DOE Bioenergy Technologies Office (BETO)

2023 Project Peer Review

Production of Algae Biofuel with CO_2 Direct Air Capture

April 4, 2023

Renewable Carbon Resources – Algae

David Hazlebeck

Global Algae Innovations

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Global Algae Innovations
Algae Solutions to Global Dilemmas

Vision

Harness the unparalleled productivity of algae to provide food and fuel for the world, dramatically improving the environment, economy, and quality of life for all people

- Founded Dec 2013
- Algae for commodities
- Technology development in 8-acre Kauai Algae Farm
- Radical advances throughout the entire process
- Selected as XPRIZE Carbon Removal milestone award winner in 2022
- Scaling–up suite of novel technologies in new San Luis Obispo County Farm

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Project Overview – Goals

- **Drying, extraction, and fractionation unit operations**
  - Increase composite value of product mix by 75%
  - Product markets commensurate with billions of gallons of algal biofuel
  - Test and validate product value for fuel, polymers, and aquaculture feed
  - A minimum fuel selling price of $2.50 per gallon of gasoline equivalent
- **Cultivation via direct air capture CO_2 supply**
  - Reduce loss of productivity after rain in direct air capture cultivation to 10% relative to control without direct air capture

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Project Overview – Context and History

- **Developed a few novel unit operations for lower energy drying and extraction at laboratory-scale under a prior project**
- **Need to obtain higher value from co-products than low-quality protein meal**
- **Developed direct air capture CO2 supply approach under prior projects**
  - Loss of productivity after rain was 30-50% relative to control

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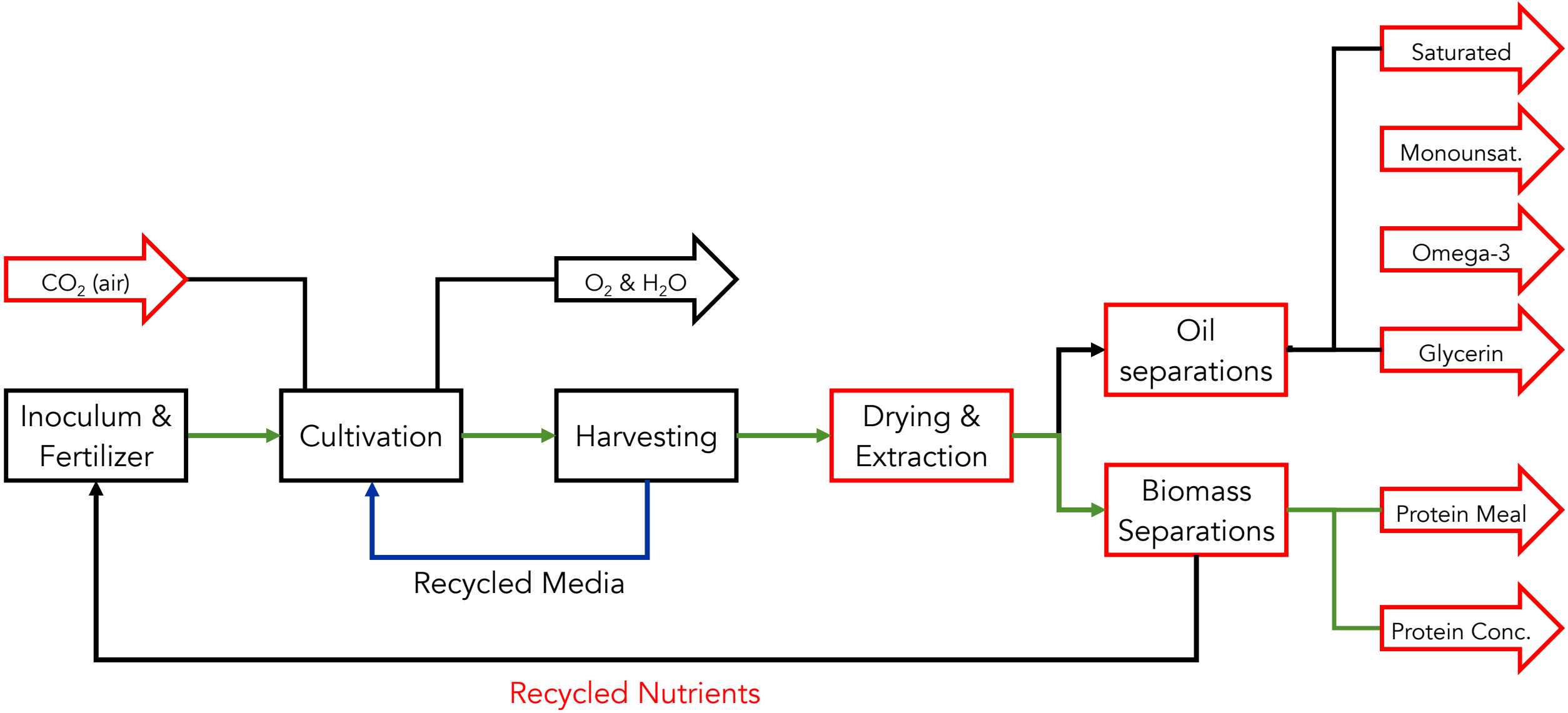
Approach – Overall Algae Process



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Approach – Project Tasks

Update techno-economic analysis (TEA) throughout to support decision making and data requirements

Utilize algae cultivated via direct air capture at the Kauai Algae Farm

1. Test previously developed drying and extraction unit operations for efficacy
2. Develop new unit operations for drying, extraction, and fractionation
3. Parametric testing of multiple flow sheets incorporating the operations
4. Down-select process based on efficacy, scalability, and cost per TEA
5. Optimize down-selected flow sheet based on TEA and produce samples
6. Product samples to sub-recipients for testing
    a. Jet and diesel fuel - Neste
    b. Polymers – Algenesis
    c. Aquaculture feed -Hubb's SeaWorld Research Institute, Zeigler, and USDA ARS

CO_2 Direct Air Capture with rain perturbations

1. Testing in 2m^2 raceways with simulated rain events for DAC and control
2. Monitor chemistry and algae stress levels to determine cause of decrease
3. Adjust media or other cultivation conditions to maintain productivity decrease similar to control

Approach – Challenges and Milestones

- **Key Technical Challenges**
  - Many process options
    - Multiple unit operation options for drying and each separation step
    - Separation steps can occur in different orders and dependent on prior separations
  - Algae biomass variability can affect separation results
  - Consistency and efficacy of separations in an economically viable process
- **Milestones**
  - Unit operations for specific separations demonstrated
  - Economically viable overall process
  - Interim and final TEA
  - Product samples to sub-recipients
  - Test results from sub-recipients validate product quality and value
  - End of project goal for productivity variation of CO_2 DAC raceway relative to control after rain

Approach – Challenges & Risks

Risk	Mitigation
Adequate oil separation	Testing eight solvents and six extraction process options
Problematic contaminants in oil	Multiple extraction process and oil clean-up options
Separation of protein meal and recycle nutrients	Multiple separation processes and unit operation options
Consistent product quality with seasonal changes	Year-round testing to evaluate effect changes in algae composition Adjust process as needed to accommodate feed variation
Too many options impacts making products for later objectives	Initial period of testing many unit operations Test a fewer number of processes that incorporate the operations Down-select to viable process and save other innovations for future work
Algae biomass availability	Regular cultivation at Kauai Algae Farm Refrigerated storage of solid products and slurry is available when needed

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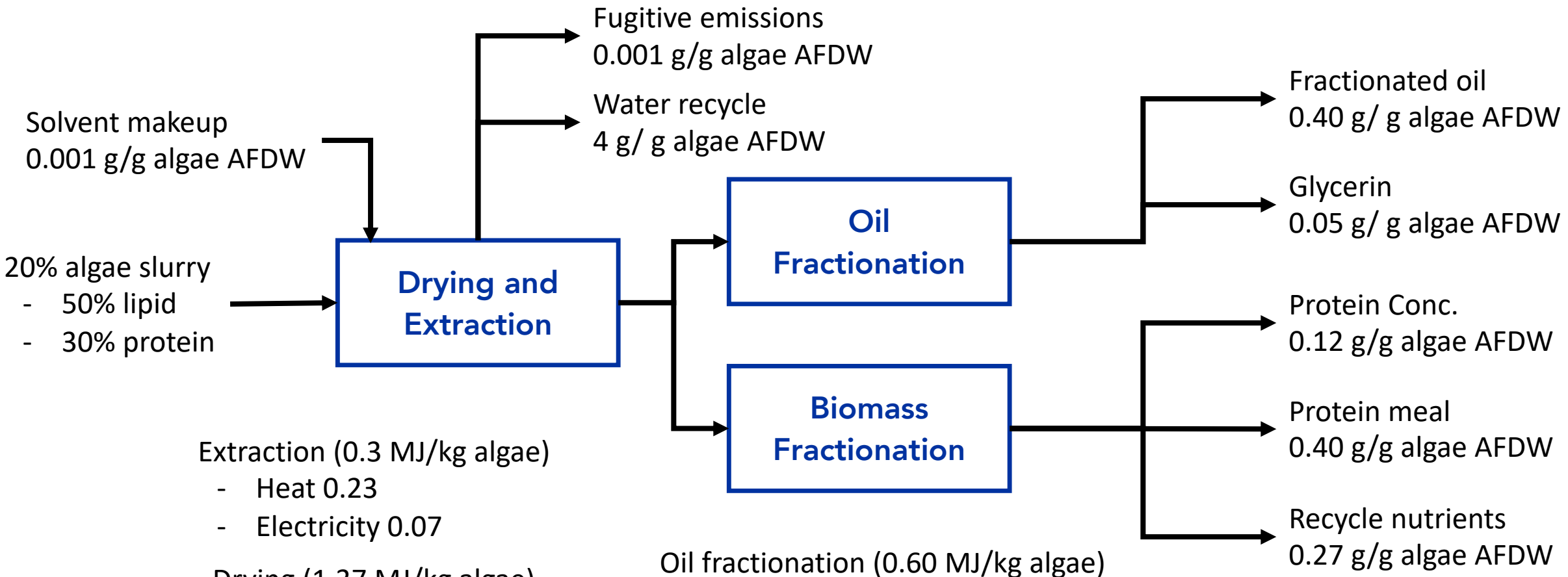
Progress and Outcomes - Overview

- **Currently at the project mid-point**
- **Completed study of unit operations**
  - Many novel unit operations, plan to apply for 26 patents this year
  - Five main processes that incorporate various novel unit operations
  - Tested each of the processes with freshly harvested algae
  - Completed mass and energy balance (M&EB) for each process
  - Integrated M&EB's into TEA with options to vary unit operations order within the processes
  - Down-selected to two processes based on efficacy and maturity
  - Down-selected to one process based on the TEA results
  - Reviewed results with DOE technology manager and verification team January 2023
- **Down-selected process**
  - Includes 11 of the potentially patentable unit operations
  - Product spectrum that doubles value and is commensurate with biofuel market
  - Focus now on solidifying integrated process and generating material for testing

Progress and Outcomes – M&EB Summary



Extraction (0.3 MJ/kg algae)
- Heat 0.23
- Electricity 0.07

Drying (1.37 MJ/kg algae)
- Heat 0.60
- Electricity 0.77

Oil fractionation (0.60 MJ/kg algae)
- Heat 0.46
- Electricity 0.14

Biomass fractionation (2.73 MJ/kg algae)
- Heat 1.81
- Electricity 0.91

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Progress and Outcomes - Products

Original

Market	Fraction (% AFDW)	Selling Price ($/mt)	Composite ($/mt)
Biofuel	50%	825	410
Protein meal	50%	570	290
Total	**100%**		**700**

New

Market	Fraction (% AFDW)	Selling Price ($/mt)	Composite ($/mt)
Biofuel	17%	825	140
Polymer	17%	2300	390
Omega-3 feed	6%	4200	250
Glycerin	5%	1100	60
Protein Conc.	12%	1800	220
Protein meal	40%	800	320
Nutrient Recycle	27%	200	50
Total	**120%**		**1430**

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Progress and Outcomes - TEA

Area	Capital cost ($/mt)*	Operating Cost ($/mt)**	Total Cost ($/mt)
Laboratory & Inoculum	1	2	3
CO2 supply	0	0	0
Nutrients	62	145	208
Cultivation	309	46	355
Harvesting	67	40	107
Drying & Extraction	89	120	208
Oil fractionation	80	33	114
Biomass fractionation	91	117	209
Total	**700**	**504**	**1204**

All calculations in 2023 dollars

* Capital charge factor of 0.1327 assumes minimum selling price Internal Rate of Return of 8%

** Assumes on-site solar power with electricity cost assumed to be $0.30 kWh

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Impact

- **Accelerate commercialization**
  - New process for algae biofuel with projected 25% unlevered internal rate of return
  - Product validation will support obtaining off-take agreements
  - Down-stream processing is ready to move to engineering-scale
- **New process options available for downstream processing**
  - Planning to submit 26 patent applications this year
  - Process options with better life cycle analysis and lower costs
- **Higher fidelity techno-economic analyses**
  - Data on downstream processing, product quality and product value
  - Global Algae is a contributor to NREL, ANL, and several university TEA

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Summary

- **Accelerate commercialization**
  - Higher return on investment
  - Ability to obtain off-take agreements
  - Ready to move to next scale
- **Partnerships with potential off-takers**
  - Multiple partners on the team
- **Status**
  - Process down-select complete, meets TEA goals
- **Next steps**
  - Optimizing downstream process and generating product samples for testing
  - Completing rain perturbation testing for DAC

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QUAD Chart Overview

Timeline

- *BP2 start date: May 2021*
- *Project end date: December 2023*

	FY22 Costed	Total Award
DOE Funding	*$607,000*	*$2,000,000*
Project Cost Share	$202,000	$500,000

TRL at Project Start: 3
TRL at Project End: 4

Project Goal

Develop novel drying, extraction, and fractionation unit operations that increase the product value by 75% with algae cultivated via direct air capture; test the product samples for fuel, polymer, and aquafeed applications.

End of Project Milestones

- 75% product value increase with constraint of 50% of the oil going to biofuel at $2.50/GGE
- Productivity after rain with DAC CO_2 < 10%
- Demonstrate product quality for biofuel, polymers, aquafeed

Funding Mechanism

FY20 Multi-Topic FOA - ABCDE

Project Partners:

- TSD (engineering)
- Neste (fuel)
- Algenesis (polymer)
- Zeigler (aquafeed)
- Hubbs SeaWorld Research Inst. (aquafeed)

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Additional Slides

Responses to Previous Reviewers' Comments

- **Not previously reviewed**

- **Go/No-Go Review**
  - Verification in December 2020
  - Verified prior proof-of-principle and other supporting data
  - Verified risk management and project approach is acceptable

- **Project Review**
  - January 2023
  - Presented information on 26 novel unit operations
  - Presented 5 processes that incorporate subsets of the unit operations
  - Team concurred with down-selected process

Publications, Patents, Presentations, Awards, and Commercialization

- None to date
- Planning to submit patent applications in 2023