CO$_2$ Capture and Utilization using Microalgae

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Energy in Kentucky

- 92% of KY electricity from coal
- KY is 1.4% of US population
- KY produces:
  - 2.3% of US electricity
  - 3.7% of carbon dioxide
- KY electricity use:
  - 2.7% of US industrial
    - 35% of US stainless steel production
    - 40% of US aluminum production
  - 1.7% of US residential
CO₂ Capture and Utilization Using Microalgae

Project goals:

• Selection of sulfur-tolerant algae strains, identification of optimum conditions for cultivation/CO₂ capture

• Development of low cost cultivation medium

• Photobioreactor design

• Optimization of algae processing: algae recovery, dewatering

• Algae oil extraction and upgrading to fuel

• Utilization of algae cake
Overall Process

- CO₂ Lean Gas
- Recovered Media
- Recovered Water
- Recovered Nutrients (N,P,K)
- Proteins, Carbohydrates, Lipids
  - Liquid fuels, Biogas, etc.
Screening for Optimal Algae Strain

- 150 candidate strains identified from literature
- Screening for specific growth rate at pH 5.5 and 35 °C
- Four different growth media used

Promising strain of *Scenedesmus* identified – native to KY; currently our strain of choice

*Scenedesmus acutus*
Ponds vs. Photobioreactors (PBRs)

- Lower capital cost than PBR
- Easier to operate
- Contamination by other strains/organisms problematic
- Water loss by evaporation

- Better CO₂ capture efficiency
- Up to 3 times more photosynthetically active volume per unit area of land
- Efficient water utilization through low evaporative losses
- Biofilm formation problematic
Evolution of CAER Photobioreactor Design (2008 - present)
UK CAER Photobioreactor

Design Criteria:

• Inexpensive to build: cheap components, simple construction
• Inexpensive to operate: low liquid pumping and gas compression costs
• Easy to operate: maintain optimal conditions for algae growth (pH, adequate dissolved CO₂ concentration, etc.)
Key Design Features of UK Photobioreactor:

- PET packaging tubes: 3.5” diameter, 8’ in length; significantly cheaper than PVC or glass
- Flue gas introduced at return (3” pipe) – sufficient suction generated to enable flue gas entrainment; hence no compression costs
- Pressure driven; uses variable speed pump
- PBR cost estimated at < $1/L of photoactive volume at scale
- Modular design for easy scale up
- Dissolved oxygen reading is excellent indicator of algal growth/health
- Strong correlation between dissolved oxygen and PAR
Medium-scale (650 L) Experimental Growth Studies

Varicon PBR - Algal Growth Curve

- Varicon Growth Campaign
  (May 20th - June 7th 2010)

\[ y = 3.5182 \times 10^{-3}x^2 - 2.8371 \times 10^2x + 5.7194 \times 10^6 \]

R² = 9.6292E-01

Inoculation

Harvest
Carbon Balance (by Mass)

**Input**

- Total V of tank: 552 L
- Density of algae: 1.5 g/L
- g of C input (as CO₂): 667 g

**Output**

- Our *Scenedesmus* is 42% carbon via elemental analysis
- 348 g C in our *Scenedesmus*

\[
\frac{\text{g Carbon in algae}}{\text{g Carbon input}} \times 100 = \% \text{ Carbon used by algae}
\]

- 52% CO₂ used by our algae

400X magnification
Algae Harvesting

1. Flocculation and sedimentation
   - Leverages experience in coal preparation and waste products utilization
   - Low molecular weight cationic flocculant (3 ppm)

2. Decanting tank increases density of biomass (2-10% solids)

3. Further dewatering via filtration (up to 28% solids)
Algae Harvesting

Flocculant-Assisted Sedimentation

- 828 g of algae in system (based on dry mass samples)
- Recovered 751 g of dried algae 90% of algae in system was recovered
- 99% of H₂O recovered
- All water, nutrients and unrecovered algae recycled back to system

Pre-flocculation
1.56 g/L

Left over after flock

Flocked biomass
55 g/L
East Bend Station Demonstration Facility

- Define kinetics of process
  - Monitor dissolved CO$_2$ and O$_2$ to determine photosynthetic rate
  - Help size large system and next generation design
- Gain understanding of real capital and operating costs
  - Minimize energy consumption
- Measure biomass composition to track heavy metals and other flue gas constituents
East Bend Photobioreactor (18,000 L)

East Bend Growth Study: Winter 2012
Productivity & Photosynthetically Active Radiation (PAR)

Average growth rate = 10 g/(m².day)
East Bend Growth Study: Summer 2013

Average growth rate = 39.4 g/(m².day)
Techno-economic Analysis

Effect of payback period (10 vs. 30 years), capital cost reduction and algae growth rate

![Graph showing the effect of payback period, capital cost reduction, and algae growth rate.](image-url)
Algal Biomass Utilization

Value

FDA Regulated Applications

Nutraceuticals
Personal Hygiene
Cosmetics
Food Products

Animal Feed Supplements
Animal Feed
Aquaculture Feed

Fuels
Fertilizers
Energy (Combustion)
Conclusions

• CO₂ recycling using microalgae is feasible from a technical point of view:
  - a low cost PBR has been designed, built and operated
  - a low cost methodology for algae harvesting and dewatering has been devised
  - areal productivity of routinely ≥ 30 g/m²/day (summer) and ≥ 10 g/m²/day (winter) has been demonstrated at significant scale (18,000 L)
  - lipid extraction and conversion to biodiesel and diesel range hydrocarbons has been demonstrated

• At present, the economics remain uncertain. Current calculations suggest that the cost of capturing and recycling CO₂ using microalgae will fall close to $1600/ton CO₂

• The largest sources of cost reside in the algae culturing stage of the process, corresponding mainly to the capital cost of the photobioreactor system

• The overall economics will be driven by the value of the biomass - hence, the production of high value products is a pre-requisite
Summary: From Flue Gas to Liquid Fuels

CO₂ in flue gas

Algae cultivation

Flocculation, sedimentation & gravity filtration

Diesel-range hydrocarbons

Catalytic upgrading

Column purification

Lipid extraction

Acknowledgements

- KY Department of Energy Development and Independence
- Duke Energy
- Department of Energy: CERC-ACTC
- The UK algae team:
  Michael Wilson  
  Dr. Jack Groppo  
  Dr. Eduardo Santillan-Jimenez  
  Dr. Czarena Crofcheck  
  Aubrey Shea  
  Xinyi (Abby) E  
  Tonya Morgan  
  Robby Pace  
  Sarah Marques  
  Renan Sales  
  Stephanie Kesner
Questions?

http://greenchicgeek.blogspot.com/2009_08_01_archive.html