University of Kentucky CAER-Duke Energy East Bend Algae Demonstration Project

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Project Timeline

- 2008 – UK Approached by Kentucky Department of Energy Development and Independence to investigate the techno-economic feasibility of algae based CO_2 mitigation
- 2011-2012: Initial Demonstration Work started at EKPC's Dale Station
- 2012-Present: Demonstration Project at Duke Energy's East Bend Station
- 2011-Present: Part of US-China Clean Energy Research Center (CERC)
- August, 2015: NETL Biological CO_2 Utilization Award

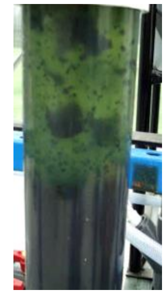
- Research Focus Areas
  - Power Plant Integration
  - PBR Design/Operation
  - Dewatering
  - Techno-economic modeling
  - Utilization
- Utilization Focus Areas
  - Bio-polymers
  - Lipid Extraction
  - Catalytic Upgrading
  - HTL
  - Pyrolysis
  - Aquaculture
  - Anaerobic Digestion

Overall Concept: CO_2 Utilization

CO_2 as flue gas

Cultivation in low cost PBR

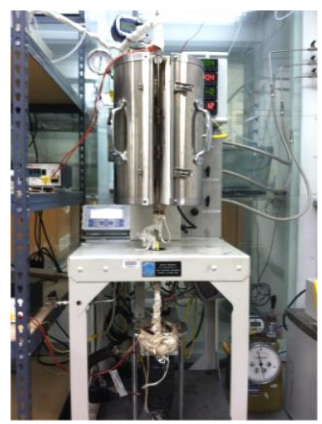
Flocculation/
Sedimentation



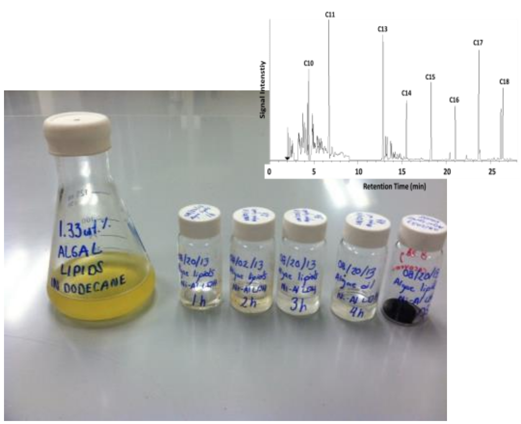
Gravity Filtration

Bio-Plastics

Catalytic Upgrading of Lipids

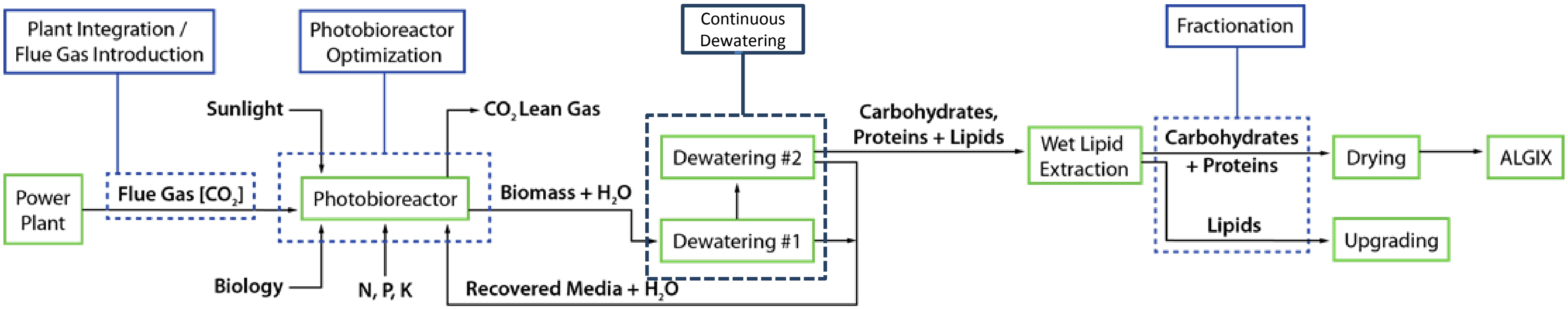


Fuel Like Hydrocarbons

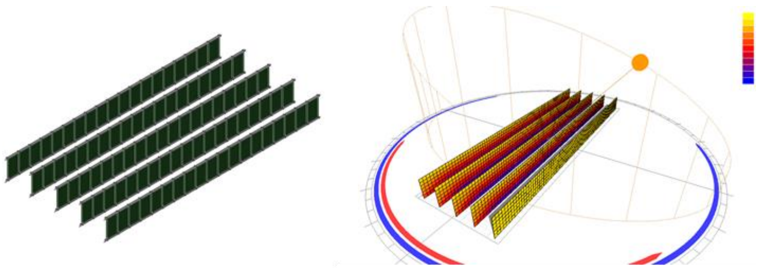


M.H. Wilson, J. Groppo, E. Santillan-Jimenez, M. Crocker *et al.*, *Appl. Petrochem. Res.* 4 (2014) 41

Current Research Focus

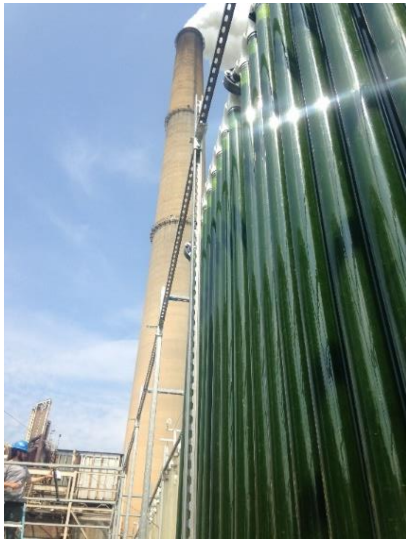


Flow Chart of Process With Research Focus Areas Highlighted in Blue



Solar modeling for optimum photobioreactor spacing

Field Demonstration



- Pilot algae facility at Duke Energy's East Bend Station in 2012
  - 1st generation UK photobioreactor (top)
- Primary PBR Components
  - 3.5" d x 8' tall clear PET packaging tubes
  - PVC pipe fittings
- Routine Areal productivity
  - ≥ 0.25 g/l/day (summer)
  - ≥ 0.10 g/l/day (winter)
- System Volume
  - 18,000 L/5,000 gallons
- New "cyclic flow" photobioreactor
  - deployed in 2014 (bottom)
    - lower cost
    - higher productivity
    - more robust operation

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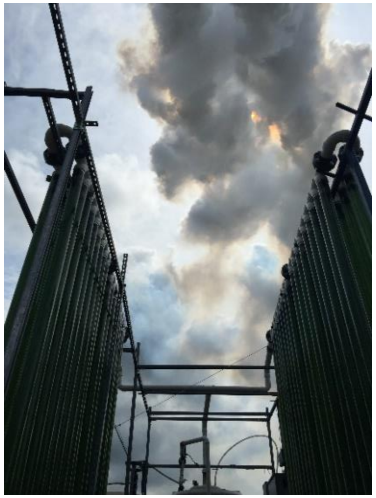
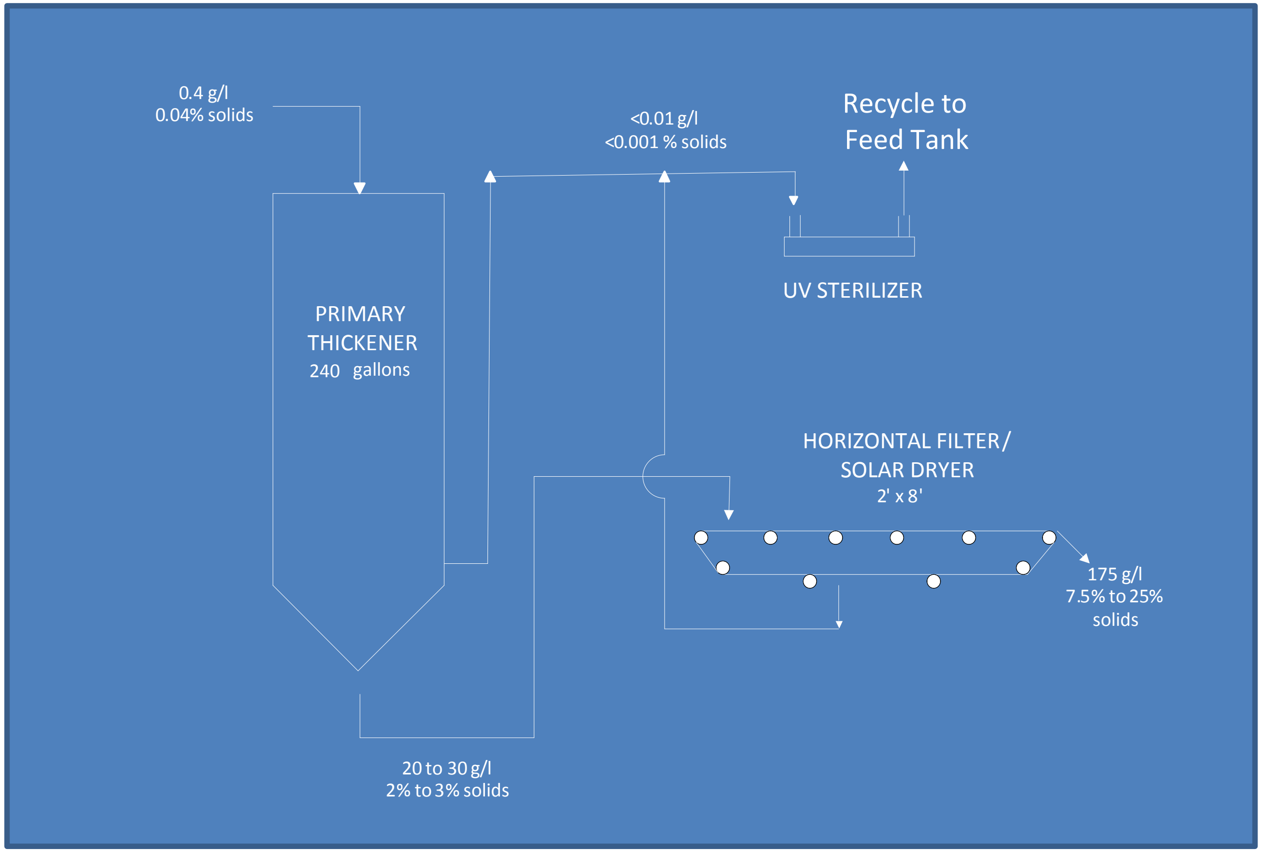
DUKE ENERGY

Field Demonstration

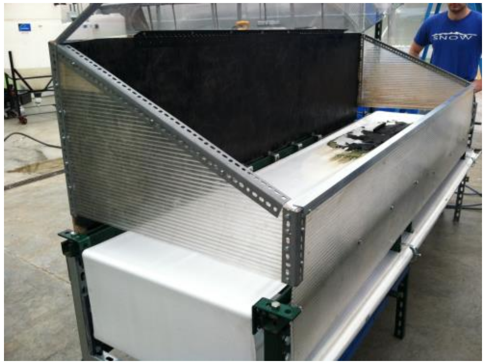


Cyclic operation to
- reduce energy costs
- control biofilm formation

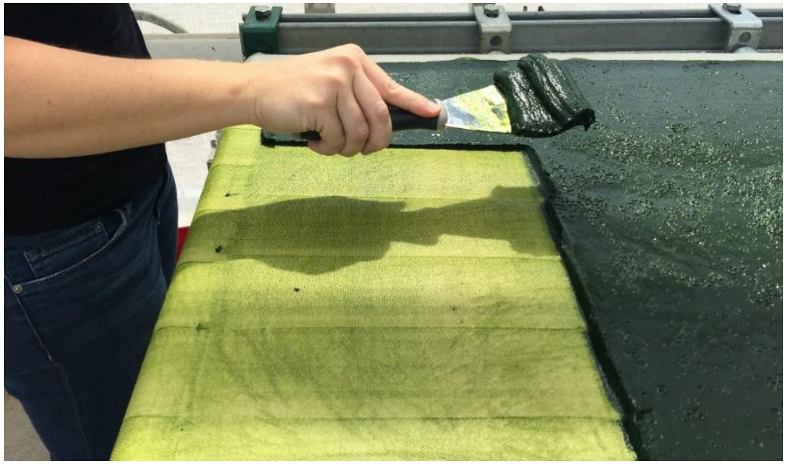
Harvesting/Dewatering Flowsheet



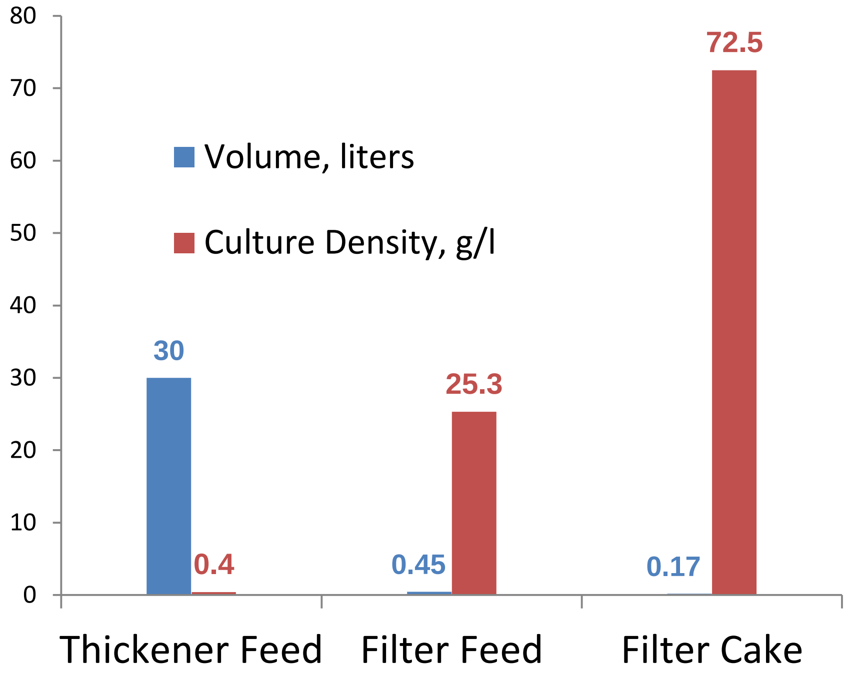
Prototype Gravity Filter/Solar Dryer

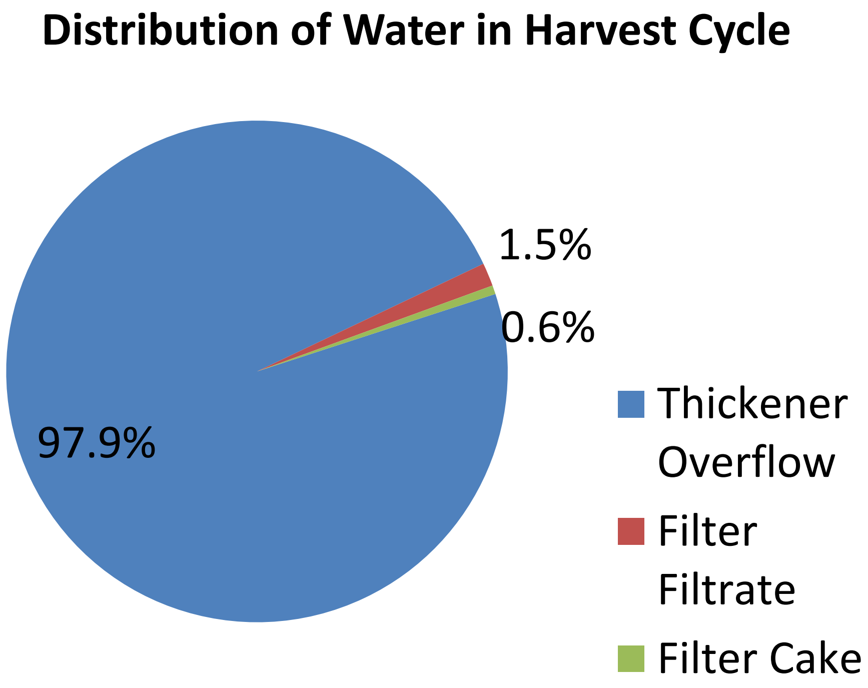


- Multifilament nylon media for rapid cake formation and high solids capture (>99%)
- Allows separation and recycling of all free water containing unused nutrients
- Short vacuum pulse after cake formation can improve throughput
- Can produce 10-25% solids for utilization
- Solar oven can reach 60^{o}C in summer

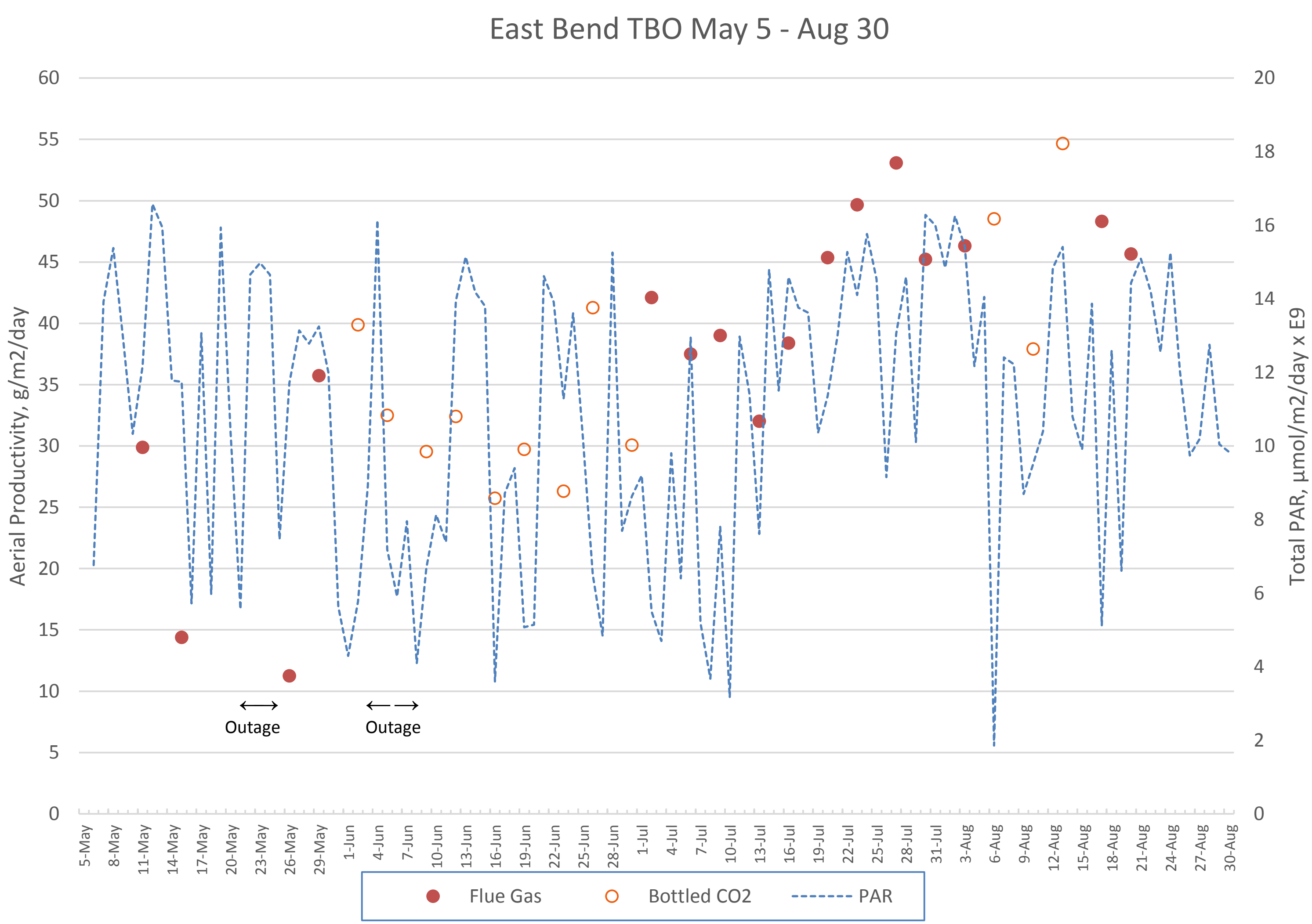


Harvest/Dewatering: Typical Results





System Productivity



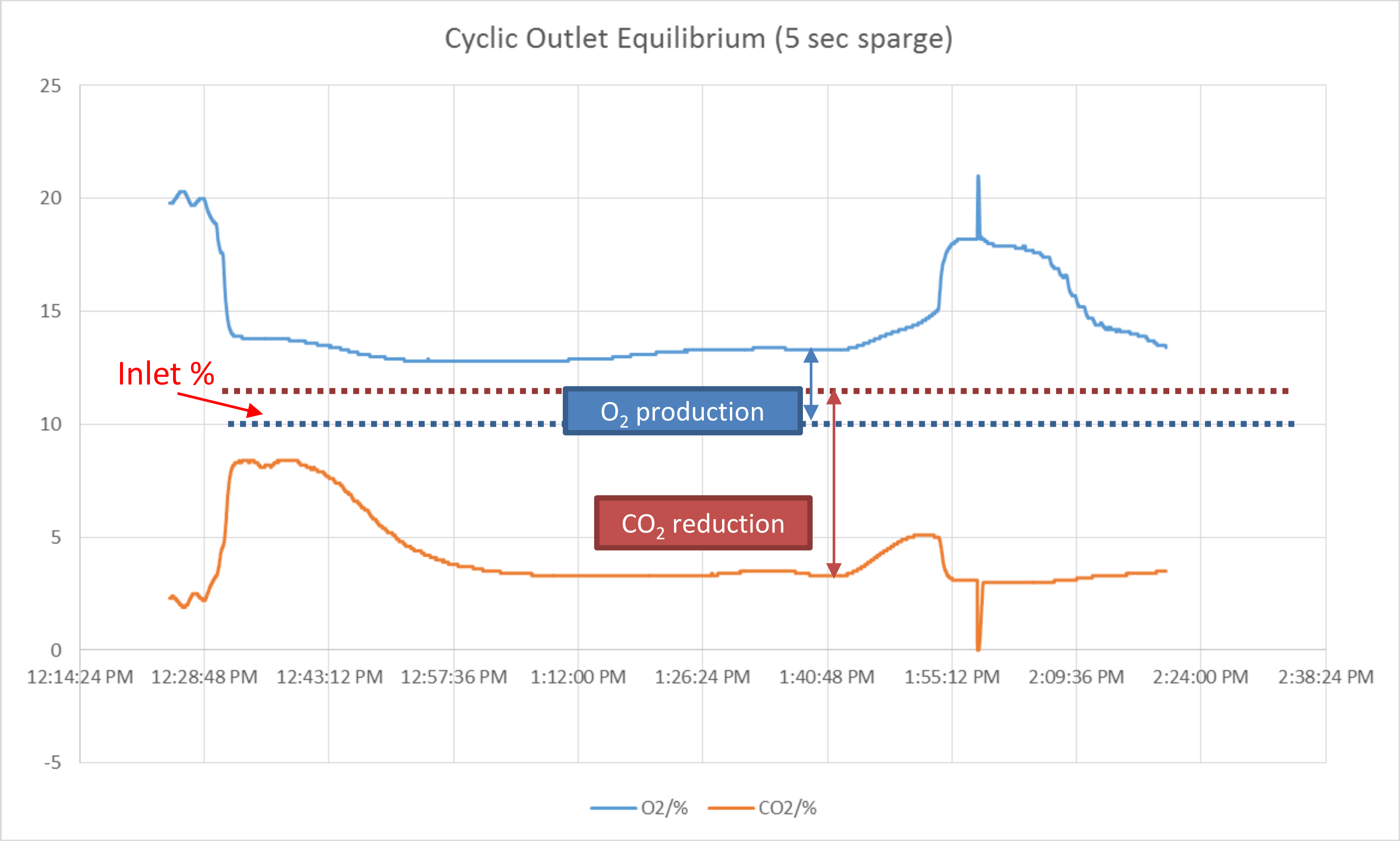
Mass Balance Determination

Reactor Measurements
Temp, dissolved O_2, pH

Flue Gas Measurements
inlet and outlet streams
MRU Flue Gas analyzers
Temp, CO_2, O_2,
NO_x, SO_x, CO, and CH_4.

Data measured every 30 seconds and stored automatically.

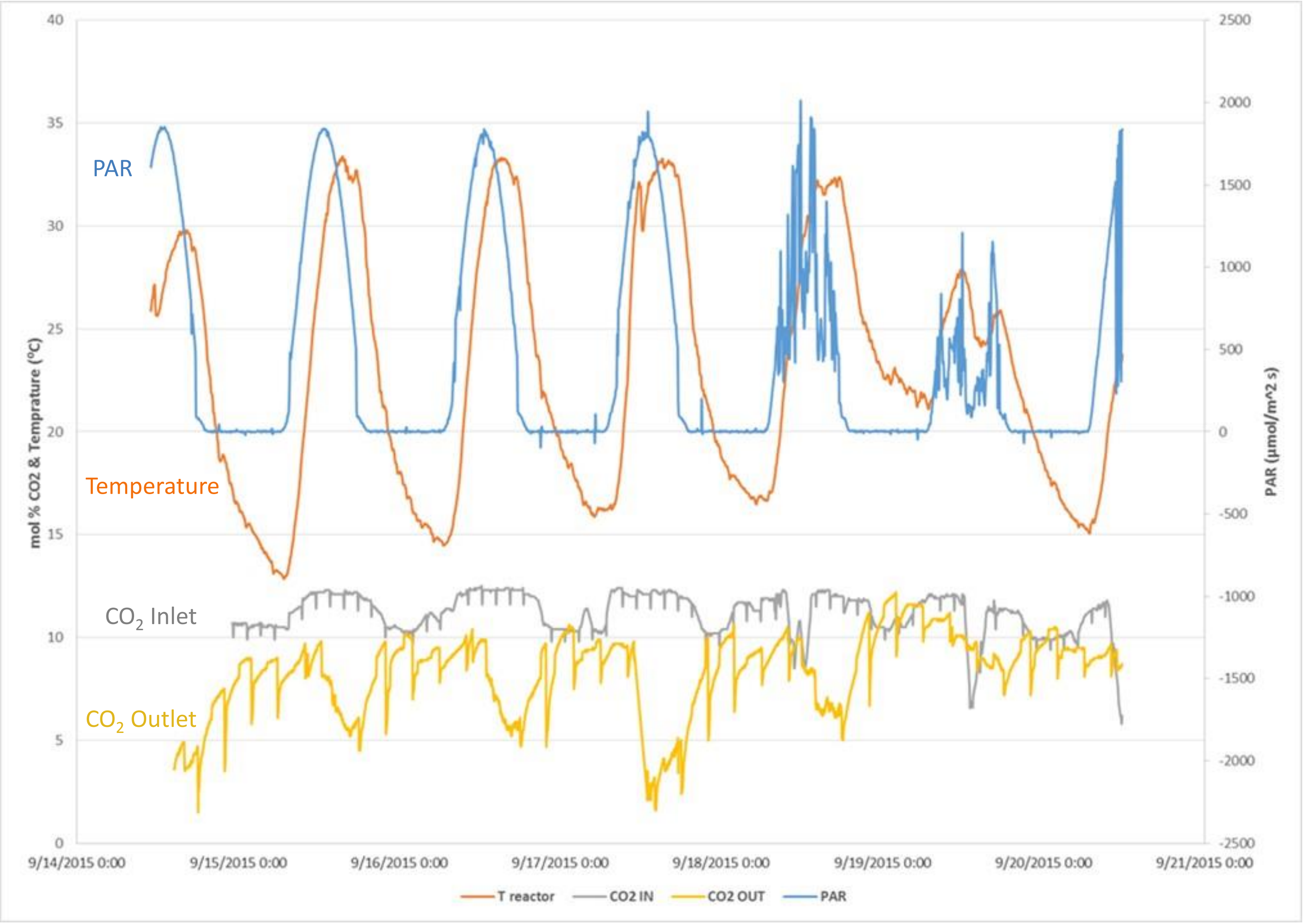
Mass Balance Data



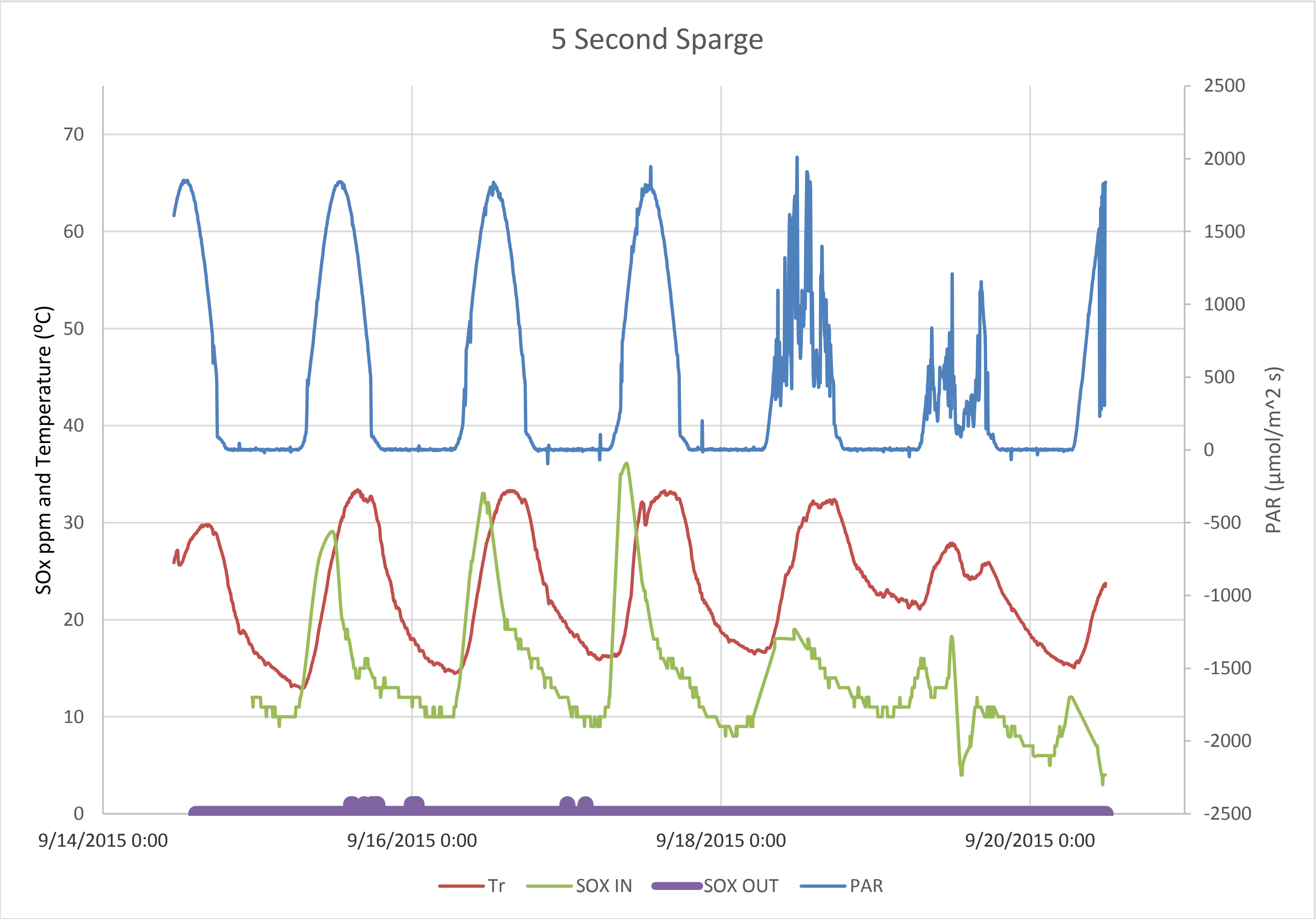
Indicates CO_2 conversion to O_2 via photosynthesis.

Highlights opportunity to optimize CO_2 conversion. Targeting 75%

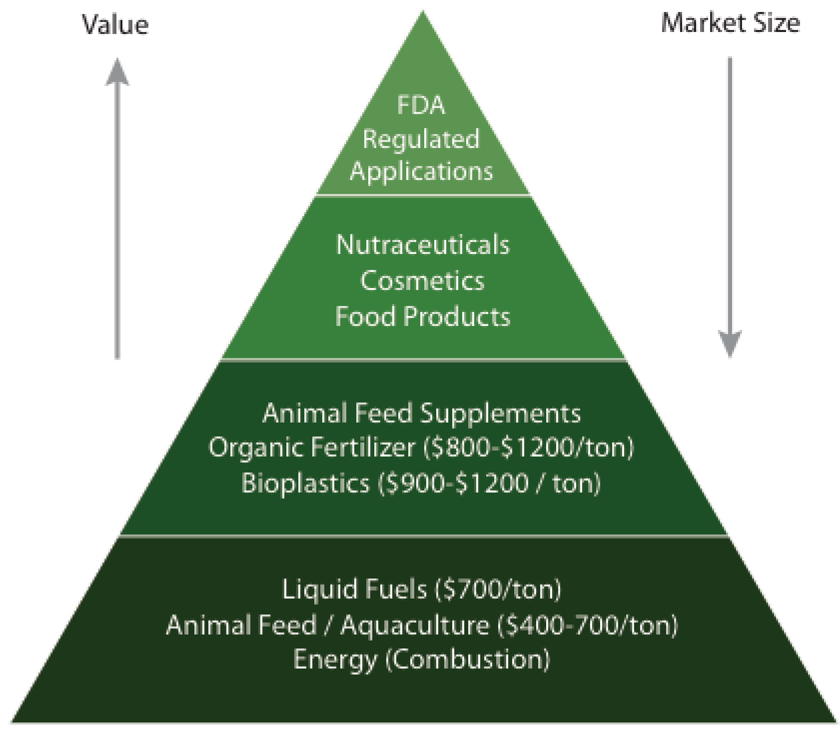
Mass Balance Data: CO_2



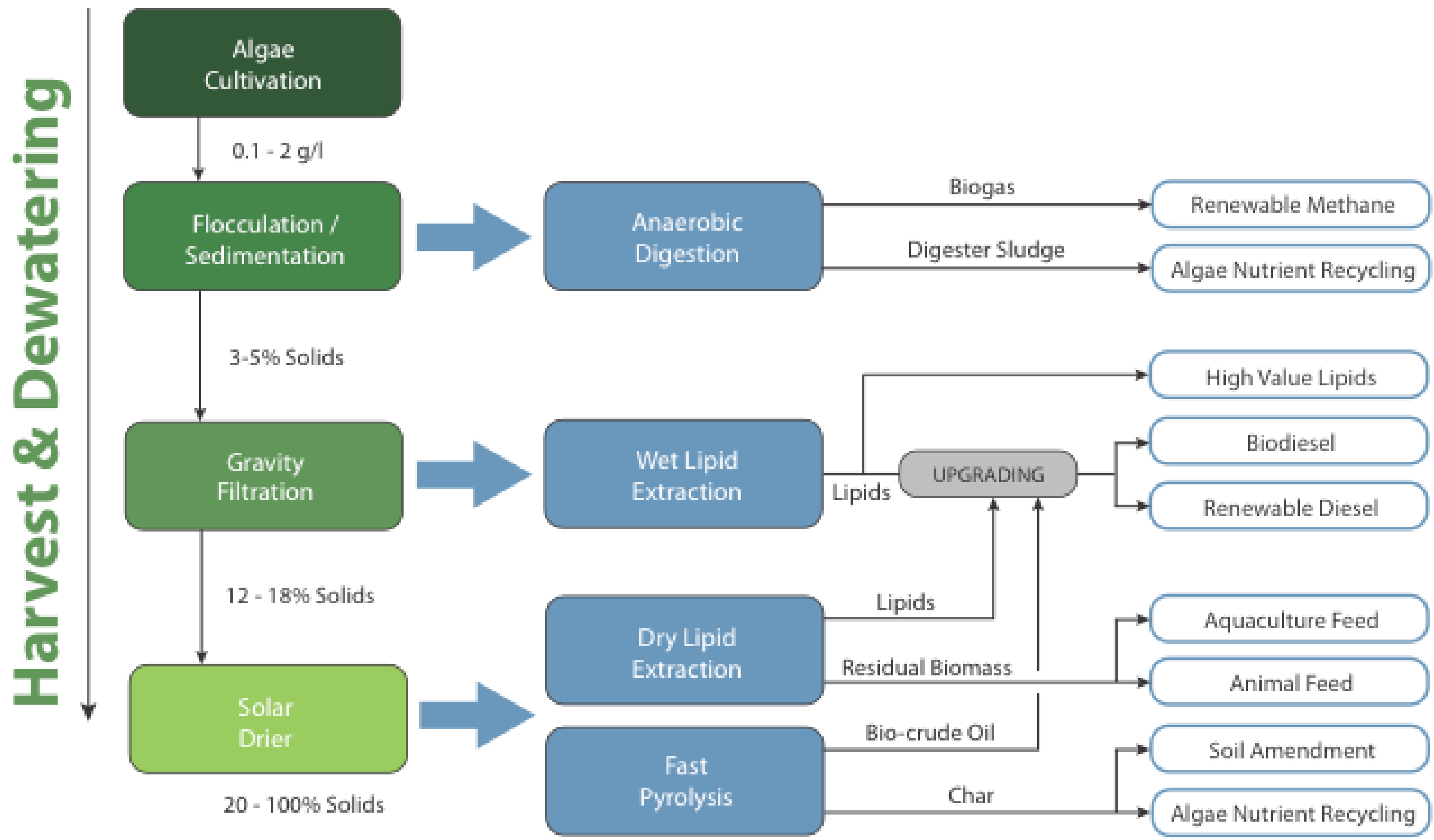
Mass Balance Data: SO_x



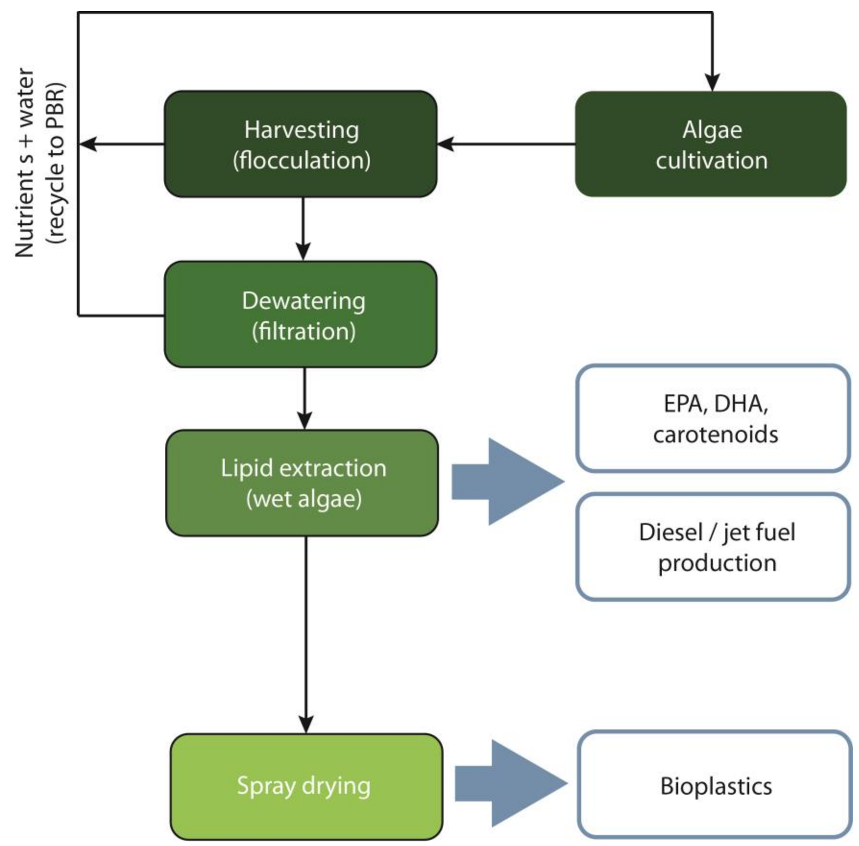
Algal Biomass Utilization



Algal Biomass Utilization Pathways

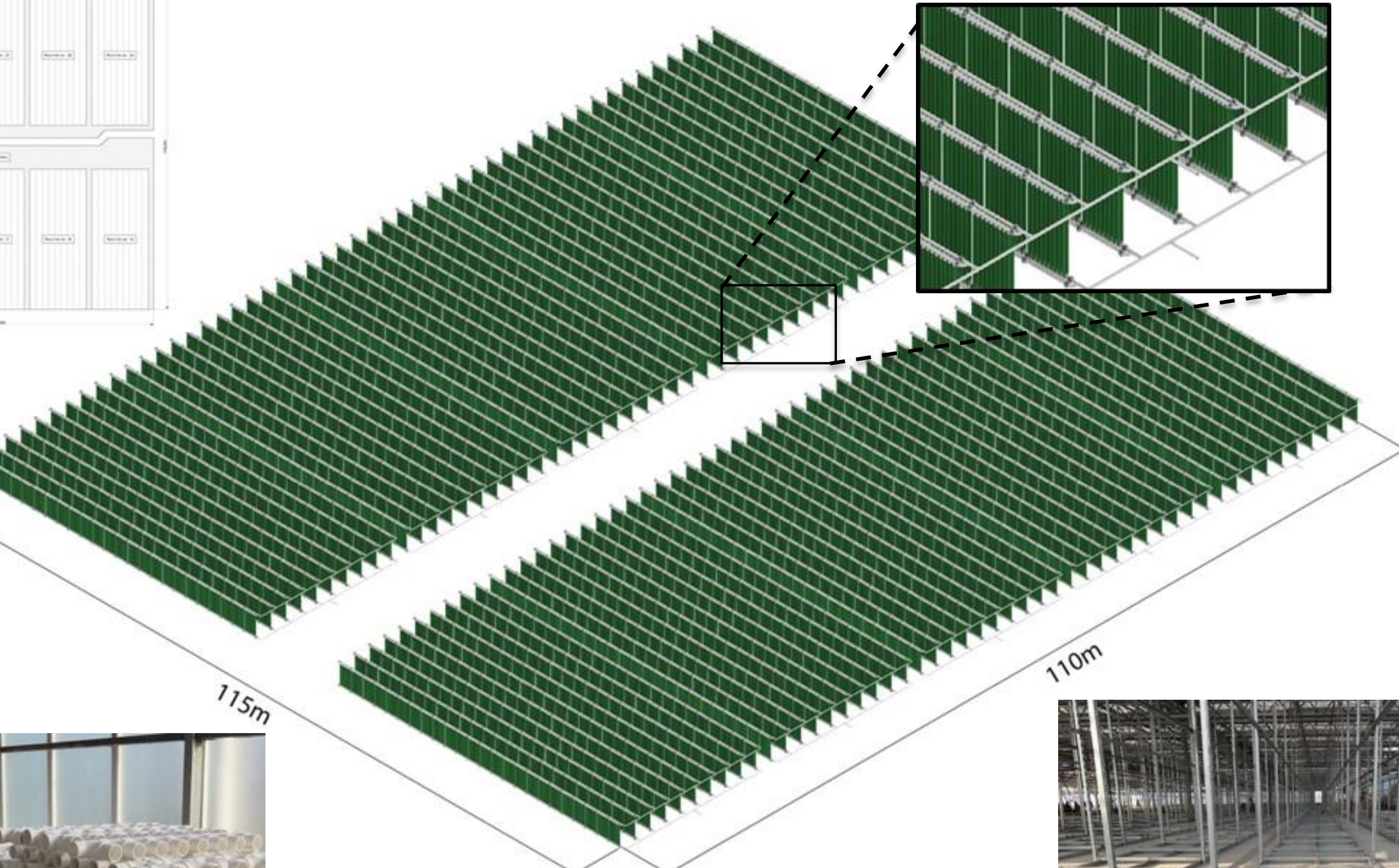


Current UK Concept for CO_2 Capture/Bio-product Production



Proposed Layout of a 3 Acre Photobioreactor

Zhengzhou, China



57,600 tubes
265,000 gallons

How Big?

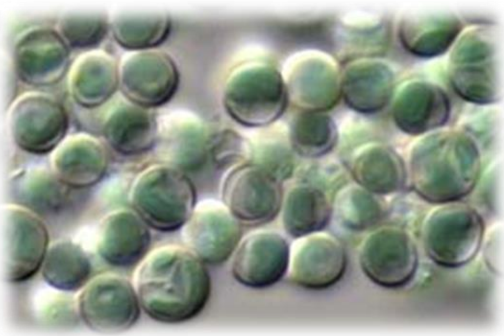
		1 MW	500 MW
Emissions	tons CO_2/MW	1	1
Emission rate	tons CO_2/day	24	12,000
@40% CO_2 Capture			
	tons CO_2/day	9.6	4,800
@1.78 tons CO_2/ton algae			
	tons algae/day	5.4	2,697
@35 g/m^2/day productivity			
	g algae/day	139,916	69.96×10^6
Land Required	acres	35	17,287

Why Bother?

- CO_2 utilization can be revenue positive
  - Bioplastics
  - Biofuels

- While achieving 40% CO_2 capture is unreasonable
  - Marginal CO_2 reductions can be achieved profitably
    - Offset reduction requirements

Ongoing Collaborations



Extremophiles

Cyanidium merolae
Dr. Pete Lammers
AZ State University

Culture Adaptation

Dr. Jennifer Stewart,
University of Delaware

Bioplastics

ALGIX™
Formulating The Potential of Algae

Student Engagement

Student involvement is an important focus of the project, leveraging creative problem solving and enthusiasm to solve real world research problems while developing the scientists and engineers of tomorrow.

- Student Employment / Experiential Learning
  - Undergraduate Engineers, Scientists, and Architects contribute to day to day research activities
- Senior Design Projects
  - CAER researchers act as customer/advisor to provide real world projects for student teams in Mechanical, Electrical, and Chemical Engineering
  - Students get exposed to research and researchers at CAER get prototype equipment and/or models to aid research
- College of Design Studios
  - Architecture and/or Interior Design students work on developing forward thinking designs, large scale instillations, next generation research facilities, and creative applications of current research
- Graduate Students / Postdocs

Acknowledgments

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Duke Energy

Department of Energy: U.S.-China Clean Energy Research Center

The UK algae team:

Dr. Mark Crocker
Dr. Czarena Crofcheck
Thomas Grubbs
Stephanie Kesner
Daniel Mohler
Tonya Morgan
Robert Pace
Dr. Eduardo Santillan-Jimenez
Aubrey Shea

and….. ca. 30 students

Future Work

- Reduce Cost / Increase Productivity
  - Optimized photobioreactor design and operation
  - Batch→ continuous dewatering process
- Conceptual Design of System Integrated with Power Plant
  - Mass and Energy Balances
  - Power plant integration (heat, flue gas, etc.)
  - Life Cycle Assessment
  - Techno Economic Analysis
- Biomass Utilization / Valorization
  - Focus on fuels/chemicals and biopoloymers
  - Investigate alternative / multi-product utilization pathways
  - Fate of NOx, SOx, heavy metals
- Systems Biology
  - Power plant outage mitigation system
  - Flue gas constituents on biomass composition
  - Abiotic Parameter Optimization