DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Improving the Productivity & Performance of Large-Scale Integrated Algal Systems for Wastewater Treatment & Biofuels

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Advanced Algal Systems

Lance Schideman, PhD, PE
University of Illinois, Urbana-Champaign
Illinois Sustainable Technology Center

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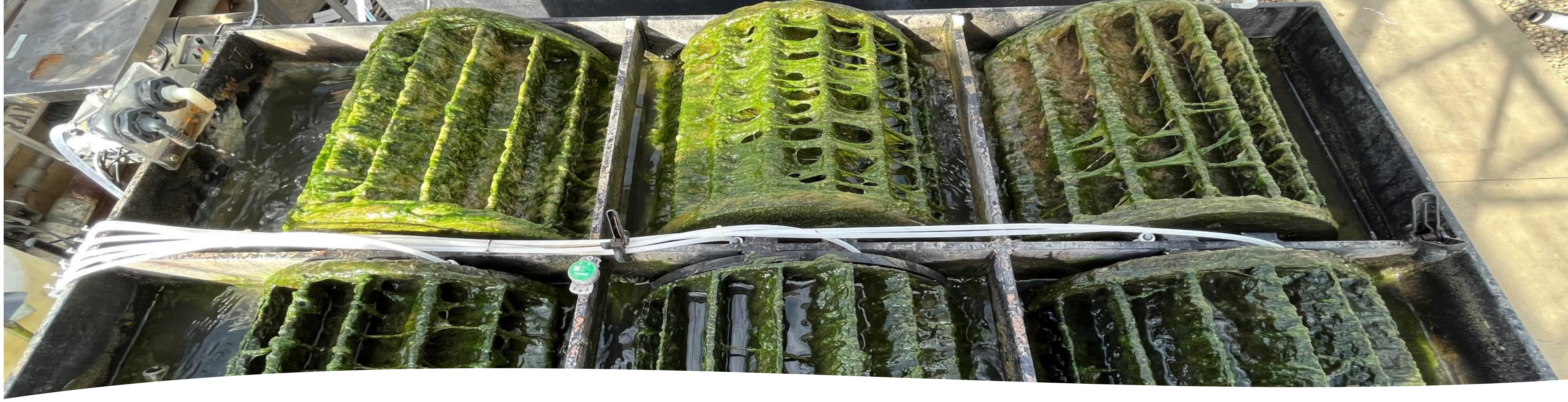
Project Overview

- Our project integrates advanced algal wastewater treatment with maximized biofuel production
  - Wastewater treatment fees pay for algae cultivation
  - This renewable feedstock is currently not being utilized for biofuel production
- Researching several methods to improve quantity & quality of mixed algal biomass at pilot- and full-scale
- DE-FOA-0002029, 5 years, $3,764,553 total value, currently starting Budget Period 3 (BP3)
- BETO research priorities addressed:
  - Aft-B (Sustainable Algae Production): Beneficial reuse of waste resources for growing algal biomass
  - Aft-C (Biomass Genetics & Development): Bioaugmentation and Endoreduplication
  - Aft-J (Resource Recapture/Recycle): Membrane separation & recycle of organics from the aqueous by-product of hydrothermal liquefaction conversion

Approach-Overview

- **Pilot Scale**
  - Algaewheel demo w/ 20g/m^2/day productivity baseline
  - Test bioaugmentation, endoreduplication, optimized harvesting, adsorbents & increased WW loading
  - Integrate proposed strategies to show 50% biomass productivity improvement over baseline (30g/m^2/day)
- **Separation & Recycling of HTL Aqueous Product**
  - Bench-scale nanofiltration and recycle experiments
- **Field demonstrations: Illinois & Florida**
  - Successful pilot-tested strategies implemented at a full-scale wastewater facility in two regions to show >25% productivity increase & >10% conversion yield
- **Final Project Goals**
  - Field tests with >50% increase in biomass productivity and >20% increase in biocrude conversion yield
  - LCA/TEA evaluation of integrated full-scale systems



Approach: Proposed Technologies

Bioaugmentation

Azospirillium and *Pseudomonas*

Pilot scale implementation moving to full scale implementation

Endoreduplication

UBV, Dessication, Salt on 3 species

Laboratory scale:

- Flow cytometry, dry weight, cell size

Adsorbents

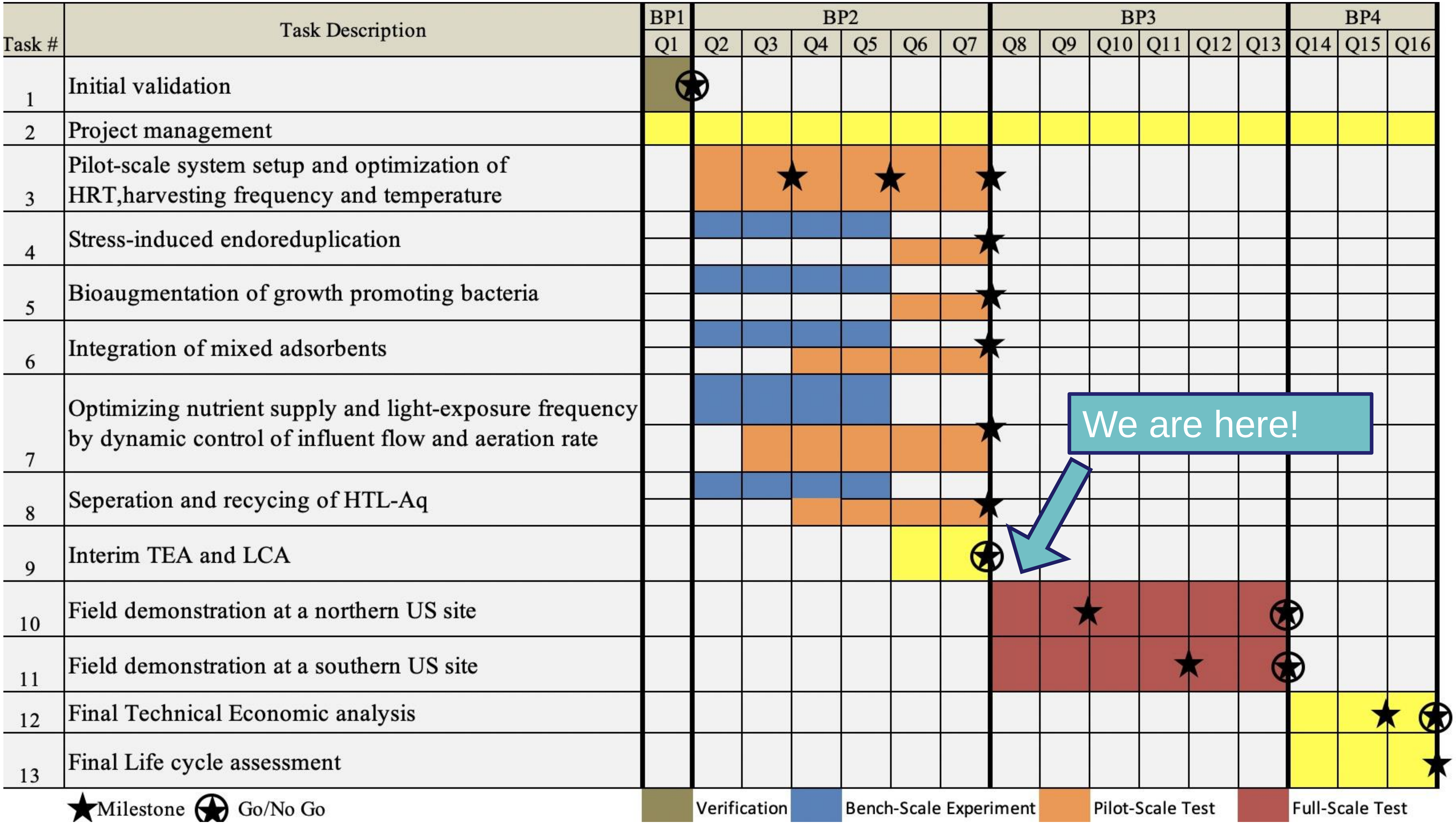
Pilot scale integration moving to full scale integration

Granulated activated carbon and clinoptilolite

Automation

Pilot scale operation with programmed air flow rates

Approach: Project Timeline *(BP2 Extended by 1 yr)*



Approach: TEA & LCA

- Goals:
  - Primary goal to develop a process model to compare Algaewheel to conventional wastewater treatment (activated sludge) and raceway ponds used for algal wastewater treatment
  - Evaluate impact of biomass productivity improvements on cost
  - Interim target to demonstrate $188/ton biomass
- TEA/LCA challenges:
  - Lack of specific data for process modeling and cost or life-cycle inventory data

Approach: Key Risks, Mitigation, & Challenges

- Risk: Implementation of treatments could harm effluent water quality
  - Mitigation: Treatments are chosen that have proven to be positive or neutral on water quality at pilot scale. Full-scale treatments occur in 1 of 6 parallel trains at a time to dilute out any unforeseen negative affects.
- Risk: Bioaugmenting bacteria are inhibited by contaminants in wastewater
  - Mitigation: Grow bacteria in media separately, acclimate bacteria to wastewater in advance, co-treat with adsorbents to reduce contaminants, utilizing *Pseudomonas denitrificans* which is common in wastewater.
- Challenges: Timeline and biological system variability, data collection points weekly, and biomass harvesting is labor intensive at pilot-scale.

Approach

G/NG-2 Integrated pilot-scale test showing >50% increase of baseline productivity, with <25% ash, and >20% oil conversion yield increase.

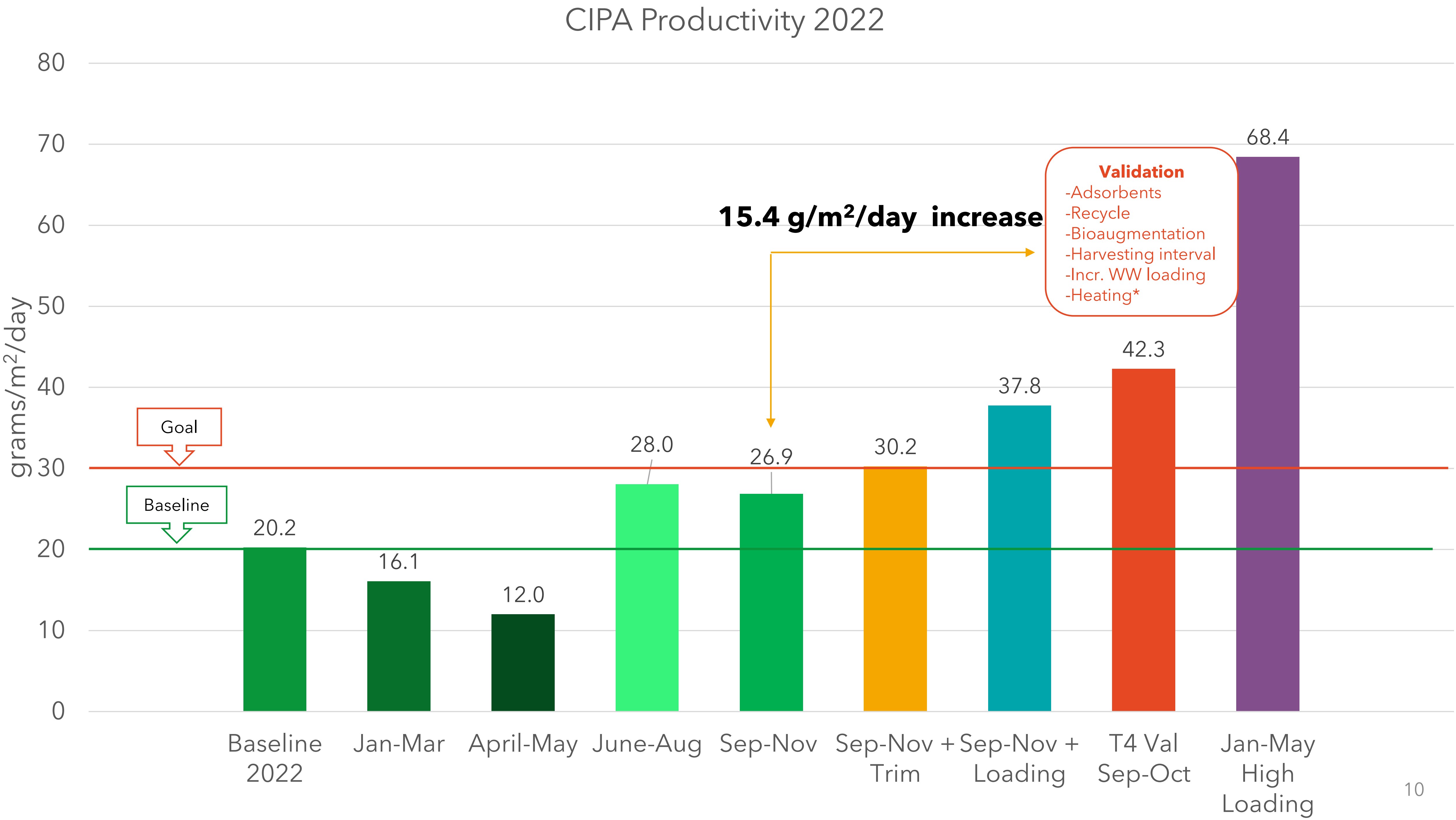
G/NG-3 Integrated field scale test showing >50% productivity increase, and >20% oil conversion yield increase

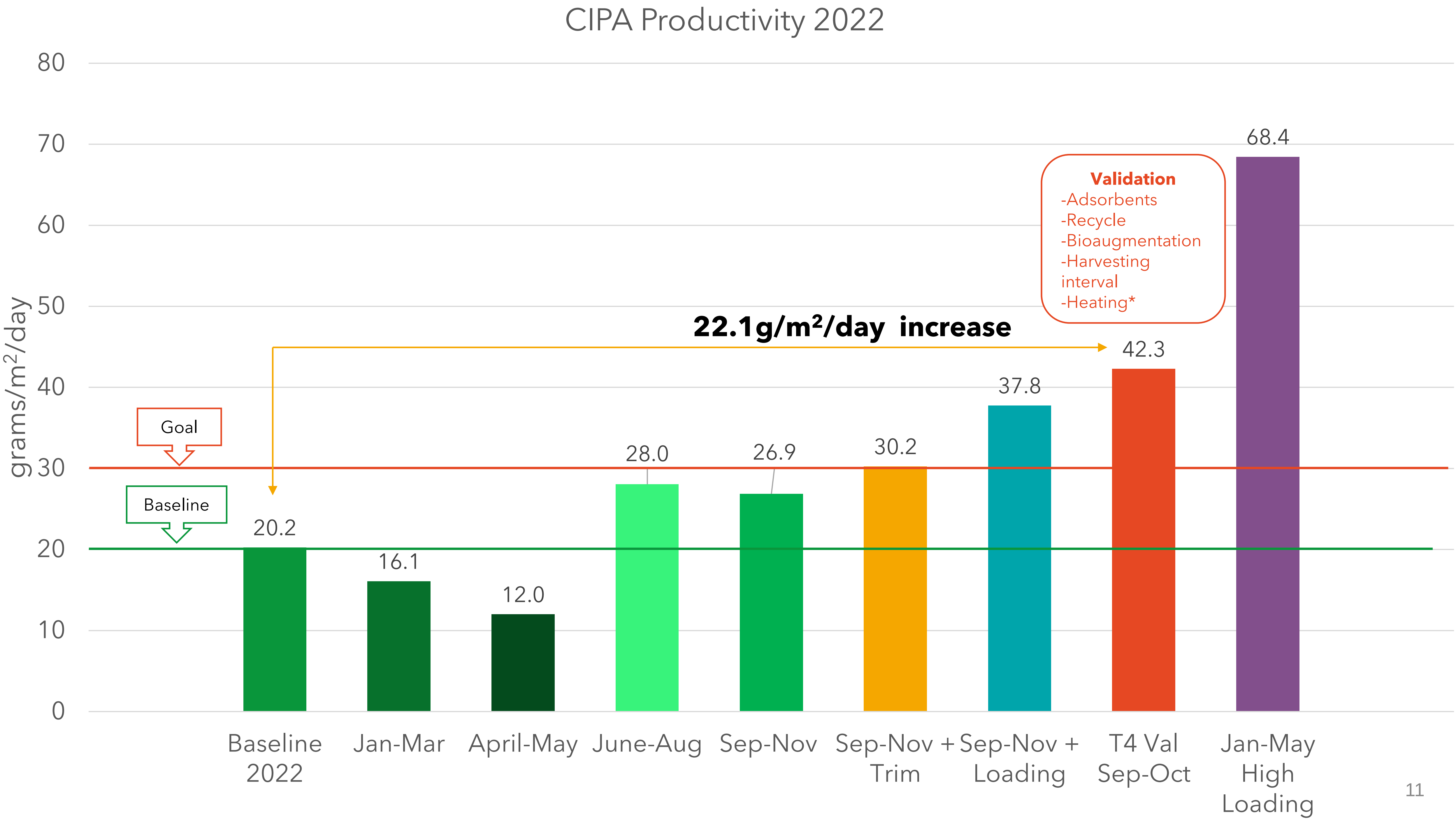
G/NG-4 Final evaluation of proposed technologies by TEA and LCA

Progress and Outcomes

Successfully completed G/NG-2 for BP2

- G/NG 2: Integrated pilot-scale test showing >50% productivity increase, with <25% ash, and >20% oil conversion yield increase.
  - Increased productivity from baseline of 20 $g/m^2/day$ to 42 $g/m^2/day$ with implemented treatments
  - Adsorbents, Bioaugmentation, Enhanced Harvesting, Heating, Increased WW Loading, Recycling
  - Ash content reduced from 39% to 11%
  - Increased oil conversion from 23% to 40%


CIPA Productivity 2022
grams/m2/day
80
70
60
50
40
30
20
10
0
Goal
Baseline
20.2
16.1
12.0
28.0
26.9
30.2
37.8
42.3
68.4
15.4 g/m2/day increase
Validation
-Adsorbents
-Recycle
-Bioaugmentation
-Harvesting interval
-Incr. WW loading
-Heating*
Baseline 2022
Jan-Mar
April-May
June-Aug
Sep-Nov
Sep-Nov + Trim
Sep-Nov + Loading
T4 Val Sep-Oct
Jan-May High Loading


CIPA Productivity 2022
grams/m²/day
80
70
60
50
40
30
20
10
0
Goal
Baseline
22.1g/m²/day increase
Validation
-Adsorbents
-Recycle
-Bioaugmentation
-Harvesting interval
-Heating*
20.2
16.1
12.0
28.0
26.9
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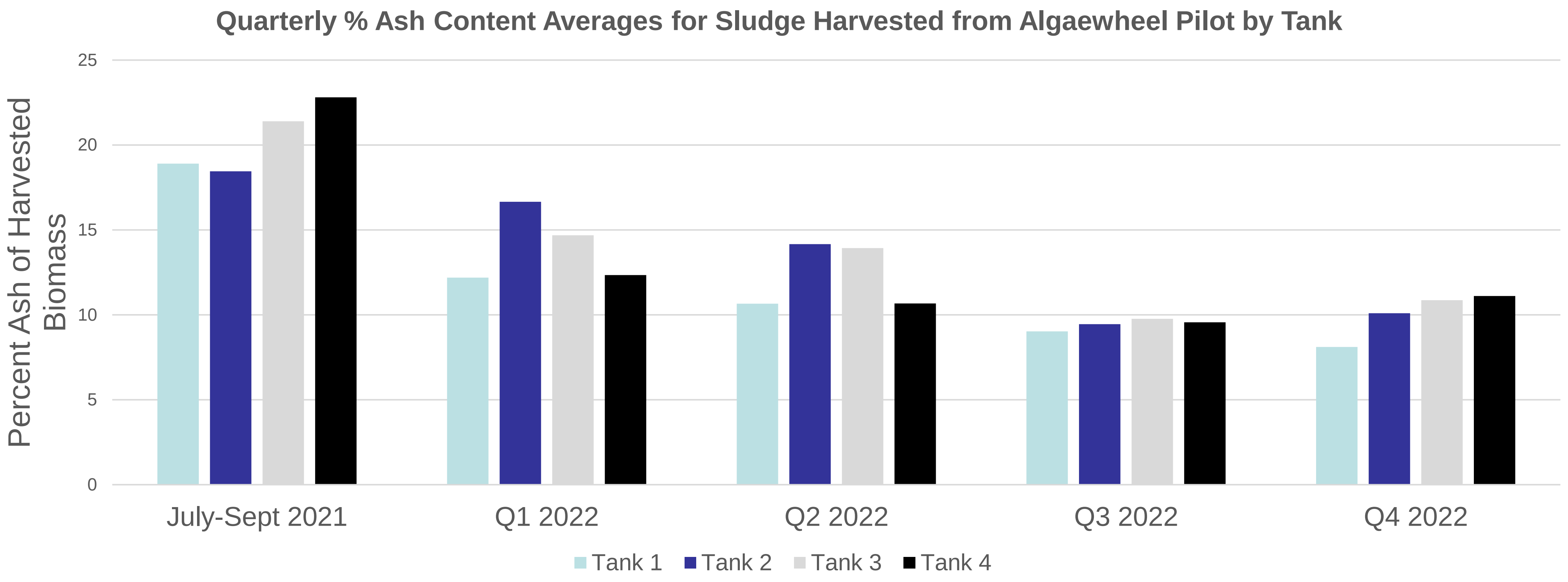
37.8
42.3
68.4
Baseline 2022
Jan-Mar
April-May
June-Aug
Sep-Nov
Sep-Nov + Trim
Sep-Nov + Loading
T4 Val Sep-Oct
Jan-May High Loading

Improved Biomass Quality- Reduced Ash Content from 18% in 2021 to 12% in 2022



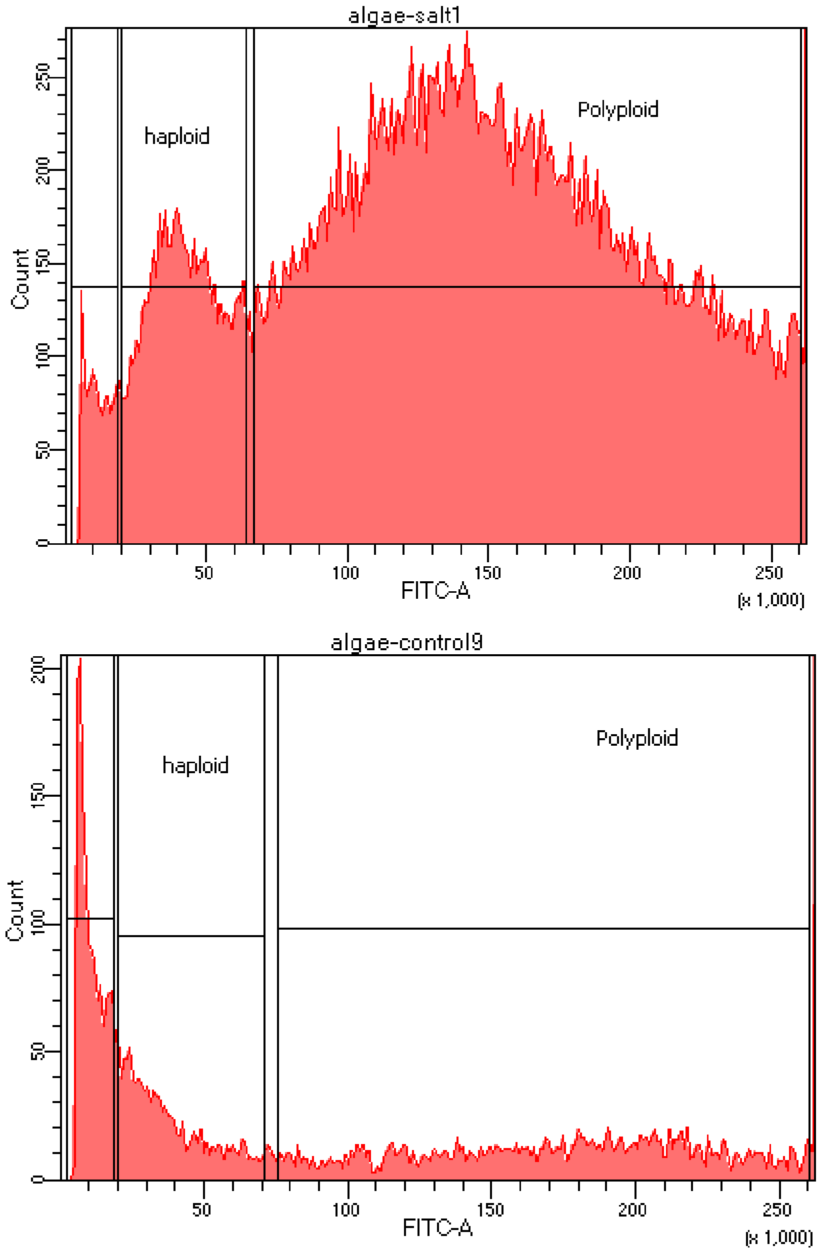
Progress and Outcomes- Endoreduplication

- Successfully induced endopolyploidy in *Ankistrodesmus sp.* and *Chlorella vulgaris* using salt treatment
    - Confirmed by cell sorting after fluorescent nucleus staining

- UVB also induced *C. vulgaris* endopolyploidy

- Desiccation did not work in any trials

- Presently working on tradeoff between cell size and total biomass quantity

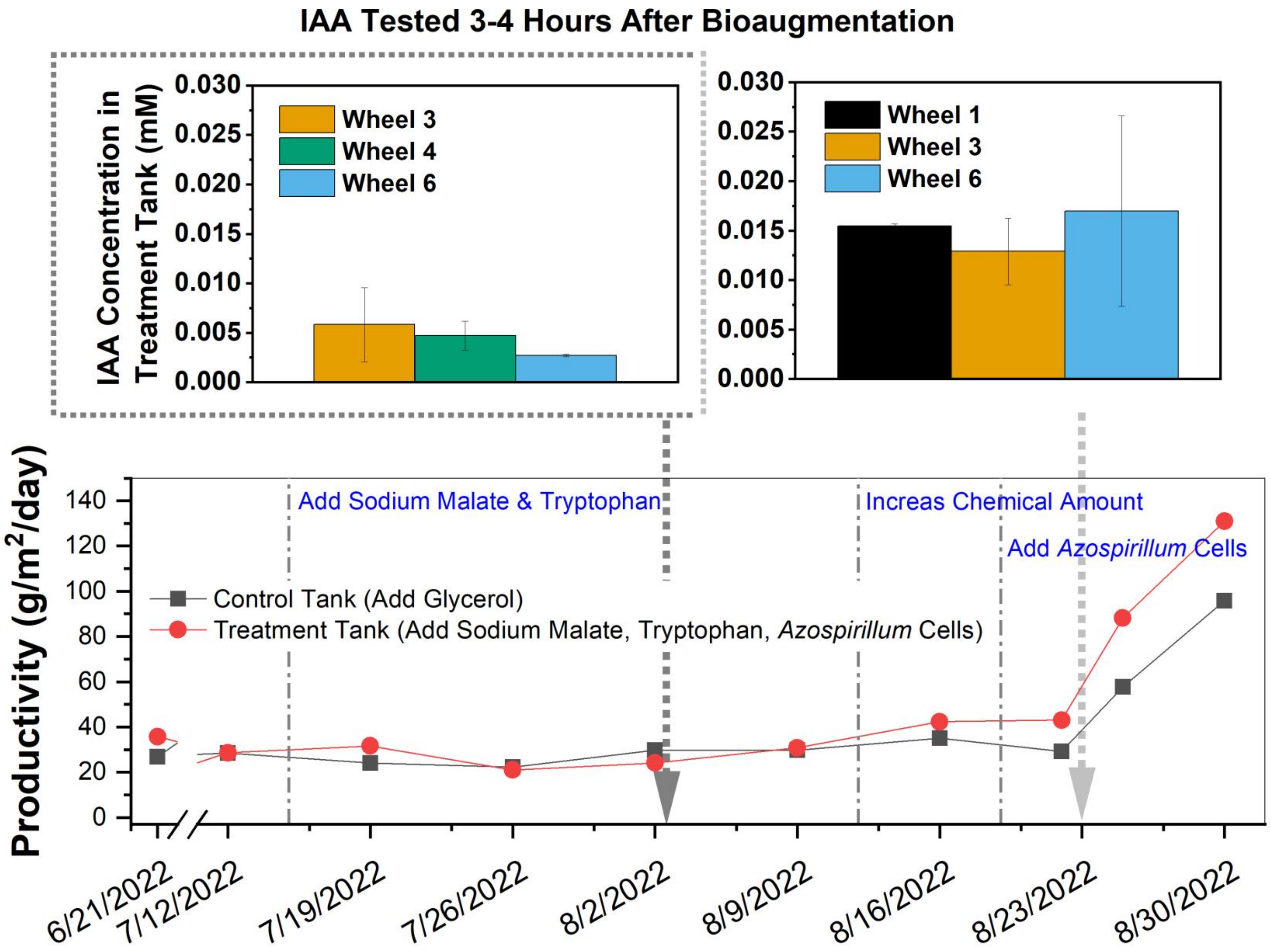


Ankistrodesmus with and w/o 0.1M NaCl treatment

Progress and Outcomes: Bioaugmentation

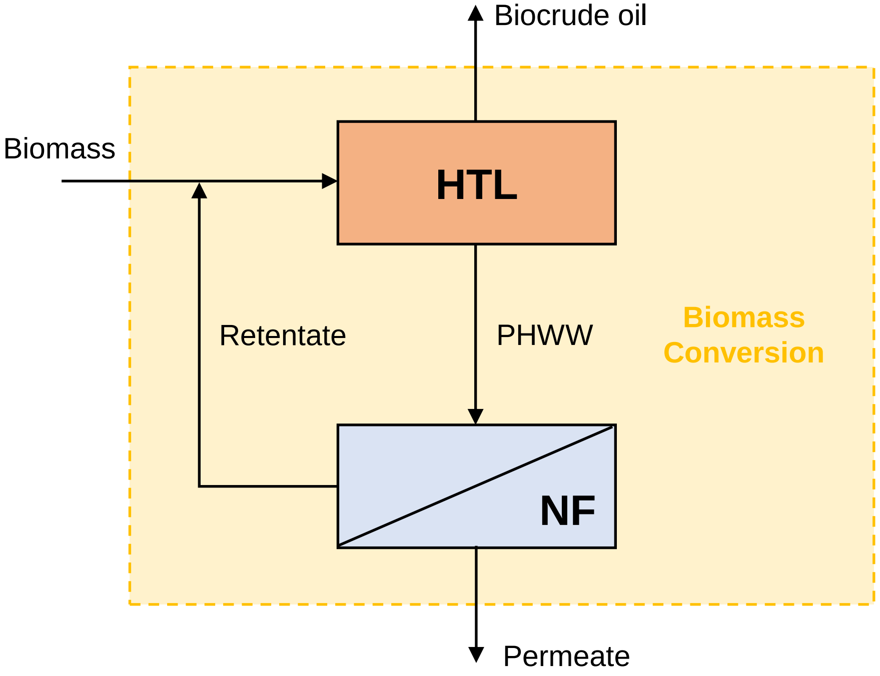
- Addition of *Azospiriullium* to elevate the plant hormone IAA, yielded a >20% increase in biomass productivity

- Bioaugmentation with *Pseudomonas* to produce vitamin B12 showed mixed results



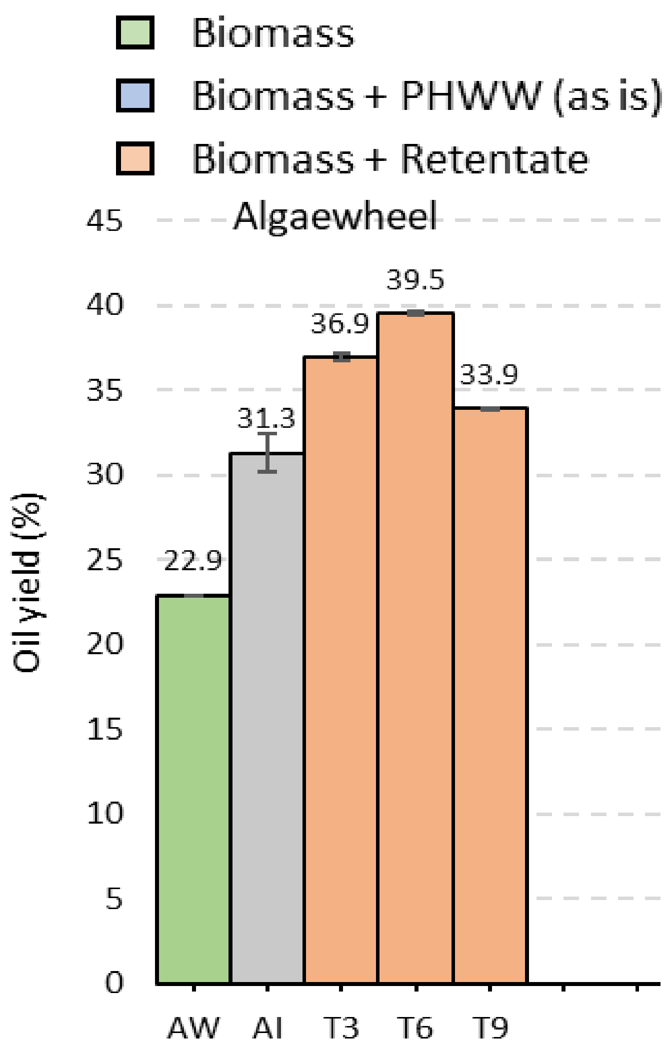
Progress and Outcomes: HTL Biomass Conversion

- Developed novel nanofiltration (NF) process to recover concentrated organics from post-hydrothermal wastewater (PHWW)
- Recycling NF retentate increased HTL oil yield from 22.9% to 39.5% (an increase of 73%)
- NF also allowed separation of N from organics

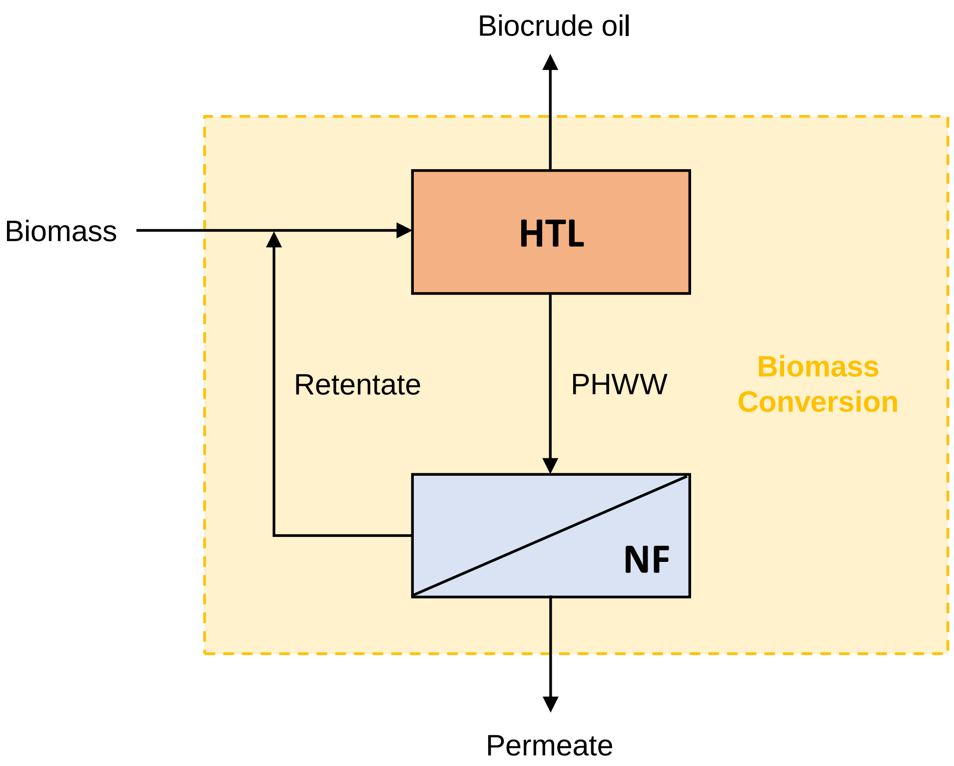


$$Yield_{mix}(\%) = \left(\frac{M_{oil}}{M_{biomass}}\right) \times 100$$

M_{oil} : mass of oil
$M_{biomass}$: mass of biomass (AFDW)



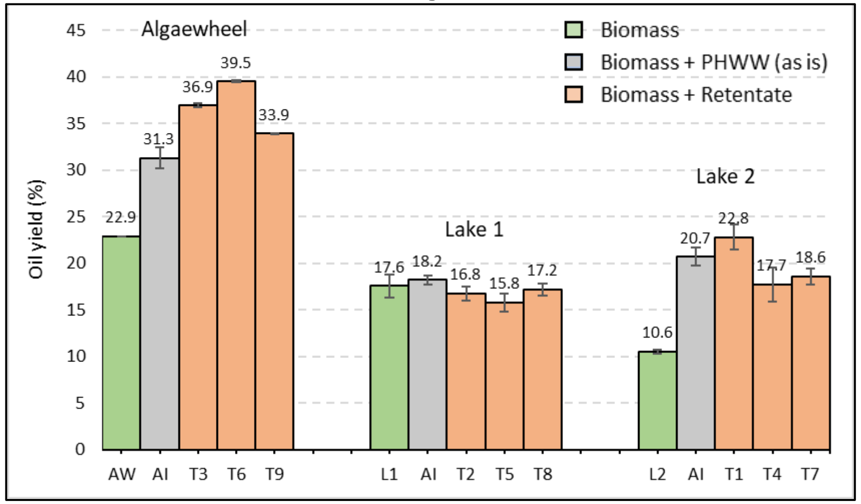
Progress and Outcomes: Biomass conversion



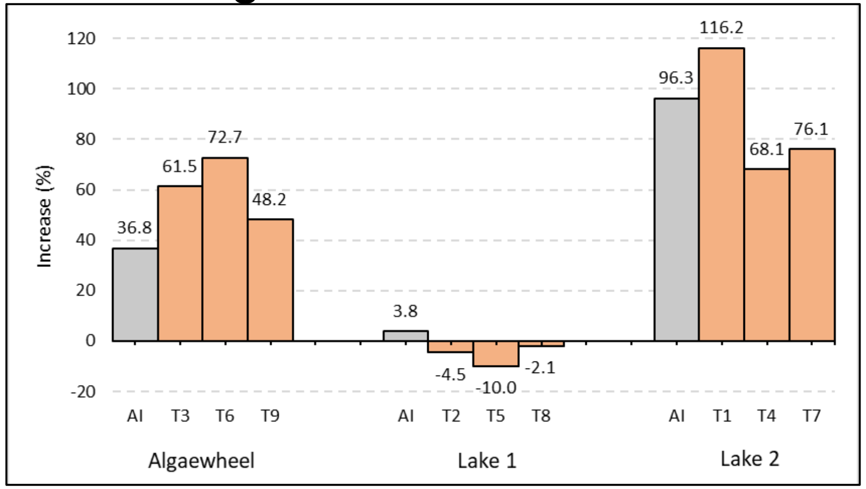
$$Yield_{mix}(\%) = \left(\frac{M_{oil}}{M_{biomass}}\right) \times 100$$

M_{oil} : mass of oil
$M_{mixture}$: mass of biomass (AFDW)

Oil yield



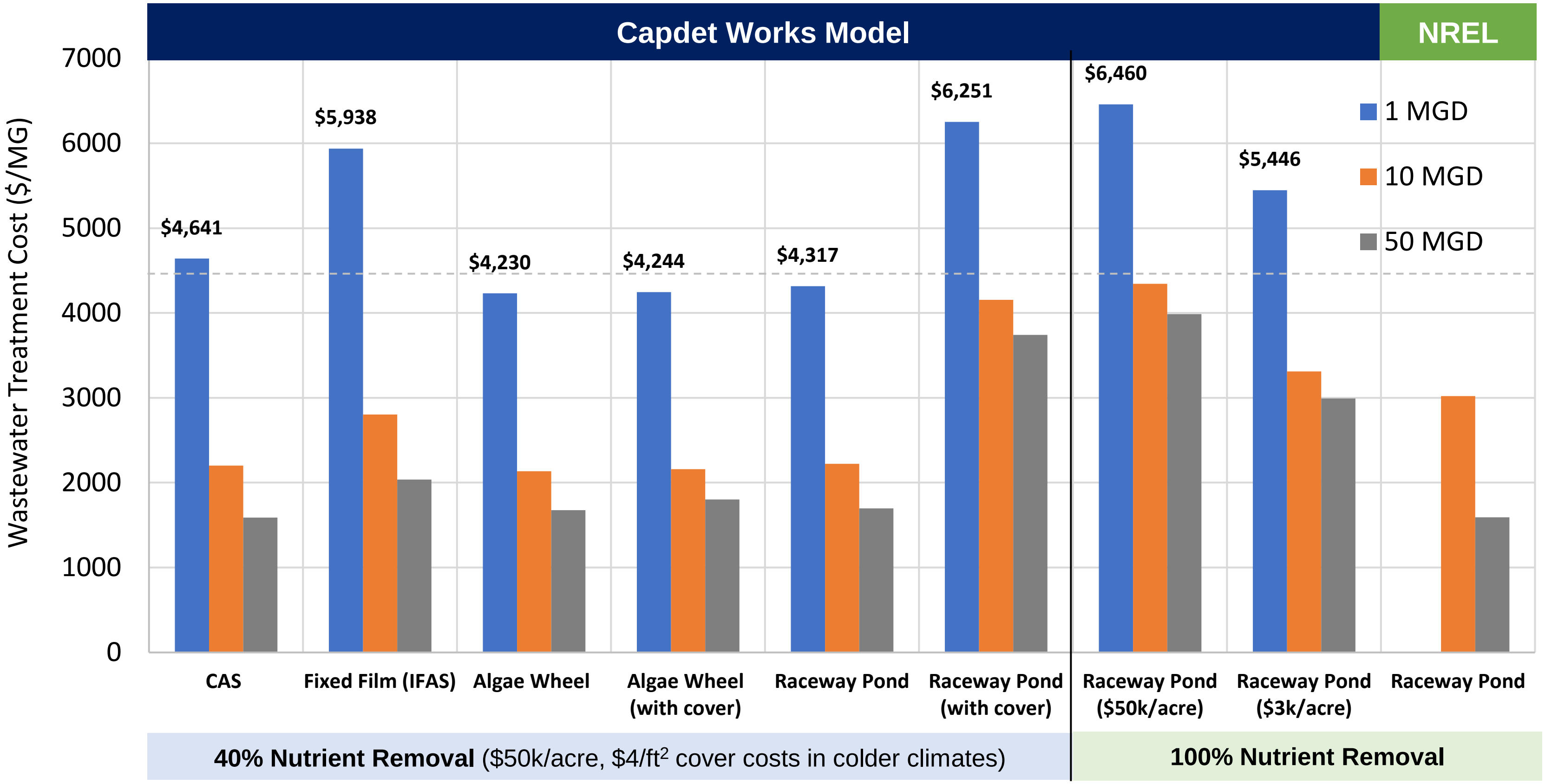
Change in relation to control



Start of BP3: Field Demonstrations in Two Climatic Regions

- Initial Milestone for each site: >25% productivity increase and >10% oil conversion yield increase
- G/NG 3: Integrated field test showing >50% productivity increase and >20% oil conversion yield increase
- Currently planning implementation of enhanced productivity treatments for first field demonstration site
  - Adsorbents, Bioaugmentation, Enhanced harvesting, Heating, Increased WW loading and Recycling
  - Northern IL residential subdivision wastewater plant treating 38,000 gal/day
- Second field-scale demonstration to occur in Florida

LCA/TEA Comparison of Full-scale Wastewater Treatment Costs



- Algae Wheel cost at 1 MGD size is significantly less than Conventional Activated Sludge (CAS)
- Algae Wheel land requirements are slightly more than CAS

- Algae Wheel cost at 1 MGD size is slightly less than Raceway Ponds
- Algae Wheel land requirements are much less than Raceway Ponds

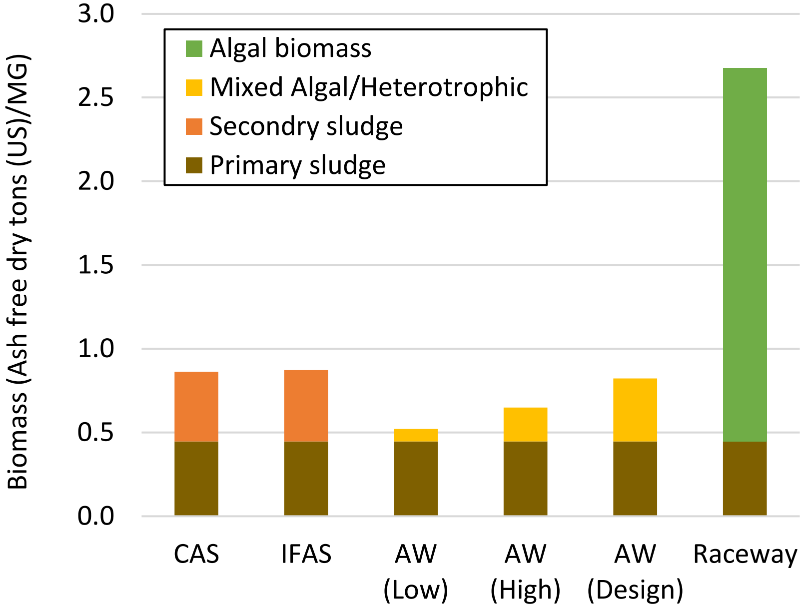
- 10 MGD Algal Raceway Pond costs by NREL similar to TEA estimates with same design assumptions

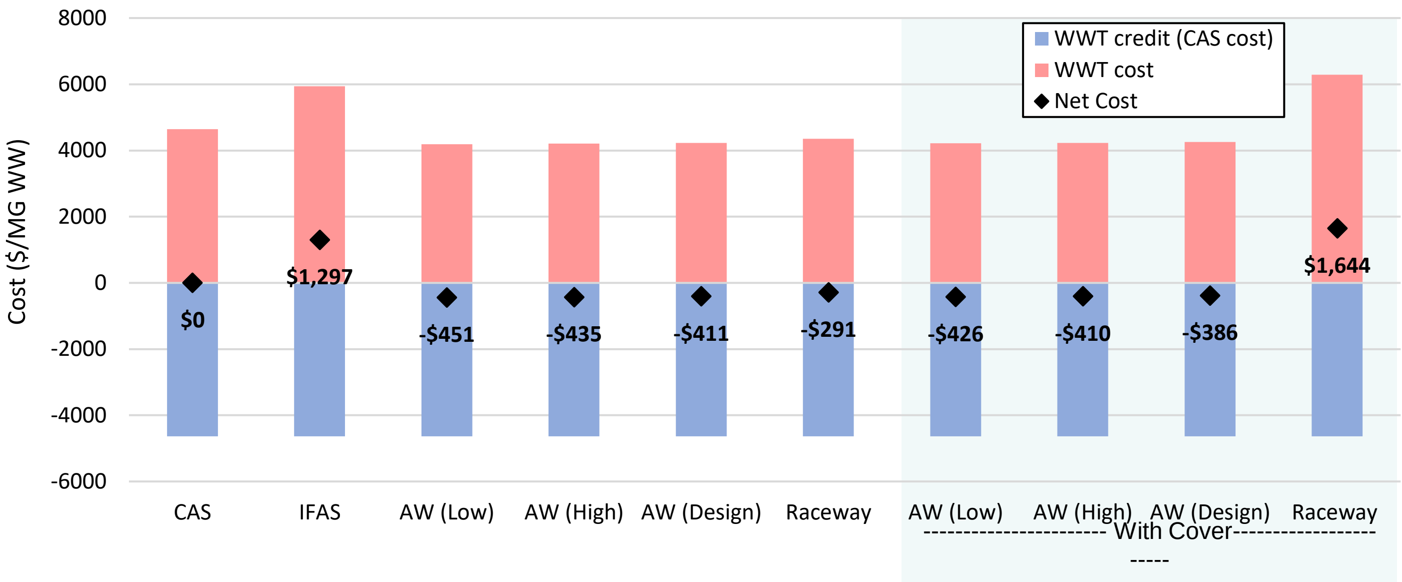
Land Area (acre)	1 MGD	10 MGD	50 MGD
CAS	11	20	47
Fixed Film (IFAS)	11	20	47
Algae Wheel	11.1	20.4	54
Raceway (40%)	30.9	218	1,042
Raceway (100%)	61	518	2,542

Key CapdetWorks model assumptions:
- 40% nutrient removal (or discharge standards)
- $50k/ac land costs (Typ. for AlgaeWheel sites)
- Cover required in colder climates for year-round operations ($4/ft^2)

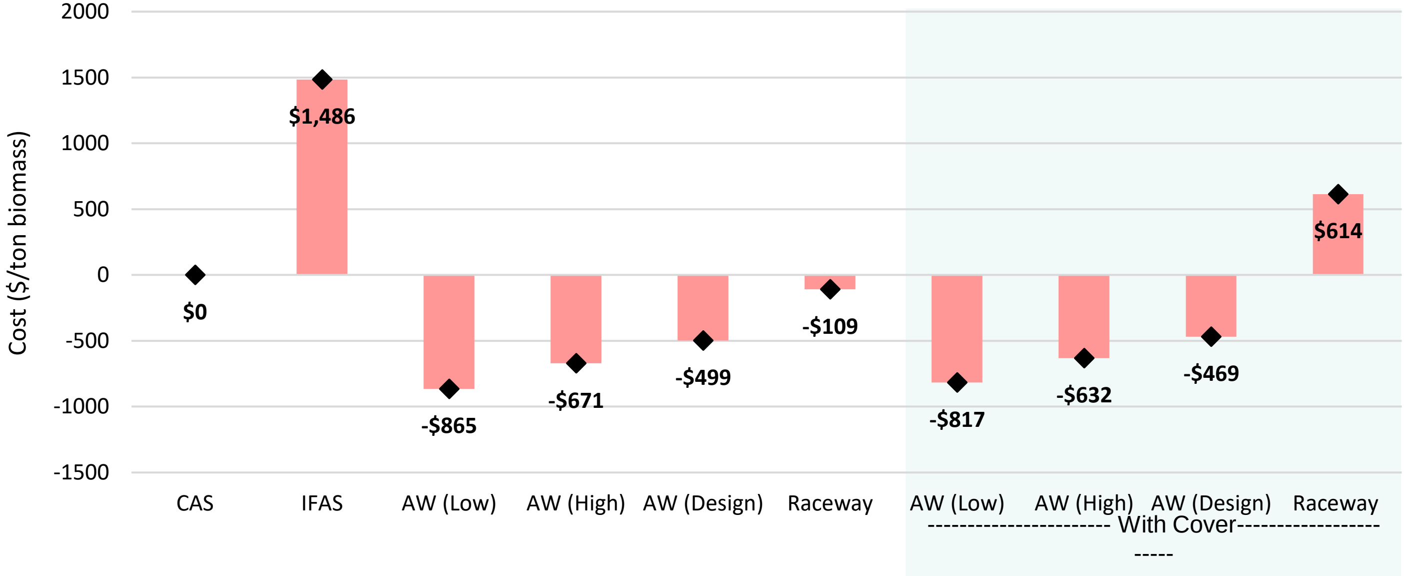
Key NREL model assumptions:
- 100% nutrient removal assumed
- Addition of CO_2 required for 100% nutrient removal
- Land cost assumed @ $3k/ac (Davis et al, 2016)
- High Content Protein Algae: 25 g/m^2/day
- NREL assumed WWT Credit of $4500/MG

TEA/LCA- Biomass Production Cost and Net Cost (1 MGD)





Algae Wheel (AW) Biomass Productivity Rates ($g/m^2/day$)	Low	High	Design
Small Wheel (0.45 m dia)	20	70	130
Large Wheel (1.8 m dia)	78	210	392



Impact

Goal: Integrated system for algal biofuel and wastewater treatment can reduce biofuel costs <$2.50/GGE

- Dual-use infrastructure can provide algal biomass at a negative cost
- Enhanced algal productivity can increase biomass and biofuels derived from WW treatment
- Reduced ash content enhances oil yield and improves oil quality
- Partnership with OneWater Inc. can accelerate market penetration

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Summary

Demonstrated increased productivity from 20 $g/m^2/day$ to 42 $g/m^2/day$ with combined treatments at pilot-scale

Interim TEA/LCA suggests algal biomass can be produced at a net negative cost when integrated with wastewater treatment

Increased HTL oil conversion from 22% to 40% with membrane separation and recycle of organics in HTL aqueous byproduct

Field demonstrations are starting to test enhanced prod-uctivity treatments in a full-scale wastewater treatment system

Quad Chart Overview

Timeline

- July 2019 to current

	FY22 Costed	Total Award
DOE Funding	*(10/01/2021 – 9/30/2022)* *No- cost extension for 2022: $211,258*	*$3,011,701*
Project Cost Share	$752,852	$3,764,553

TRL at Project Start: 4
TRL at Project End: 6

Project Goal

Overall goal is to improve mixed algal biomass productivity and quality in an integrated system for wastewater treatment and biofuel production.

We aim to achieve this goal using a variety of strategies including: endoreduplication, adding adsorbents, bioaugmentation, automated flow control; increased wastewater loading, enhanced biomass harvesting and recycling of biofuel conversion by-products.

End of Project Milestone

Field scale test showing >50% biomass productivity increase and >10% conversion yield increase.

Final TEA/LCA on proposed technology

Funding Mechanism

DE-FOA-0002029 Cultivation Intensification Processes for Algae

Project Partners

- OneWater, Inc.
- University of Florida
- Hannon and Associates