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

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ALGIX

DUKE ENERGY

Project Overview
(DE-FE0029632)

- **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.

Technical Approach/Project Scope

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)

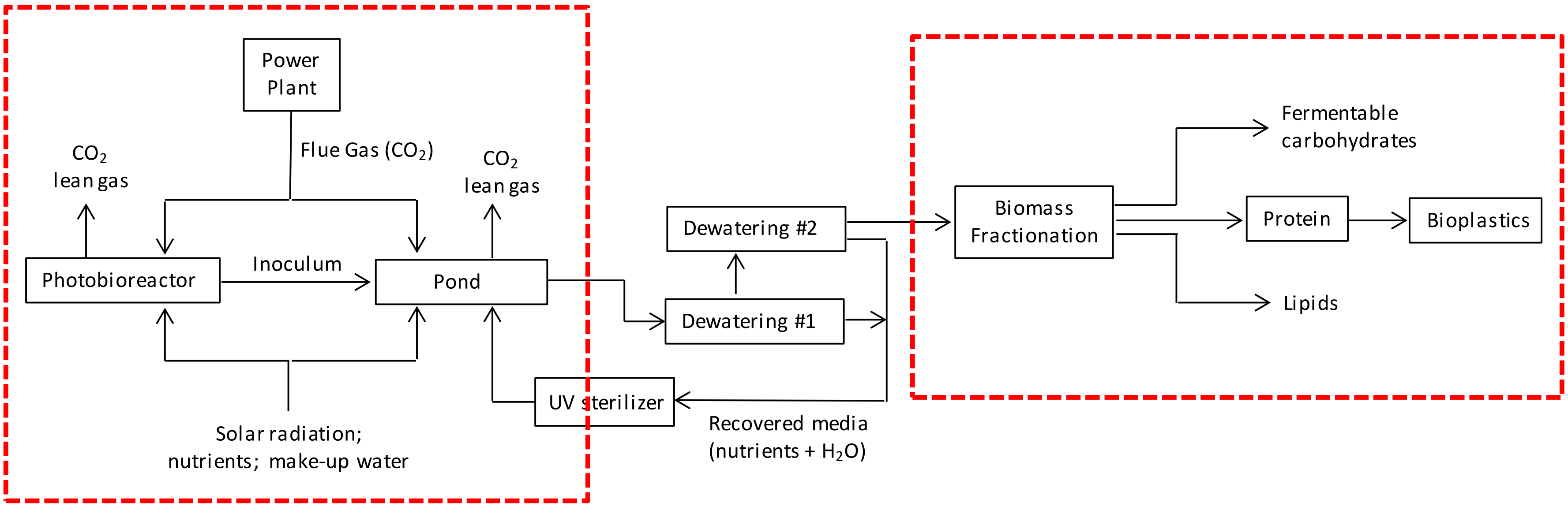
3) From a TEA and LCA perspective, which cultivation system and processing scheme(s) offer the greatest potential?

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 require high value applications for produced algae biomass
- Market size generally inversely related to application value (hence risk of market saturation)

Technical Approach/Project Scope (1)



- Focus on algae cultivation (maximize productivity / minimize cost) and biomass fractionation (maximize value of produced biomass)
- Algae cultivation studies at UK CAER in Year 1, transitioning to Duke Energy's East Bend Station in Year 2

Technical Approach/Project Scope (2)

Year 1:

- Task 1: Project Management
- Task 2: LCA and TEA
  - develop engineering process model for ponds, PBR and PBR/pond hybrid system
- Task 3: Algae Cultivation
  - pond and PBR installation
  - pond operation: comparison of pond and PBR/pond hybrid system
  - monitor hydrolysate quality and composition
- Task 4: Biomass Processing
  - wet lipid extraction with carbohydrate recovery
  - combined algal processing evaluation
  - bioplastic compounding

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	-
Fractionation of algal biomass	5/31/2019	(i) 10 lb of algae produced for utilization studies (ii) >80% lipids and >50% fermentable sugars recovered from algae	-
Validation of bioplastic properties	5/31/2019	At least one bioplastic formulated with defatted algae identified to be commercially viable based on material properties	-
Algae productivity	5/31/2019	>15 g/m^2 algae production demonstrated for hybrid cultivation system using coal-derived flue gas	-
Life cycle assessment	5/31/2019	Life cycle assessment shows net positive greenhouse gas emission reduction	-
Techno-economic analysis	5/31/2020	Economic viability of proposed process demonstrated	-

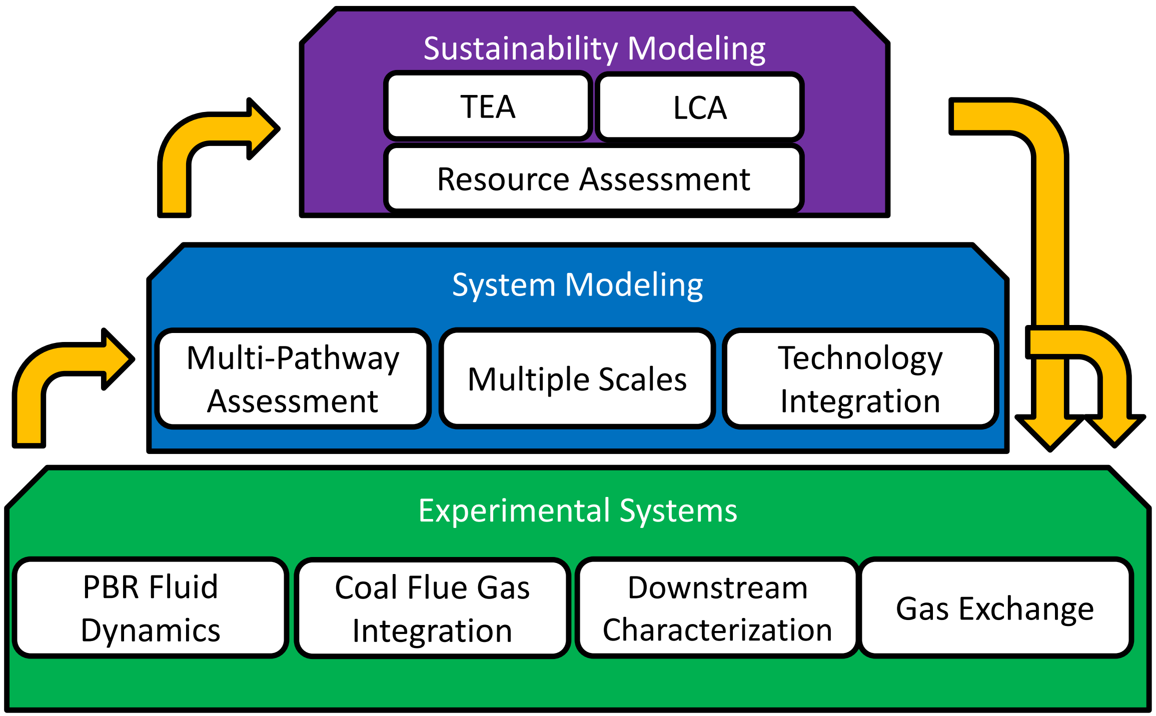
Key Milestones – Year 1

Task	Description	Planned completion date	Status
Task 1: Project Management	Kickoff meeting	6/30/2017	Completed: 8/8/2017
Task 3: Algae Cultivation	Ponds installed at UK CAER	8/31/2017	Projected date: 9/30/2017
Task 2: LCA and TEA	Engineering process model developed	5/31/2018	No change
Task 4: Biomass Processing	>80% lipids & >50% fermentable sugars recovered from algae	5/31/2018	No change

Technical Risks and Mitigation Strategies

Description of Risk	Probability	Impact	Risk Management Mitigation and Response Strategies
Pond crashes due to contamination by rotifers or algal viruses	Moderate	High	Ponds to be sterilized after culture crash; continuous operation of PBR will allow for immediate pond re-seeding
Culture contamination due to invasive species in pond	High	Moderate	By maintaining high *Scenedesmus* culture density (by means of PBR “overseeding” strategy), major contamination will be minimized
Inclement weather (heat wave)	Low	High	Switch to warm weather algae strain
Algae meal from CAP unsuitable for bioplastics	Moderate	Moderate	Use algae meal obtained from wet lipid extraction
LCA shows process to be net CO_2 positive	Low	High	Use results to inform process development (avoid processing steps with high CO_2 emissions)

Task 2: Sustainability Modeling



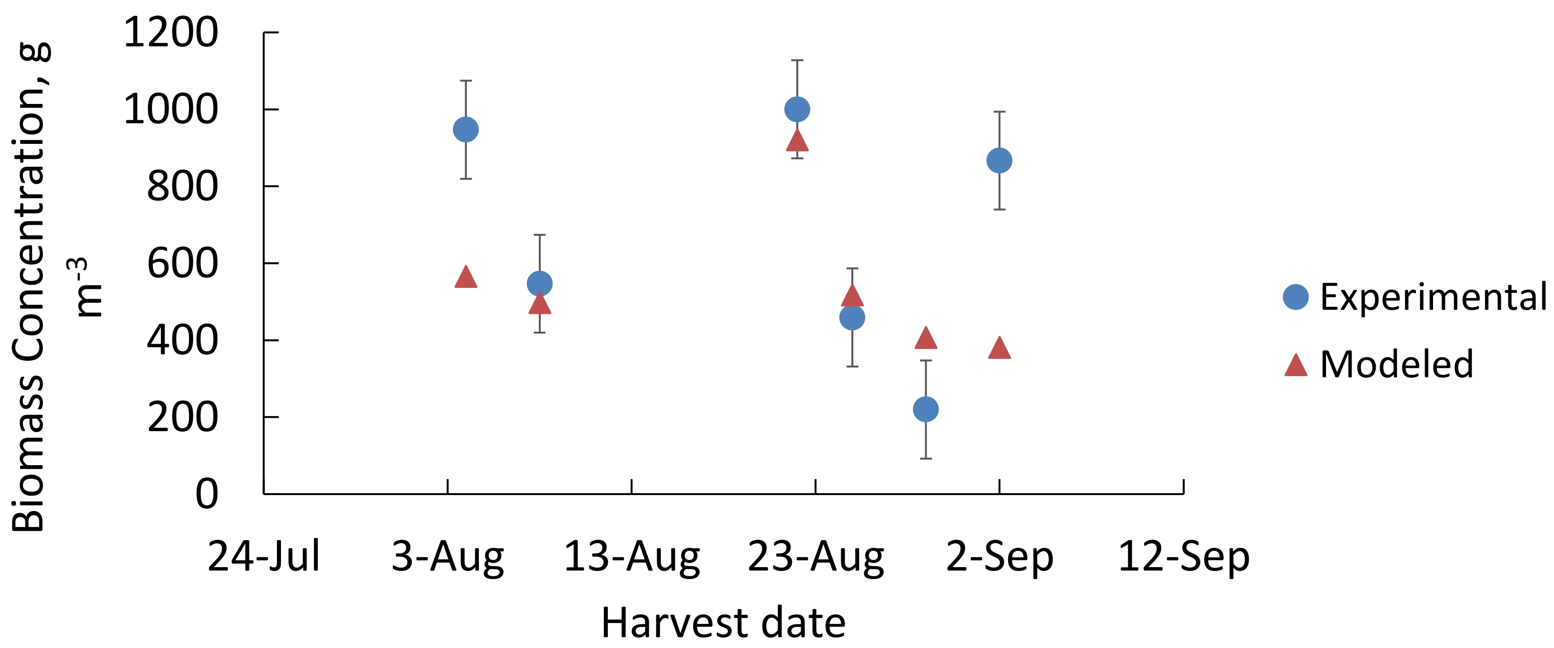
Growth Modeling: Methodology (CSU)

- Correlate growth to moles of photons incident on culture
- Adjust for:
  - Culture concentration
  - Temperature
  - Light inhibition
- Temperature modeled dynamically as well

$$\frac{dC_x}{dt} = \frac{\varphi_L \cdot \varphi_T \cdot \varphi_C \cdot P \cdot \emptyset_{photon}}{V} - D/V \qquad \rho C_p V \frac{dT}{dt} = \sum Q_n$$

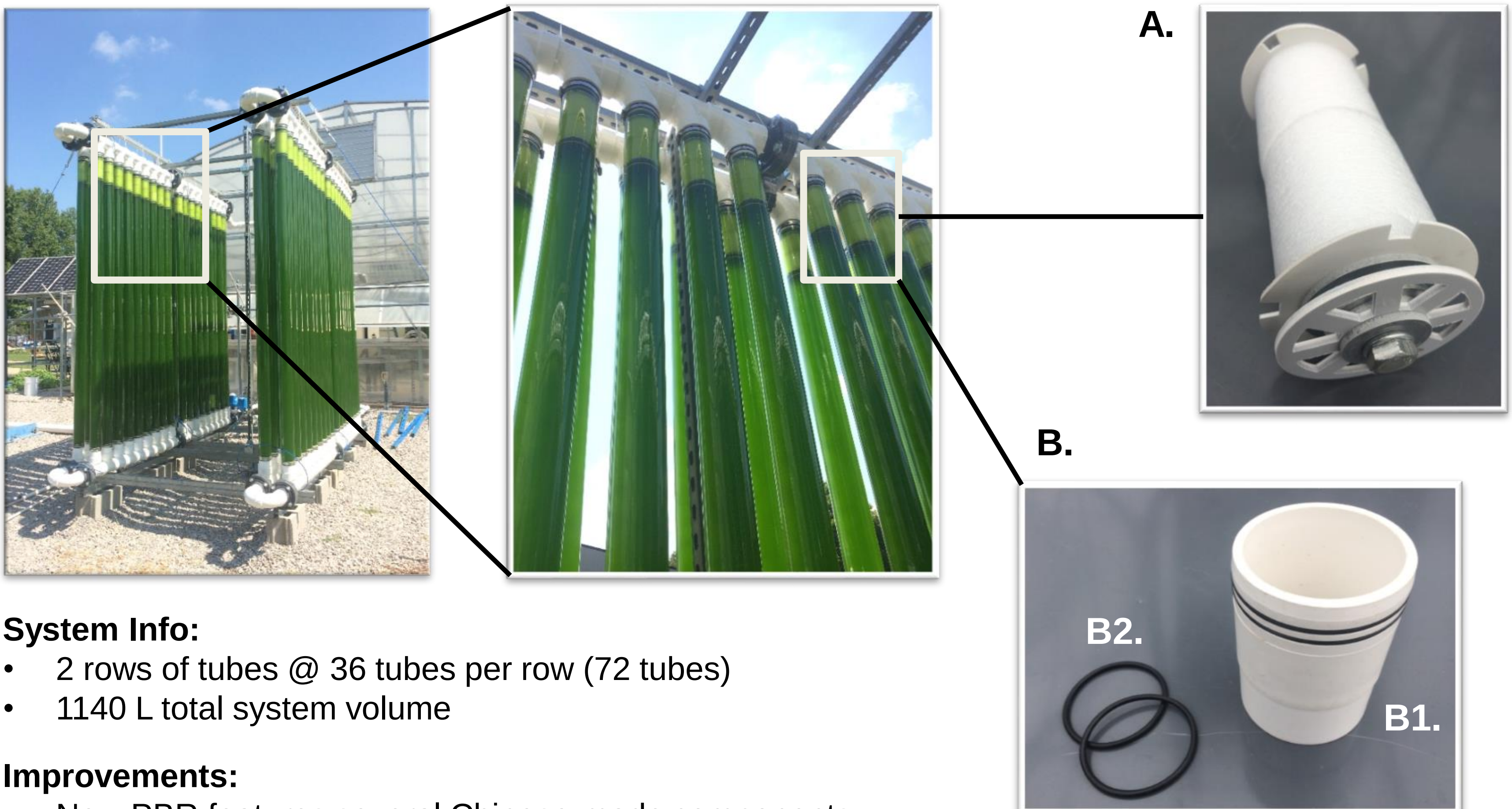
- ρ: Culture density assumed similar to water (~1000 [kg/m^3])
- $\varphi_L \cdot \varphi_T \cdot \varphi_C$ Light intensity, temperature, and concentration modifiers, [dimensionless]
- P : Rate of light incident in [uE/m^{2}s]
- $\emptyset_{photon}$: Biomass to photon correlation, g Biomass / mole photon
- V : Culture volume [m^3]
- D : Biomass loss rate, a function of temperature, light intensity, and mass of biomass in system, g/s
- $\frac{dC_x}{dt}$: Time derivative of biomass concentration, [g m^{-3} s^{-1}]
- $\frac{dT}{dt}$: Time derivative of system temperature (assumed homogeneous in space) [K / s]
- $\sum Q_n$: Sum of thermodynamic fluxes, [W/m^2 * area] → [Watts]
- C_p : Specific heat of the culture, assumed similar to water

Growth Modeling: Results in Progress



- Preliminary fitting gives mixed results
- Much more to be done in terms of model refinement and data fitting

Task 3: Construction of Updated Cyclic Flow Photobioreactor

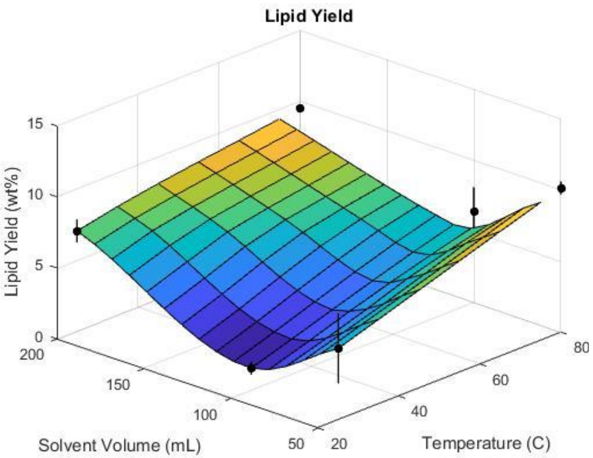


System Info:
- 2 rows of tubes @ 36 tubes per row (72 tubes)
- 1140 L total system volume

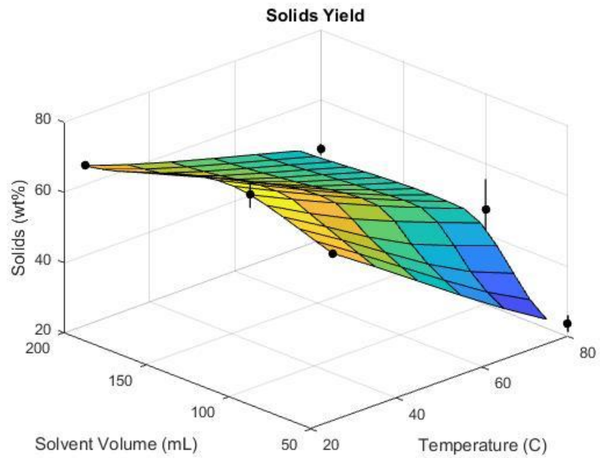
Improvements:
- New PBR features several Chinese-made components:
  - Pipe-cleaning pigs (**A**) are now mass produced.
  - PVC stubs (**B1**) used to mount the PET tubes now utilize rubber O-rings (**B2**) instead of the previously used rubber bands, creating a more leak resistant connection.
- Improved gas delivery system with more consistent bubble column.

Task 4: Optimization of Algae Fractionation Process

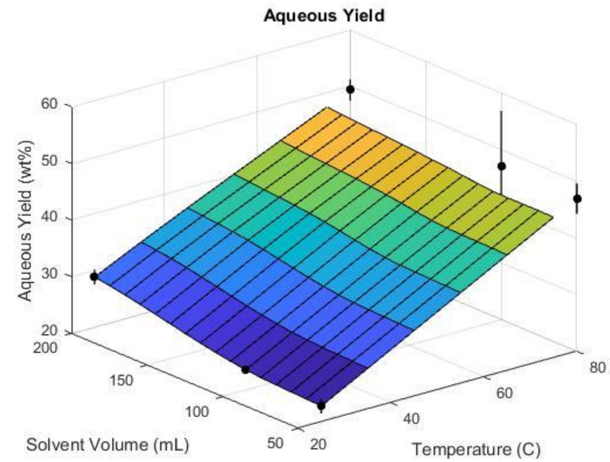
- Lipids are isolated from wet algae biomass via in situ transesterification/esterification
- 5 wt% HCl in methanol is used as pretreatment solvent (pH 1-2)
- Lipids recovered via hexane washing, solids via filtration
- Aqueous phase contains mainly dissolved sugars (with some protein)



Lipids



Residual solid biomass



Solid from aq. phase

- Yields of residual solid biomass and dissolved matter in aqueous phase can be tuned to a large degree
- Additional experiments will include variation of acid concentrations and complete analysis of products

Summary

- Work commenced on building model for algae growth in cyclic flow PBR
- 1100 L cyclic flow PBR installed at UK CAER
- 4 x 1100 L ponds ordered (for installation at UK CAER)
- Utilities installed for ponds
- DoE underway, with goal of optimizing wet lipid extraction process

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