DOE Award Number DE-FE0032229

Algal Biorefinery Conversion of Utility CO_2 to High-Value Products (ABC-UC)

Colorado State University: Kenneth F. Reardon (Principal Investigator), Steve Conrad, Graham Peers, Jason Quinn, Peter Chen, Asim Phadke, Katelyn Whiting, Conor Bertucci, Himaghna Kuntumalla, Courtney Pimentel

University of Wyoming: Maohong Fan, Zhe Chen

Living Ink Technologies: Fiona Davies, Lucas Quintana

Wyoming Integrated Test Center: Will Morris

Acknowledgement and Disclaimer

Acknowledgement
This material is based upon work supported by the Department of Energy under Award Number DE-FE0032229.

Disclaimer
This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof.

The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

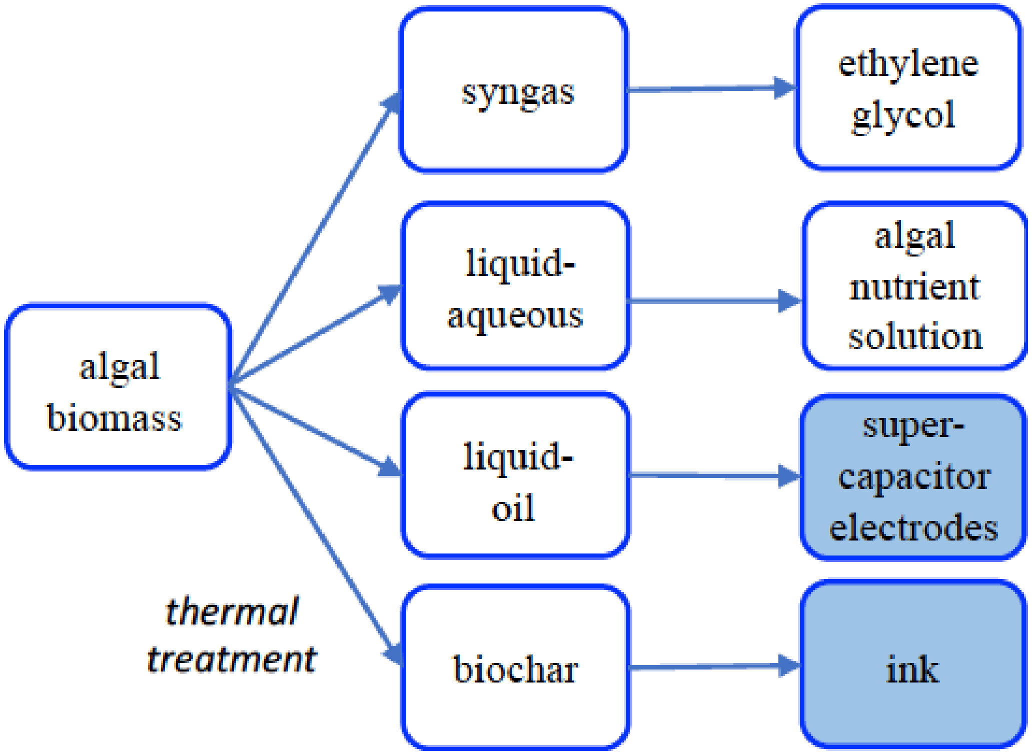
Project goals

- Demonstrate, characterize, and optimize a biorefinery process for converting a utility source of CO_2 to high value bioproducts via algal cultivation; and
- Demonstrate a carbon utilization efficiency greater than 50%, along with algal productivity greater than 20 g AFDW/$m^2 \cdot d$ in two 30-day campaigns.

Project objectives

- Develop/demonstrate efficient CO_2 transfer to algal cultivations;
- Develop strains and operations for algal cultivation from flue gas;
- Develop and optimize algal biomass conversion to products; and
- Conduct techno-economic analysis and life-cycle assessment.

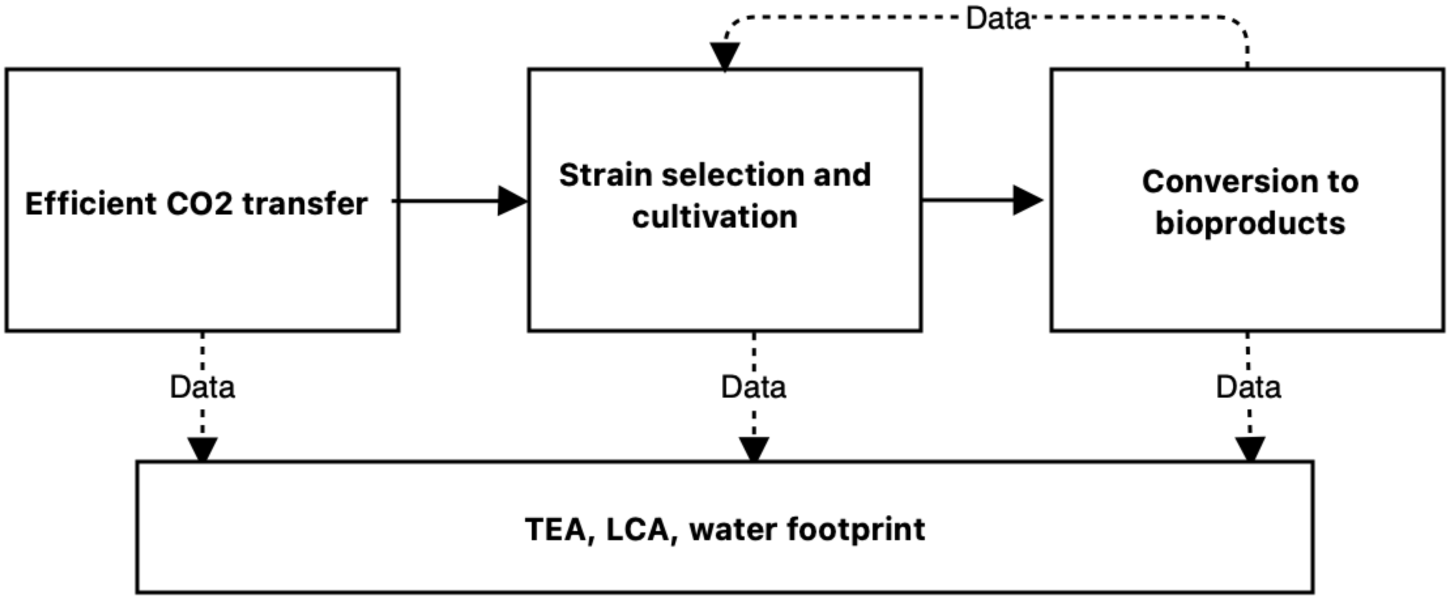
Bioproducts



>$200/kg; $22.7 B global (2017)

$40/kg; $12.9 B global

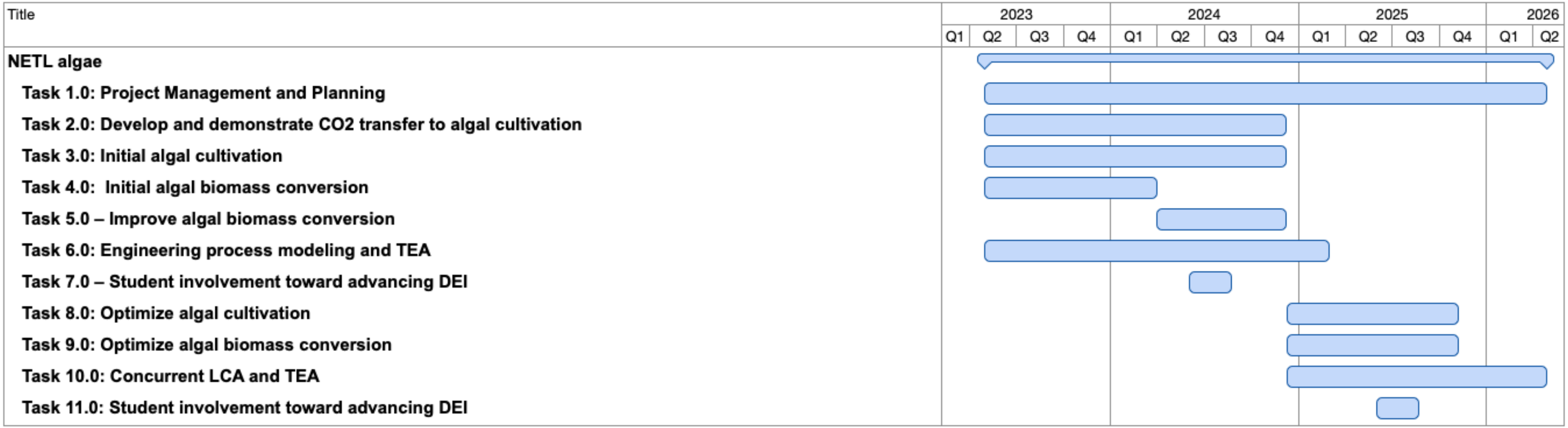
Project plan



UW LIVING INK ITC WYOMING INTEGRATED TEST CENTER Colorado State University

Project timeline

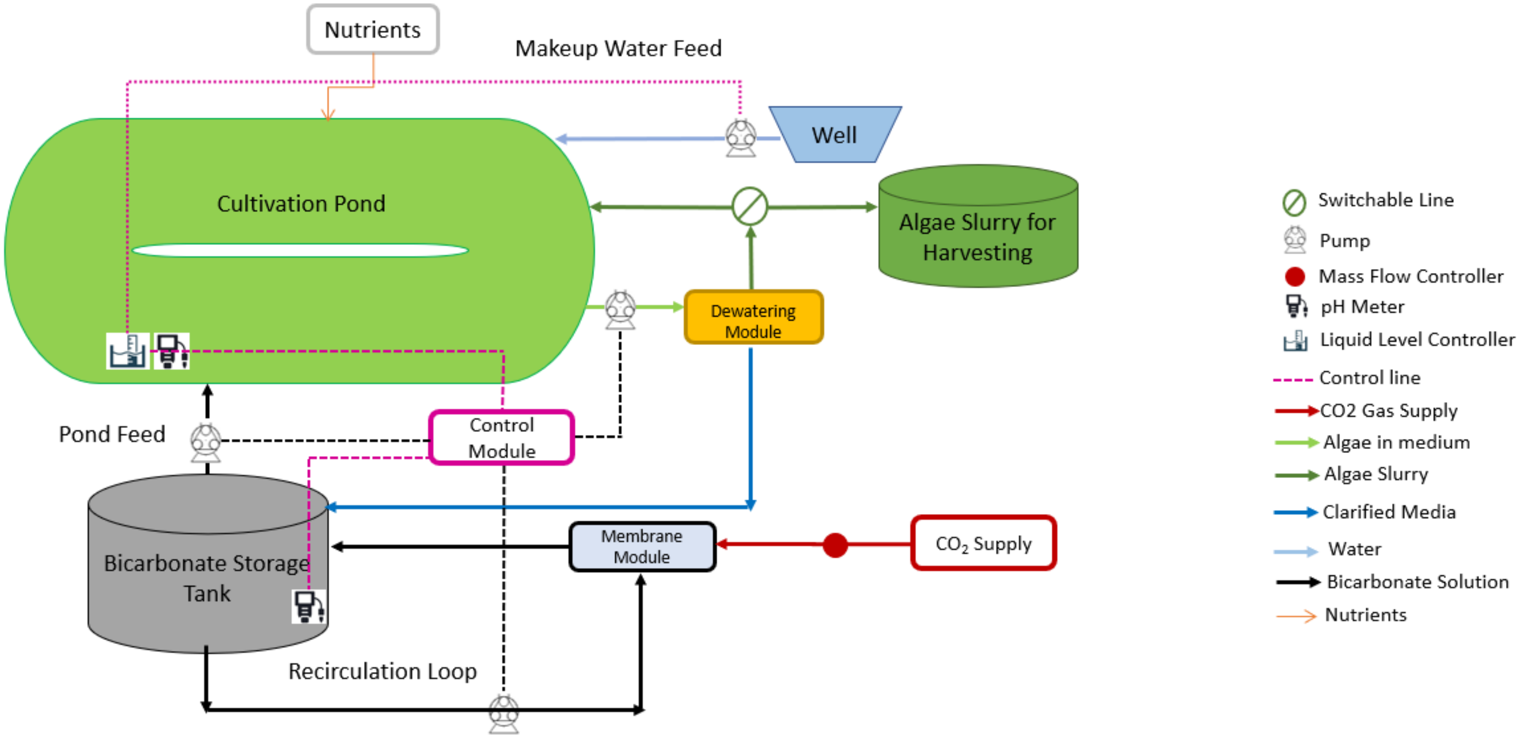
Budget period 1: 5/1/2023 - 1/31/2025
Budget period 2: 2/1/2025 - 4/30/2026



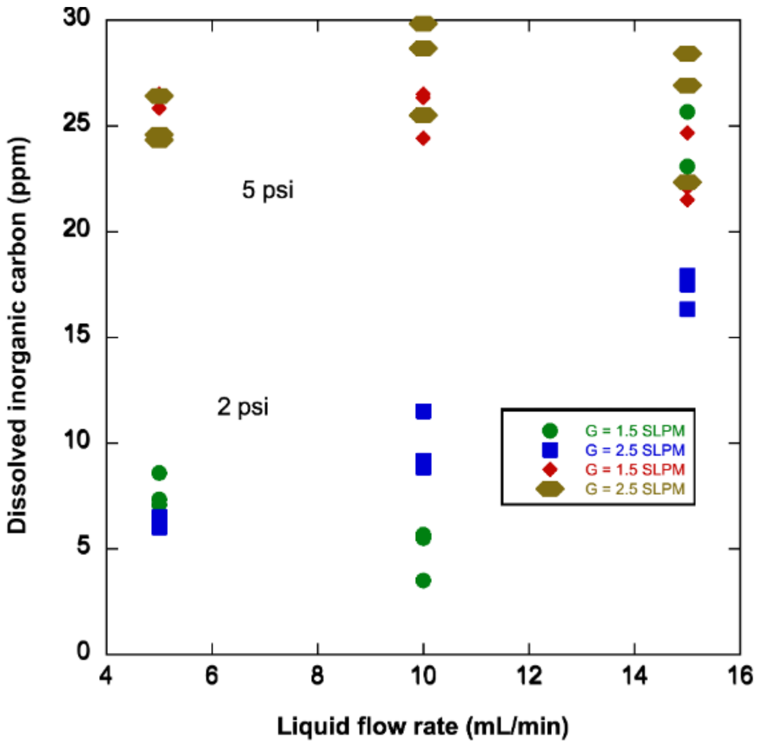
Task 2: Develop and demonstrate CO_2 transfer to algal cultivation

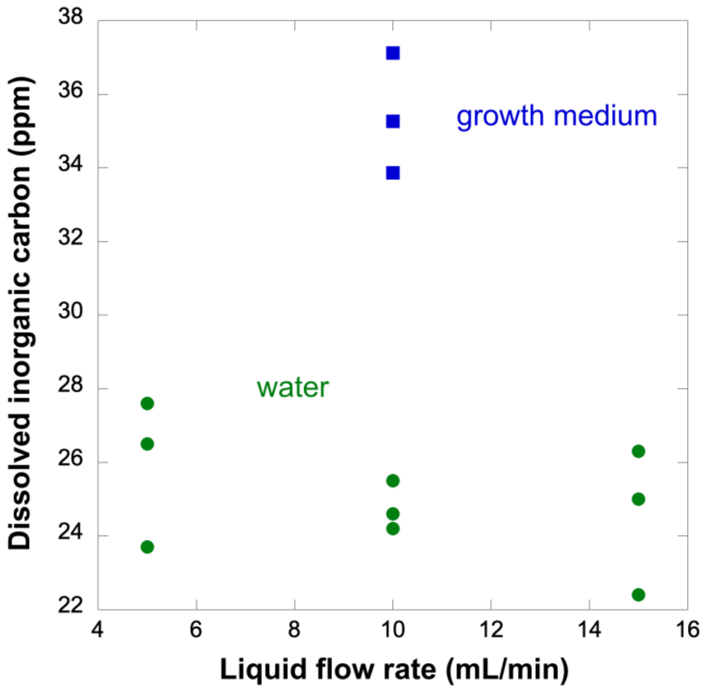
- 2.1 – Develop CO_2 transfer system with synthetic flue gas
- 2.2 – Evaluate performance of CO_2 transfer system with flue gas
- 2.3 – Optimize performance of CO_2 transfer system with flue gas

Task 2: Develop and demonstrate CO_2 transfer to algal cultivation



Membrane module for C transfer: 12% CO_2





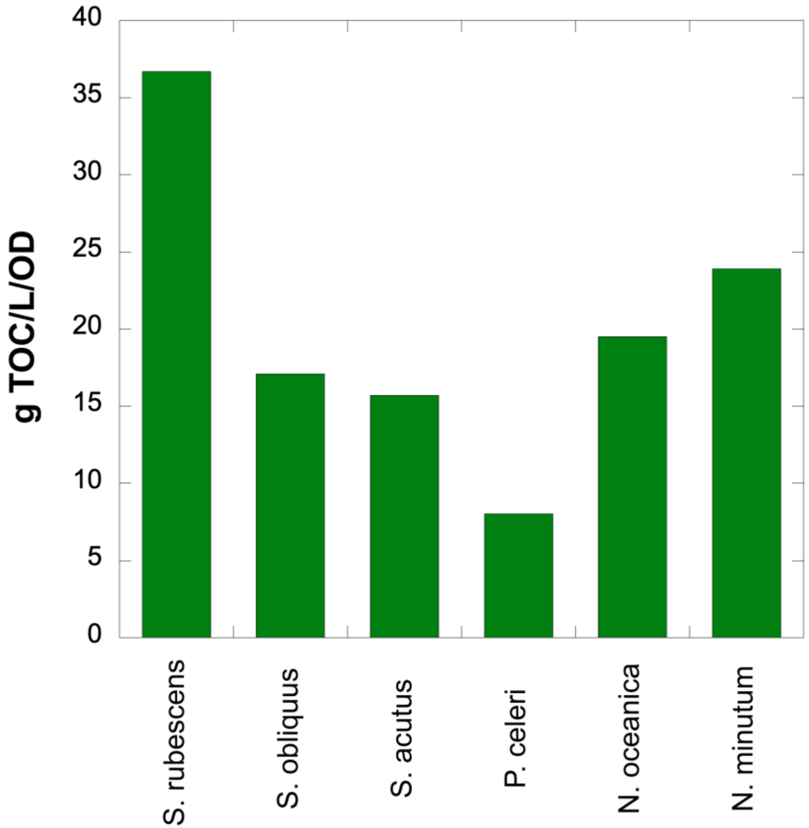
Membrane module for C transfer

- Challenge: Delivery of synthetic flue gas
- Next steps:
  - Use of module for algae cultivation
  - Optimize for removal of CO_2 from flue gas

Task 3: Initial algal cultivation

- 3.1 – Cultivation of Tier 1 algal species
- 3.2 – Cultivation of Tier 2 algal species

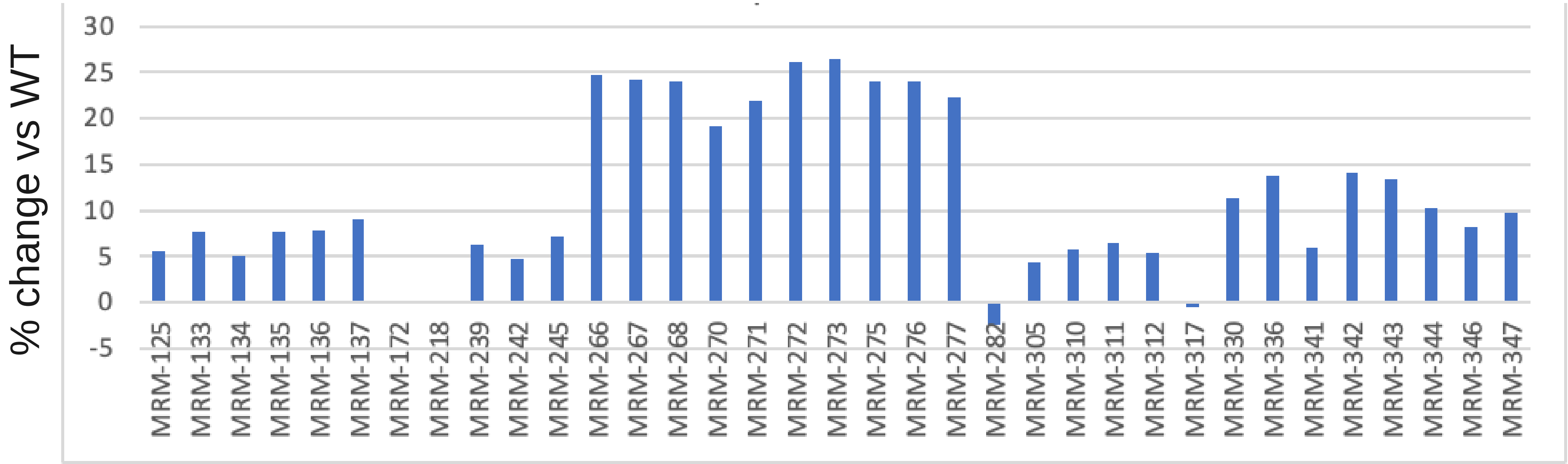
Task 3: Tier 1 algal cultivation



Conditions:

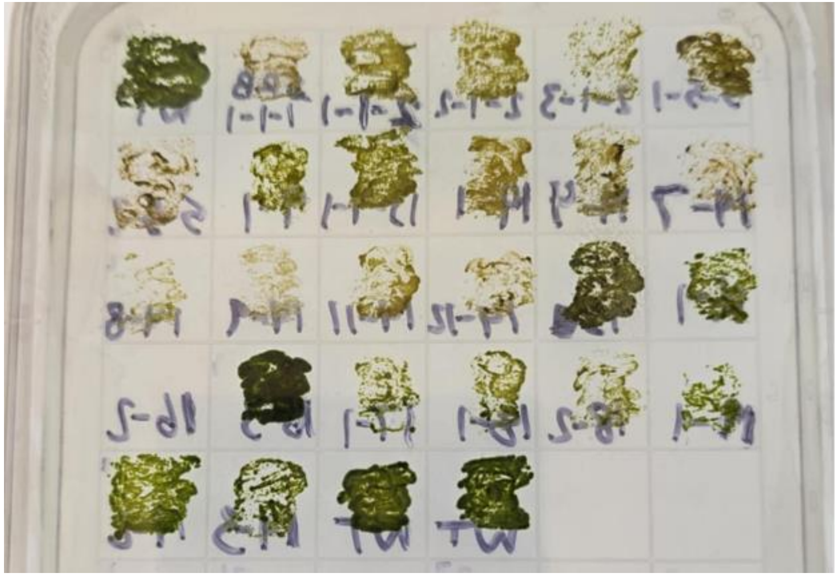
- ambient CO_2
- 18:6 light program at 320 mmol photons·m^{-2}·s^{-1}
- 20 and 35 °C

Task 3: Strain improvement by gamma irradiation



- *Monoraphidium minutum* mutants screened for photosynthetic quantum yield (Fv/Fm) – indicative of photosynthetic efficiency
- **Higher is better**

Task 3: Strain improvement by gamma irradiation



- *Scenedesmus rubescens* mutants screened for pigment changes – indicative of altered photosynthetic health

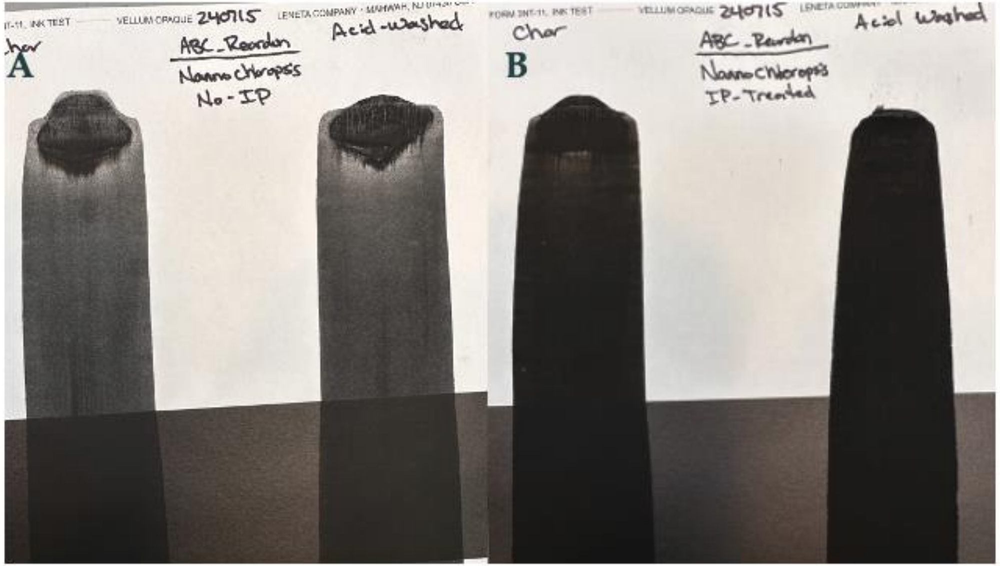
UW LIVING INK ITC WYOMING INTEGRATED TEST CENTER Colorado State University

Task 4: Initial algal biomass conversion

- 4.1 – Initial thermochemical biomass conversion
- 4.2 – Development of thermal treatment liquid product separation method
- 4.3 – Evaluation of Tier 1 candidate biomass for ink
- 4.4 – Evaluation of Tier 1 candidate biomass for supercapacitor electrodes

Task 4.3 – Evaluation of Tier 1 candidate biomass for ink

Task 4.3 – Evaluation of Tier 1 candidate biomass for ink



raw washed raw washed

Untreated *N. oceanica* pyrolysis char

“Salted” *N. oceanica* pyrolysis char

Ink drawdowns

Task 4.3 – Evaluation of Tier 1 candidate biomass for ink

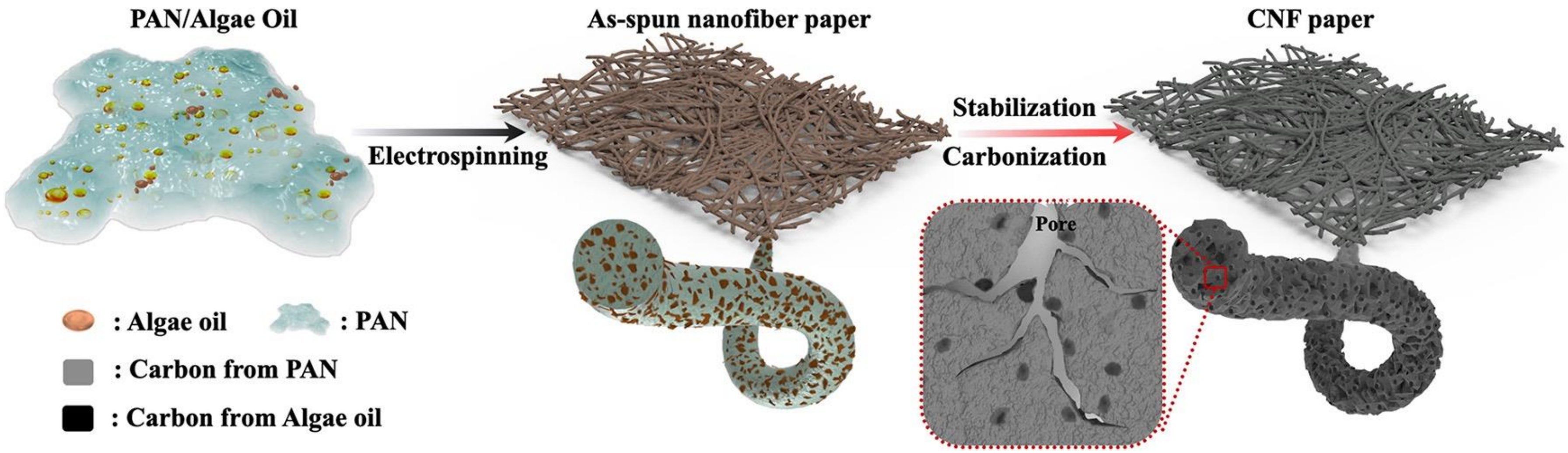
Ink drawdowns

	Untreated Nannochloropsis		Salted Nannochloropsis		Living Ink Control
	Char	Acid-Washed	Char	Acid-Washed	-
L*	27.90	26.55	17.11	14.54	16.13
A*	0.51	0.47	0.80	0.39	0.44
B*	1.42	1.65	0.95	0.66	0.96
Hiding	0.770	0.584	0.056	0.008	0.001

Untreated *N. oceanica* pyrolysis char

"Salted" *N. oceanica* pyrolysis char

Task 4.4 – Evaluation of Tier 1 candidate biomass for supercapacitor electrodes

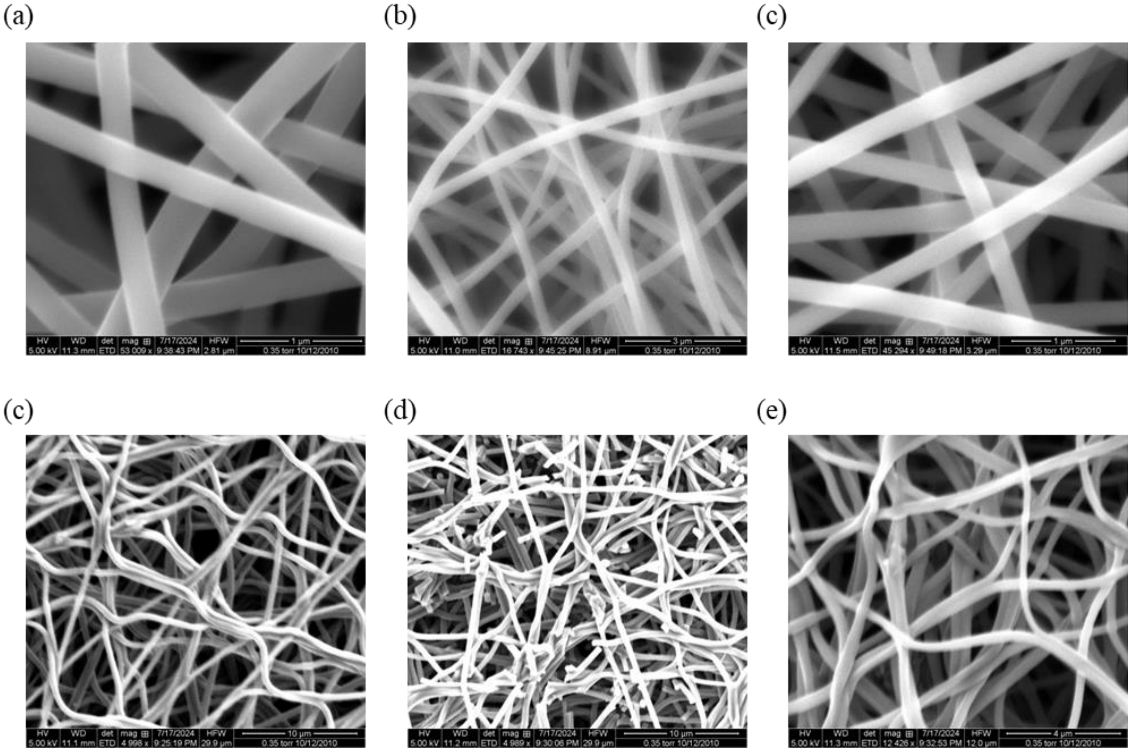


PAN: polyacrylonitrile

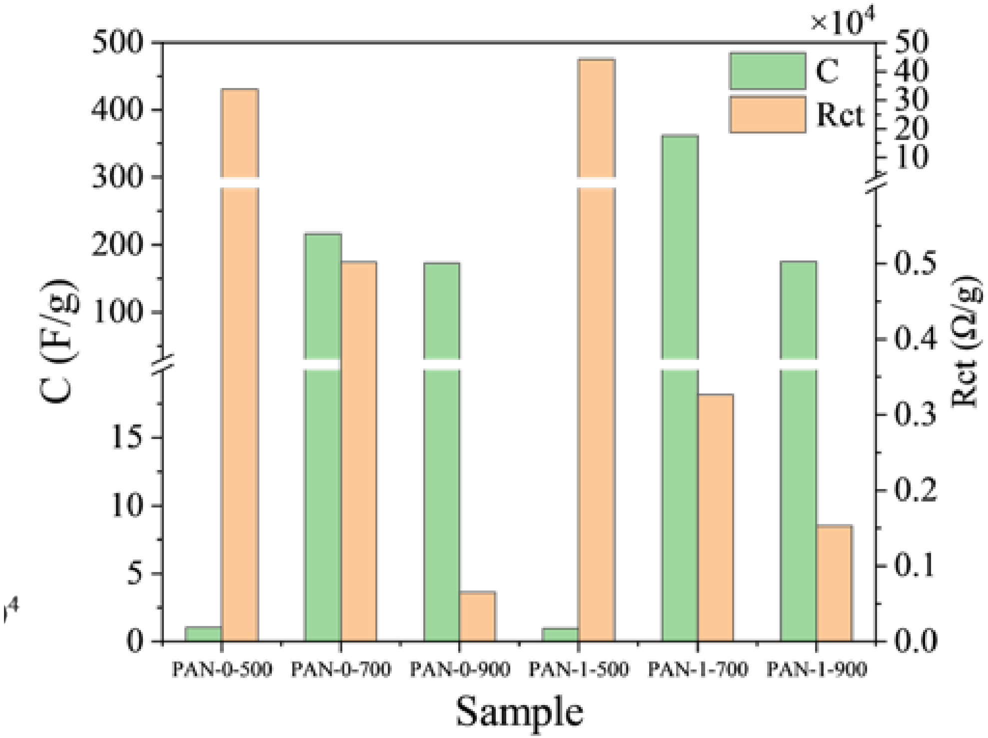
Task 4.4 – Evaluation of Tier 1 candidate biomass for supercapacitor electrodes

- *N. oceanica* HTL oil with solids
- Varied process conditions:
  - Electrospinning
  - Carbonization
  - Polyvinyl alcohol replacement for polyacrylonitrile

Task 4.4 – Evaluation of Tier 1 candidate biomass for supercapacitor electrodes



Task 4.4 – Evaluation of Tier 1 candidate biomass for supercapacitor electrodes



C: specific capacitance

Rct: charge-transfer resistance

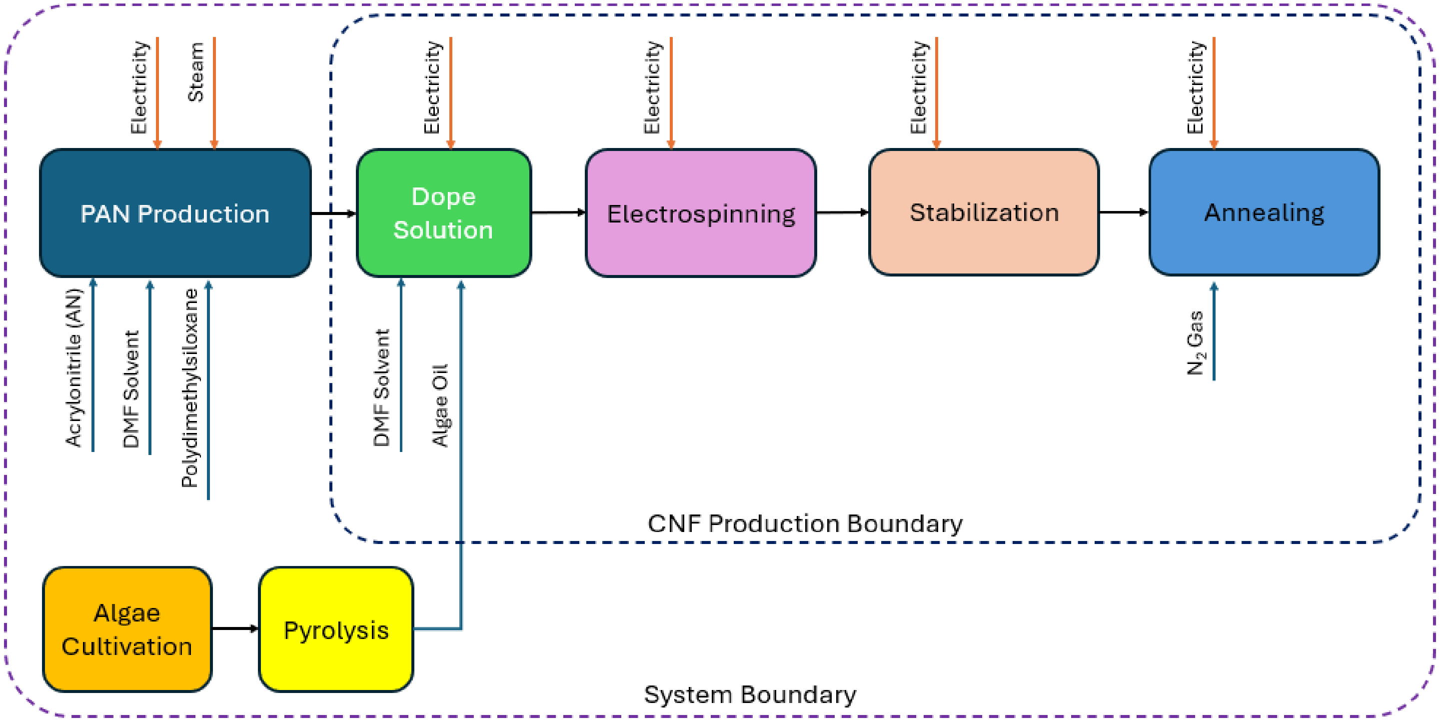
Task 6: Engineering process modeling and techno-economic assessment

- 6.1 – Engineering process modeling
- 6.2 – Techno-economic analysis
- 6.3 – Initial life-cycle assessment
- 6.4 – Initial water footprint

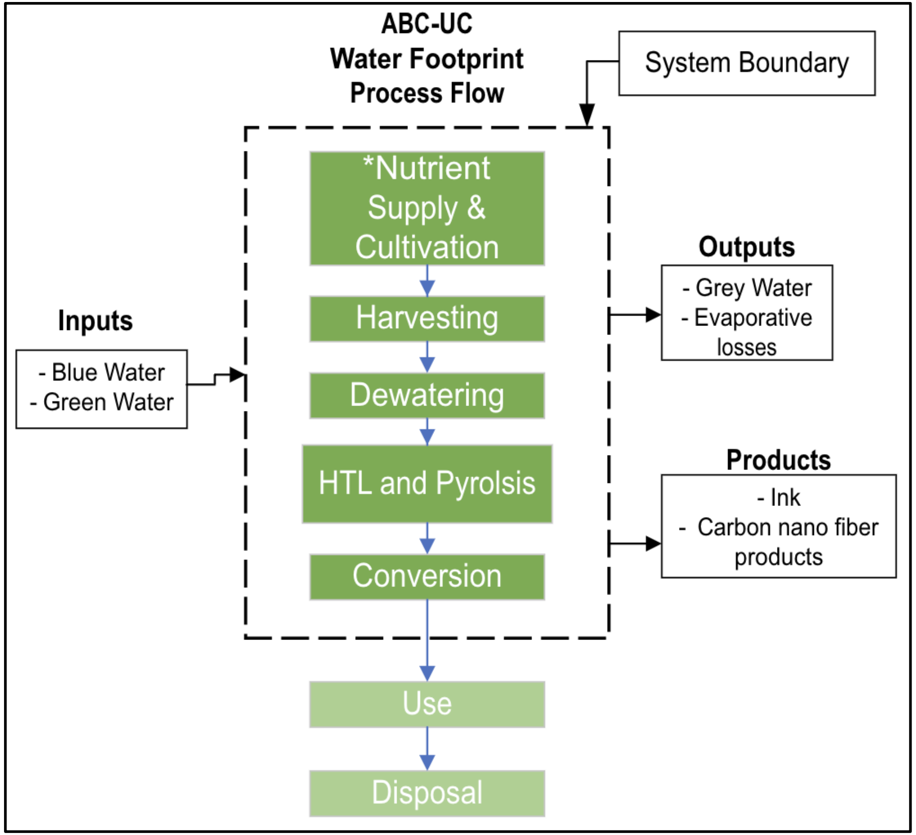
Task 6.1: Engineering process modeling: Ink

- Thermal Model
- Growth Model
- Cultivation and Dewatering Model
- Storage Model
- Pyrolysis Model
- Ink Pigment Production Model

Task 6.1: Engineering process modeling: Supercapacitors



Task 6.1: Water footprint



Task 7: Student involvement toward advancing diversity, equity, and inclusion

- 7.1 – Involve undergraduates from diverse backgrounds in research

- Summer 2024:
  - HTL experimentation
  - Algal strain improvement

BP 1 success criteria

- Demonstration of bubble-free CO_2 delivery system operation for a 1,000-L pond for 30 days using flue gas, consistently achieving 90% of inorganic carbon saturation in the system storage tank.
- Laboratory demonstration of two algal strains with superior biomass productivity that provide good quality biomass for ink and supercapacitor electrode production.
- ✓ Demonstrated production of ink pigment with acceptable color density, and texture.
- ✓ Demonstrated production of a supercapacitor material with specific capacitance of ≥300 F/g.
- Completion of water footprint framework for measuring efficiency and process decisions defined to inform environmental impact targets and source water requirements.

Summary

- Demonstrated ability to make high-value products
- Screening – and improving – algal species
- Process modeling for TEA, LCA, and water footprint