Algal Turf Scrubbers: Improving Carbon Utilization and Productivity (ATS:CUP)

DE-EE0010293

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2024 FECM/NETL Carbon Management Research Project Review Meeting
August 5 – 9, 2024

Project Overview

- Funding
  - DOE: $2.99M
  - Cost share: $0.75M
- Overall Project Performance Dates: Oct 2022 – Aug 2025
- Overall Project Objectives:
  - Strain improvements: Enhance algal strains for high lipid content (>25%) and low ash biomass (<22%) to support sustainable aviation fuel production.
  - Engineering solutions: Optimize carbon delivery and utilization through experimental systems, increasing productivity with 3D substrates and improved harvesting.
  - System modeling: Perform sustainability and performance modeling to assess economic and environmental impacts, guiding experimental work with data-driven insights.

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HydroMentia, LLC

Mark Zivojnovich

Czero, Inc.

Chris Turner
Ben Alexander

Technology Background

ATS:CUP is a **Direct Air Capture** project

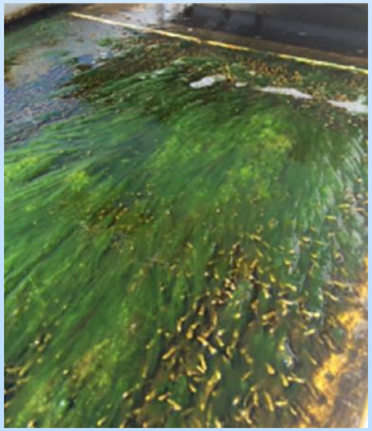
- Natural periphytic communities seeded onto turf surfaces
- Carbon delivered through dissolved and atmospheric CO_2

ATS as a **value-added environmental service**

- Remove excess nitrogen and phosphorus from impaired waters

HydroMentia, LLC
Field deployment in FL
10 million GPD capacity treatment

Sandia National Laboratories
Field deployments in CA, TX, HI
Lab-scale flow-way channels



Technology Background

Major technical advantages

+ Direct Air Capture with >90% carbon utilization efficiency
+ Minimal operating and harvesting energy
+ Integrates with tertiary wastewater treatment
+ Water quality service credits
+ Economically competitive with conventional wastewater treatment

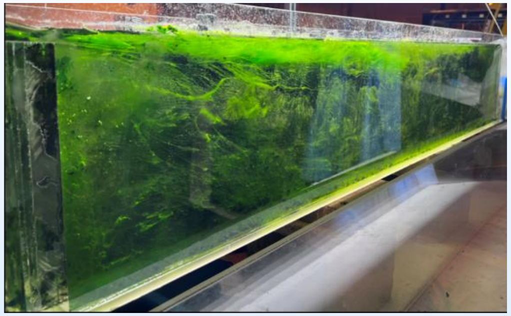
Major technical challenges

- High ash content
- Low biomass quality to fractionate into value-added products
- Turf community variance

Technical Approach/Project Scope

Technical capabilities by facility

SNL
- Multi-channeled flow-way
- 2× 30 ft length flow-ways
- Miniature flow-ways
- Field deployments
- Genomic sequencing



HydroMentia, LLC
- Commercial experience

CSU
- 3× triplicate channel 7 ft length flow-ways
- 2× 4 ft length miniature flow-ways
- Genomic sequencing
- Process modeling and sustainability assessments

Technical Approach/Project Scope

Key milestones

Budget Period 2 (M3 – M19)

- Demonstrate improved productivity from baseline by optimizing:
    - Strain/community characteristics (M19)
    - Hydrodynamic flow patterns (M19)
    - Substrate materials (M19)
- Scalability models through HUC8 data evaluation (M8)
- Techno-economic analysis and life cycle assessment (M17)

Note: BP2 was granted a 6-month no-cost extension

Budget Period 3 (M20 – M36)

- Demonstrate >30 g m^{-2} d^{-1} ATS productivity under conditions selected in BP2 (M36)
- Cost-benefit comparison vs. other nutrient removal strategies (M36)
- Demonstrate viable pathway meeting Renewable Fuel Standard (Project end)

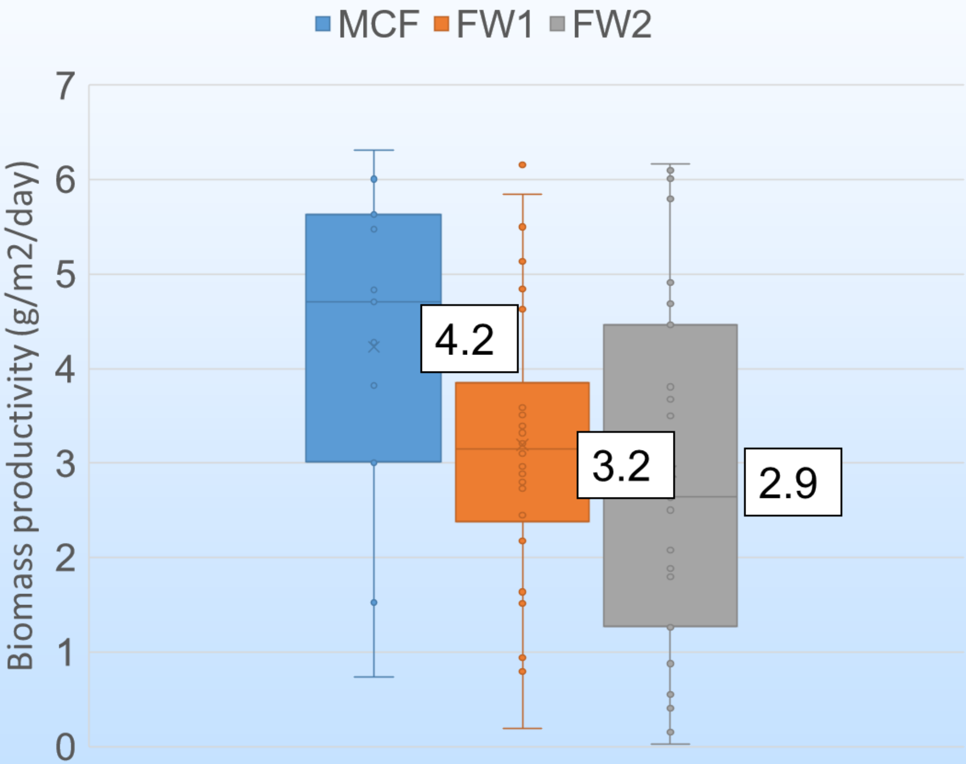
Progress and Current Status

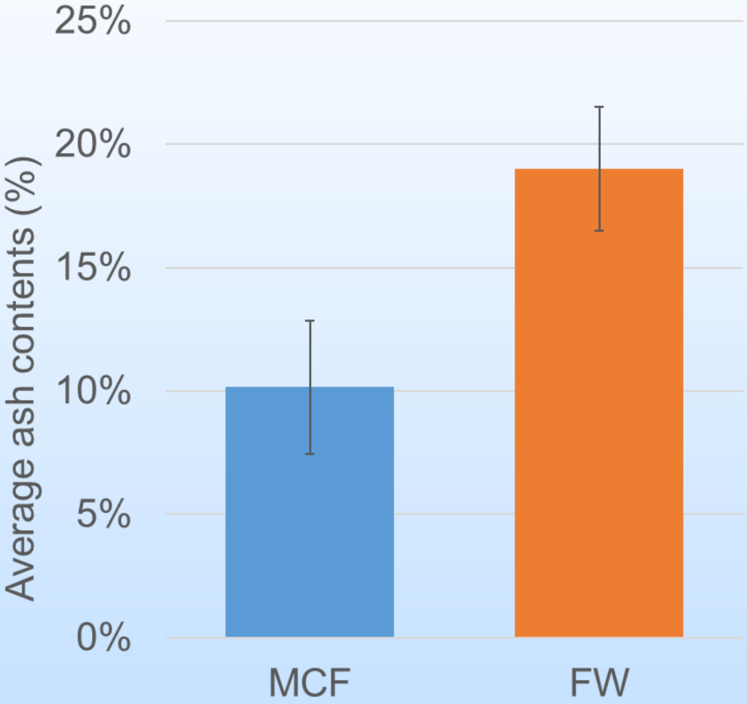
Biomass selection

- SNL
  - Robust growth from pilot-scale flow-way cultures
- CSU
  - Original planned biomass from Osprey Marsh, FL
    - Poor growth in flow-ways
    - Response to light intensity? Water quality?
  - Switched to local periphyte seeding from Poudre River, CO

Progress and Current Status

Surface-to-volume optimization – SNL





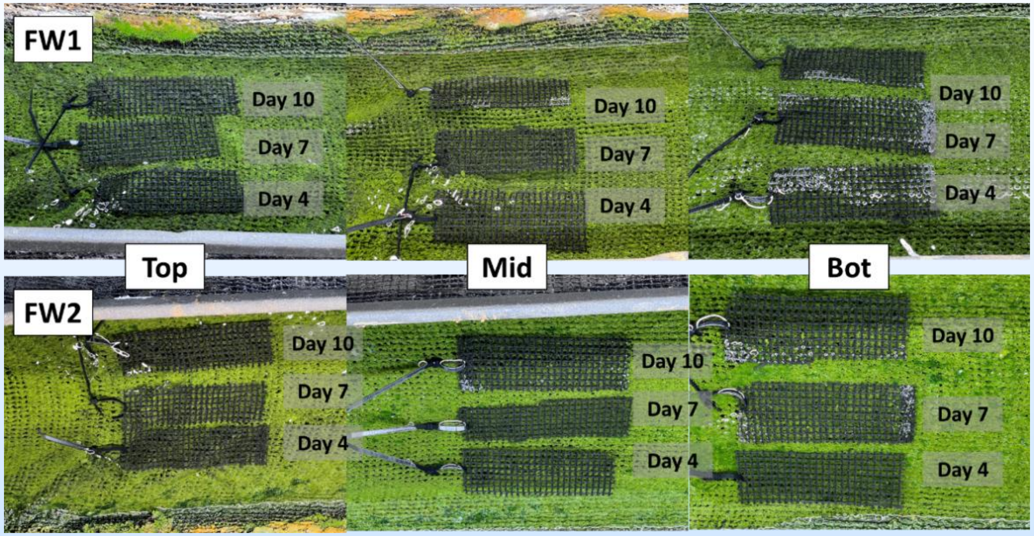
MCF had average of 4.2±1.7 g m^{-2} d^{-1}, which is 30-45% higher than average productivities of both SNL flow-ways during the same period. Average ash content of the biomass harvested from MCF was 10.1%, 46.6% lower than the average ash content of biomass from flow-ways.

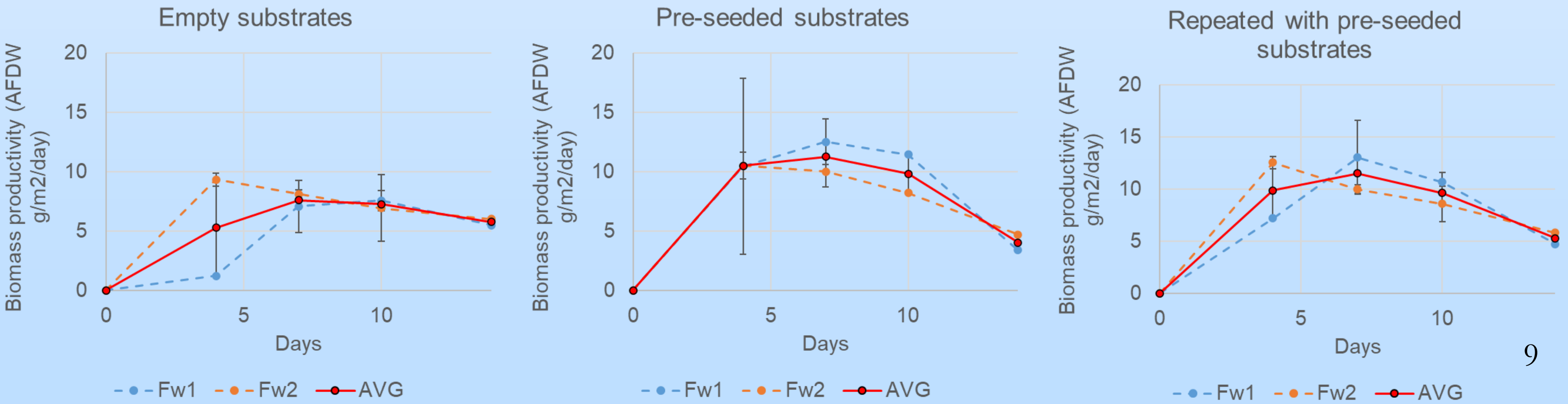
Progress and Current Status

Engineering solutions – SNL

Harvesting frequency has effect on productivity

- **7.3 g m^{-2} d^{-1}** average productivity of two flow-ways after 1-week harvest
- 130% higher than average productivity after 2-week harvest

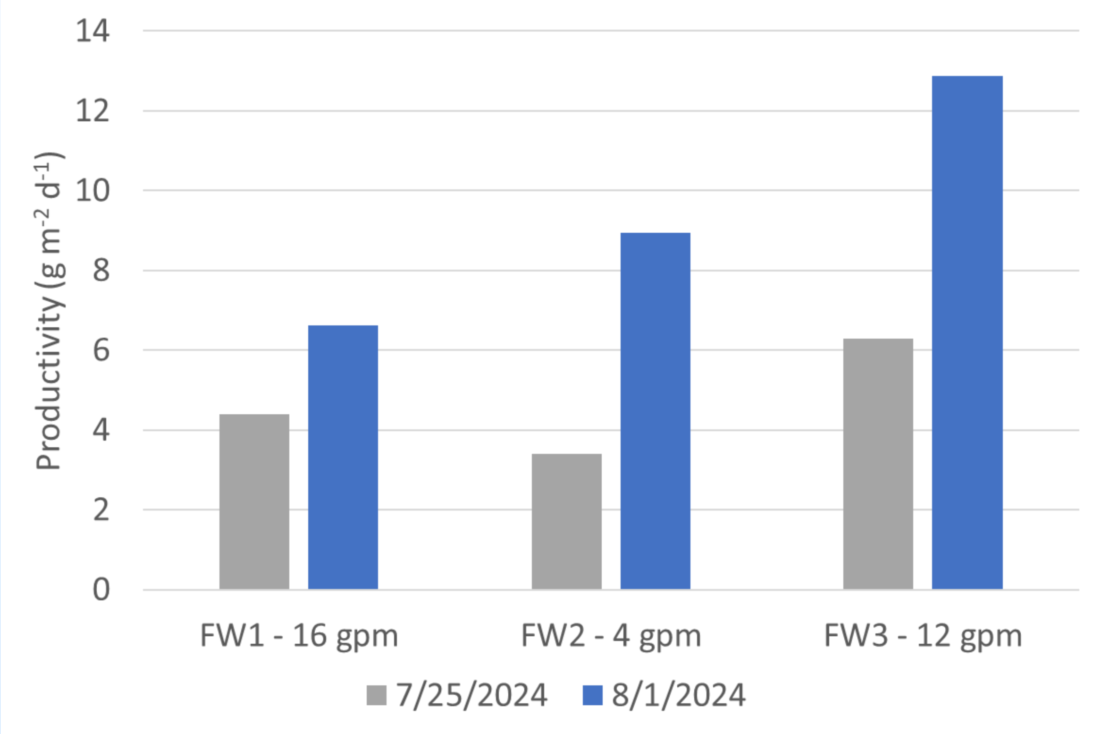


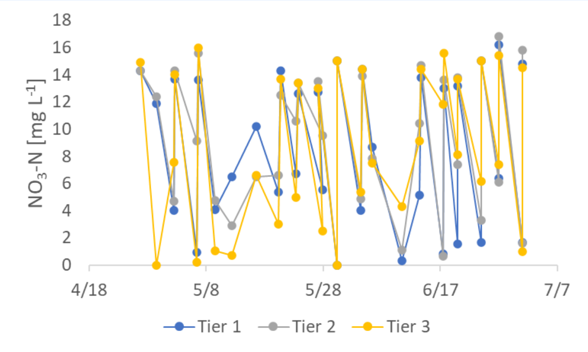


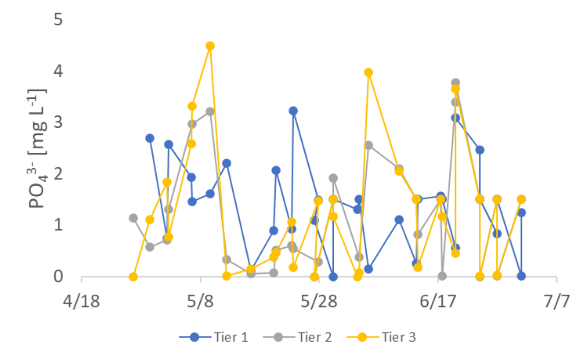
Progress and Current Status

Hydrodynamic operations – CSU

- Linear flow experiments have just started
- Pulsed flow experiments in progress
- Culture health from previous growth cycle affects productivity over following growth cycles



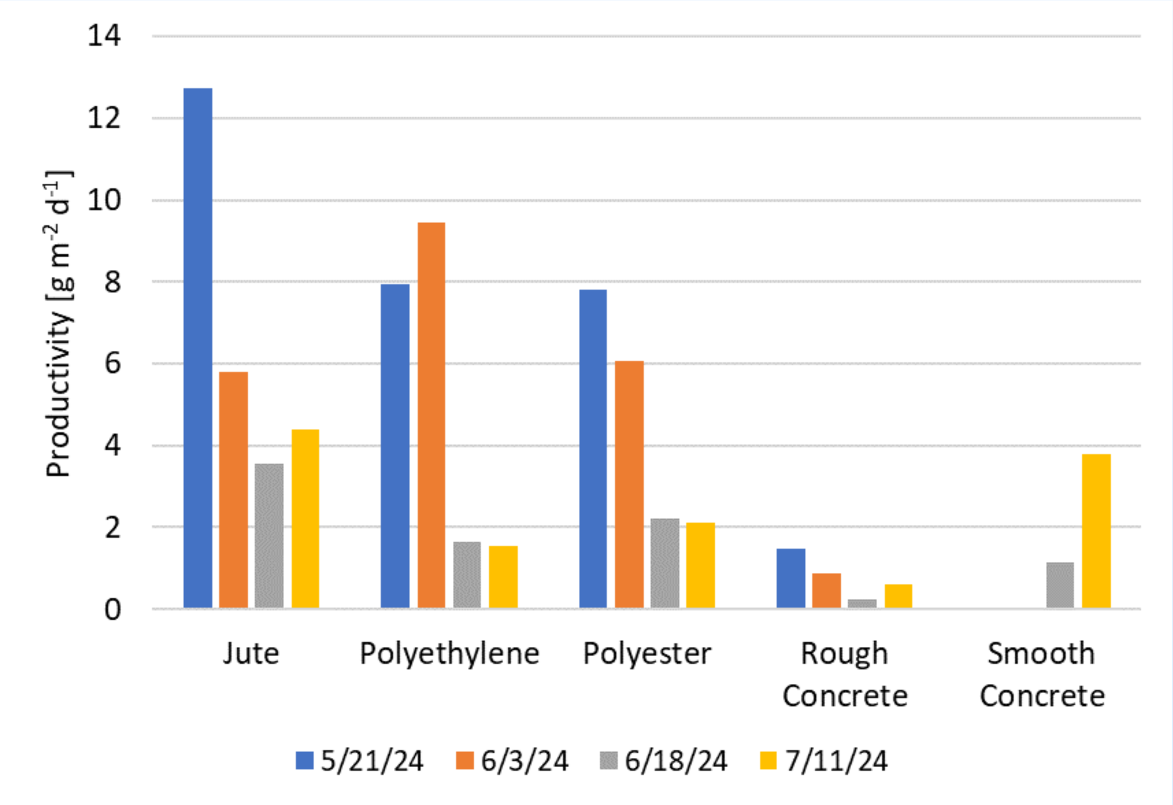


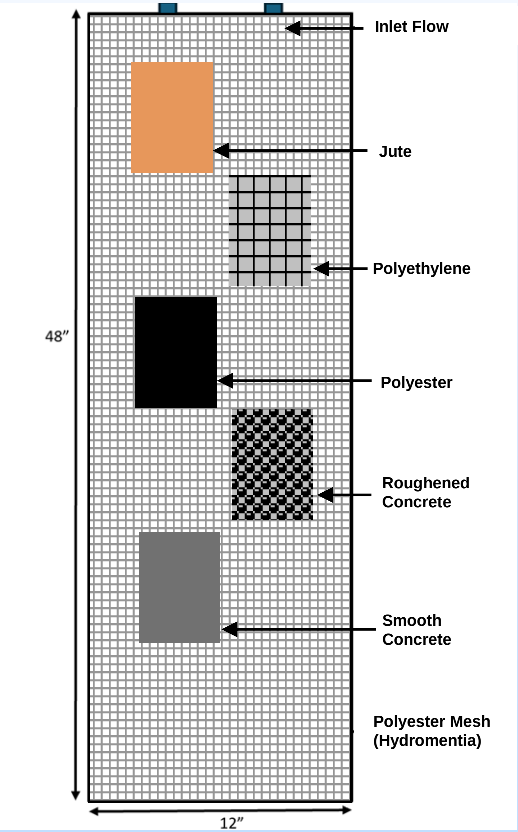


Progress and Current Status

Substrate materials – CSU

- Preliminary mini flow-way results show jute (burlap) and layered polyester mesh as promising alternatives
- Harvest area and flow patterns to be considered at scale

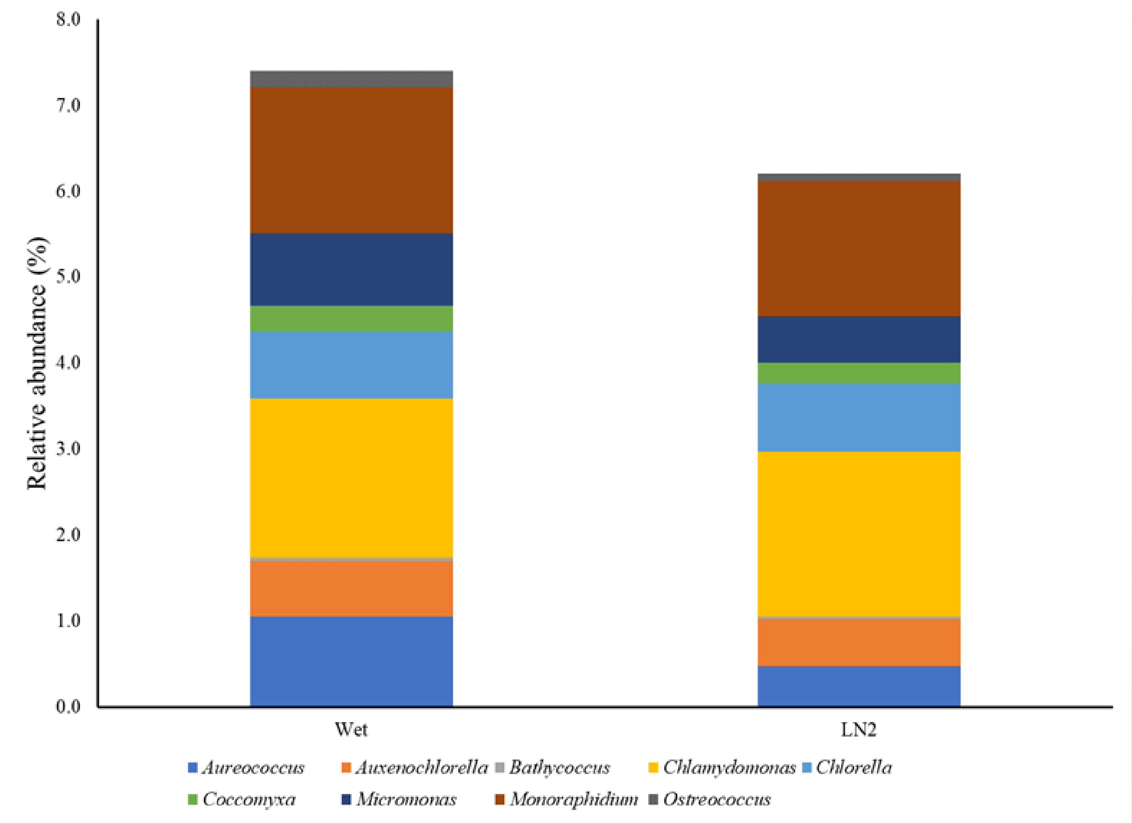




Progress and Current Status

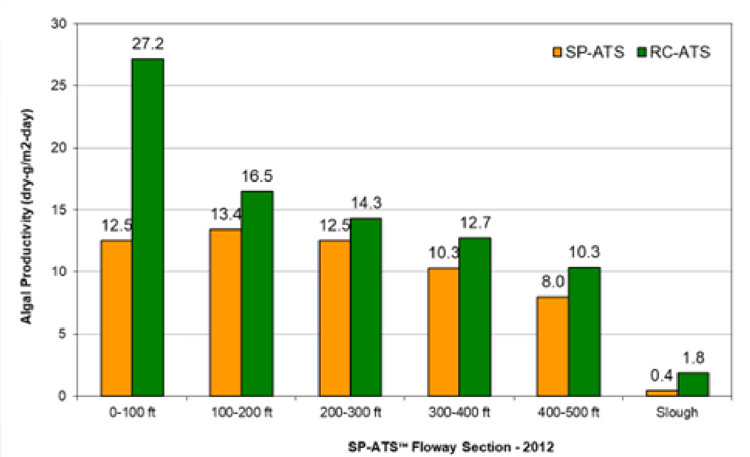
Microbial community characterization – CSU/SNL

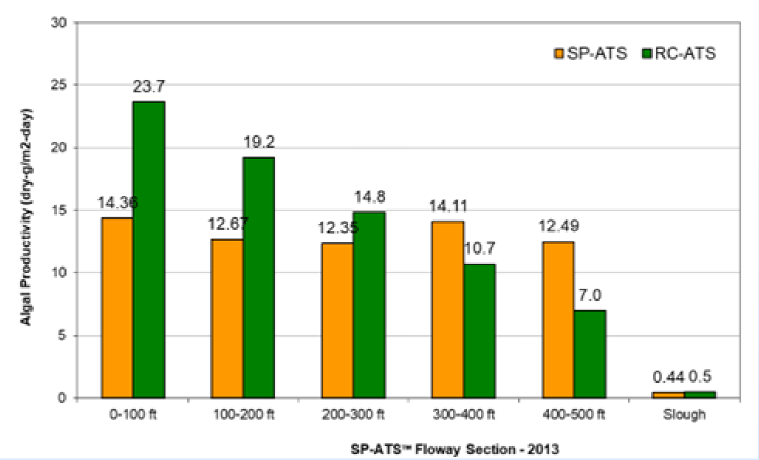
- 16S and 18S sequencing to be performed at CSU with updated SNL libraries
- Extraction methodology for 18S sequencing in development
- Separation of turf culture characterization by layer (attachment level vs. water surface) in development

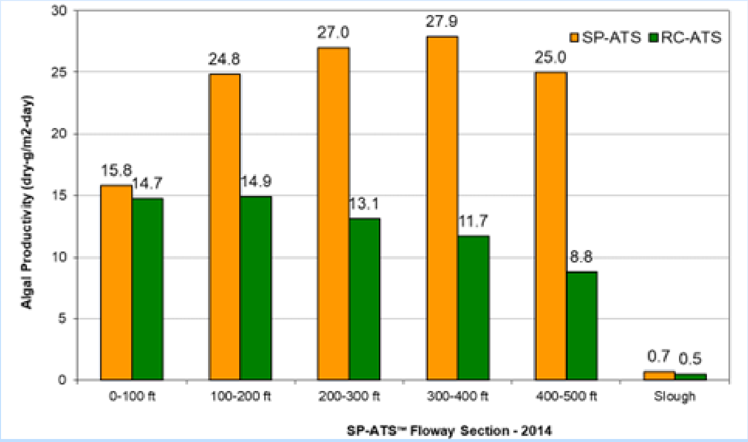


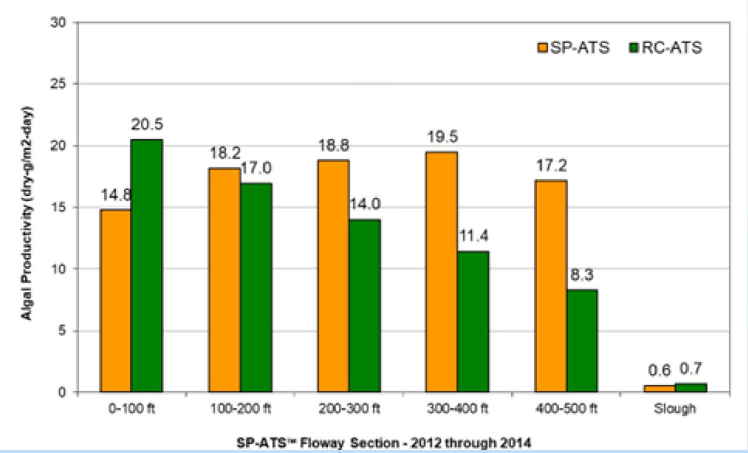
Progress and Current Status

Industry assessment - HydroMentia



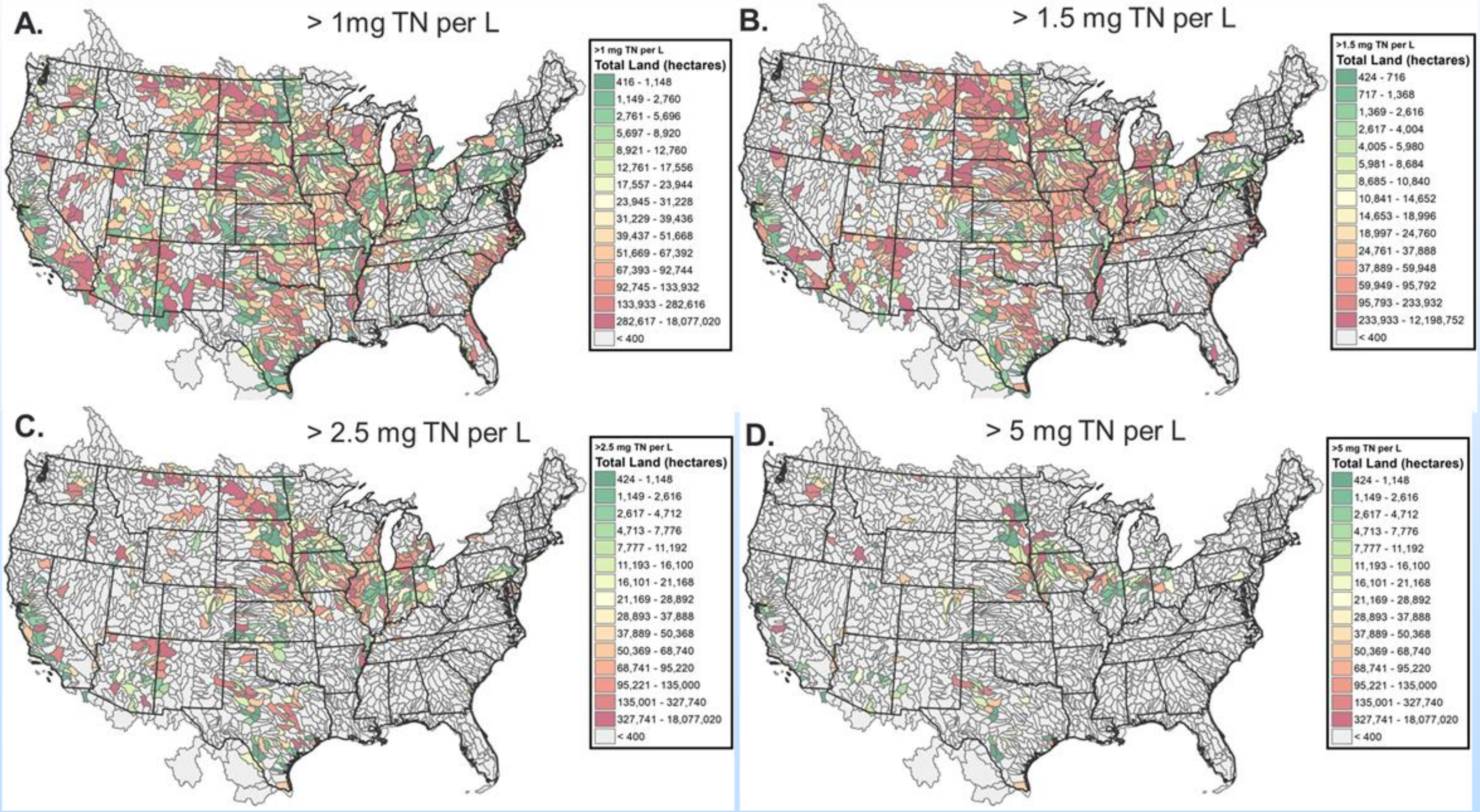






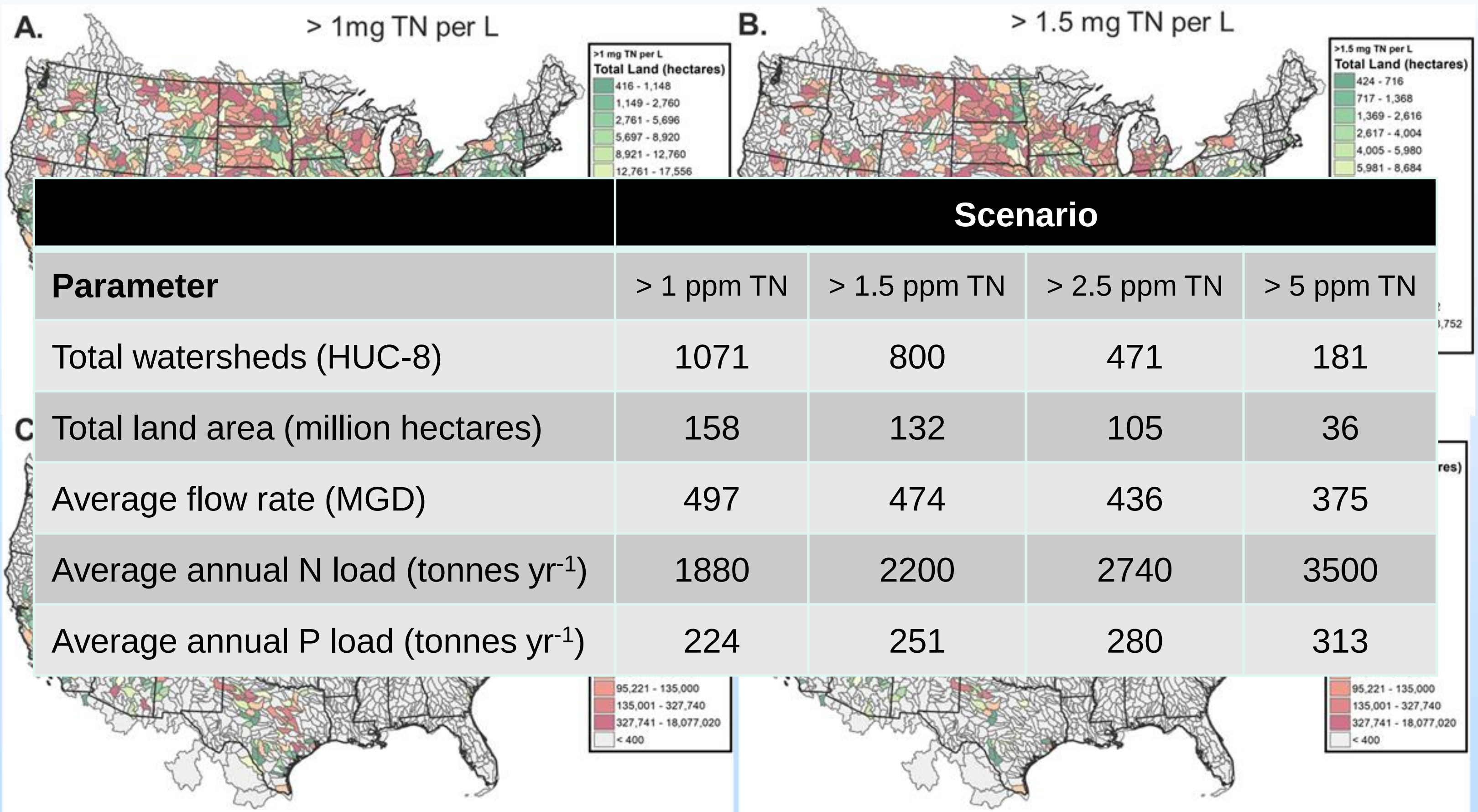
Progress and Current Status

Scalability assessment - CSU



Progress and Current Status

Scalability assessment - CSU

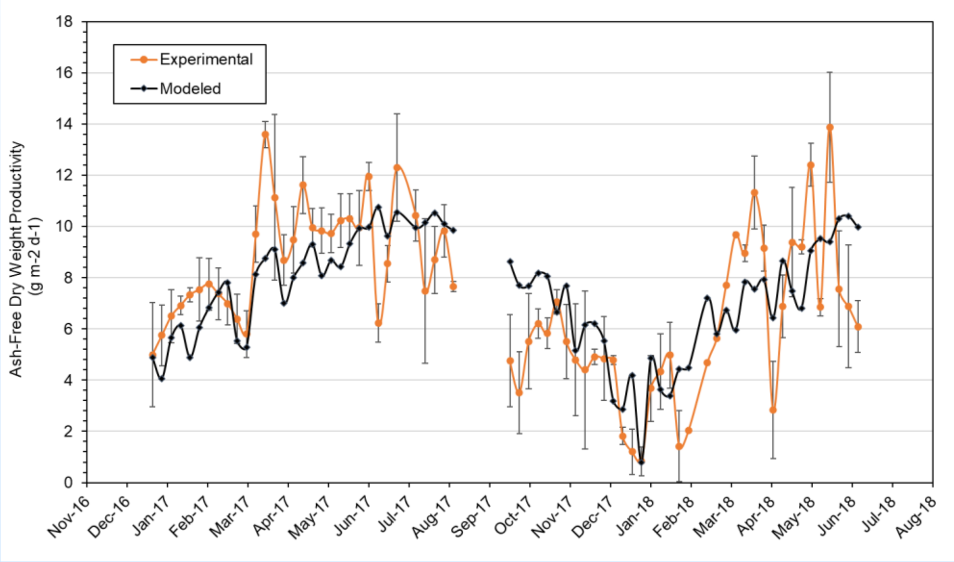


	Scenario			
Parameter	> 1 ppm TN	> 1.5 ppm TN	> 2.5 ppm TN	> 5 ppm TN
Total watersheds (HUC-8)	1071	800	471	181
Total land area (million hectares)	158	132	105	36
Average flow rate (MGD)	497	474	436	375
Average annual N load (tonnes yr^{-1})	1880	2200	2740	3500
Average annual P load (tonnes yr^{-1})	224	251	280	313

Progress and Current Status

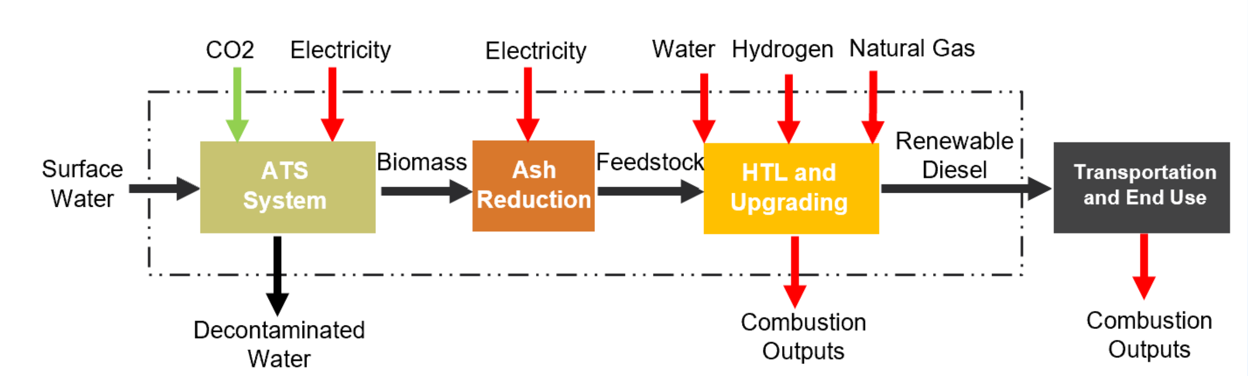
Process modeling – CSU

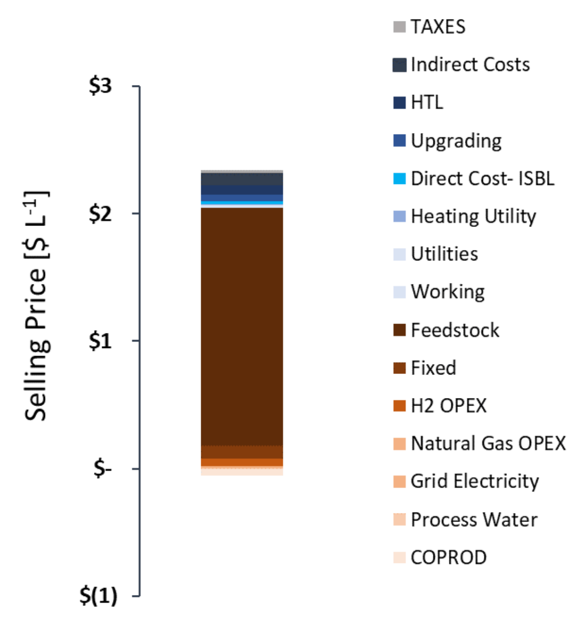
- Regression model of ambient temperature and PAR
- Trained with dataset from system in **Durham, NC**
  - **61 weeks** of growth from Sept 2015 to Dec 2016
- Validated with **Corpus Christi, TX** dataset
  - **69 cultivation weeks**
  - **RMSE = 2.21 g m^{-2} d^{-1}**
- Comparison to other models:
  - Kim et al. **RMSE of 1.78 – 2.17 g m^{-2} d^{-1}**
  - Kim et al. requires other inputs like salinity and pH (not always available)

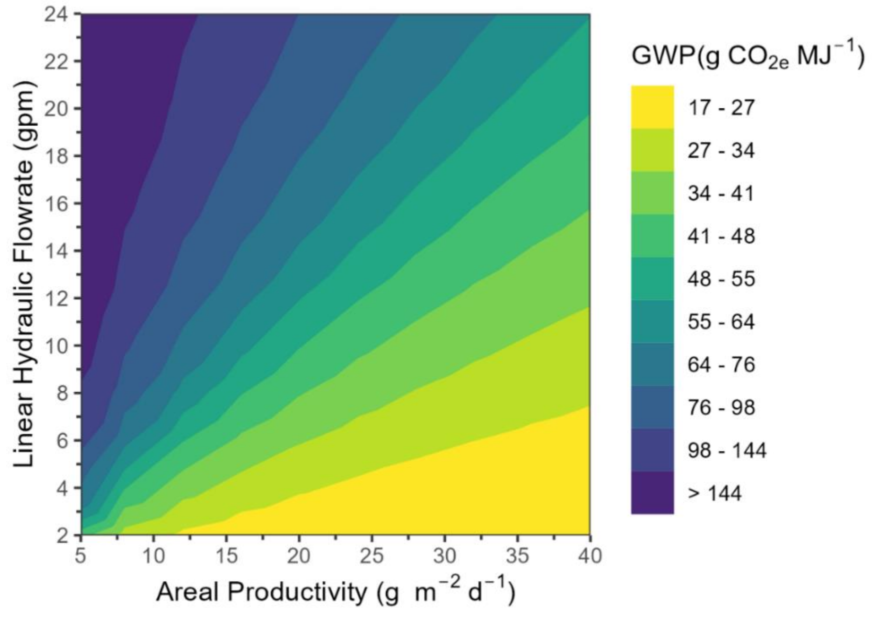


Progress and Current Status

Techno-economic analysis and life-cycle assessment - CSU







Summary of Community Benefits / Societal Considerations (CB/SCI) and Impacts

Algae Lab is on tour:
Over 3000 visitors this year at CSU Powerhouse campus

Project has a diverse team with 56% of the team members from under-represented groups in STEM

- Hiring underrepresented students and researchers

Lessons Learned

- Learning curve for turf operation compared to suspended phytoplankton cultures
- Additional time to establish healthy, mature turf cultures needs to be accounted for in future projects
- New seeding strategies can affect harvesting cycle periods and productivity
- Continuous flow + pilot-scale vs. recirculating flow + lab-scale turf operations have different considerations
- Local water quality may impact strain selection in laboratory setting

Plans for future testing/development/ commercialization

a. In this project
    a. Establish seeding and harvest methodologies
    b. Long-term operation needs to account for culture maturity (BP3 – project end)
b. After this project
    a. Implement new hydrodynamic parameters and substrate candidates at field deployment sites
c. Scale-up potential
    a. Assess HUC8 watershed data to prioritize key regions for deployment

Summary

ATS technology is a promising pathway for **carbon uptake** and a **value-added environmental service**.

Flow parameters and **novel seeding methods** are being optimized on a laboratory scale to improve ATS productivity.

Research efforts at the laboratory scale will help commercial deployments optimize parameters for **biomass productivity** and **nutrient removal rates**.

Scalability, economic, and sustainability analyses highlight the benefits of ATS technology compared with conventional water treatment.

Organization Chart

Colorado State University | **Sandia National Laboratories** | **HydroMentia, LLC** | **Czero, Inc.**

Jason C. Quinn
Principal investigator

Kenneth F. Reardon
Co-investigator

David Quiroz
Process modeling, TEA, LCA

Peter H. Chen
Ashley Ryland
Lara Janiszewski
Xingfeng Huang
Experimental team

Aidan Smith
Alyssa Singh
Kay Willock
Undergraduate interns

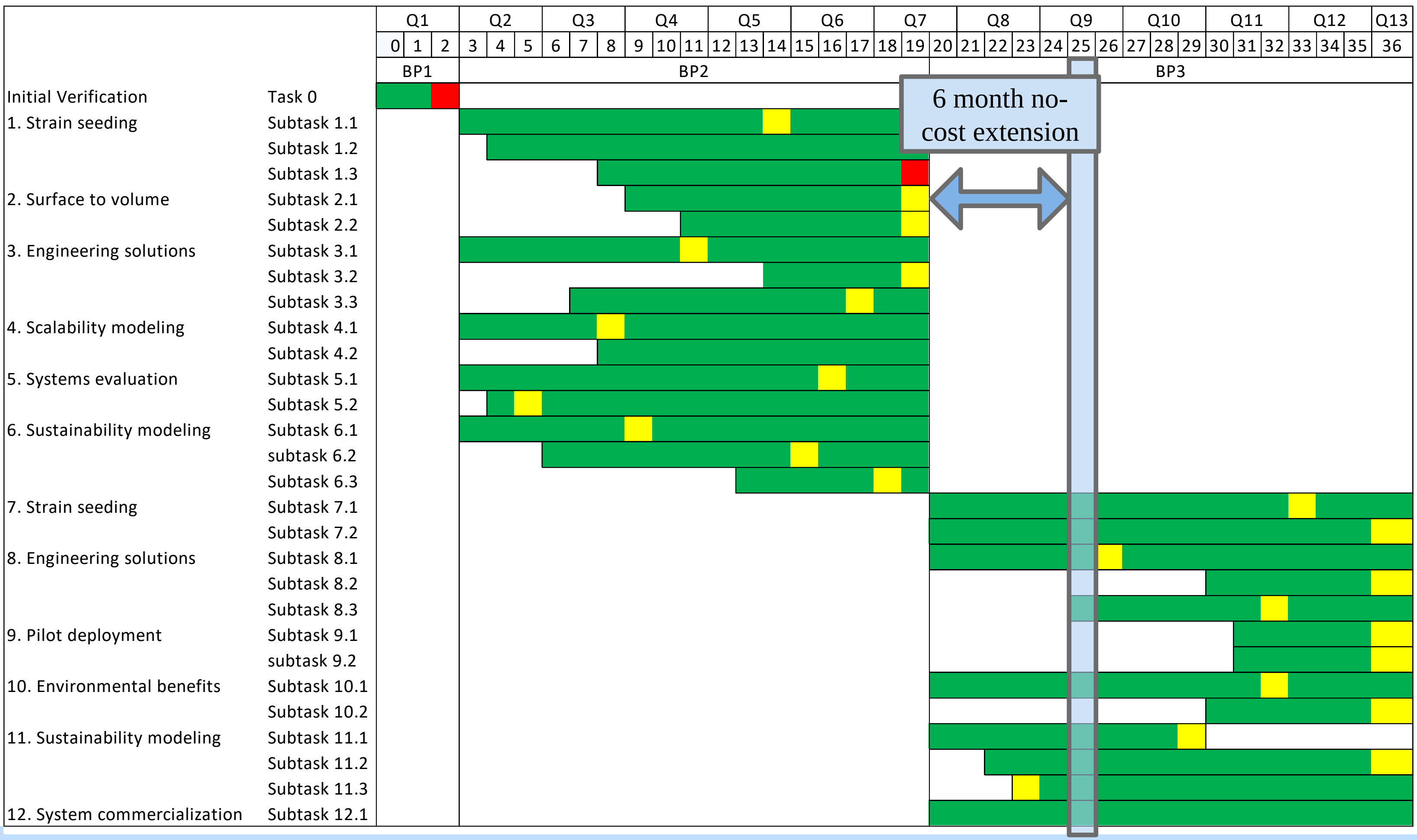
Ryan W. Davis
Co-investigator

Sungwhan Kim
Tyler Eckles
Experimental team

Chris Turner
Ben Alexander
Design and construction

Mark Zivojnovich
Industry consultant

Gantt Chart


Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8 Q9 Q10 Q11 Q12 Q13
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
BP1
BP2
BP3
6 month no-cost extension
Initial Verification
Task 0
1. Strain seeding
Subtask 1.1
Subtask 1.2
Subtask 1.3
2. Surface to volume
Subtask 2.1
Subtask 2.2
3. Engineering solutions
Subtask 3.1
Subtask 3.2
Subtask 3.3
4. Scalability modeling
Subtask 4.1
Subtask 4.2
5. Systems evaluation
Subtask 5.1
Subtask 5.2
6. Sustainability modeling
Subtask 6.1
subtask 6.2
Subtask 6.3
7. Strain seeding
Subtask 7.1
Subtask 7.2
8. Engineering solutions
Subtask 8.1
Subtask 8.2
Subtask 8.3
9. Pilot deployment
Subtask 9.1
subtask 9.2
10. Environmental benefits
Subtask 10.1
Subtask 10.2
11. Sustainability modeling
Subtask 11.1
Subtask 11.2
Subtask 11.3
12. System commercialization
Subtask 12.1