Microalgae Commodities from Coal Plant Flue Gas CO_2

U.S. Department of Energy, Office of Fossil Energy, NETL

Cooperative Agreement DE-FE0026490, 10/01/15– 09/30/17

May 24, 2017

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

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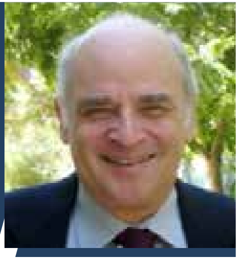
- Wastewater Reclamation
- Nutraceuticals, Aquafeeds
- Biofuels, Biofertilizers


J. Benemann


T. Lundquist

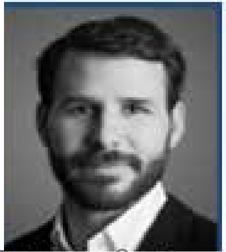

Ian Woertz

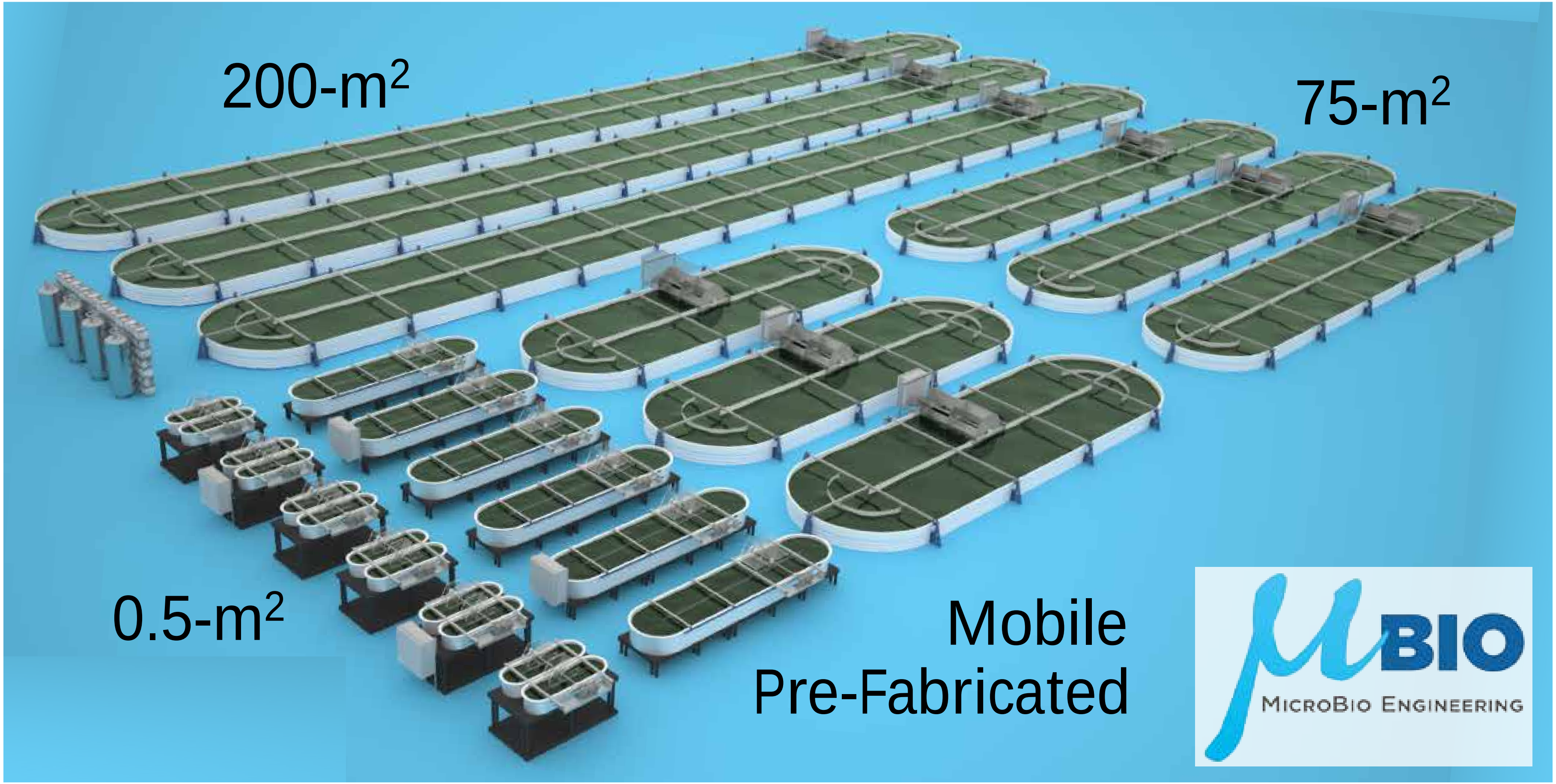

Ruth Spierling


Braden Crowe


Matt Hutton


Neal Adler


Kyle Poole


200-m2
75-m2
0.5-m2
Mobile
Pre-Fabricated
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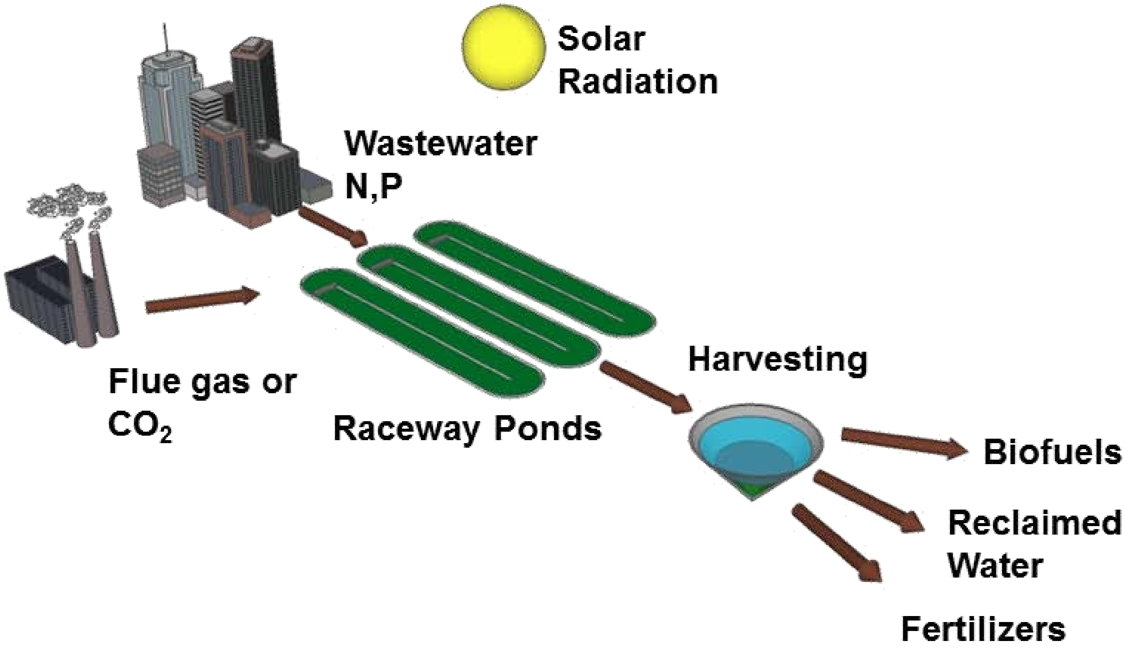
MBE's RNEW® Process for wastewater treatment and biofuels production

Recycle
Nutrients
Energy
Water



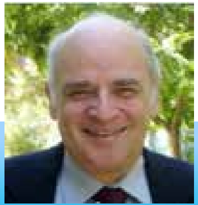
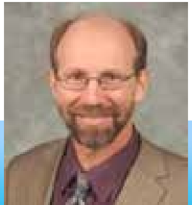
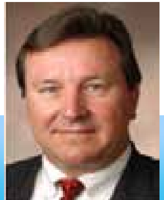
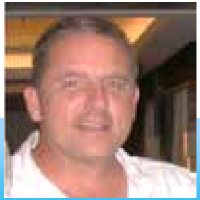
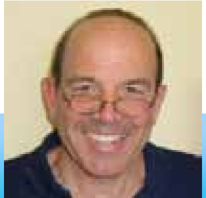
NETL Project Objectives

- **Primary Objective**: Develop detailed techno-economic and life cycle assessments specifically for OUC SEC coal-fired power plant with two microalgae CO_2 utilization/mitigation options:
  1. Biogas production to replace coal for maximum CO_2 mitigation (task modified to produce vehicle biofuel).
  2. Commodity animal feeds production for maximum economic benefit of flue gas CO_2 use.

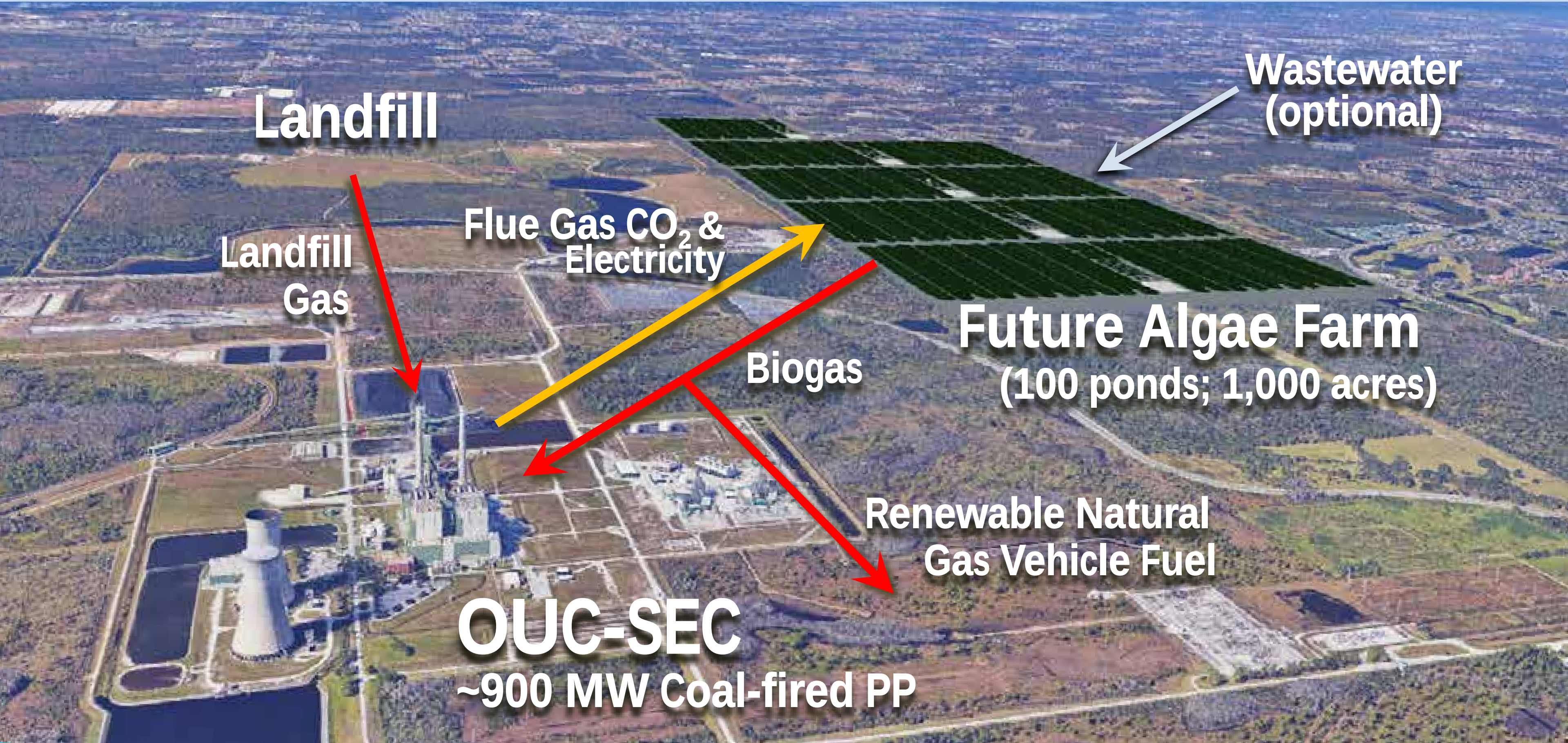
- **Secondary Objective**: Demonstrate algae biomass production using OUC SEC flue gas with native algae and conversion to biogas; evaluate suitability as animal feed.

Participants

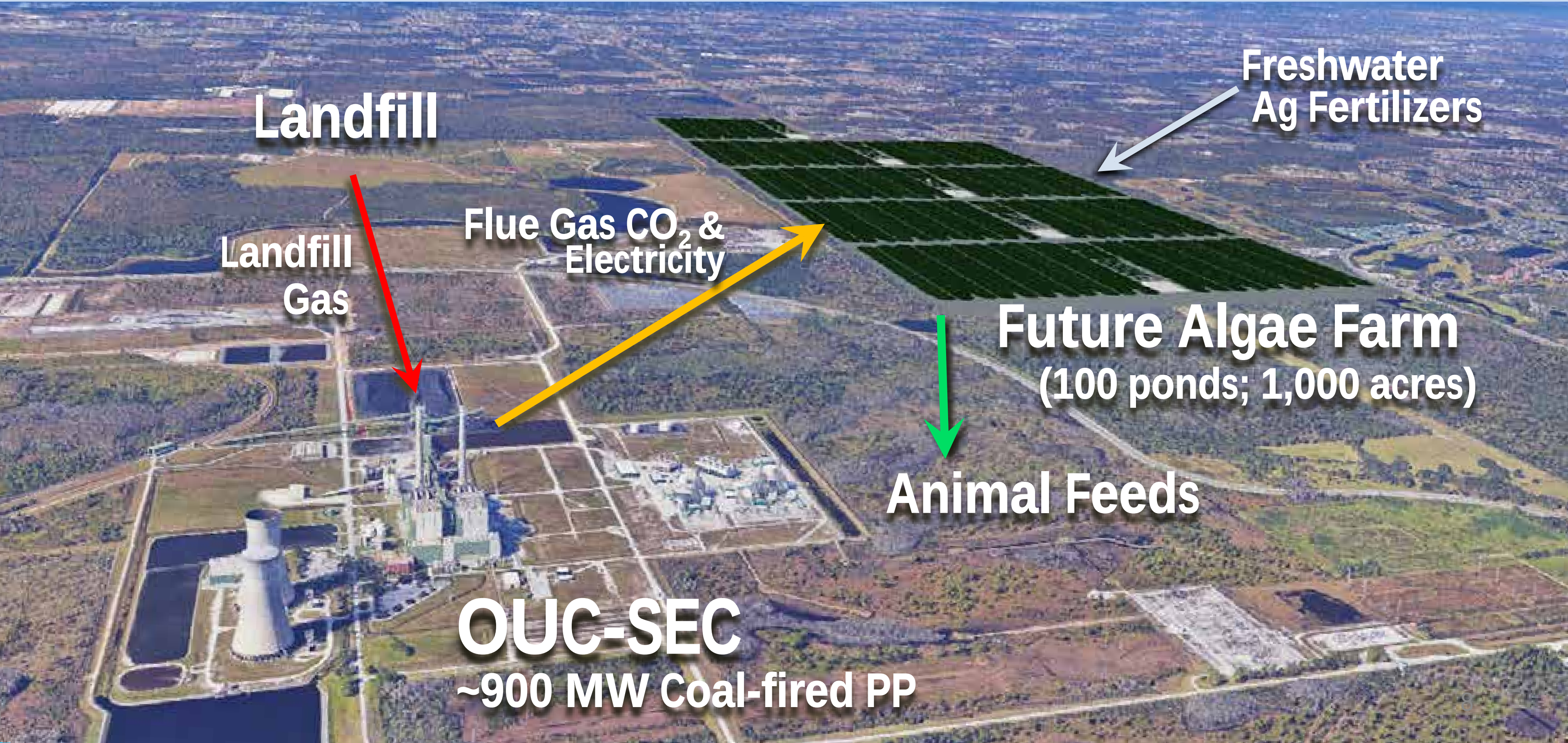
- **MicroBio Engineering Inc. (MBE), Prime , P.I.: John Benemann, CEO**
  TEAs, LCAs, gap analyses, ponds for OUC,UF, Project management
- **Subrecipients:**
  - **Orlando Utilities Commission (OUC)**: provide data on SEC power plant, emissions, etc. ; Operate test ponds at SEC with flue gas CO_2
  - **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

MBE John Benemann	MBE Tryg Lundquist	OUC Rob Teegarden	UF Ann Wilkie	ASU Tom Dempster	SIO Dominick Mendola	LCA Stefan Unnasch	SFA Dale Simbeck
							

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



2. Algae à animal feed production (this year)



Technology Background

3-acre raceway pond with CO_2 injection

Lamellar settler for harvesting

Sump for CO2 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.

Algae are coagulated, settled , and solar dried.

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

Solar dried algae

Concrete drying pad

5-acre covered lagoon digester at a California dairy. Such low-cost design could be used for algae digestion.

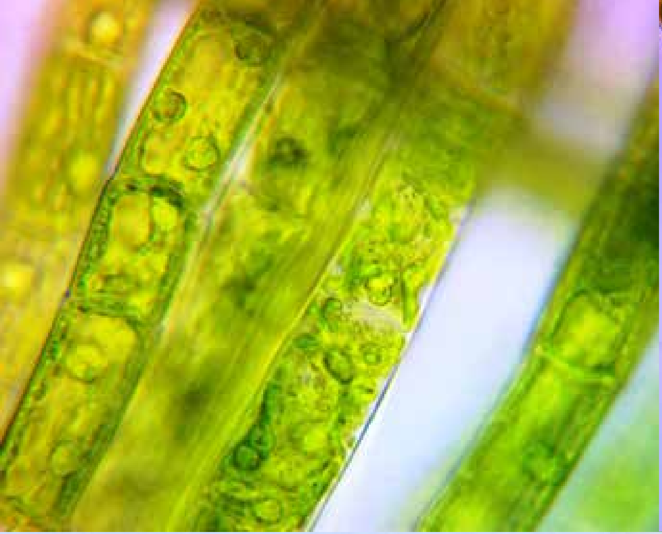
Experimental Work

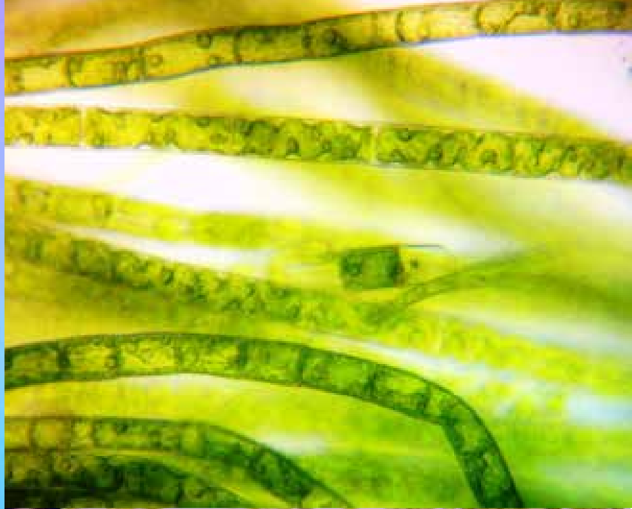
Task 2: Experimental Work at OUC and UF

- 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



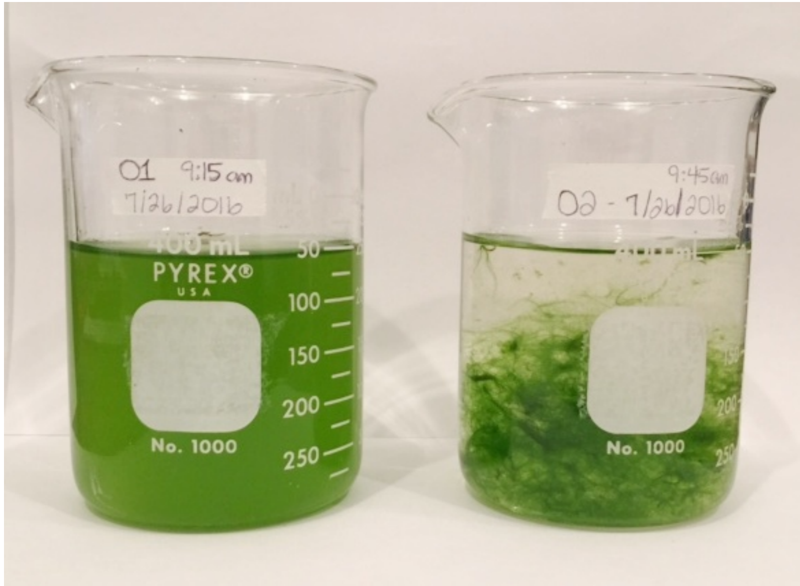


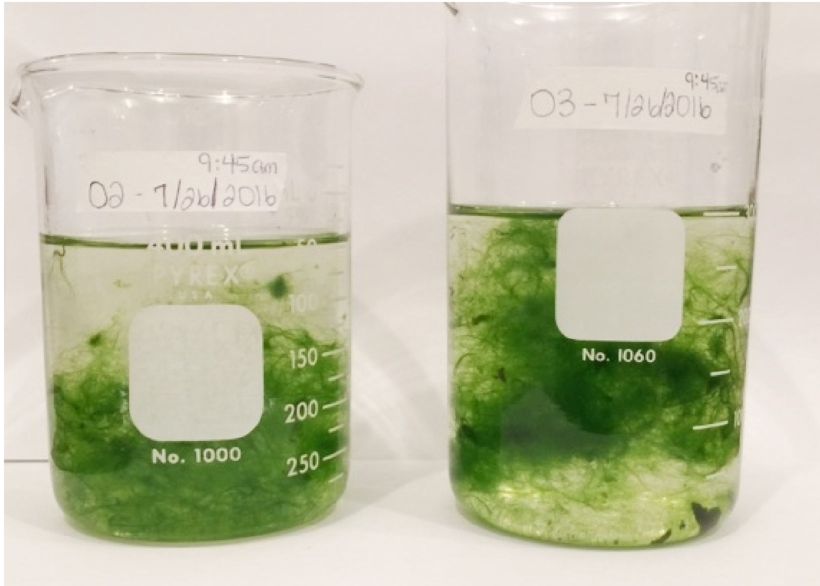
Microalgae observed at OUC-SEC Ponds




Filamentous algae dominate at OUC, which allows for easy harvesting of the biomass.

Filamentous algae dominate at OUC.

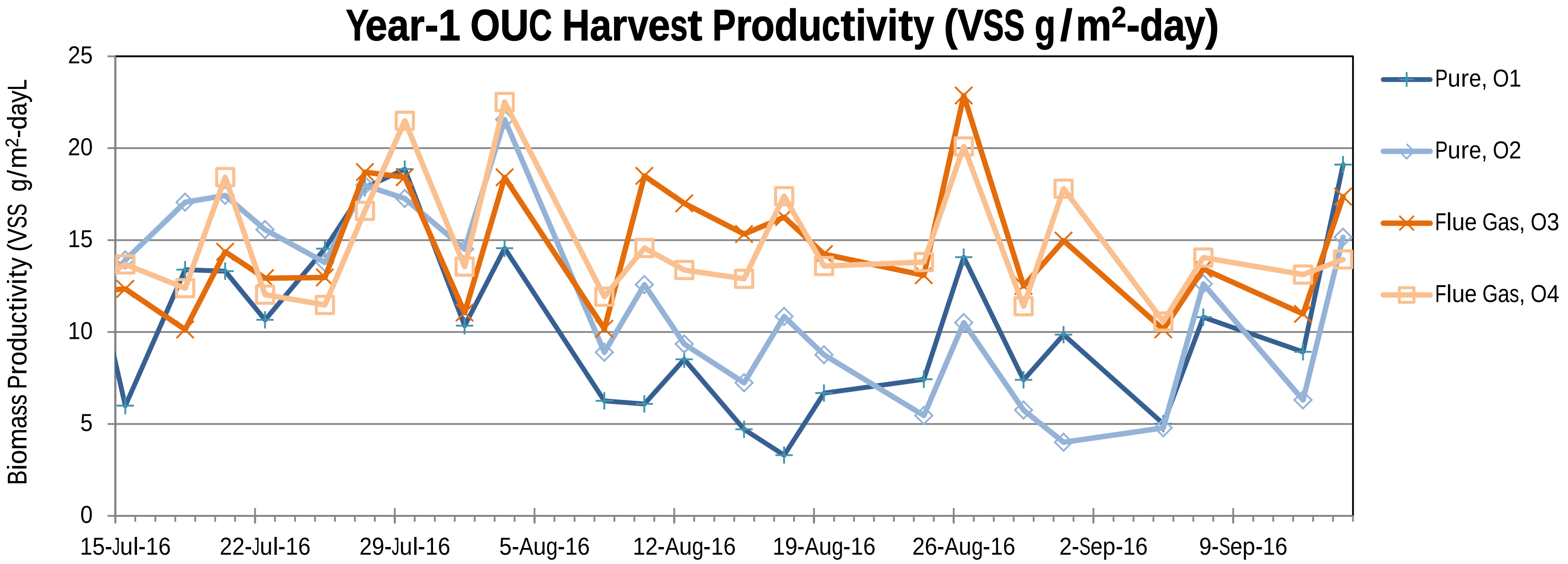




Pilot ponds at University of Florida - Gainesville

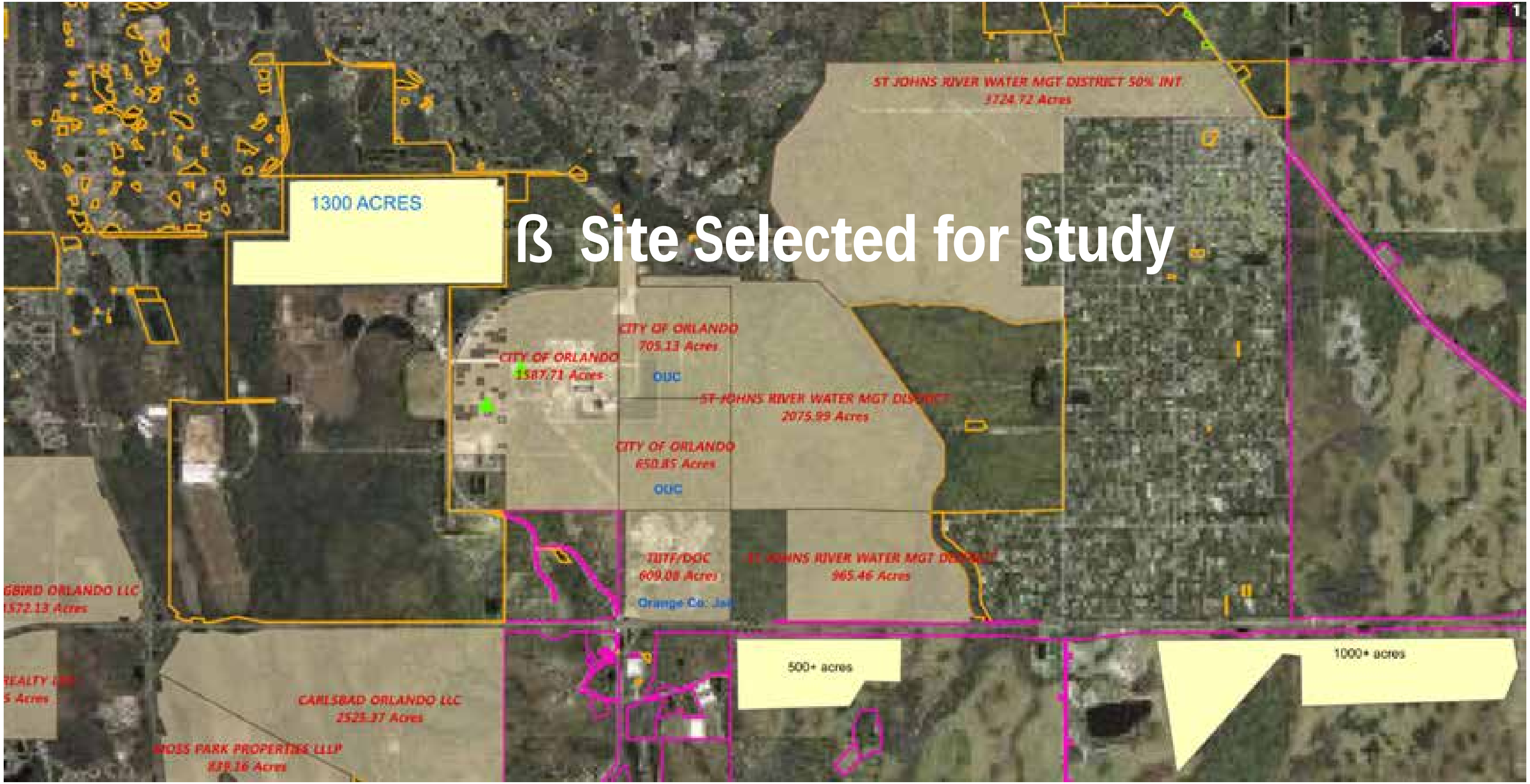
Bioflocculating cultures that settle

Flue gas cultures have been more productivity than pure CO_2 cultures. Follow-up experiments to confirm.



Site Selection

Potential Sites near OUC-SEC



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/m^2-d
  - 15 g/m^2-d: autotrophic growth on flue gas CO_2
  - 18 g/m^2-d: mixo-/hetero-trophic growth on organic C from recycle of whole anaerobic digestate to raceways
  - 4.5 g/m^2-hr: Peak summer productivity on flue gas CO_2
- 45% Overall loss factor in flue gas CO_2 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

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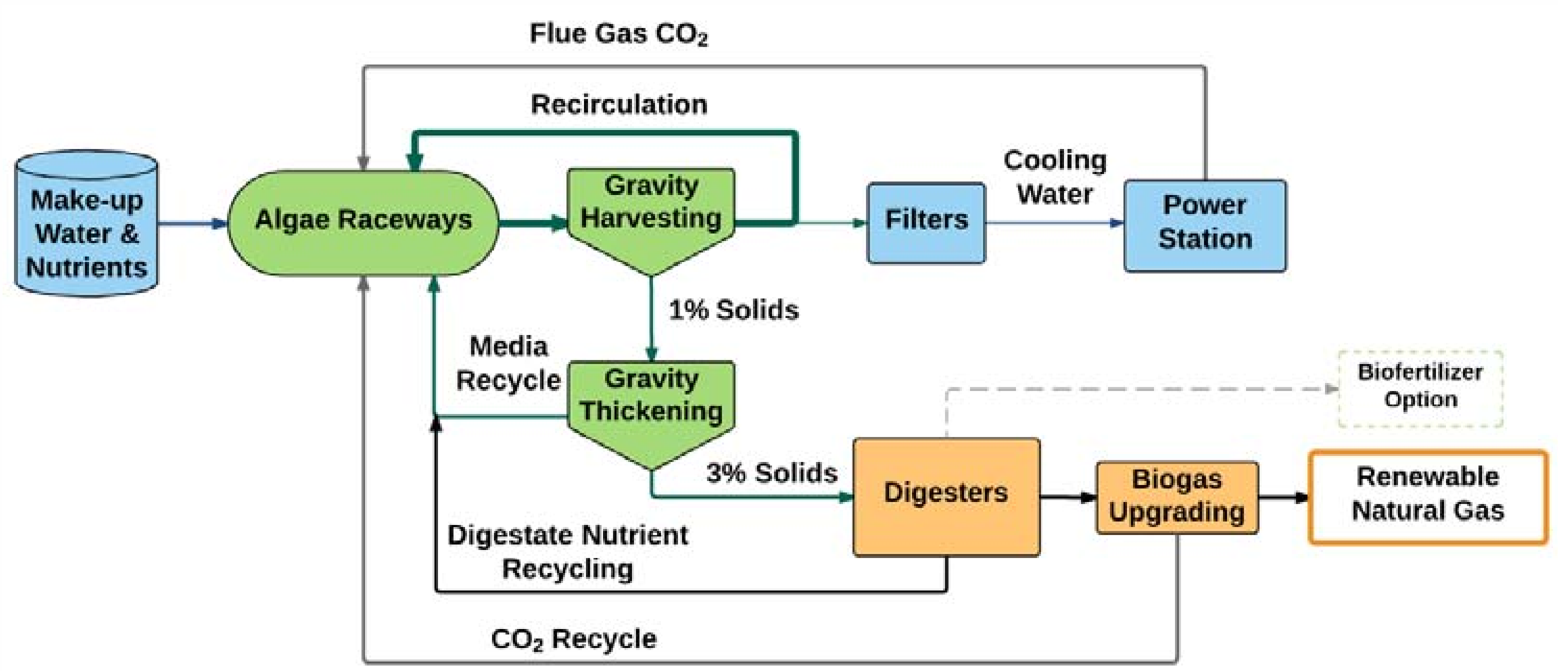
Power plant assumptions are based on OUC Stanton Energy Center actual values.

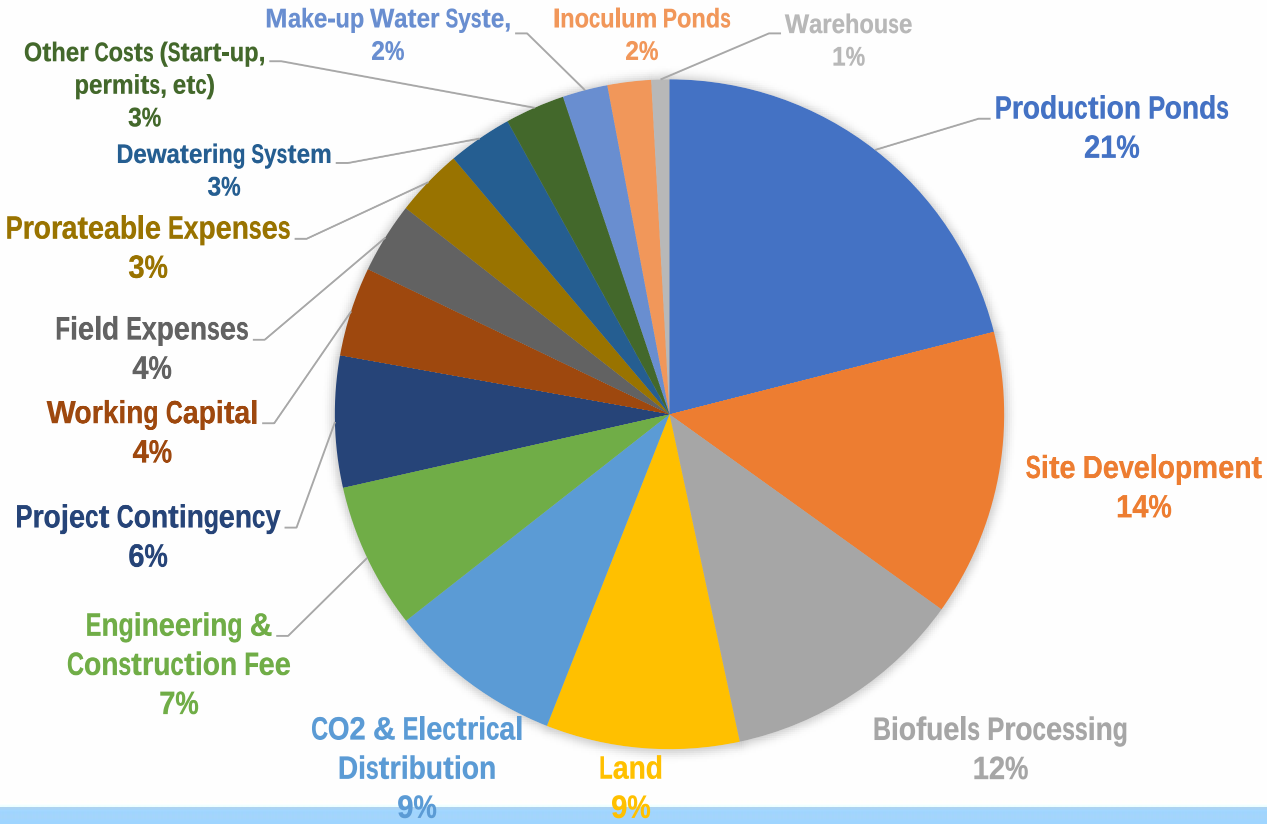
- Coal Type: Illinois Basin Bituminous
- 2014 CO_2 Emissions: 5,076,875 tons
- Flue gas composition (Post Desulfurization)
  - 11% CO_2
  - 80 ppm SO_2
  - 140 ppm NOx
  - 100 ppm CO
  - 1.5 ug/scm Hg

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

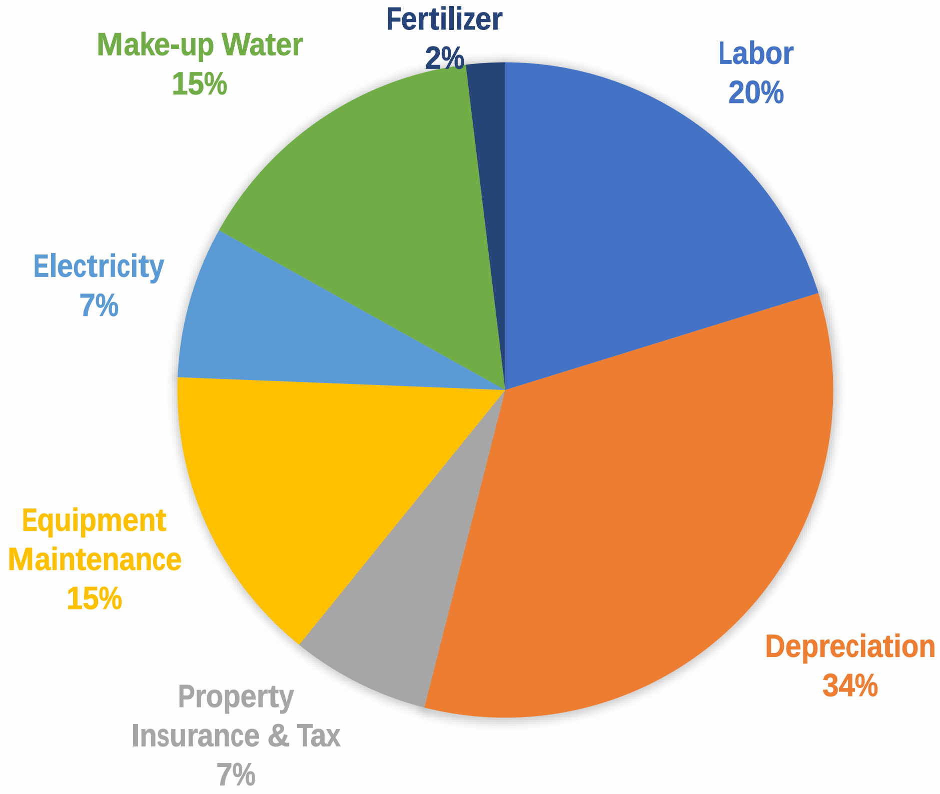
Debt: Equity **80%:20%**

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

Return on Equity (15%):
$3,900,000 /yr

Preliminary

Opex is mostly labor, water, and maintenance for RNG case. Co-product revenue is needed for CO_2 utilization.



<u>Distribution of opex and annualized capex</u>

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

CO_2 Utilization Cost: **$816 /metric ton**
(without coproducts)

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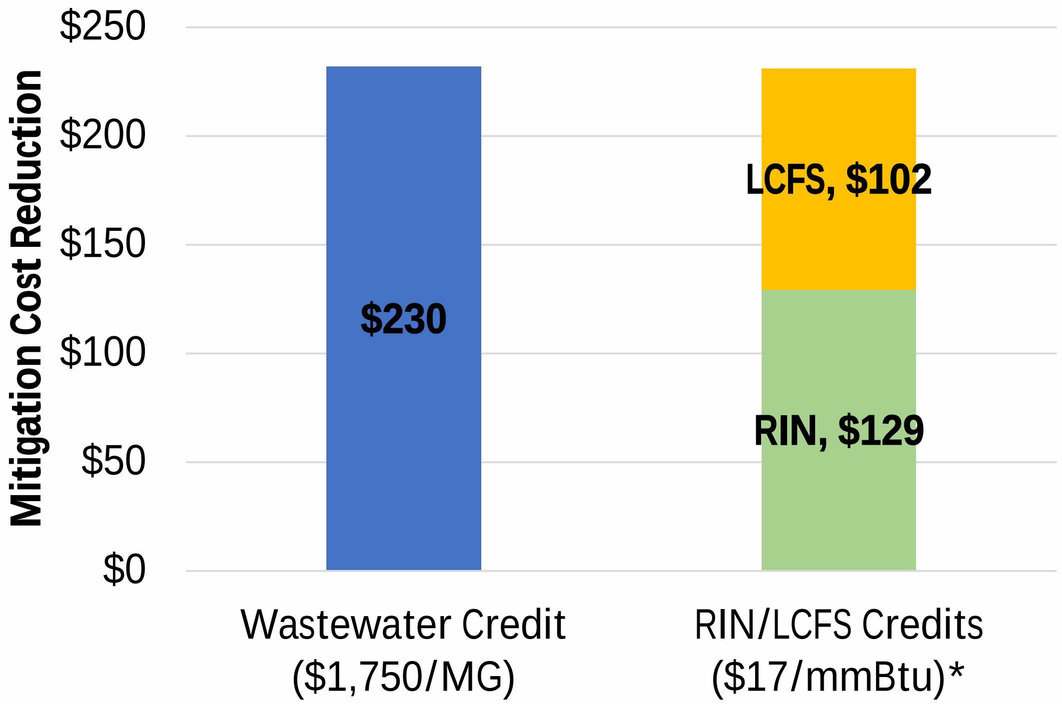
Preliminary

Wastewater treatment and transportation carbon credits are potential revenue sources.

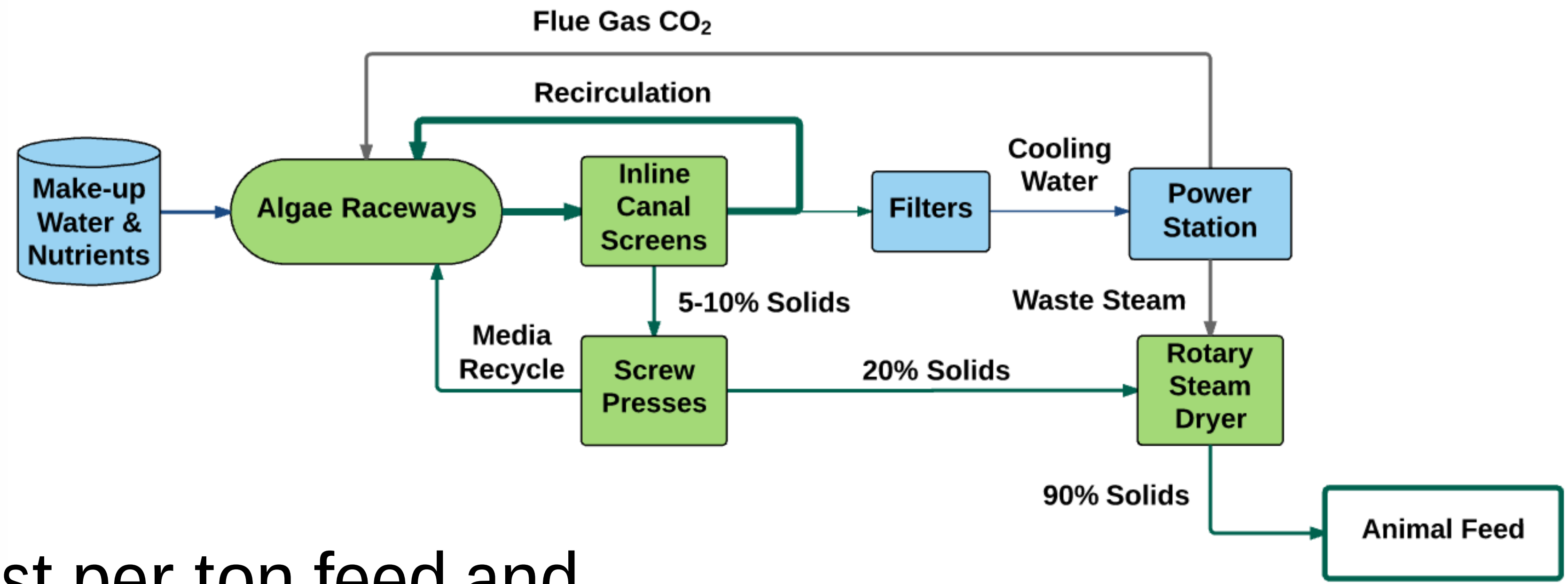


$816/mt (cost with out coproducts)
-$230/mt (wwt credit)
-$102/mt (LCFS credit)
-$129/mt (RIN credit)

$355 /mt

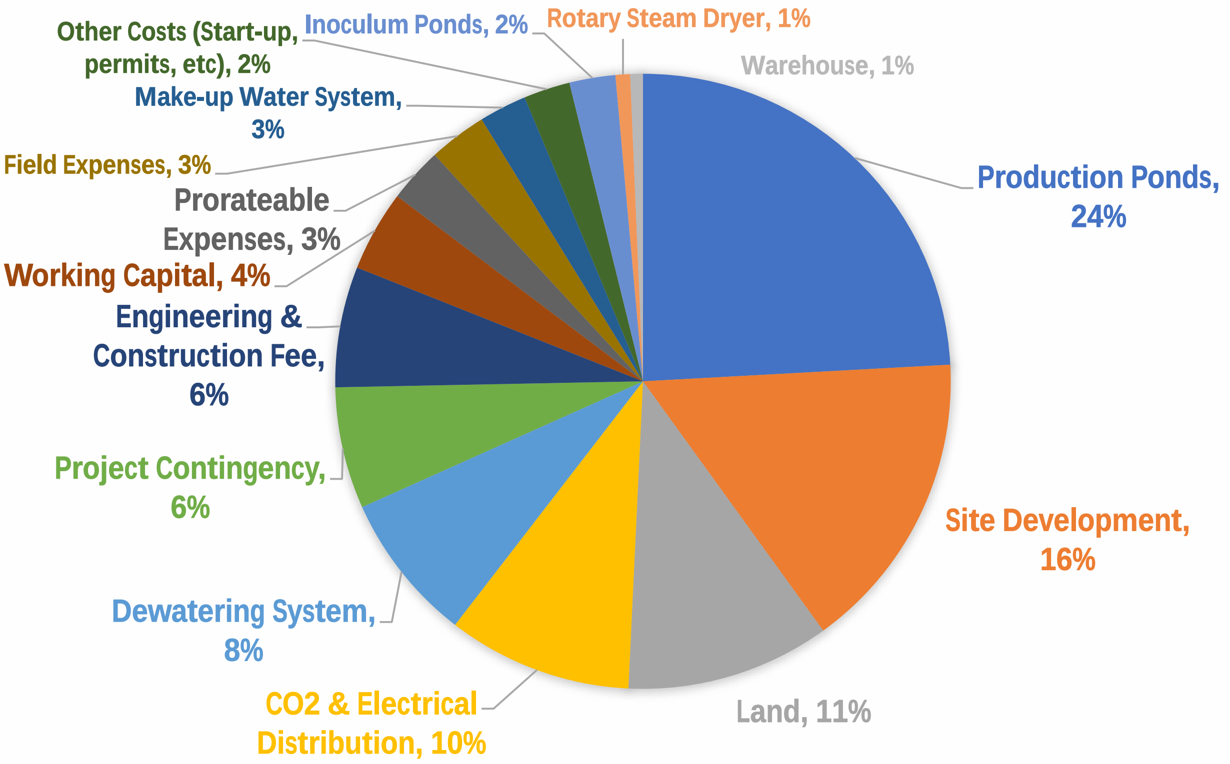
Preliminary

Animal feed case uses clean water and fertilizer.



Cost per ton feed and
per ton CO_2 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%

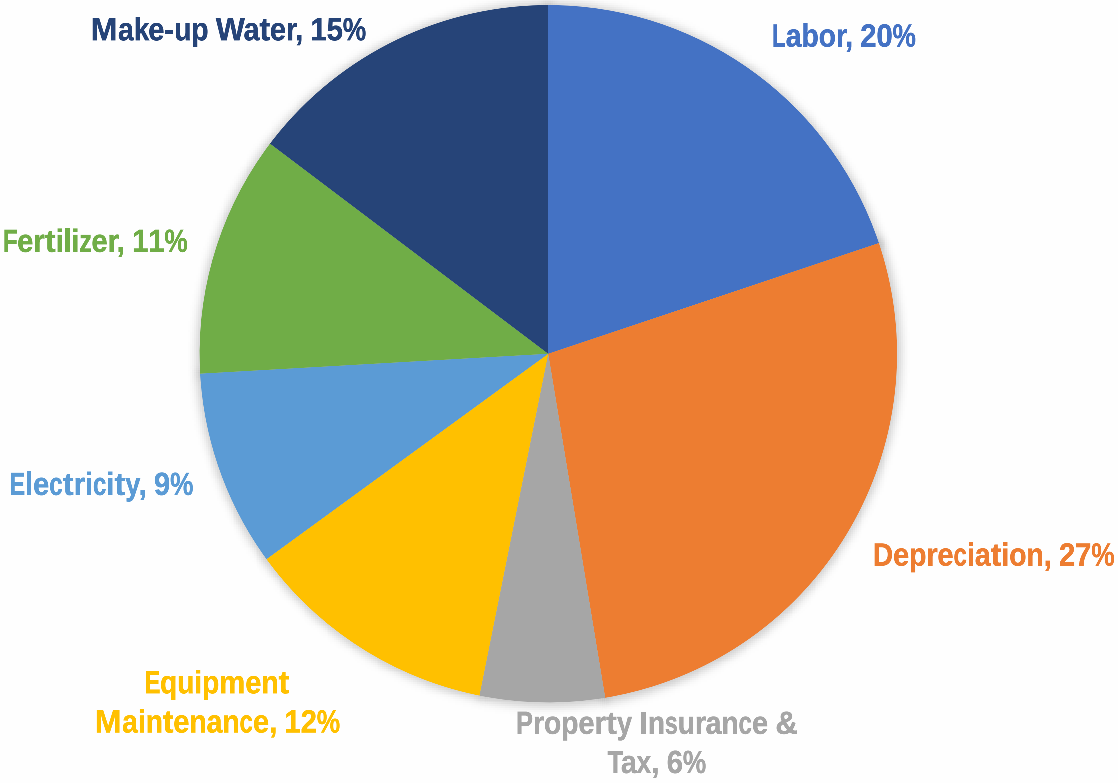
Percent Financed by equity:
20%

Bond Payment (20 yr pond at 5%):
$7,400,000 /yr

Return on Equity (15%):
$3,500,000 /yr

Preliminary

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

CO_2 Utilization Cost
$249/metric ton

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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TrygLundquist@MicroBioEngineering.com