CO_2 to Bioplastics: Beneficial Re-use of Carbon Emissions from Coal-Fired Power Plants Using Microalgae

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Project Overview
(DE-FE0029623)

- **Funding:**
  DOE: $999,742
  Cost share: $258,720
  Total project: $1,258,462

- **Performance dates:**
  6/1/2017 – 5/31/2020

- **Project Participants:**
  - University of Kentucky
  - Colorado State U.
  - Algix LLC
  - Duke Energy

Project Objectives:

- A dual PBR/pond cultivation system will be evaluated with respect to capital and operational costs, productivity, and culture health, and compared to pond-only cultivation systems

- A high-value biomass utilization strategy will be developed to simultaneously produce a lipid feedstock for the production of fuels, a carbohydrate feedstock for conversion to chemicals and/or bio-ethanol, and a protein-rich meal for the production of algal-based bioplastics

- Techno-economic analyses will be performed to calculate the cost of CO_2 capture and recycle using this approach, and a life cycle assessment will evaluate the potential for reducing greenhouse gas emissions.

Advantages and Challenges

- Ability to generate a valuable product, thereby off-setting costs of CO_2 capture (potential for new industry)
- No need to concentrate CO_2 stream
- Potential to polish NOx and SOx emissions

- Areal productivity such that very large algae farms required for significant CO_2 capture
- CO_2 capture efficiency modest for conventional systems (<50%)
- Challenging economics: cost of algae cultivation is high (currently >$1,000/MT), hence improved productivity is required, along with medium/high value applications for produced algal biomass
- Market size generally inversely related to application value (hence risk of market saturation)

Technical Approach

Key issues to be resolved:

1) Can algal biomass production costs be lowered by the use of a combined PBR + pond cultivation system?

   → Combine the low capex of ponds with the high productivity of PBRs

2) In the case of algae-based bioplastic production, which processing scheme offers the greatest potential for revenue generation and large-scale application?

   → Whole biomass vs. wet lipid extraction vs. combined algal processing (CAP)

3) From a TEA and LCA perspective, which cultivation system and processing scheme(s) offer the greatest potential?

Project Scope/Milestones (BP 2)

- **LCA and TEA**
  - initial TEA
  - initial LCA

→ Demonstrate bioplastic production using this process is <0 g CO_2-eq/kg

- **Algae Cultivation: Demonstration**
  - site preparation
  - PBR and pond operation
  - monitor culture health and identify potential contaminant

→ PBR + ponds installed and operating at East Bend Station

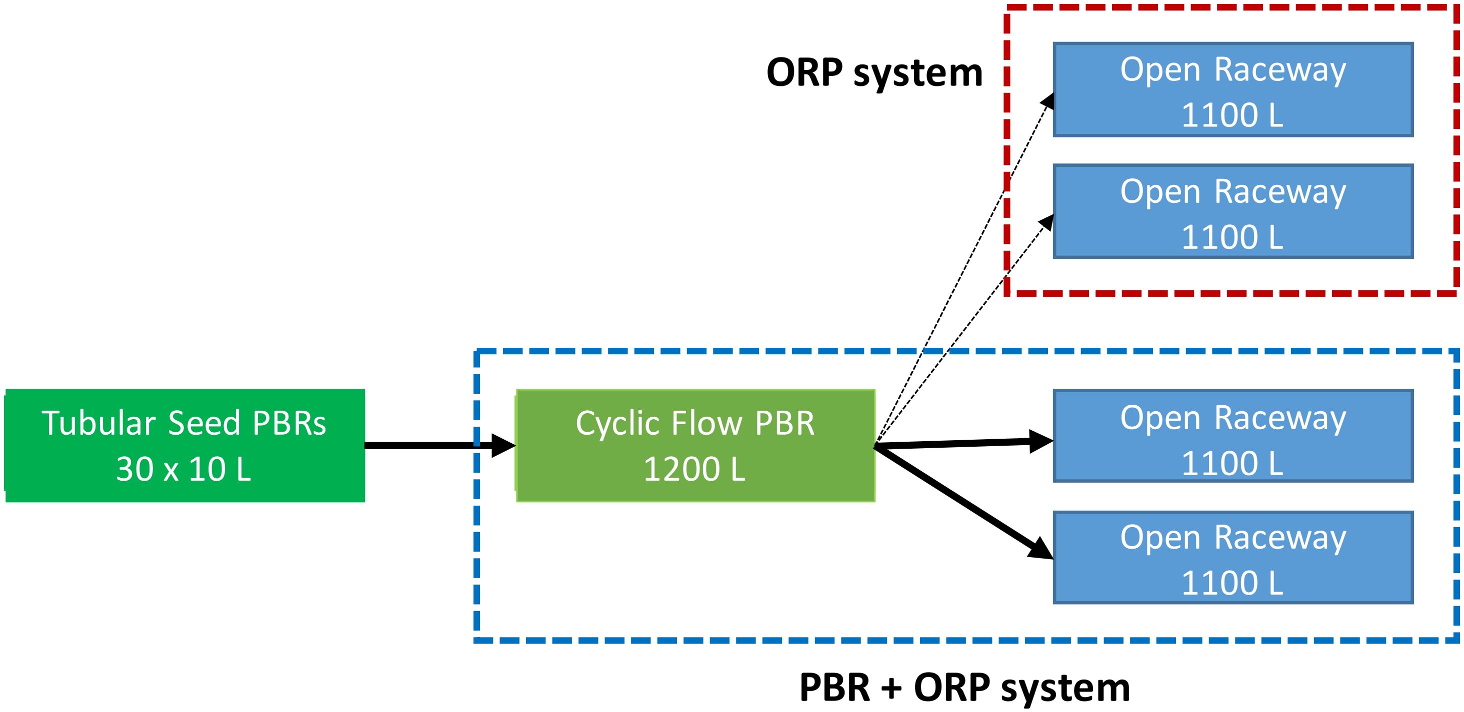
- **Biomass Processing: Valorization and Scale-up**
  - market analysis – sugars and lipids
  - bioplastic material characterization and film/fiber demonstration

→ Algae meal from biomass fractionation has increased protein content (>45 wt%) and lower ash content (<11 wt%) compared to whole biomass

Success Criteria

Decision Point	Date	Success Criteria	Status
Algae productivity	5/31/2018	PBR/pond cultivation system demonstrated to show superior productivity to pond-only system	Completed (Continuation Application, April 2018)
Fractionation of algal biomass	5/31/2018	(i) 10 lb of algae produced for utilization studies (ii) >80% lipids and >50% fermentable sugars recovered from algae	Completed (Continuation Application, April 2018)
Validation of bioplastic properties	**5/31/2019**	**Algae meal meets Algix's QC standards, including total odor compound count <200**	**Completed** (BP2 review meeting, May 2019)
Algae productivity	**5/31/2019**	**>15 g/m^2 algae production demonstrated for hybrid cultivation system using coal-derived flue gas**	**Target not met** (Continuation Application, April 2019)
Life cycle assessment	**5/31/2019**	**Demonstrate bioplastic production using this process is <0 g CO_2-eq / kg bioplastic**	**Completed** (Continuation Application, April 2019)
Techno-economic analysis	5/31/2020	Demonstrate a pathway to produce algae bioplastic feedstock for <$1,000 / ton biomass	Pending

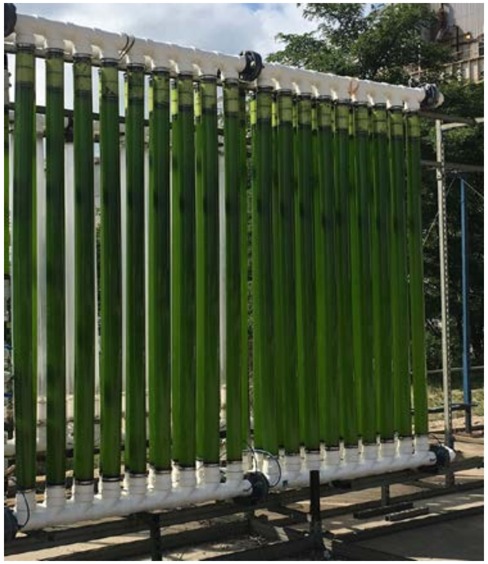
Algae Cultivation: PBR-ORP versus ORP Systems



<u>Operating Conditions</u>

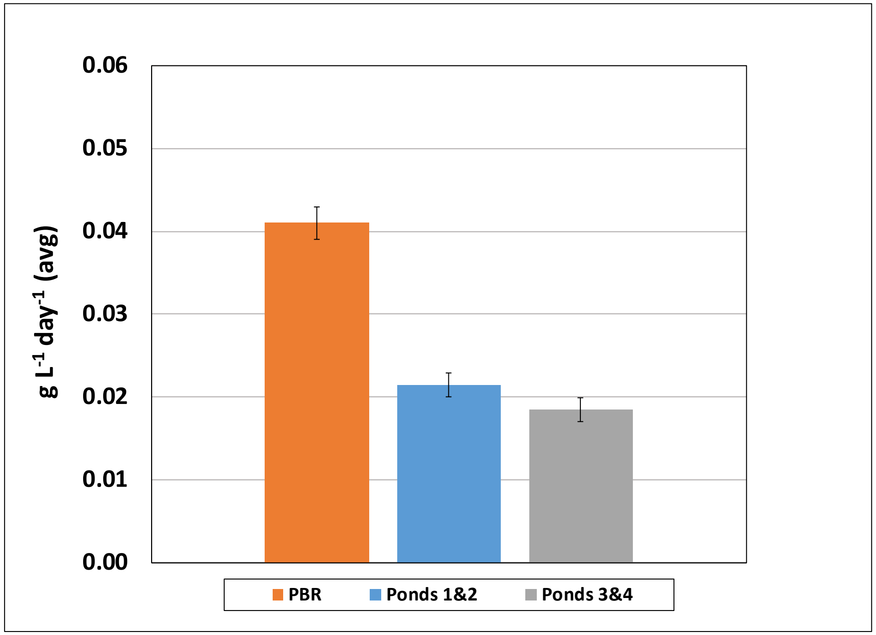
- Open Raceway Pond (ORP) system operated traditionally in semi-batch mode, with harvesting and dilution from 0.6 g/l to 0.2 g/l
- PBR + ORP system harvested at 0.6 g/l to 0.1 g/l with an additional ‘over seed’ of 0.1 g/l from PBR
- PBR system harvested to match the other systems at 0.2 g/l

Results: PBR-ORP vs. ORP Productivity



- PBR showed higher productivity than ponds
- PBR-fed ponds showed 14% improvement in productivity over conventionally operated ponds
- Areal productivity target not met (15 g $m^{-2}day^{-1}$) due to poor weather

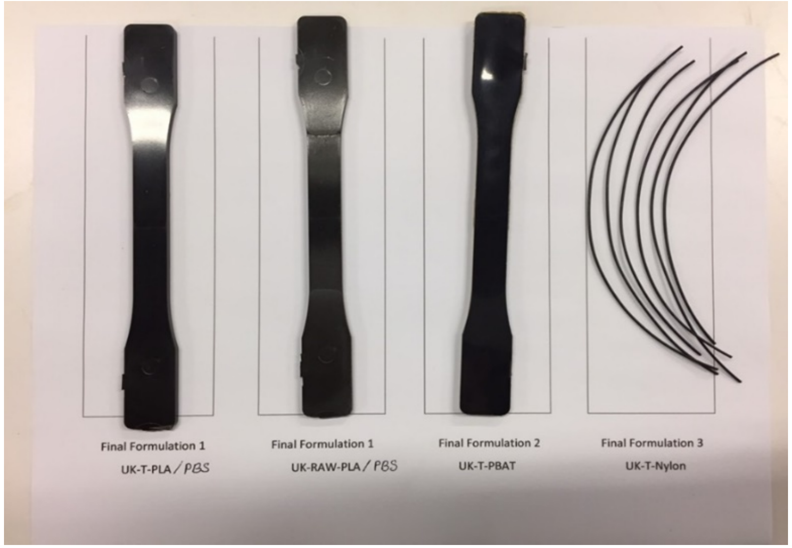
East Bend Station power plant, fall 2018 (ponds 1 & 2 PBR-fed)



Algal Biomass Processing

Sample	Protein (%, db)	Nitrogen, sulfur and furans at 140 °C
Proteinaceous solid from fractionation	52.3	7
Defatted biomass	50.7	12
Whole biomass	44.2	16

- Biomass fractionation according to CAP protocol*
- Increased protein content after processing (52%) and decreased ash (2%)
- GCMS volatile compound test found only 7 problematic odor compounds, well below threshold count
- Biomass passed every qualification test according to Algix's metrics

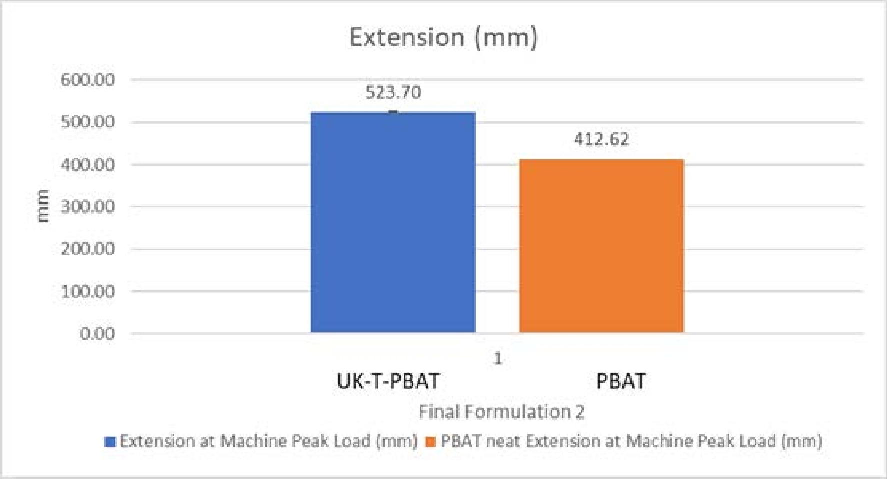


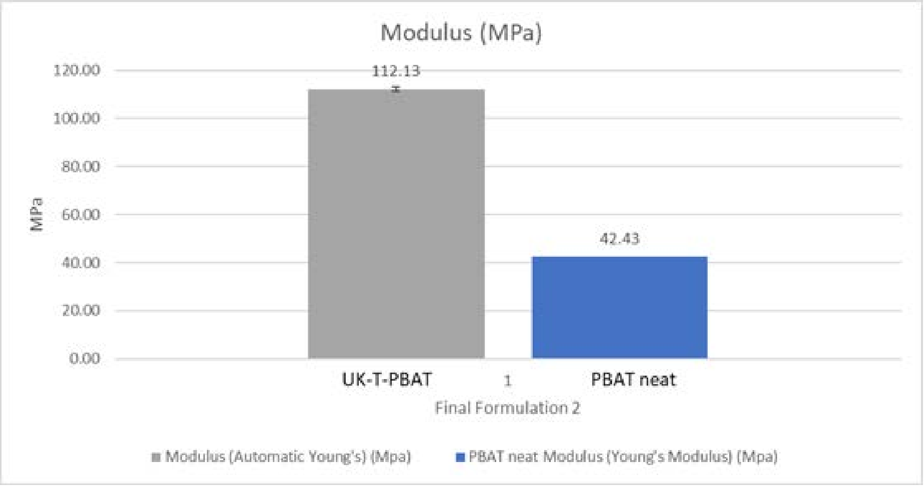
Bioplastic tensile bars and filament

*T. Dong, E.P. Knoshaug, R. Davis et al., *Algal Res.*, 2016, 19,316-323

Bioplastic Material Characterization

Fractionated algae ("UK-T-PBAT") + PBAT versus neat PBAT

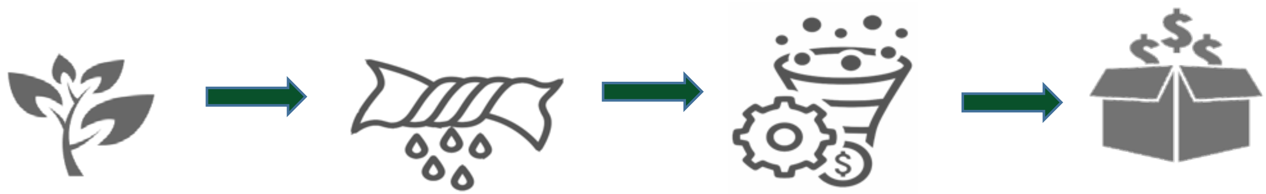


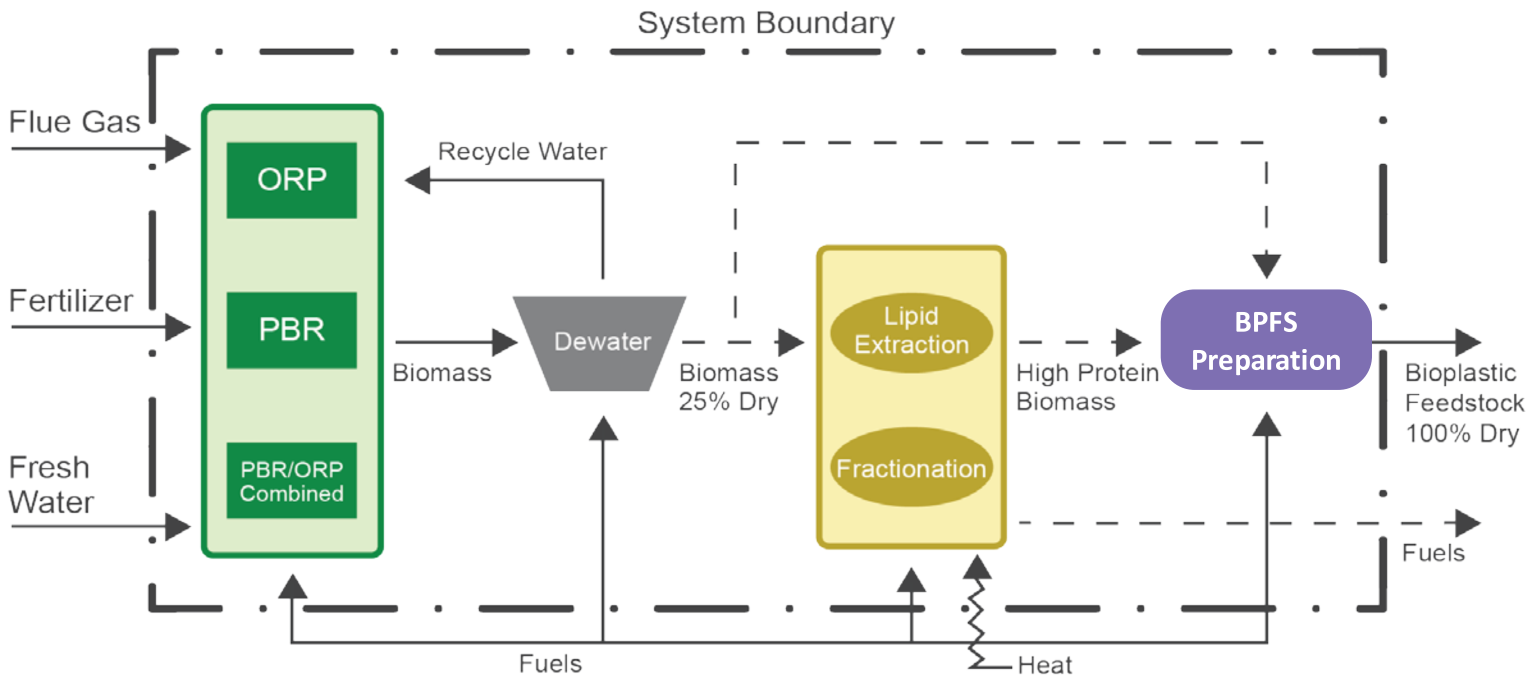


- Raw (dried-only), lipid-extracted and fractionated algal biomass used to prepare bioplastics
- PLA (polylactic acid)-PBS (polybutylene succinate), PBAT (polybutylene adipate terephthalate) and Nylon resins used
- Raw and lipid-extracted biomass gave similar results
- Nylon fiber and PLA-PBS products showed suitable properties for commercial use, but did not show significant improvements compared to the neat polymer
- Significant increase in extension found for fractionated biomass-PBAT tensile bars of >21% before breaking over neat PBAT. Promising for film applications with higher toughness and better suitability film applications

Sustainability Modeling

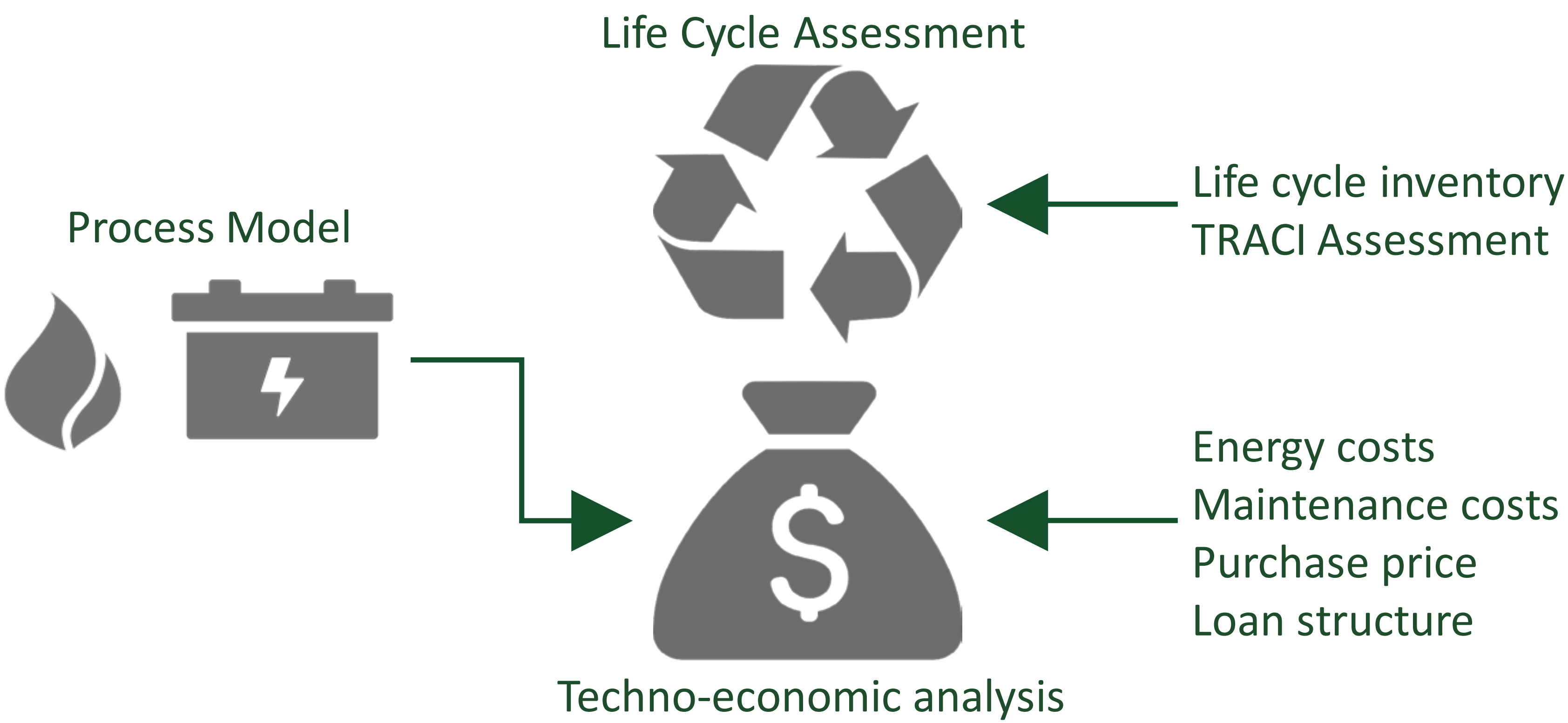
Process Overview



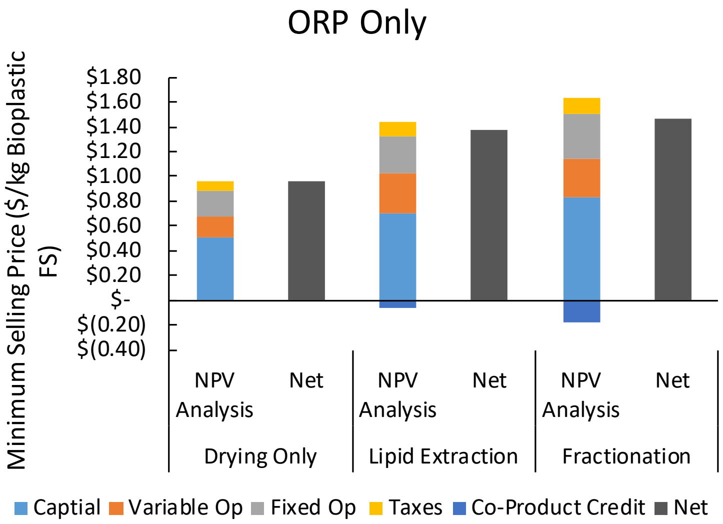


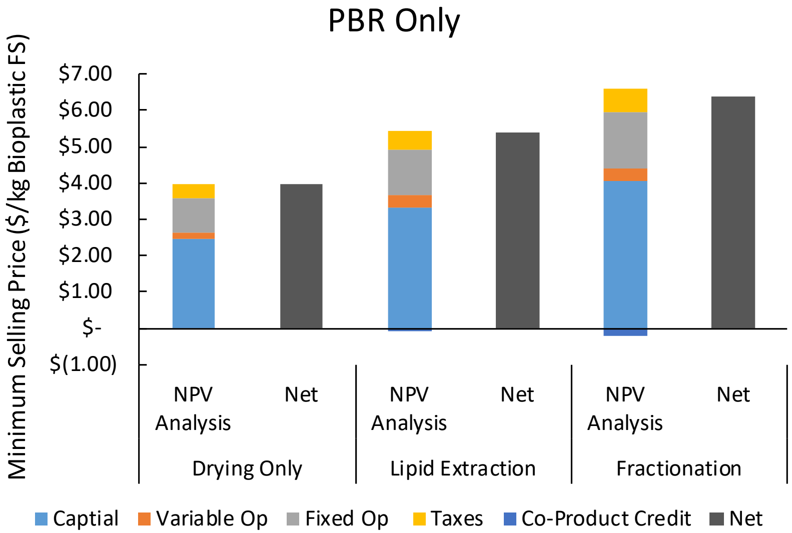
Sustainability Modeling

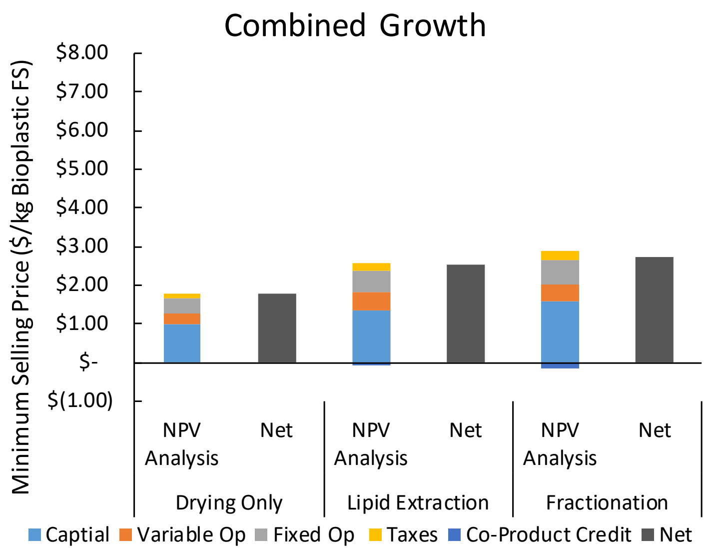
Methods Overview



TEA Results

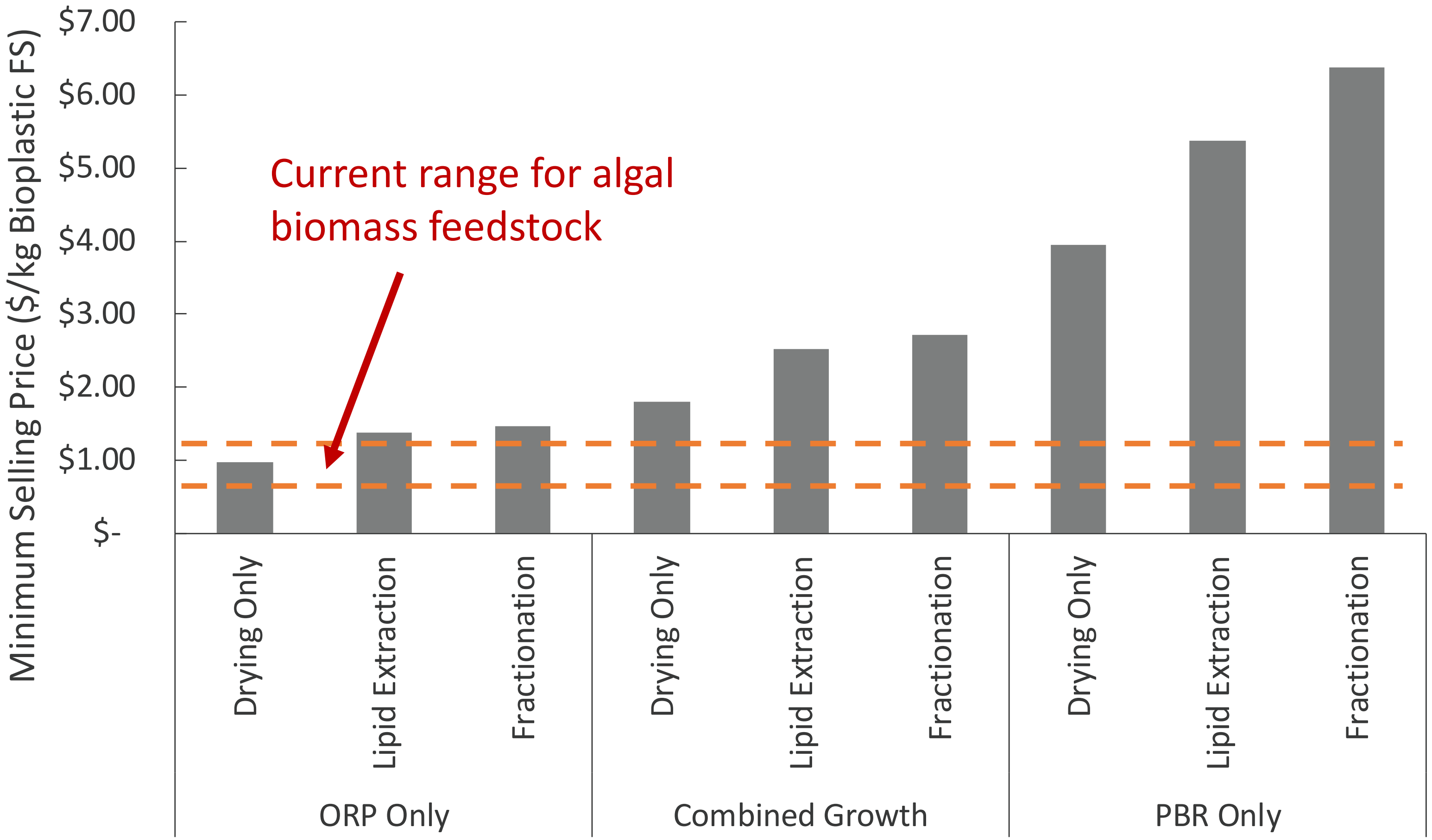




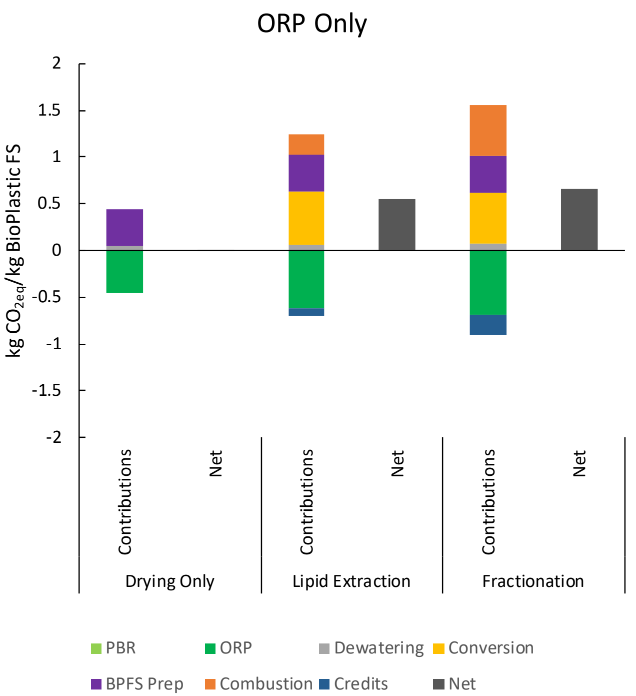


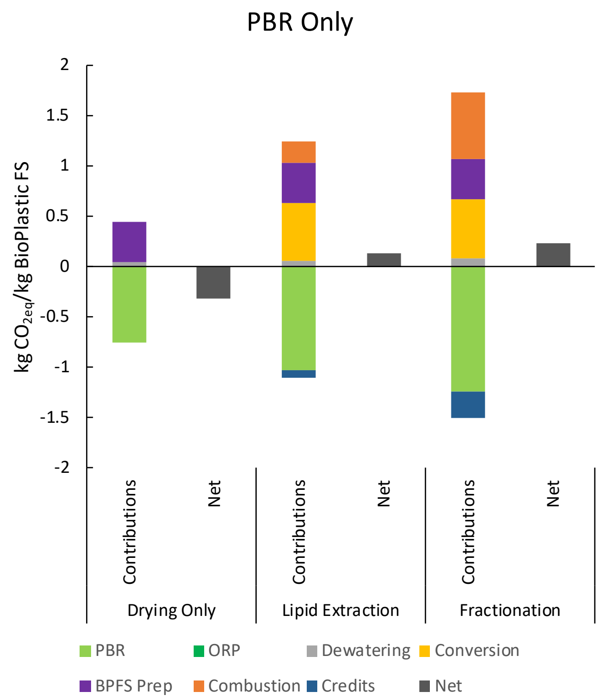
- Cost of biomass production:
  PBR > PBR-ORP > ORP
  Fractionation > Lipid extractn. > Drying only
- Capital costs dominate
- Co-production credits minimal (if fuel)

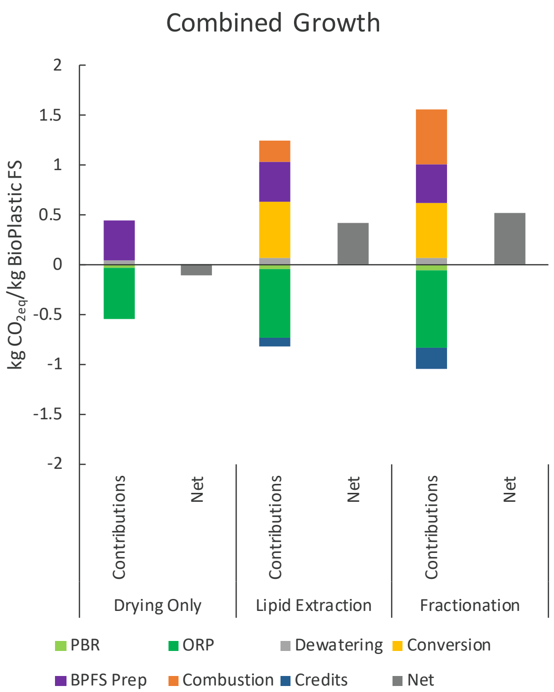
TEA Results Summary



LCA Results

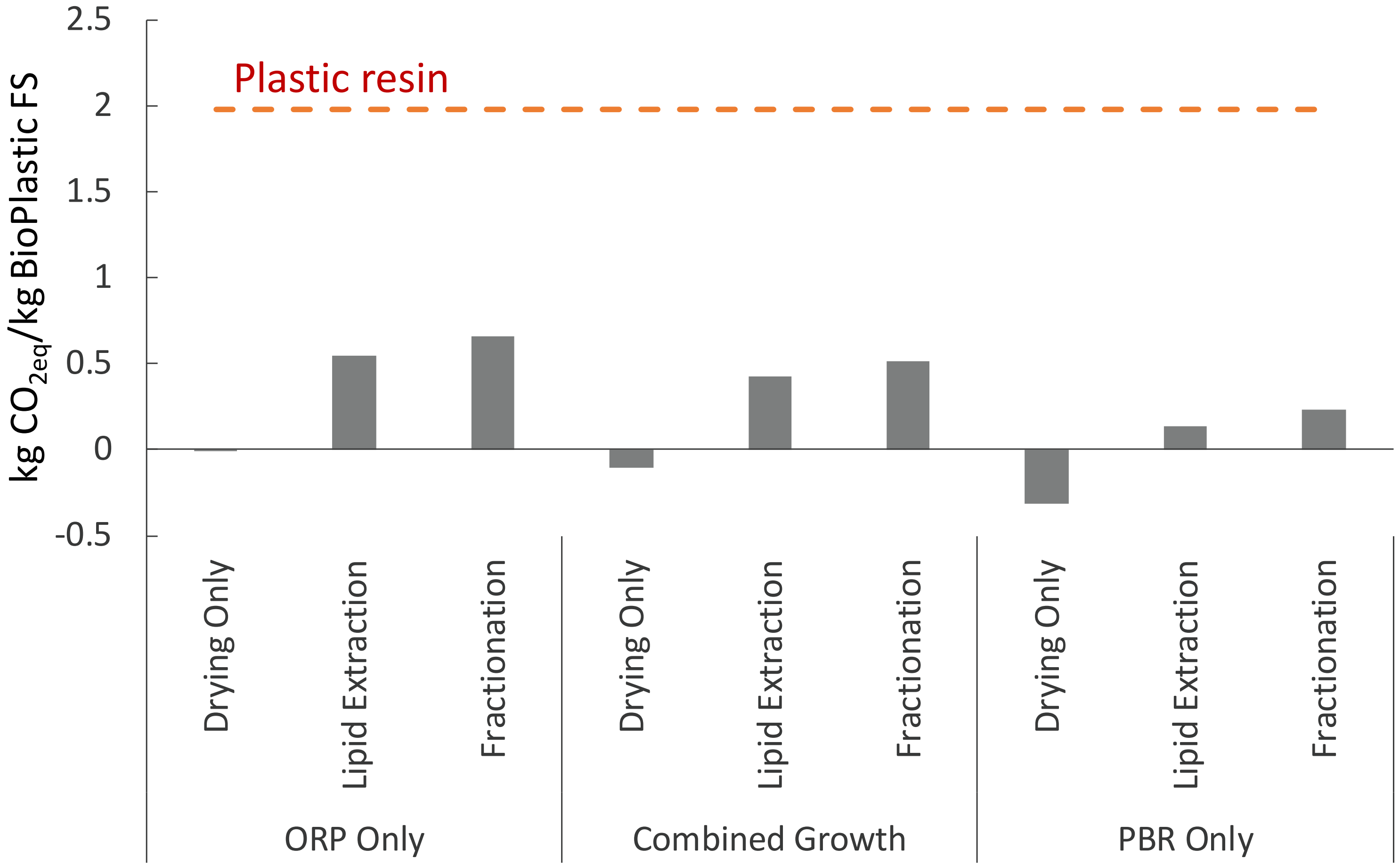




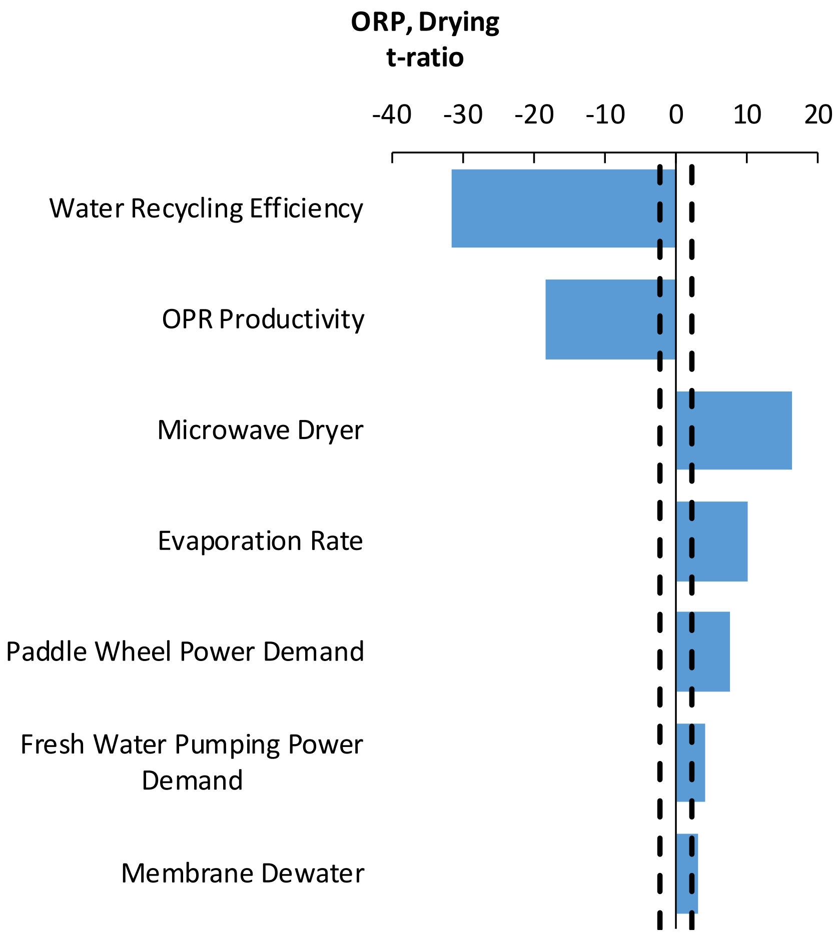


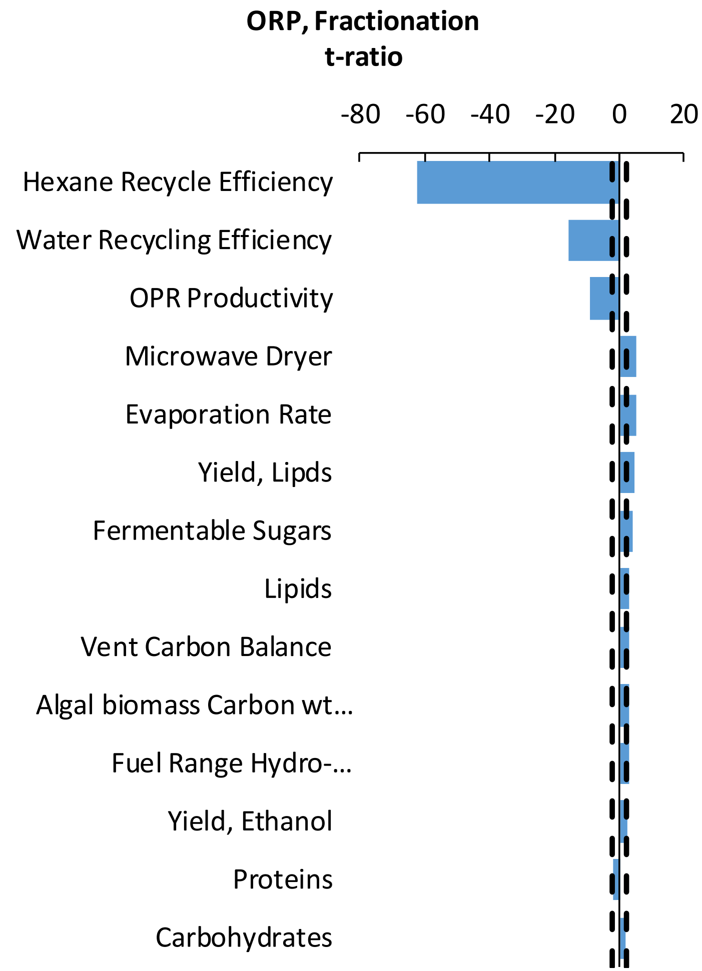
Net CO_2 emission reduction: PBR > PBR-ORP > ORP

LCA Results Summary



Sensitivity Analysis: Drying only vs. Fractionation





Future

- Develop PBR and ORP growth models such that TEA and LCA analyses can be tailored to different geographic regions
- Investigate the effect of the PBR to ORP ratio on the TEA and LCA of the system. Identify strategies to optimize the ratio
- Update TEA with projected value for proteinaceous biomass from fractionation – does the added value justify the extra cost of fractionation?
- Reporting

Summary

Based on these results, algae bioplastics could be made economically in an NOAK plant today.

All scenarios are more environmentally favorable than petroleum plastic resins.

A fuels co-product is not the best choice for this system

Proteinaceous algal biomass from fractionation shows promise as a feedstock for bioplastic film applications

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