Microalgae Commodities from Coal Plant Flue Gas CO$_2$
U.S. Department of Energy, Office of Fossil Energy, NETL

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MicroBio Engineering Inc.
John Benemann, Principal Investigator, Tryg Lundquist Co-P.I.
- Facilities Designs
- Algae Equipment
- R&D and Business Consulting
- Techno-Economic Analyses
- Life Cycle Assessments

- Wastewater Reclamation
- Nutraceuticals, Aquafeeds
- Biofuels, Biofertilizers

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200-m²

75-m²

0.5-m²

Mobile Pre-Fabricated

MicroBio Engineering
MBE’s RNEW® Process for wastewater treatment and biofuels production

Recycle
Nutrients
Energy
Water

Solar Radiation
Wastewater N,P
Raceway Ponds
Flue gas or CO₂
Harvesting
Biofuels
Reclaimed Water
Fertilizers
NETL Project Objectives

• Primary Objective: Develop detailed techno-economic and life cycle assessments specifically for OUC SEC coal-fired power plant with two microalgae CO₂ utilization/mitigation options:
  1. Biogas production to replace coal for maximum CO₂ mitigation (task modified to produce vehicle biofuel).
  2. Commodity animal feeds production for maximum economic benefit of flue gas CO₂ use.

• Secondary Objective: Demonstrate algae biomass production using OUC SEC flue gas with native algae and conversion to biogas; evaluate suitability as animal feed.
Participants

- MicroBio Engineering Inc. (MBE), Prime, P.I.: John Benemann, CEO
  TEAs, LCAs, gap analyses, ponds for OUC, UF, Project management
- Subrecipients:
  - Orlando Utilities Commission (OUC): provide data on SEC power plant, emissions, etc.; Operate test ponds at SEC with flue gas CO₂
  - Univ. of Florida (UF): operate test ponds, algae anaerobic digestion
  - Arizona State Univ.: Train OUC and UF staff in algae cultivation
  - Scripps Institution of Oceanography (SIO), Lifecycle Associates (LCA), SFA Pacific Inc.: LCA, TEA and engineering assistance to MBE

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1. Algae → biogas for power generation (1st Year)

- OUC-SEC ~900 MW Coal-fired PP
- Landfill
- Landfill Gas
- Flue Gas CO₂ & Electricity
- Future Algae Farm (100 ponds; 1,000 acres)
- Biogas
- Renewable Natural Gas Vehicle Fuel
- Wastewater (optional)
2. Algae → animal feed production (this year)

- OUC-SEC ~900 MW Coal-fired PP
- Landfill
- Landfill Gas
- Flue Gas CO₂ & Electricity
- Future Algae Farm (100 ponds; 1,000 acres)
- Animal Feeds
- Freshwater Ag Fertilizers
- 2. Algae à animal feed production (this year)
Technology Background
3-acre raceway pond with CO$_2$ injection

Lamellar settler for harvesting
Sump for CO$_2$ transfer
Paddle wheel
Pond floors lined with clay.

Four 1.25-ha raceways in Christchurch, New Zealand. PI: Rupert Craggs, NIWA
Hawaii spirulina farm with large raceways
Earthrise Nutritionals LLC plant is roughly equivalent to a module of larger modeled farm.

50 acres of paddle wheel mixed raceway ponds for Spirulina production.
Algae demonstration plant design at a small fossil power plant for a California utility.

MBE design: Six 5-acre raceways with smaller ponds for inoculation.
Wastewater treatment is enhanced by CO$_2$ addition.

Add CO$_2$ to achieve complete nutrient assimilation during wastewater treatment.
Full-scale wastewater project in California. MBE & Cal Poly biofuel R&D supported by DOE BETO.

1. Facultative Ponds
2. Two 3.5-acre raceways
3. Settling Ponds
Algae are coagulated, settled, and solar dried.

~100,000 gallons of 3% solids algae in decanted settling basin

Concrete drying pad

Solar dried algae
5-acre covered lagoon digester at a California dairy. Such low-cost design could be used for algae digestion.
Experimental Work
Task 2: Experimental Work at OUC and UF

• Operate four 3.5-m$^2$ ponds at each location

• At OUC, compare flue gas to pure CO$_2$
  – Productivity, metals concentration (water & biomass)

• At OUC and UF, determine seasonal productivities at optimized hydraulic residence times (HRTs)

• At UF, determine methane yields at one biomass concentration in batch methane potential tests
Flue gas from scrubbers to condensate traps to pump to pilot ponds
Flue gas from scrubbers to condensate traps to pump to pilot ponds
Microalgae observed at OUC-SEC Ponds
Filamentous algae dominate at OUC, which allows for easy harvesting of the biomass.
Filamentous algae dominate at OUC.
Pilot ponds at
University of Florida - Gainesville
Bioflocculating cultures that settle
Flue gas cultures have been more productivity than pure CO$_2$ cultures. Follow-up experiments to confirm.

Year-1 OUC Harvest Productivity (VSS g/m$^2$-day)
Site Selection
Potential Sites near OUC-SEC

Site Selected for Study
Layout of 400 ha Algae Production Ponds near OUC-SEC
Modeling
Modeling assumptions are based on MBE experimental data and analysis.

- Annual average productivity: 33 g/m²-d
  - 15 g/m²-d: autotrophic growth on flue gas CO₂
  - 18 g/m²-d: mixo-/hetero-trophic growth on organic C from recycle of whole anaerobic digestate to raceways
  - 4.5 g/m²-hr: Peak summer productivity on flue gas CO₂
- 45% Overall loss factor in flue gas CO₂ supply to ponds
- 90% efficiency in gravity harvesting (losses are recycled to ponds)
- Biogas production: 0.32 L methane/g VSS
- Nutrient recycle losses: 10% nutrient loss
Power plant assumptions are based on OUC Stanton Energy Center actual values.

- **Coal Type:** Illinois Basin Bituminous
- **2014 CO₂ Emissions:** 5,076,875 tons
- **Flue gas composition (Post Desulfurization)**
  - 11% CO₂
  - 80 ppm SO₂
  - 140 ppm NOx
  - 100 ppm CO
  - 1.5 ug/scm Hg
Techno-Economic Analysis
Renewable natural gas (RNG) production from algae is straightforward and allows for use of wastewater.
Capex is mostly ponds, site, and land for RNG case.

Total Capital Investment: $132,000,000

Debt: Equity 80%:20%

Bond Payment (20 yrs at 5%): $8,500,000 /yr

Return on Equity (15%): $3,900,000 /yr
Opex is mostly labor, water, and maintenance for RNG case. Co-product revenue is needed for $\text{CO}_2$ utilization.

Distribution of opex and annualized capex

- Bond Repayment: $8,500,000 /yr
- Return on Equity: $3,900,000 /yr
- Operating Costs: $11,600,000 /yr
- Biogas Revenue: $933,000 /yr @ $2 /mmBTU
- $\text{CO}_2$ Utilization Cost: $816 /\text{metric ton}$ (without coproducts)
Wastewater treatment and transportation carbon credits are potential revenue sources.

- Wastewater Credit ($1,750/MG)
- RIN/LCFS Credits ($17/mmBtu)*

Mitigation Cost Reduction:
- $816/mt (cost with out coproducts)
- $230/mt (wwt credit)
- $102/mt (LCFS credit)
- $129/mt (RIN credit)

$355 /mt

*Preliminary
Animal feed case uses clean water and fertilizer.

Cost per ton feed and per ton CO₂ fixed to be determined.
Capex is similar to biogas case but with dewatering costs.

Total Capital Investment: $115,000,000
Percent financed by debt: 80%
Percent Financed by equity: 20%
Bond Payment (20 yr pond at 5%): $7,400,000 /yr
Return on Equity (15%): $3,500,000 /yr
Opex is similar to RNG case but with fertilizer costs added.

- **Bond Repayment:** $7,400,000 /yr
- **Return on Equity:** $3,500,000 /yr
- **Operating Costs:** $11,900,000 /yr
- **Feed Revenue @ $350 /mt:** $10,200,000 /yr
- **CO₂ Utilization Cost:** $249/metric ton

### Pie Chart

- **Labor, 20%**
- **Depreciation, 27%**
- **Make-up Water, 15%**
- **Fertilizer, 11%**
- **Electricity, 9%**
- **Equipment Maintenance, 12%**
- **Property Insurance & Tax, 6%**

**Preliminary**
Conclusions

Economical CO$_2$ mitigation with biogas will require a combination of:

- WWT credit
- RIN and LCFS credits
- Further cost cutting/process improvements
Work in Progress

• Production of animal feed instead of biogas
• Land-use change
• Albedo change
• Non-GHG LCA impacts
• Site Specific Layout
• Additional sensitivity analysis
Thank You!

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