio 6,800L bioreactors



Robert Mroz and HY-TEK Bio Team

Approach for LCA/TEA

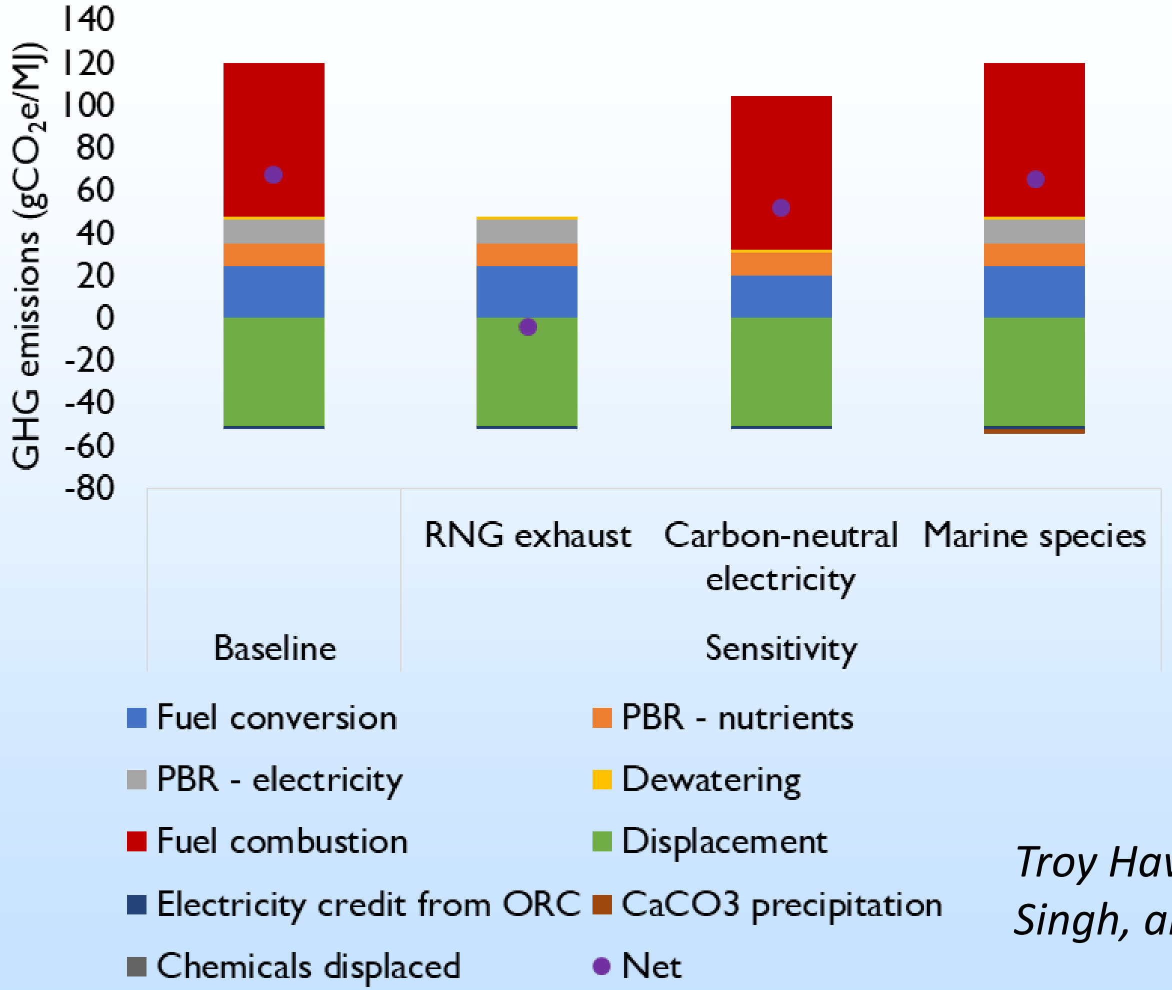
Screening LCA and TEA of Full System and Focused Analysis of Key Processes



- LCA/TEA analysis has been carried out consulting NETL's LCA guidance
- High temperature at gas boiler facilitates additional electricity generation via Organic Rankine Cycle
- Dewatering comprises dissolved air floatation and centrifuging in series
- Other sensitivities studied include different end use such as biochar

Troy Hawkins, Udayan Singh, and Farah Naaz

LCA findings



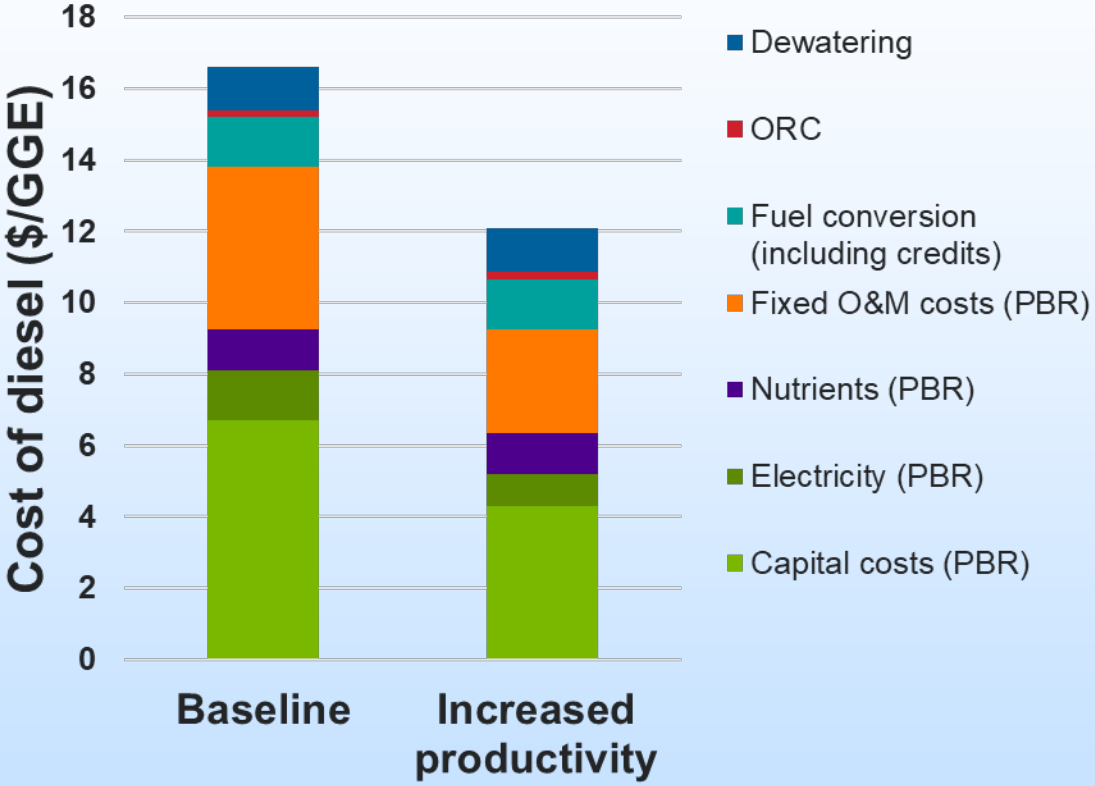
Troy Hawkins, Udayan Singh, and Farah Naaz

- Baseline emissions = 68 gCO_2e/MJ (25% reduction below fossil diesel)
- Use of biogenic carbon source (RNG) and $CaCO_3$ precipitation further reduce net emissions

__Milestone 4.4:__ Report on updated findings of the TEA and LCA

TEA findings

GGE: gallon of gasoline equivalent



- Cost of producing renewable diesel in the baseline configuration are $16/GGE
- Improved productivity, increased scale (from 500 L to 6800 L) and low-cost electricity brings down these costs to <$9/GGE
- Costs cannot be directly compared to market price of incumbents due to scale variation

Troy Hawkins, Udayan Singh, and Farah Naaz

Milestone 4.4: Report on updated findings of the TEA and LCA

Technology Readiness Level at present

BP2 | **BP3**

Basic principle
TRL 1

→

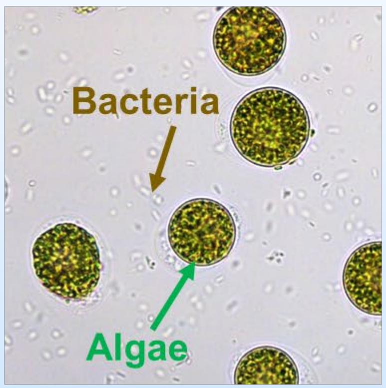
Lab scale
TRL 4

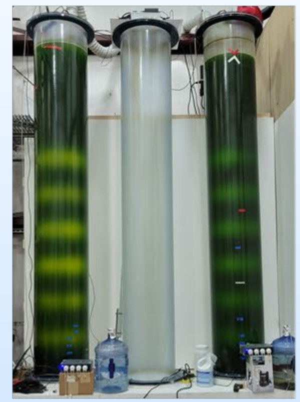
→

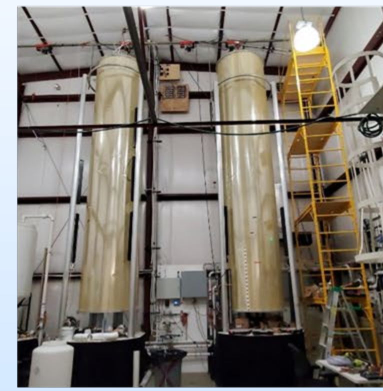
Pilot scale
TRL 6

→

Full scale
TRL 7







Algae-bacteria cell-cell interactions

Lab-scale Reactors (1-10 L)

Pilot-scale reactors (500 L each)

Full-scale reactors (6,800 L each)

10^{-15} — 10^{1} — 10^{3} — 10^{4} (L)

System volume

Plans for future work- BP3

Milestone Title	Planned Completion date	Actual Completion date	Verification Method	Comments
Milestone 4.1: Achieve 3 g/L biomass concentration and extra 50% carbon capture in lab cultures	Month 45 (06/30/2024)	4/30/2024	Oral and written reports	
Milestone 4.2: Achieve 20 $g/m^2/day$ biomass productivity and extra 50% carbon capture at 500 L	Month 42 (03/31/2024)	3/31/2024	Oral and written reports	
Milestone 4.3: Achieve 20 $g/m^2/day$ biomass productivity and extra 50% carbon capture at 6,800 L	Month 45 (06/30/2024)		Oral and written reports	
Milestone 4.4: Report on updated findings of the TEA and LCA	Month 45 (06/30/2024)	10/31/2023	Oral and written reports	

Summary

- Our freshwater *Scenedesmus* and seawater *Nannochloropsis* systems can achieve >30 g/m2/Day AFDW biomass productivity and an extra 37.8-43.9% carbon capture when grown with flue gas containing 5% CO_2 at a 500 L scale for over a month (35-82 days).
- Patescibacteria become dominant and stable in lab and 500 L pilot tests. Their role in the culture system is currently under investigated.
- There is some delay in setting up new 6,800 L bioreactor tests, and we are now ready to start the growth test.
- Updated LCA/TEA analysis shows our technology is a promising carbon capture route.