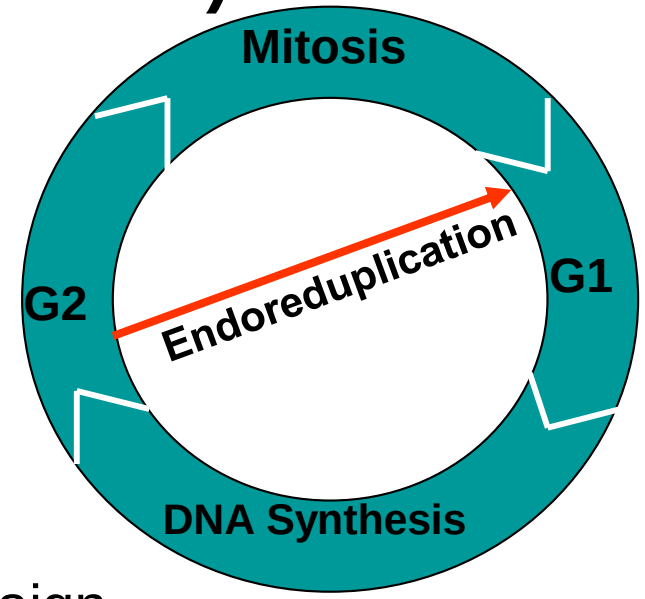
DOE Bioenergy Technologies Office (BETO)
2021 Project Peer Review

Improving the Productivity and Performance of Large-Scale Integrated Algal Systems for Wastewater Treatment and Biofuel Production (Agreement # DE-EE0008905, WBS: 1.3.5.286)



February 16, 2021
Advanced Algal Systems

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University of Illinois at Urbana-Champaign
Illinois Sustainable Technology Center

Project Overview

- *Algal biofuels have significant environmental benefits but are currently not economically viable (Best case $3.50–$4 GGE)*
  - *Increasing algal productivity and biomass quality are keys to lower costs*
  - *Treated wastewater (WW) can be a highly valuable co-product*
- *Our project seeks to synergistically integrate advanced algal wastewater (WW) treatment with maximized biofuels production*
  - *Algaewheel is a commercially available WW system w/ >10 sites*
    - *Mixed algal-bacterial biomass (sludge) not currently used for biofuels*
  - *Seeking to increase productivity, quality & produce hydrothermal biofuels*
- *WW treatment revenues provide biomass at net zero cost, so biofuels are produced at conversion costs (est. $2.25 in 2018)*

1 – Management

Project Team and Primary Roles

- ***University of Illinois at Urbana-Champaign (Prime Contractor)*** Illinois Sustainable Technology Center
  - *Project Management*
  - *Pilot Algaewheel System Operations for Enhanced Biomass Quantity and Quality*
  - *Lab Research on Endoreduplication, Bioaugmentation, and Biofuel Byproduct Recycling*
  - *Analyze Samples and Data from Field Demonstration Testing*
- ***OneWater, Inc (Subcontractor): Co-PI Dan Johnson*** algaewheel® Exclusively from ONEwater®
  - *Supply Algaewheel Wastewater Treatment Systems*
  - *Consult on Pilot-scale Algaewheel Operations*
  - *Manage Full-scale Demonstration Testing of Enhanced Algaewheel Operations*
  - *Commercialization Partner for Algaewheel System Improvements*
- ***University of Florida (Subcontractor): Co-PI Anna Martin-Ryals*** UF | UNIVERSITY of FLORIDA
  - *Techno-Economic and Life-Cycle Analysis*
  - *Sampling of southern US field testing site*
- ***Hannon and Associates, LLC (Subcontractor) Co-PI Bruce Hannon***
  - *Dynamic Computer Simulation of Algaewheel System*
  - *Consult on Algae Cultivation Improvement Testing*

Project *Schedule*

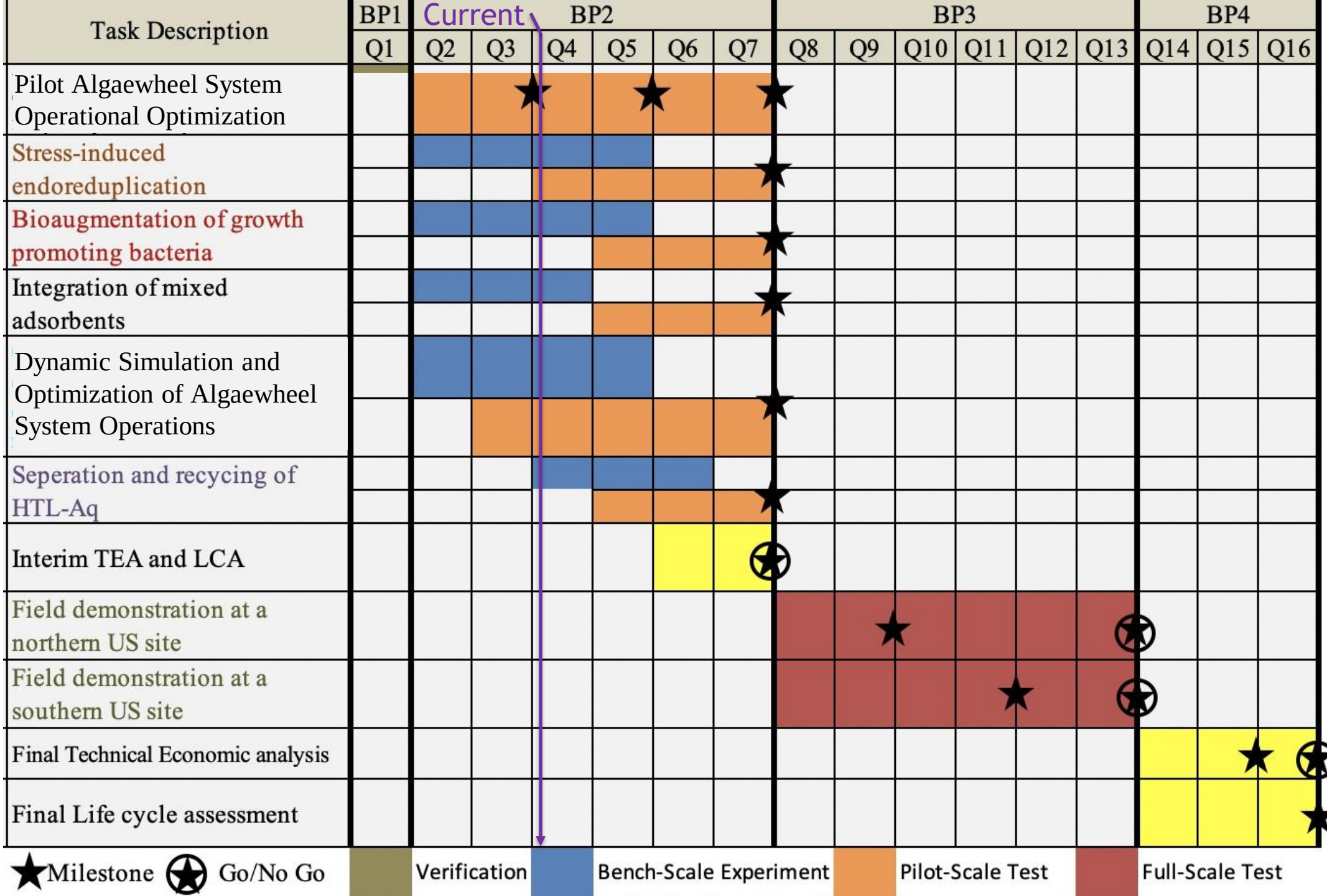
Currently in Q4 (Budget Period 2)

Work progression

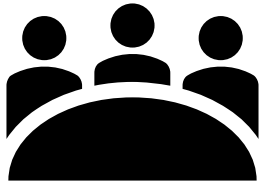
Lab/Pilot-scale work in Budget Period 2

Field-Scale Demonstration in Budget Period 3

Final System Analysis in Budget Period 4



1. Management – *Key Project Communication Links*



Monthly conference calls with the project team collaborators

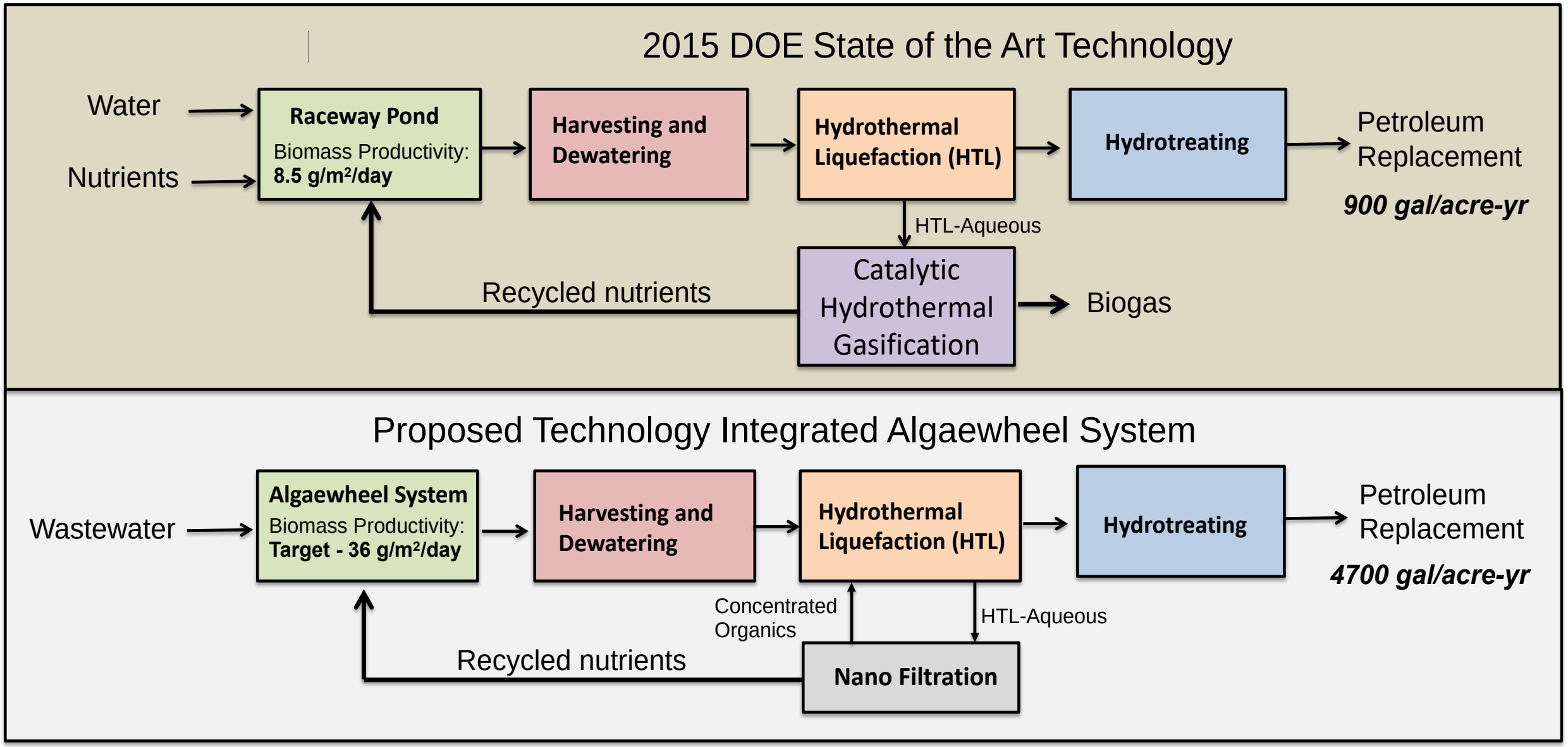
Quarterly submission of project progress report

Individual meetings with each technology working group to go over specific issues

Monthly conference call with DOE program managers

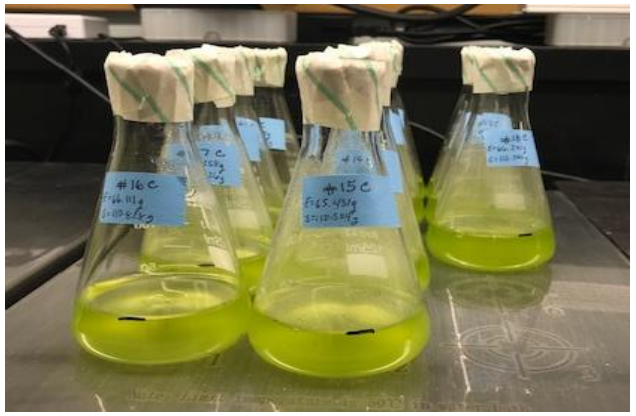
All project files uploaded to a cloud-based file share on box.com for storage and later use by the project team

2 – Approach: *Process Block Flow Diagram Comparison*

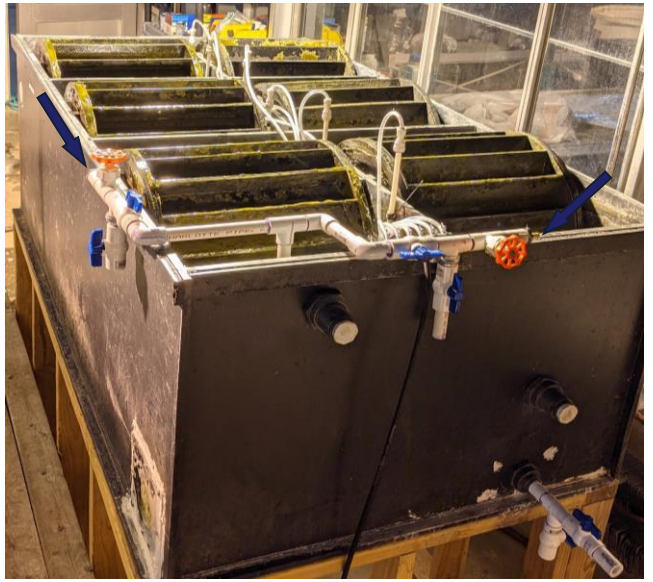


2 – Approach to Increase Biomass Productivity & Quality

- *BP2- Biological technology (Lab-scale initially → Pilot)*
  - *Stress-induced endoreduplication → Increased cell sizes & biomass quantity*
  - *Bioaugmentation with bacterial symbiotes producing:*
    - *Vitamin B12*
    - *Antibiotics*
    - *Insecticide (Bt toxin)*
    - Plant growth hormone (indole-3-acetic acid)



- *BP 2- Cultivation system operations (Pilot-scale)*
  - *Increased morning temp. for improved photochemistry*
  - *Increase harvesting freq. for reduced ash*
  - *Incorporate adsorbents to retain growth resources*
  - *Dynamic spin rate control for optimal light exposure*
  - *Interim techno-economic and life-cycle analysis*



2 – Approach (Future Budget Periods 3 & 4)

- *BP3 Field demo using current full-scale Algaewheel installations*
  - *Northern Site (Illinois or Indiana)*
  - *Southern Site (Florida)*
  - *Side by side control and improved treatment tanks*
- *BP4 Final evaluation of project technology developments*
  - *Techno-economic analysis*
    - *Comparison with DOE raceway pond algae biofuels baseline*
  - *Life-cycle analysis*
    - *Net greenhouse gas emissions*
    - *Eutrophication*
    - *Fossil fuel consumption*

3 – Impact

Major Cost Savings for Meeting Project Goals

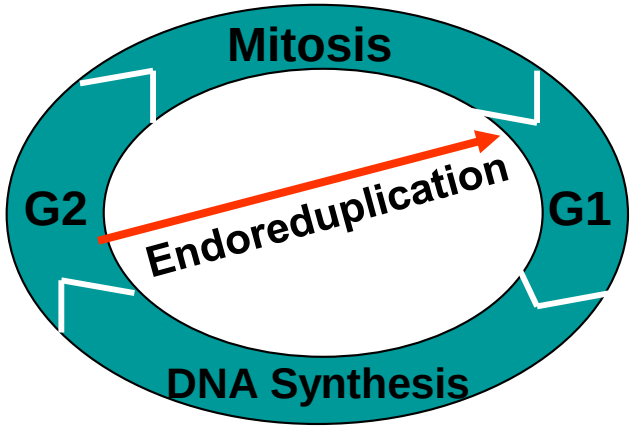
- *Increased productivity*
- *Use WW infrastructure for algae cultivation*
- *CO_2 from WW aeration & co-cultivated bacteria*
- *Nutrients from WW*
- *Internal recycling of biofuel by-products*
- *Algal biofuel prices below DOE targets*

Cost Categories	2015 DOE SOT Costs w/ Algae Productivity of 8.5 g/m²/day	2022 DOE Projected Costs w/ Algae Productivity of 25 g/m²/day	Project End Cost Estimate w/ Algae Productivity of 36 g/m²/day
Algae Biomass Prod. Costs ($/dry ton)			
Ponds & Inoculum	$ 1,359	$ 289	$ 64
CO_2 Supply	$ 99	$ 97	$ 0
Dewatering Operations	$ 82	$ 52	$ 52
Nutrient Supply	$ 25	$ 24	$ 0
Other Costs	$ 76	$ 32	$ 32
TOTAL Biomass Cost	$ 1,641 /dry ton	$ 494 /dry ton	$ 153 /dry ton
Algal Biofuel Prod. Costs ($/gal gasoline equiv.)			
Algae Biomass Supply	$ 15.15	$ 3.18	$ 1.40
Hydrothermal Liquef.	$ 1.18	$ 0.49	$ 0.49
Bio-oil Upgradation	$ 0.44	$ 0.31	$ 0.31
Aq product post-treat	$ 1.54	$ 0.57	$ 0.09
Balance of Plant	$ 0.29	$ 0.17	$ 0.17
TOTAL Biofuel Costs	$ 18.60 / gge	$ 4.72/gge	$ 2.46/gge

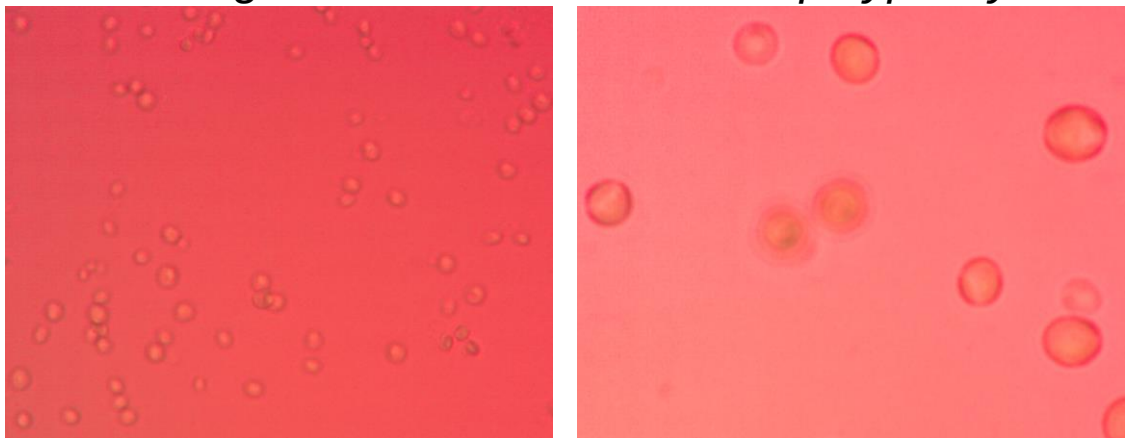
3 – Impact

- *Publication Targets and Workforce Development*
  - *Stress-Induced Endoreduplication Approaches for Increasing Algal Biomass Productivity*
  - *Bacterial Bioaugmentation Approaches for Increasing Algal Biomass Productivity*
  - *Reducing Algal Biofuel Production Costs via Synergistic Integration with Fixed-Film Algal Wastewater Treatment*
  - *Project employs 4 graduate students and post-docs to be involved in publications*
- *Commercialization Partnership*
  - *Subawardee OneWater, Inc. markets the Algaewheel system to the WW treatment industry*
  - *Achieving project goals will add value to Algaewheel operations by*
    - *Reduced sludge disposal costs*
    - *New bioenergy co-products*
    - *Improved effluent water quality*
  - *Cost impacts of project findings provide financial motivation for commercialization*

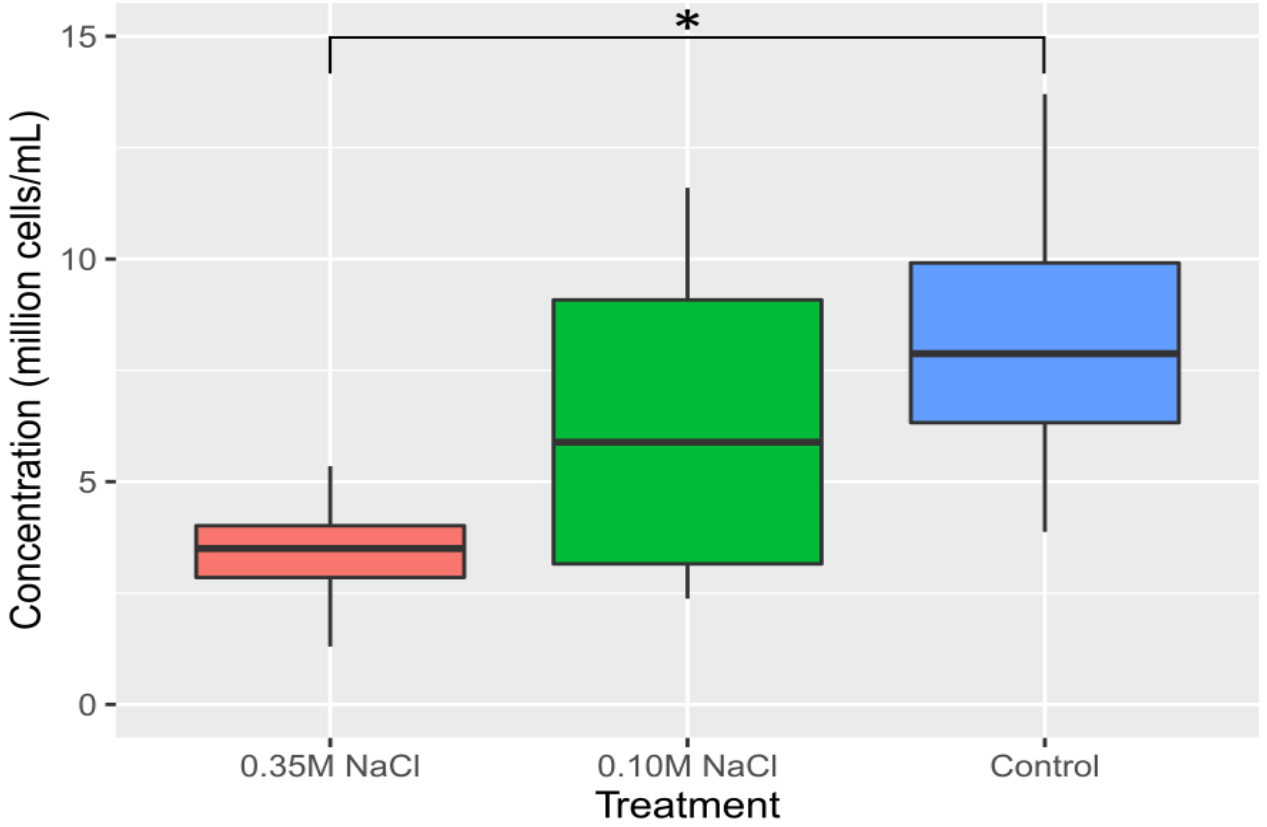
4 – Progress and Outcomes: *Endoreduplication*



- 0.1-0.35 M NaCl salt stress increased the productivity of *C. Vulgaris by 50%-90%*
- *Salt stressed cells had lower cell counts but average cell diameter was 2-3 times larger*
  - *Larger cells indicative of endopolyploidy*



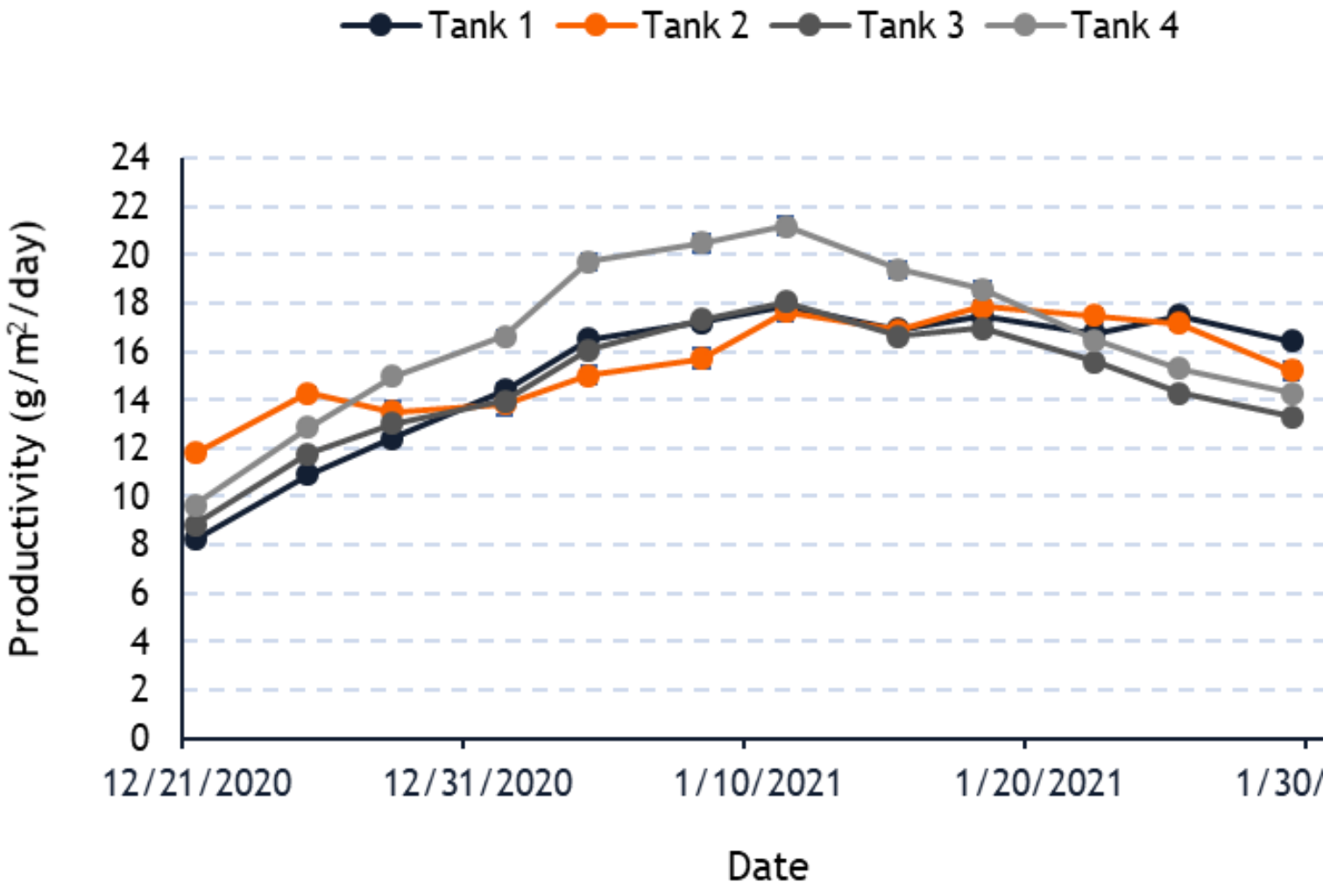
- *Cell sorting with DNA staining in process to quantify level of polyploidy*
  - *Initial difficulties with DAPI staining*
  - *Trying cell perforation pretreatments and alternative stains (SYBR Green)*



* *Indicates statistically significant difference*

4 – Progress and Outcomes: *Pilot System Start-up*

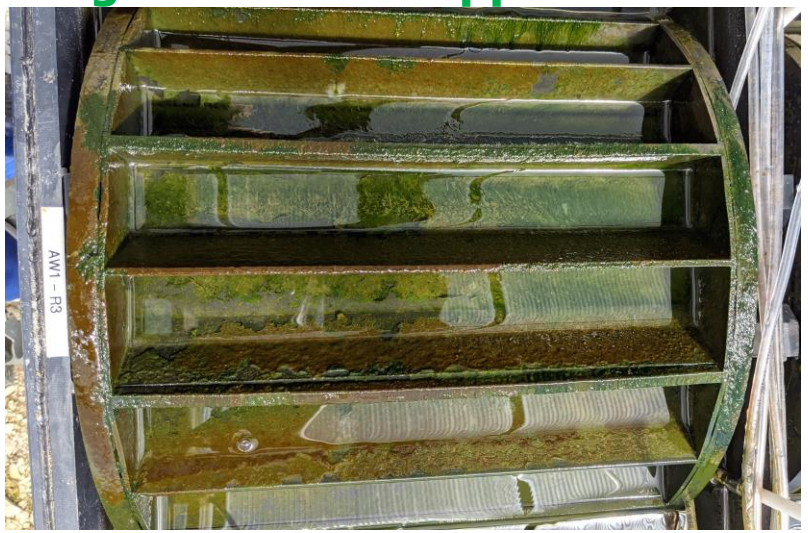
- *1st BP2 Milestone → Start-up 4 Algaewheel pilots w/ annual productivity target of 20 g/m²-day*
  - *Seasonal adjustment of avg. winter productivity (16-18 g/m²-day) met project goals*
  - *WW organics removal (sCOD) avg. 85-90% meets discharge limits*
  - *Effluent ammonia avg below 1 mg/L meets discharge limits*



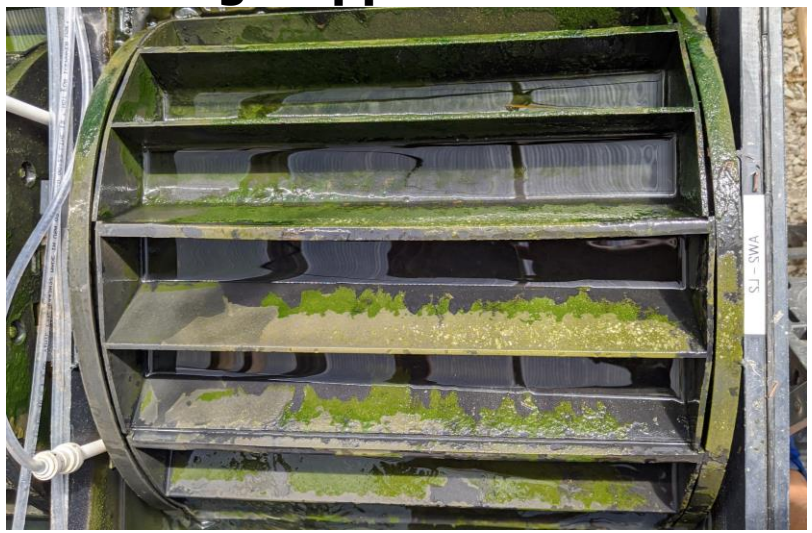
4 – Progress and Outcomes: *Algaewheel biofilm development*

- *Nualgi nanosilica nutrient additive accelerated biofilm development*
- *Bioaugmentation w/ Bt toxin producing bacteria controlled larval growth*
- *Clinoptilolite adsorbent enhanced biofilm formation*

Nualgi nanosilica supplement added

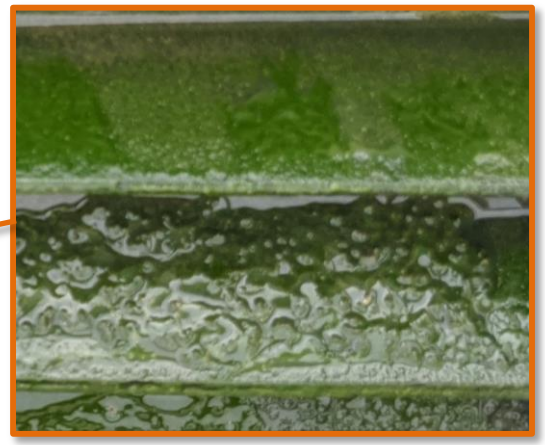


No Nualgi supplement added



Before colonization: Algaewheel surface w/ and w/o adsorbents

After colonization surface



Close-up surface view

Summary

- ***Commercially available Algaewheel wastewater treatment system provides a cost-effective pathway to algal biomass/biofuels production***
  - *Mixed algal-bacterial biomass from Algaewheel system is available as a no-cost byproduct*
  - *Previously demonstrated hydrothermal conversion Algaewheel biomass to bio-crude oil*
    - *Low bio-oil yield (30%) due to high ash and low lipid content of Algaewheel biomass*
- ***Current Algaewheel system has not been optimized for biomass or biofuel production***
  - *Biological improvements- inducing endoreduplication and symbiotic bacteria bioaugmentation*
  - *Cultivation improvements- integrating adsorbents, dynamic aeration and thermal optimization*
  - *Integration of methods to increase productivity to 36 g/m^2-day and bio-oil yield to 37.5%*
  - *Estimated algal biofuel cost below $2.50/gal by completing project objectives*
- ***Progress through first 7 months of work has shown:***
  - *Lab tests of salt-stress endoreduplication showed >50% productivity increase for C. Vulgaris*
  - *4 pilot systems started-up & avg. winter productivity of 16-18 g/m^2-day met 1st BP2 Milestone*

Quad Chart Overview for DE-EE0008905

Timeline

- October 1, 2019
- March 31, 2024

	FY20 Costed	Total Award
DOE Funding	$ 128,913	$ 3,011,601
Project Cost Share	$ 97,760	$ 752,592

Project Partners

- University of Illlinois
- OneWater, Inc.
- University of Florida
- Hannon & Associates, LLC

Project Goal

Provide lab, pilot and field demonstration data supporting:

- Annual biomass productivity > 36 g/m2/d
- Bio-crude oil yield > 37.5%
- Biofuel production cost < $2.50/gal gas equiv.

End of Project Milestone

Field-scale test showing a 50% increase in biomass productivity over initial project baseline.

Field-scale test showing enhanced biomass quality that supports a 20% increase in bio-crude oil conversion yield over initial project baseline.

Funding Mechanism

DE-FOA-0002029: Cultivation Intensification Processes for Algae, Topic Area 1 (2019)