Microalgae Commodities from Coal Plant Flue Gas CO_2

DE-FE0026490, 10/01/15– 06/30/18, Andy Aurelio, Program Manager

Funding: DOE NETL: $1,035,827

Orlando Utilities Commission (OUC) Cost Share: $325,765

<u>John Benemann</u>, P.I., Tryg Lundquist, Co-P.I., Kyle Poole, Project Engineer

MicroBio Engineering Inc., San Luis Obispo, California

PROJECT 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. (ASU)**: help train OUC, UF staff in algae cultivation

– **Scripps Institution of Oceanography (SIO), Life Cycle Associates LLC, and SFA Pacific Inc.**: LCA, TEA and engineering assistance to MBE

MBE John Benemann

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OUC Rob Teegarden

UF Ann Wilkie

ASU Tom Dempster

SIO Dominick Mendola

LCA Stefan Unnasch

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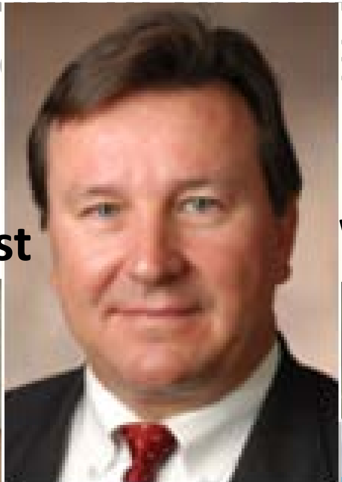
OUC, Rob Teegarden



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OUC
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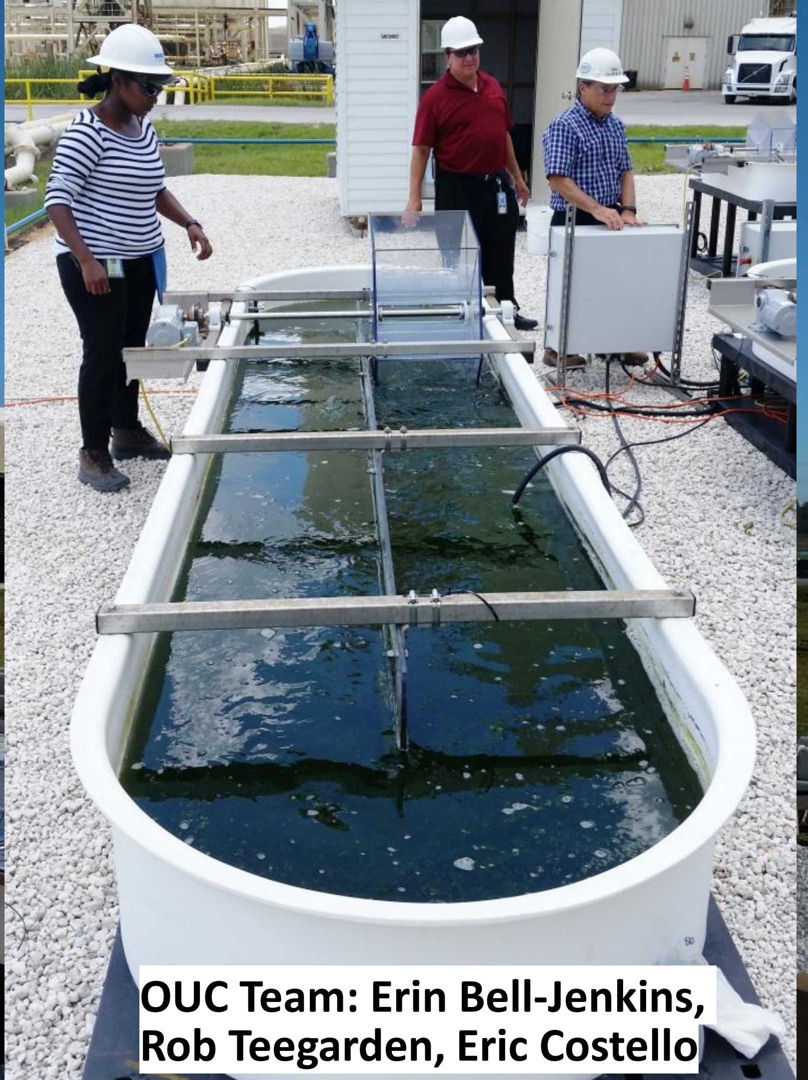


OUC Team: Erin Bell-Jenkins, Rob Teegarden, Eric Costello

MicroBio Engineering

San Luis Obispo, California

www.microbioengineering.com

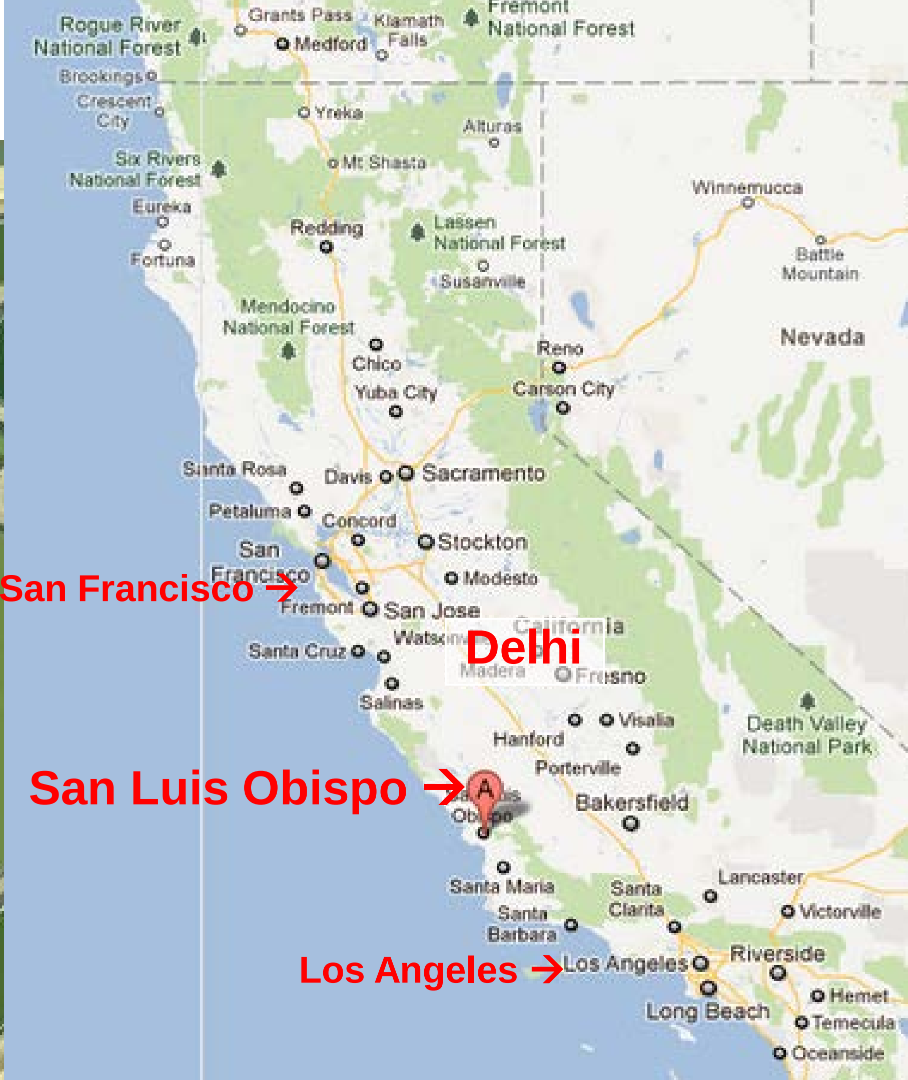
- Facility Designs
- Algae Equipment
- Research and Development
- Business Consulting
- Techno-Economic Analyses
- Life Cycle Assessments
- Wastewater Treatment



Delhi, California, wastewater treatment with raceway ponds

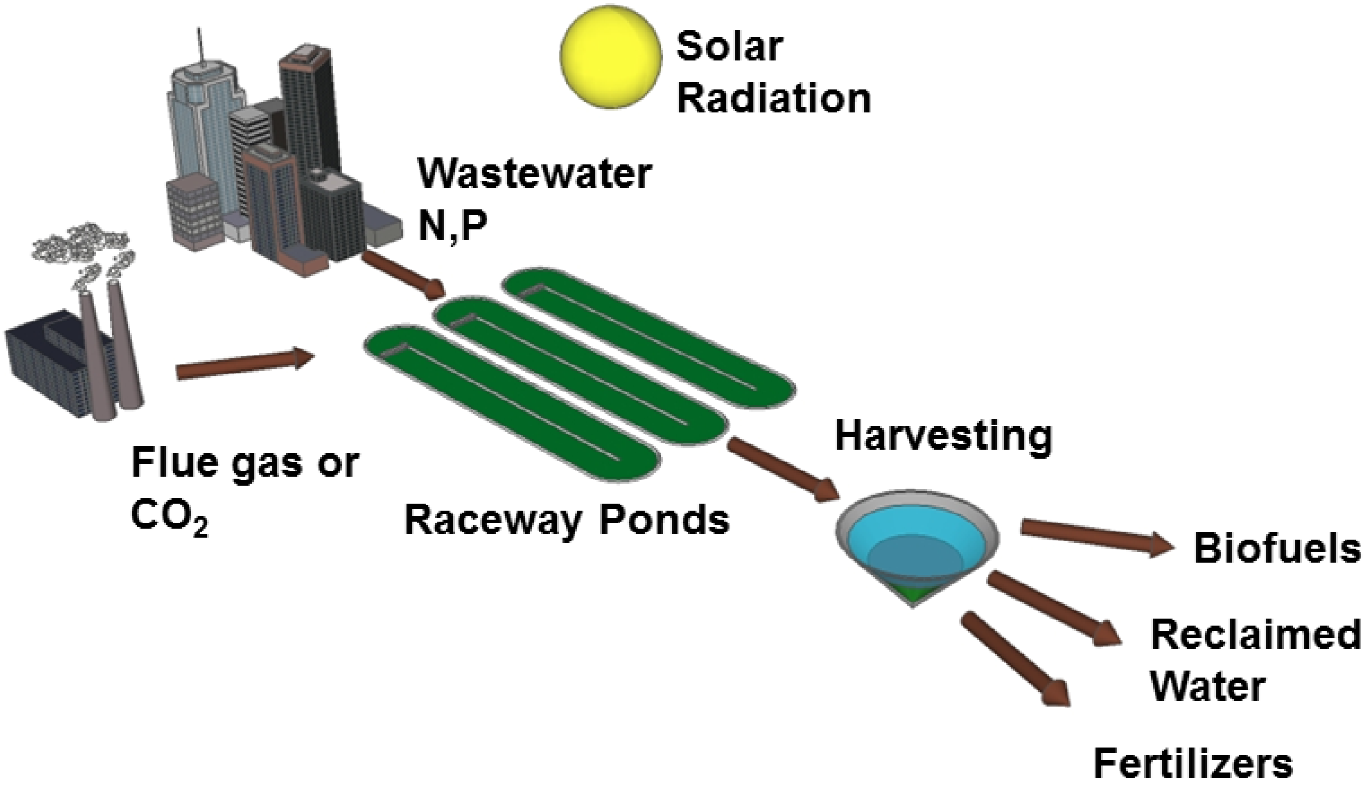
μBIO
MICROBIO ENGINEERING

CAL POLY

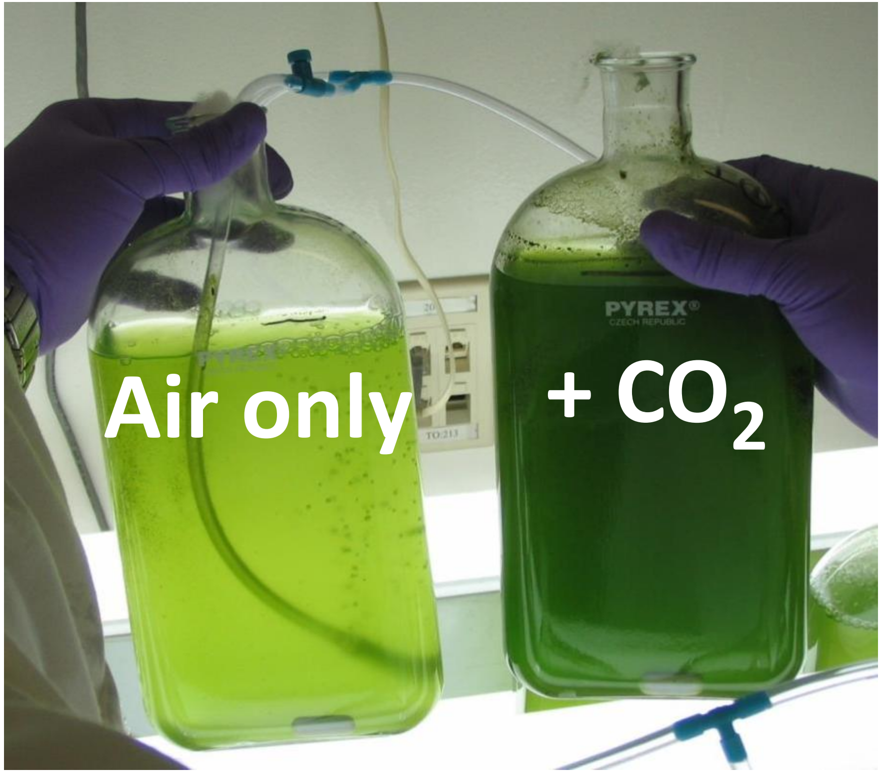


MicroBio Engineering Inc. RNEW® Process: Algal Wastewater Treatment with Biofuels Production, Water/Nutrients Reclamation, Biofertilizers

Recycle
Nutrients
Energy
Water



Algae cultures, wastewater treatment require CO_2



CO_2 supply maximizes algal biomass production and achieves complete **nutrient assimilation** in wastewater treatment.

Orlando Utilities Commission Stanton Energy Center (OUC-SEC) two ~450 MW Coal-fired Power Plants

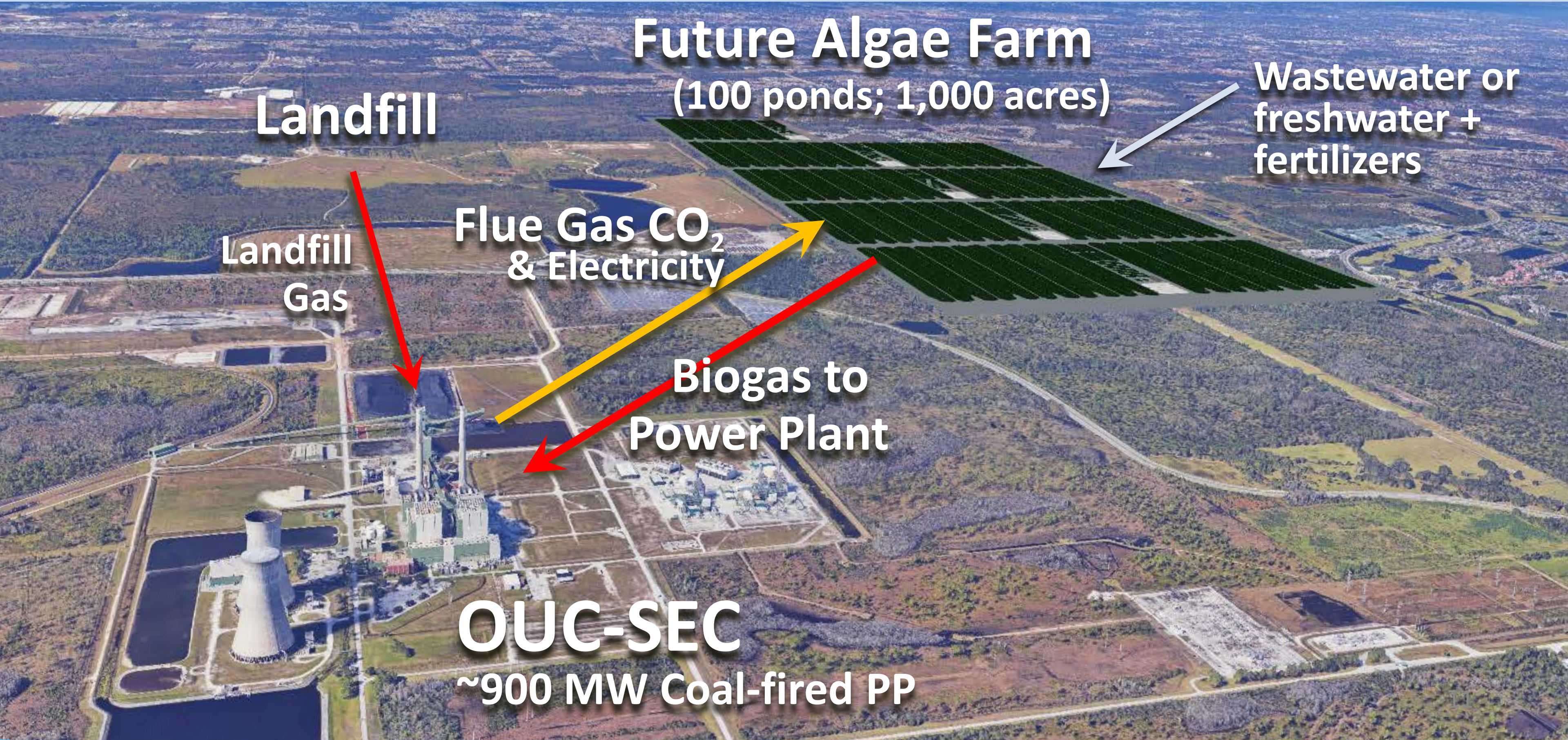
Project Objectives

- **Site Specific** Techno-economic and life cycle assessments (TEA and LCA) at the OUC Stanton Energy Center coal-fired power plant, for:

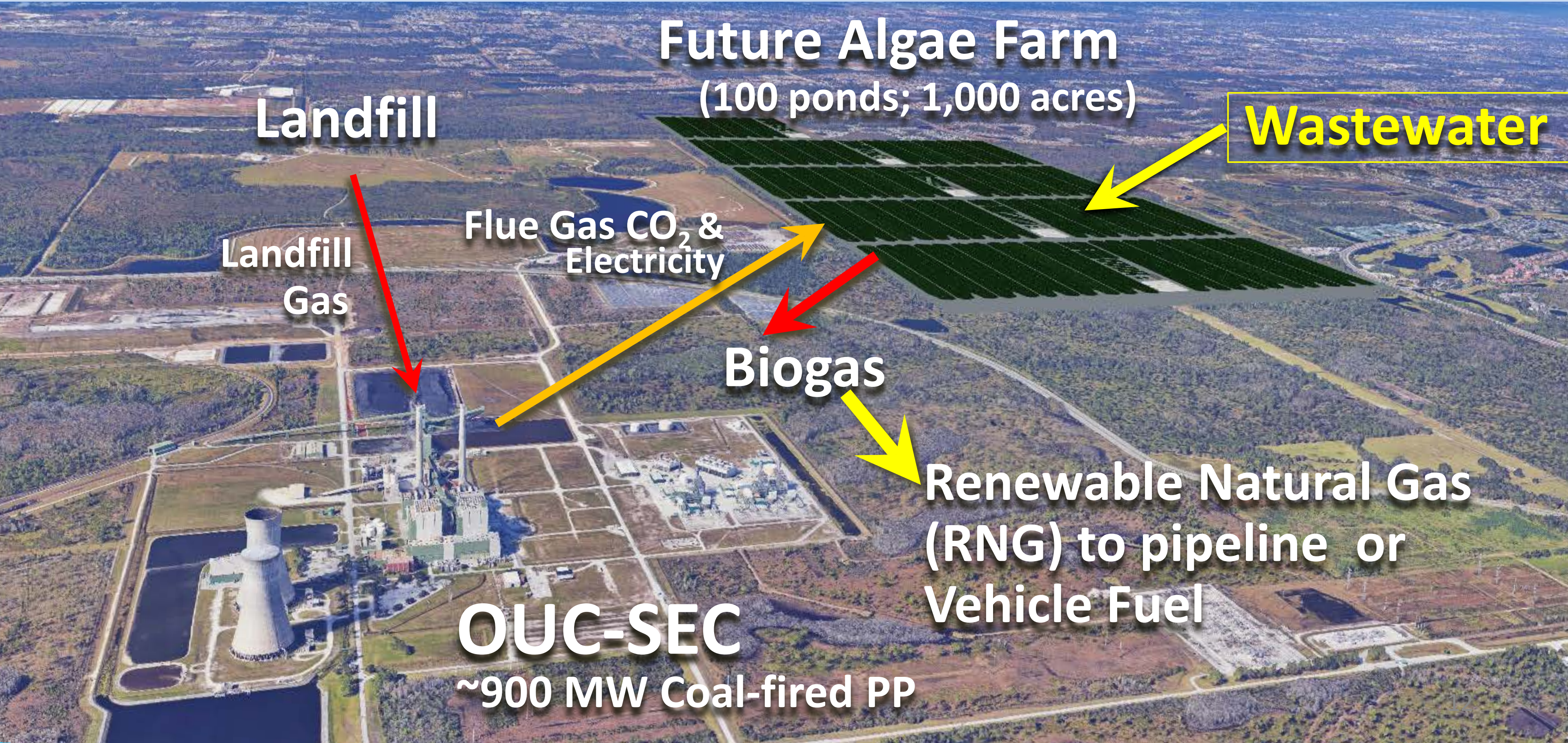
  1. **Biogas production** to replace coal for maximum CO_2 utilization (task then modified during project to produce vehicle biofuel).
  2. **Commodity animal feeds production** for maximum economic benefit of flue gas CO_2 use.

- **Demonstrate algae biomass cultivation using OUC flue gas** with native algae and conversion to biogas or animal feeds.

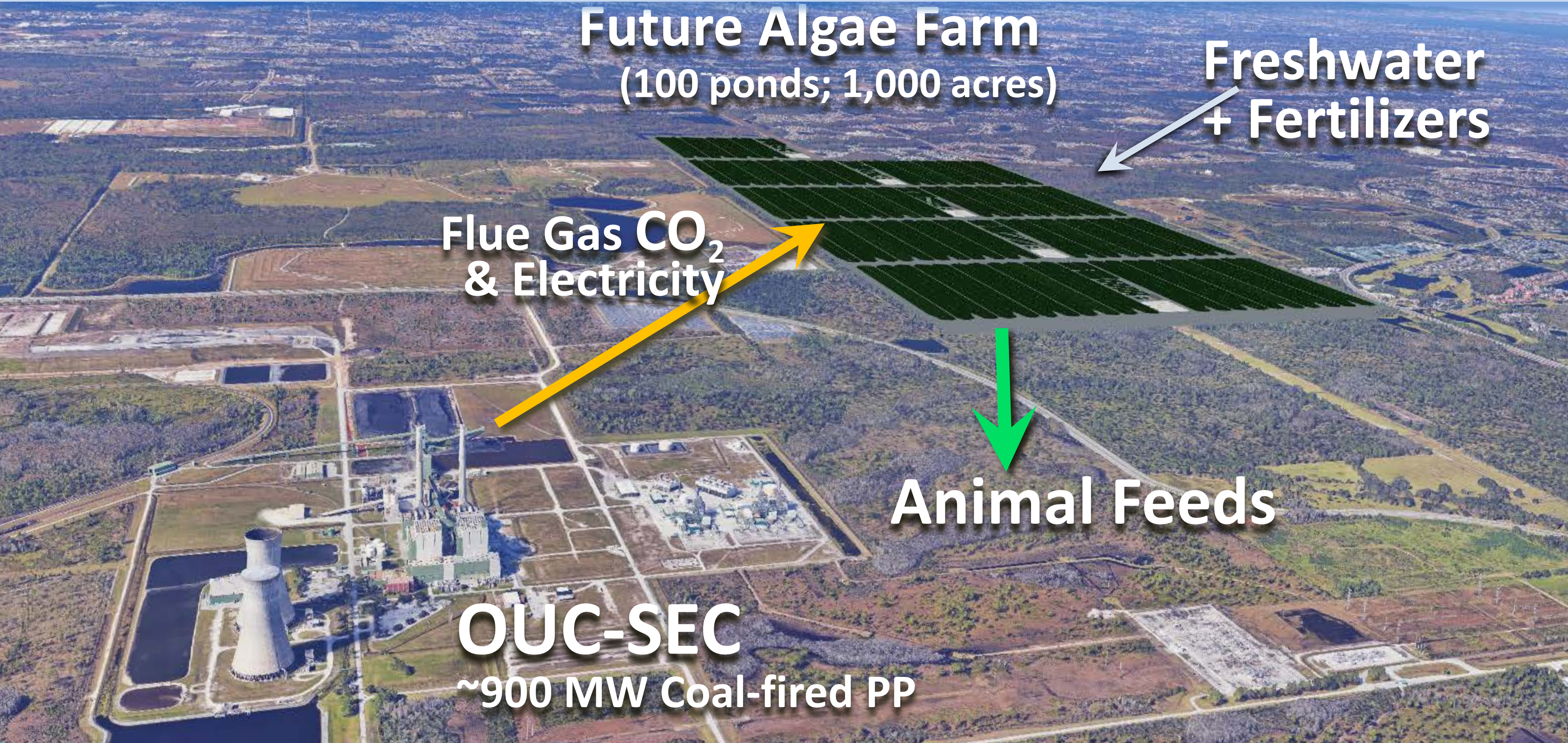
Case 1a. Flue-gas CO_2 → algae biomass → biogas → power plant



Case 1b. Flue gas CO_2 → Algae biomass → biogas → RNG



Case 2. Algae → animal feed production (2nd year, current)

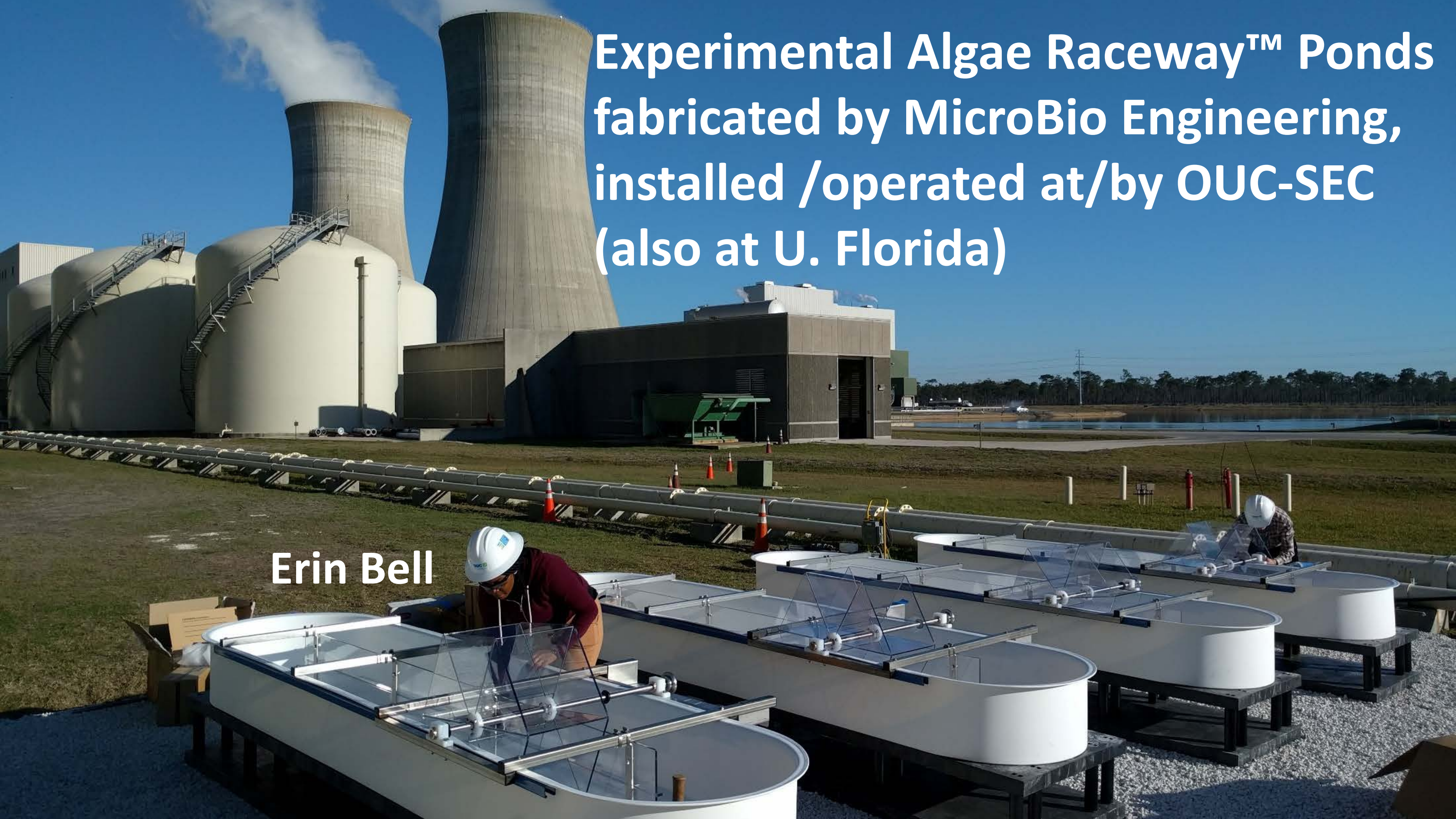


Current Commercial Microalgae Production Technology: Earthrise Nutritionals LLC, Imperial Valley, California

~50 acres, 1-2 acre raceway, paddle wheel mixed ponds, Spirulina production.

For economies of scale in CO2 utilization need ~10 x larger plant and ponds

Experimental Work

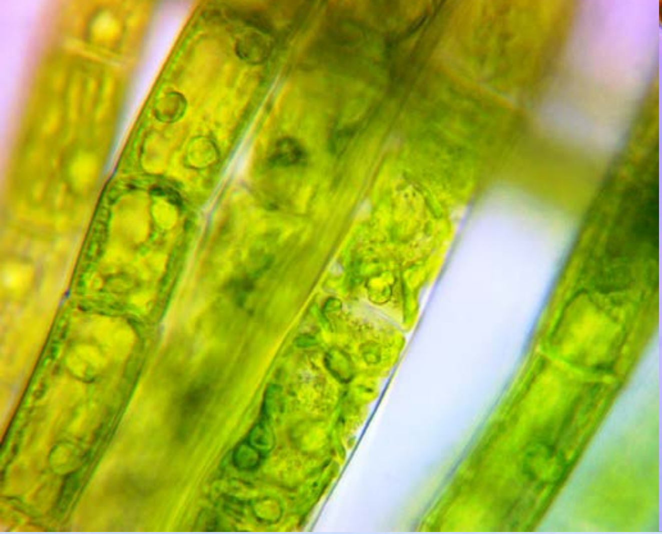

Experimental Algae Raceway™ Ponds fabricated by MicroBio Engineering, installed /operated at/by OUC-SEC (also at U. Florida)
Erin Bell

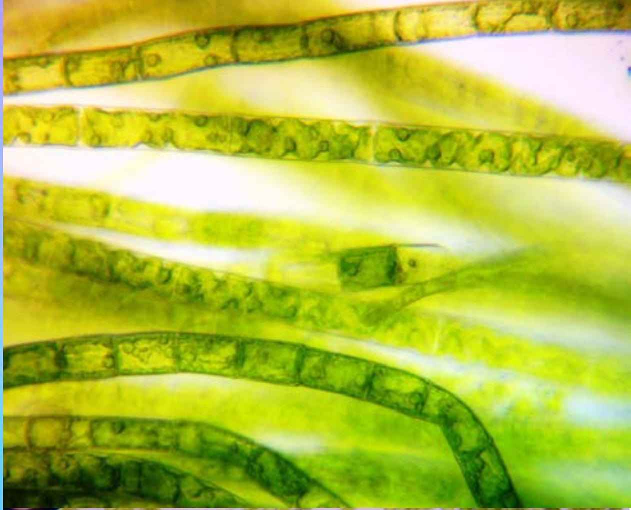
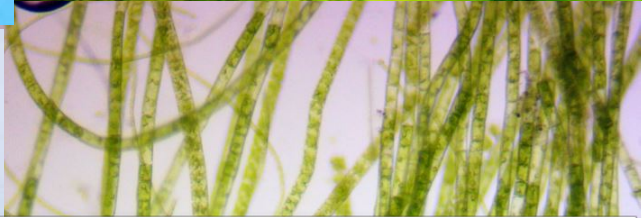
Experimental work: growth of native algae in raceway ponds at OUC (with flue gas) and U. Florida (for biogas)

- Four 3.5-m^2 raceways at each location
- At OUC and UF, determine seasonal productivities of natural algal strains/consortia, optimize hydraulic residence times, analyze biochemical composition,
- At OUC, compare flue gas to pure CO_2.
- At U. Florida, algal cultivation, biogas (methane) yields.

Flue gas from scrubbers to condensate traps to pump to pilot ponds

Flue gas from scrubbers to condensate traps to pump to pilot ponds with CO2 consumed by algae

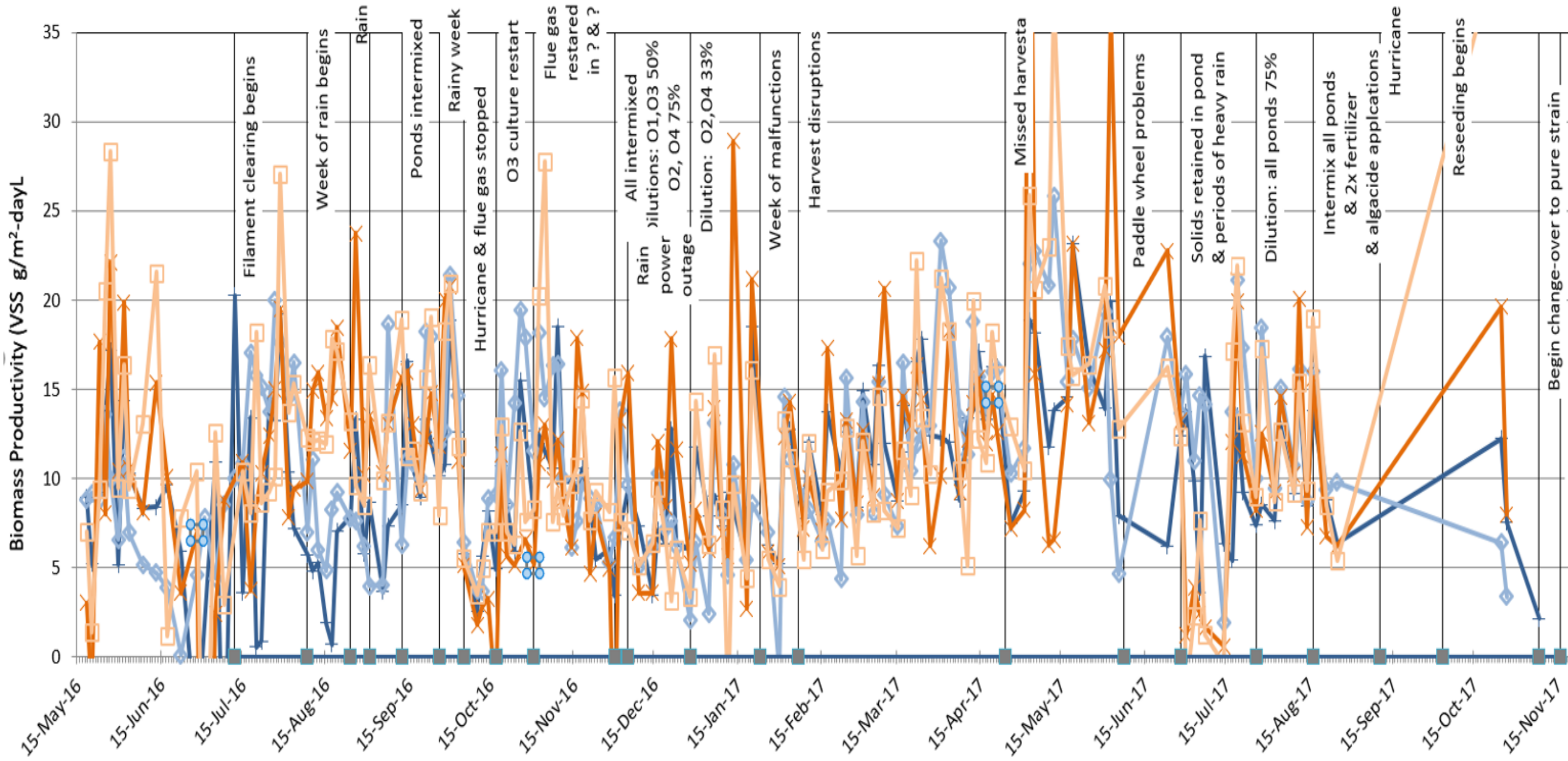


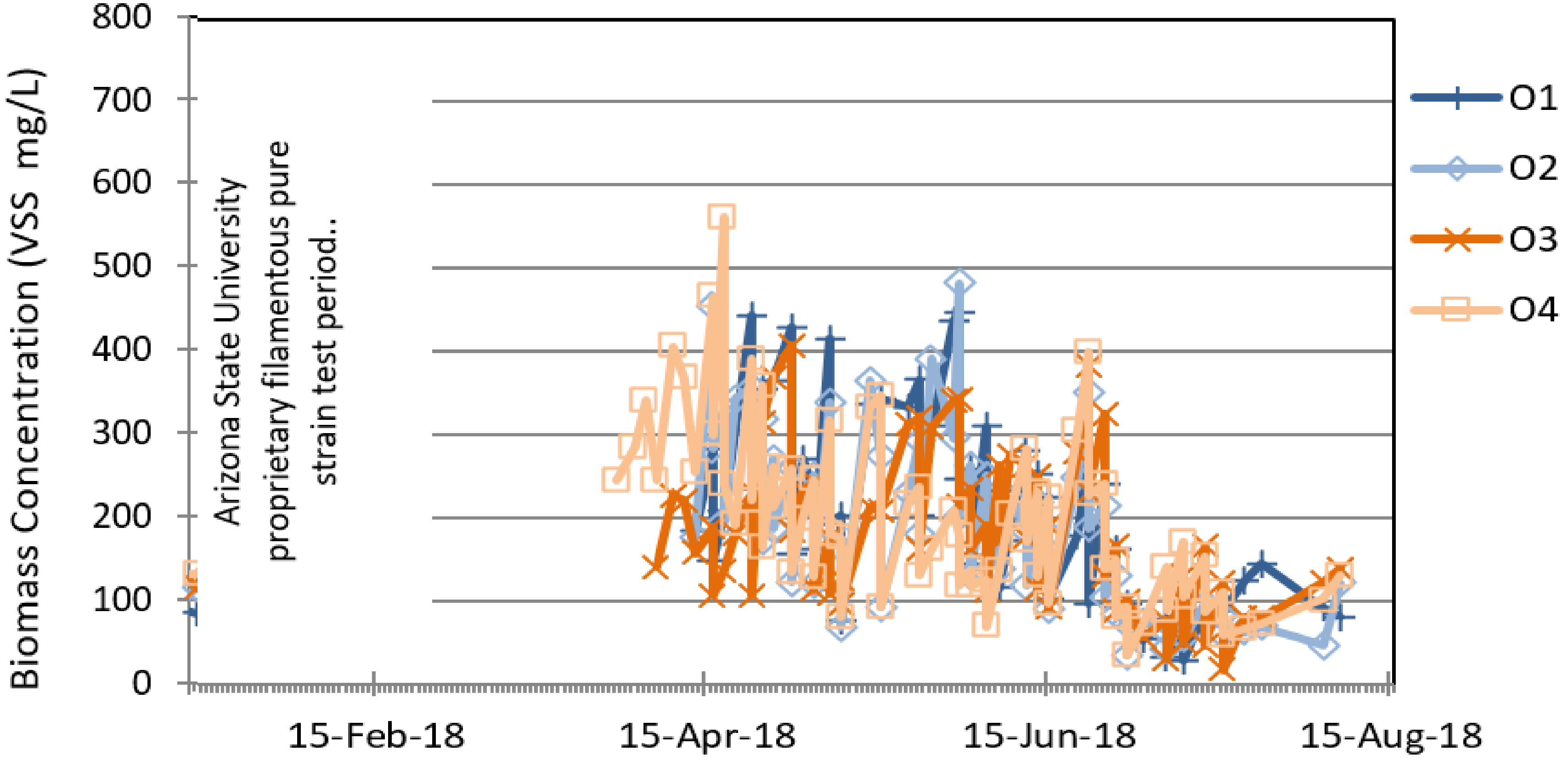
Microalgae observed at OUC-SEC Ponds



May 2016- Nov 2017 productivity averaged 13.4 g/m^2-d

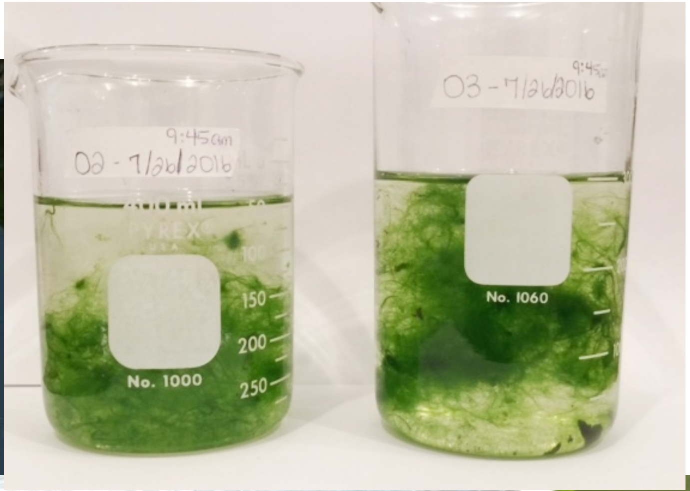


Algae cultivation continues as OUC

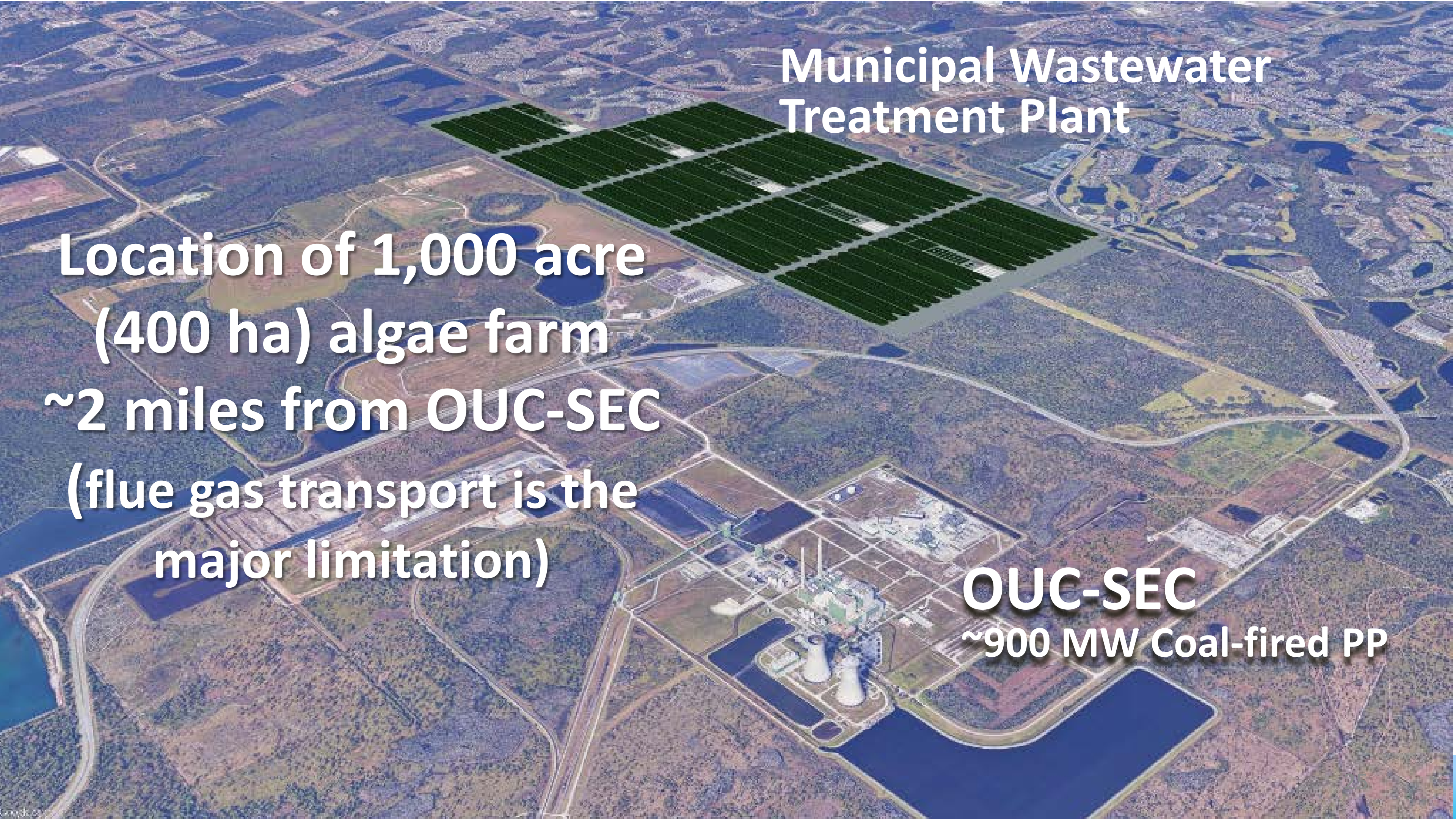


Conclusion: No difference between flue gas CO_2 and pure CO_2

Filamentous algae dominated the OUC Ponds, which allows for easy harvesting of the biomass.



TEA/LCA for OUC-SEC flue gas CO_2 utilization by microalgae projected for a 1,000 acre system

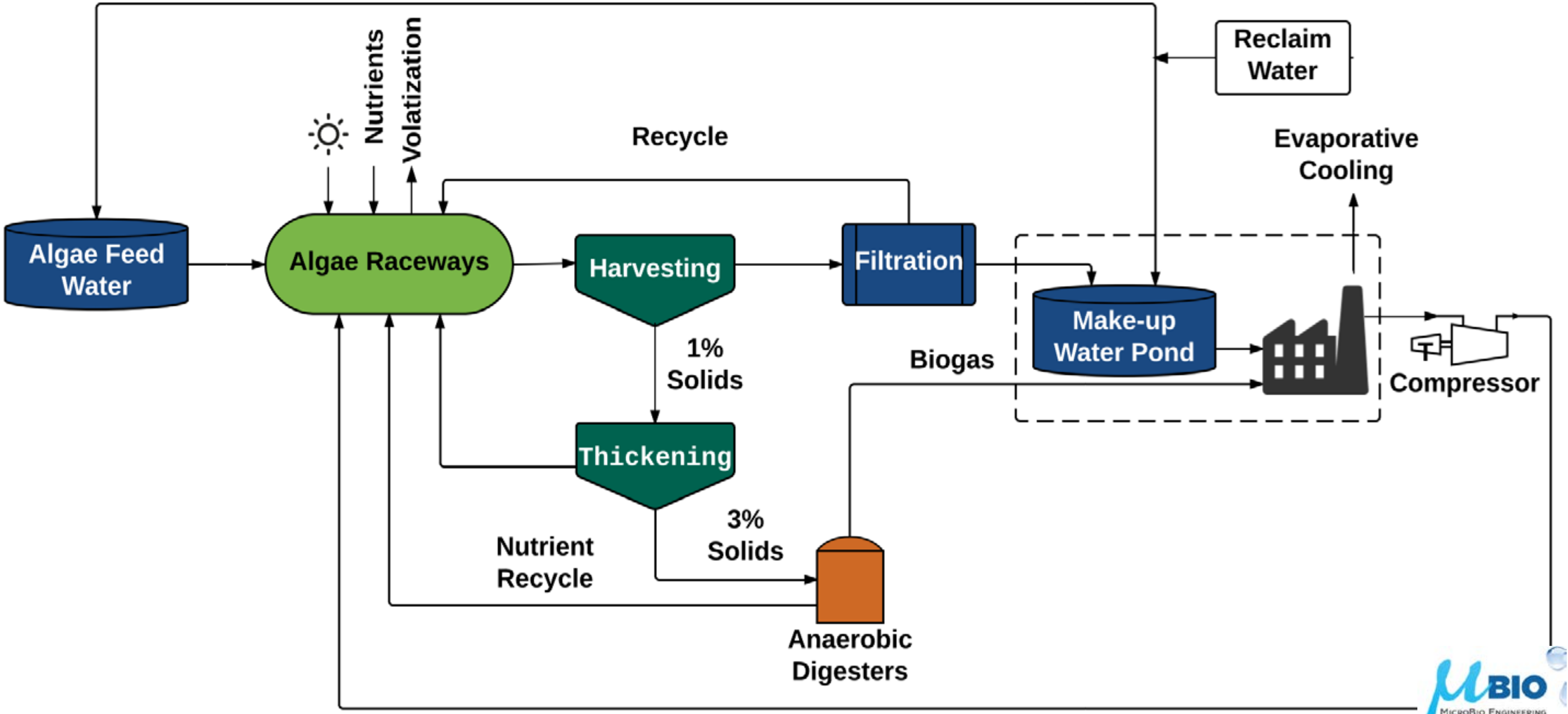

Municipal Wastewater
Treatment Plant
Location of 1,000 acre
(400 ha) algae farm
~2 miles from OUC-SEC
(flue gas transport is the
major limitation)
OUC-SEC
~900 MW Coal-fired PP

Case 1 TEA/LCA .
Power Plant Flue Gas CO_2 → Algae → Biogas

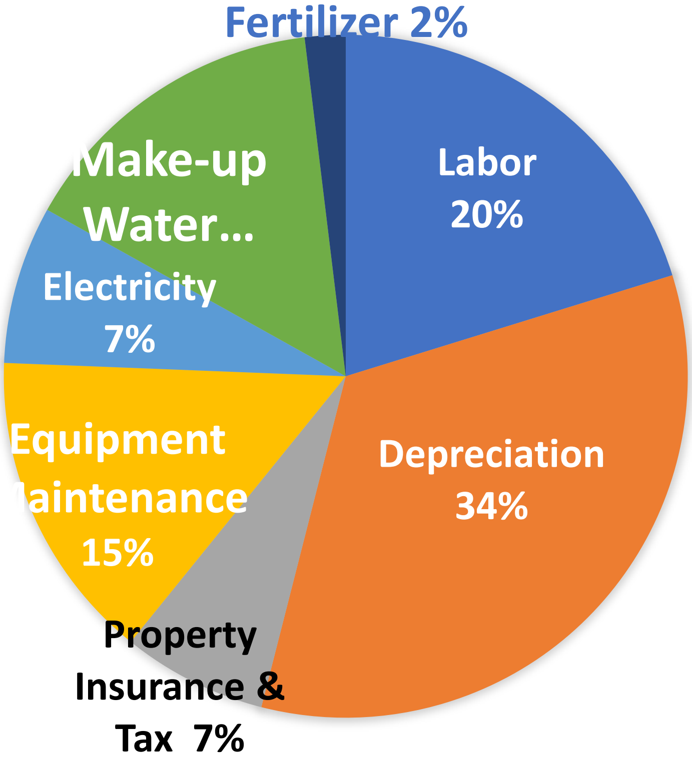
1a. Flue Gas CO_2 → Algal Biomass → Biogas → Replace Coal

1b. Flue Gas CO_2 → Algal Biomass → Biogas→ RNG

Case 1a – Algae derived biogas to replace coal in PP.



Case 1a -Biogas to Power Plant: Summary



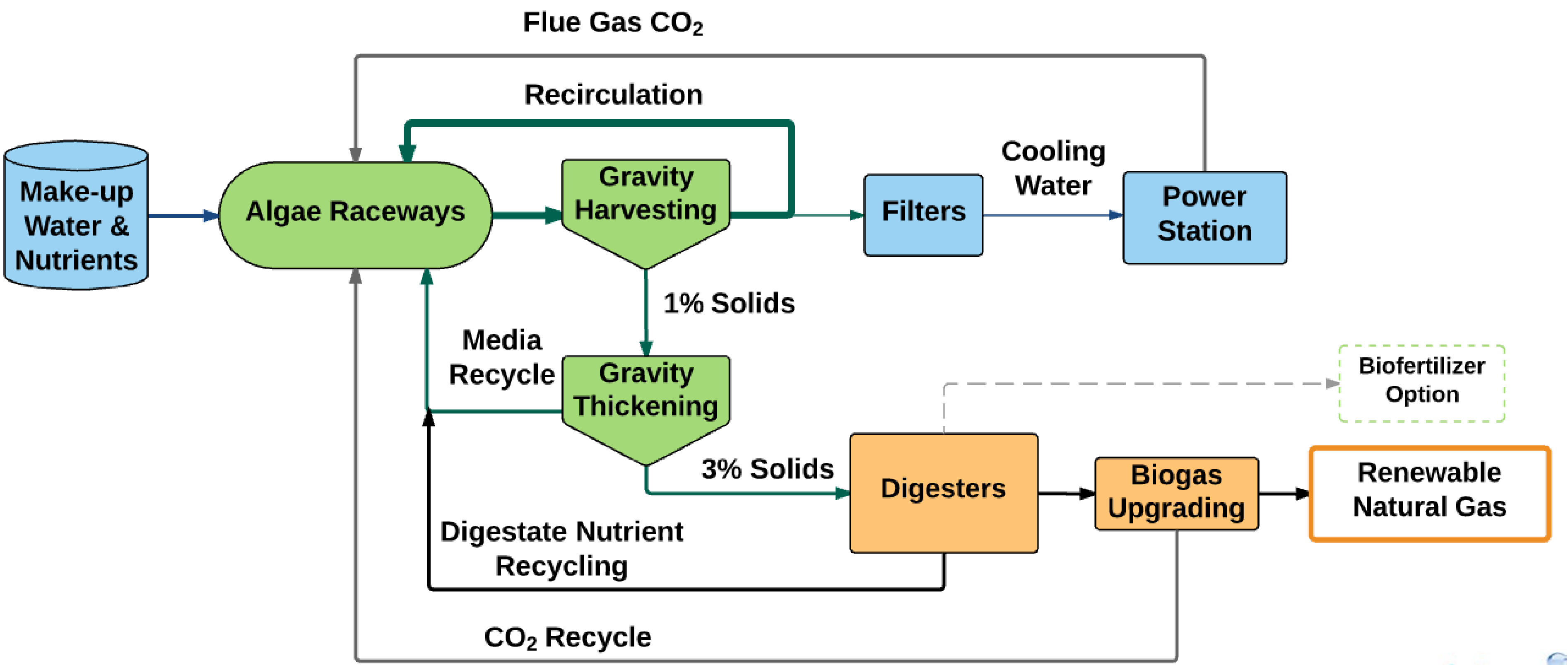
CAPEX (Bond + Equity) **$12,400 000 /yr**

OPEX : **$11,600,000 /yr**

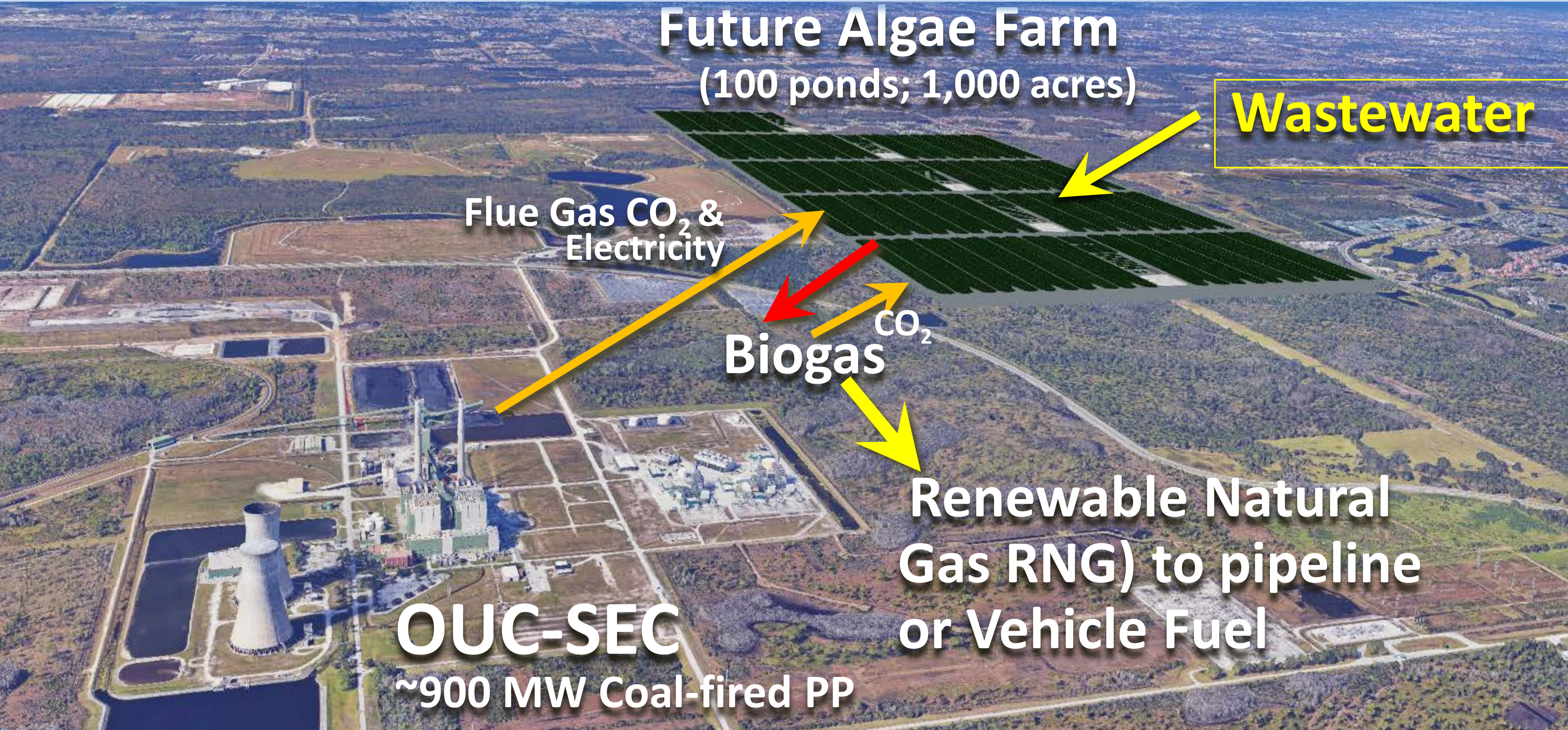
Biogas @ $2 /mmBtu: **$933,000 /yr**

CO_2 Mitigation Cost (biogas to replace coal): **$816 /mt CO2**

Case 1b: Production of Renewable Natural Gas (RNG)

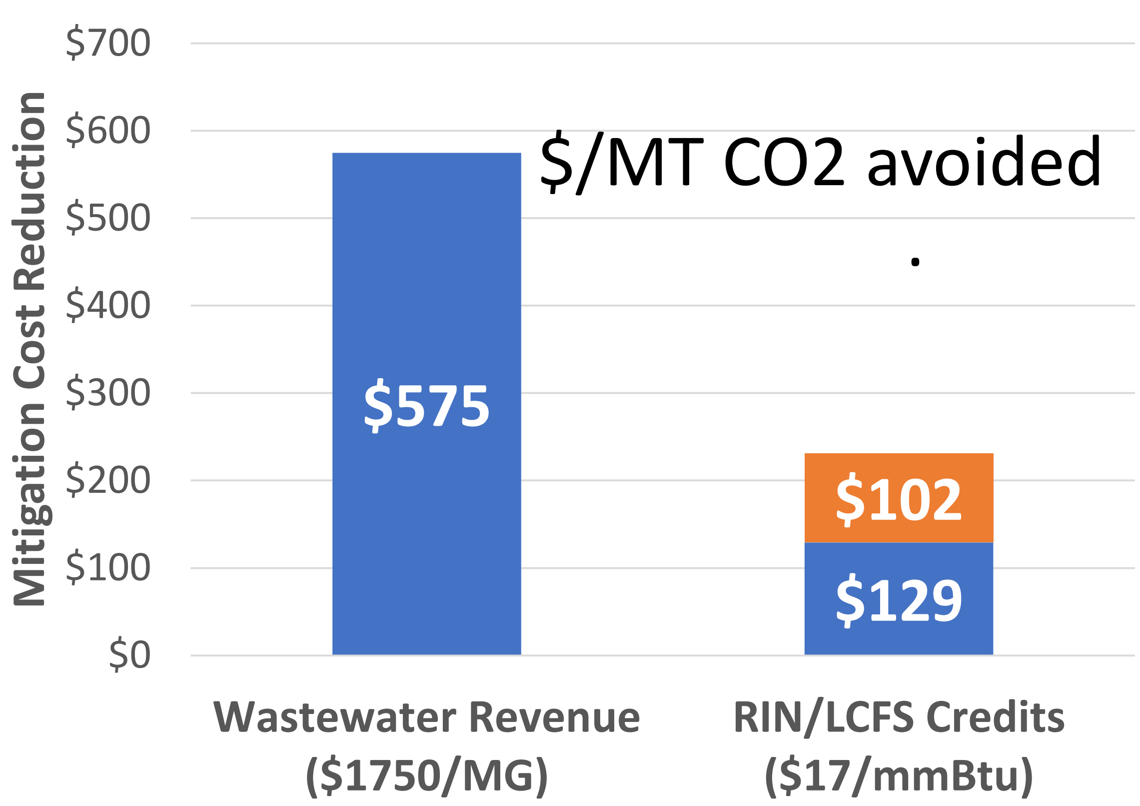


Case 1b. Alternative Process: Algae WWT → biogas→ RNG



Case 1b - RNG Alternative: Biogas production + Wastewater Treatment for economics need 30 million gallons/day, ~300,000 population

Also: upgrade to RNG ('Renewable Natural Gas') for pipelines, vehicles.



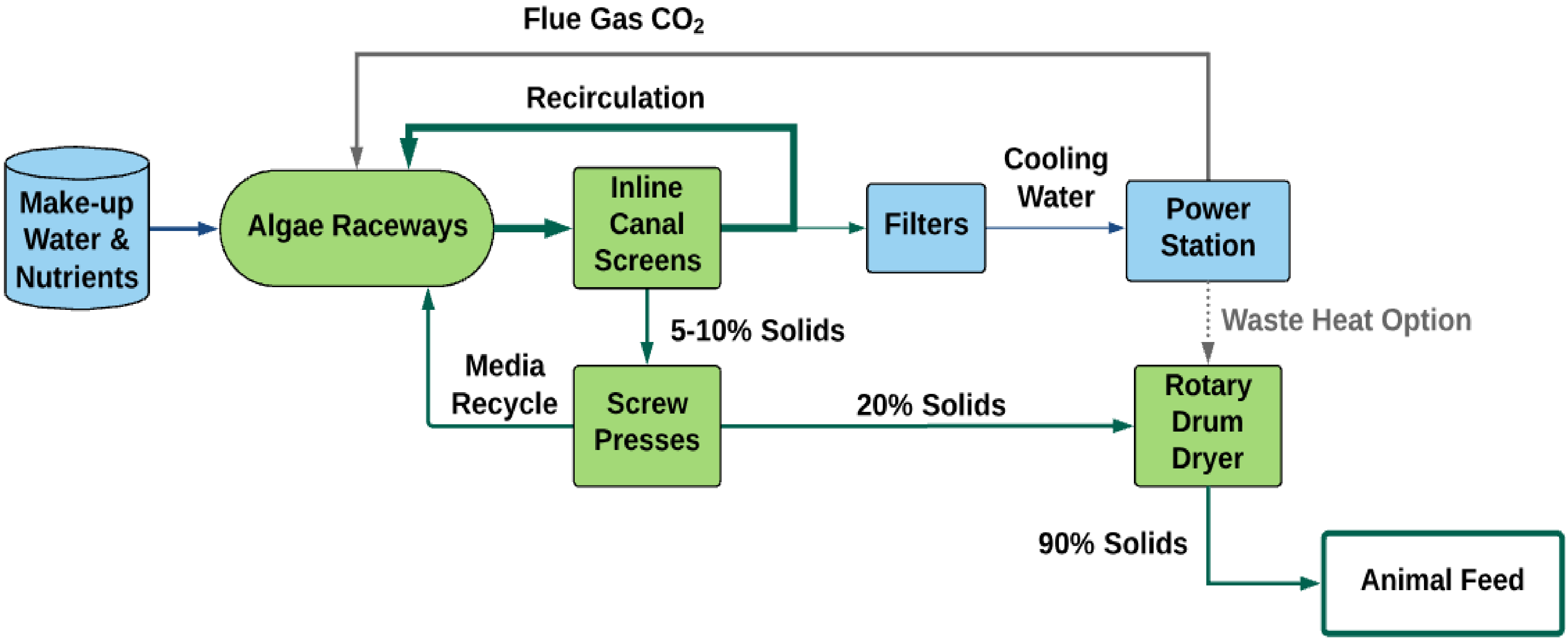
Costs $816/mt CO_2

Revenues: $806/mt CO_2

Net : $10 /mt of CO_2 emissions avoided

CONCLUSIONS: Biogas/ RNG, not a flue gas CO_2 utilization case - it is a wastewater treatment process, most of the C comes from wastewater

Case 2. Animal Feed Case



Animal feed case

Animal Feed Case Design Parameters

Farm Size: 400 ha

Productivity: 18 g/m^2*d (avg.) 35 g/m^2–d (peak)

Flue Gas Source: OUC-SEC CFPP

Distance to Farm: 2 miles

Flue Gas CO_2 Uptake Efficiency: 55%

Water Source: Municipal Wastewater Treatment Plant

Blowdown Rate: 5%

Make-up Water Rate: 38,700 m^3/d (10 MGD)

Results of TEA for Animal Feed Case

Total Capital Expense	$ 86,879,000
Annual Bond Repayment	$ 5,577,000
Annual Return on Investment Equity of 20%	$ 2,606,000
Annual Fixed Operating Costs	$ 7,084,000
Annual Variable Operating Expense	$ 8,114,000
Total annual cost of production (CAPEX +OPEX)	$ 23,381,000
Annual Animal Feed Production (90% yield)	26,276 Mg
Feed Revenue required (vs. $393/Mg soybeans)	**$ 890/Mg**

Soybean and Algae Feed Characteristics

	Soybeans*	Freshwater Algae*
Protein	42%	45%
Oil	22%	20%
Carbohydrates & Other Organics	36%	35%
Nitrogen Content	6.7%	7.2%

*Ash free dry weight basis, based on Soybeans 13% moisture and 4% ash content.

Value of Algae Components in Feeds

Conventional Feed Ingredient	**Conventional Feed Ingredient Value (USD)**	**Value of Target Component (USD)**	**Concentration of Target Component in Algal Feed**	**Algal Feed Target Value $/Mg of biomass**
Soybean Meal	$393 /Mg	$393/Mg	Same as soybean	$393
Marigold Petal Meal (0.70% xanthophyll)	$2,500 /Mg	$360 /kg of Xa.	0.15%	$535
Fish Oil 25% (EPA and DHAs)	$1,250 /Mg	5.00/kg EPA/DHA	2.5% EPA, DHA	$200
			Total Value	**$1,130/Mg**

LCA Modeling Parameters

LCA Model Type: Long-term Consequential (Co-product allocation)

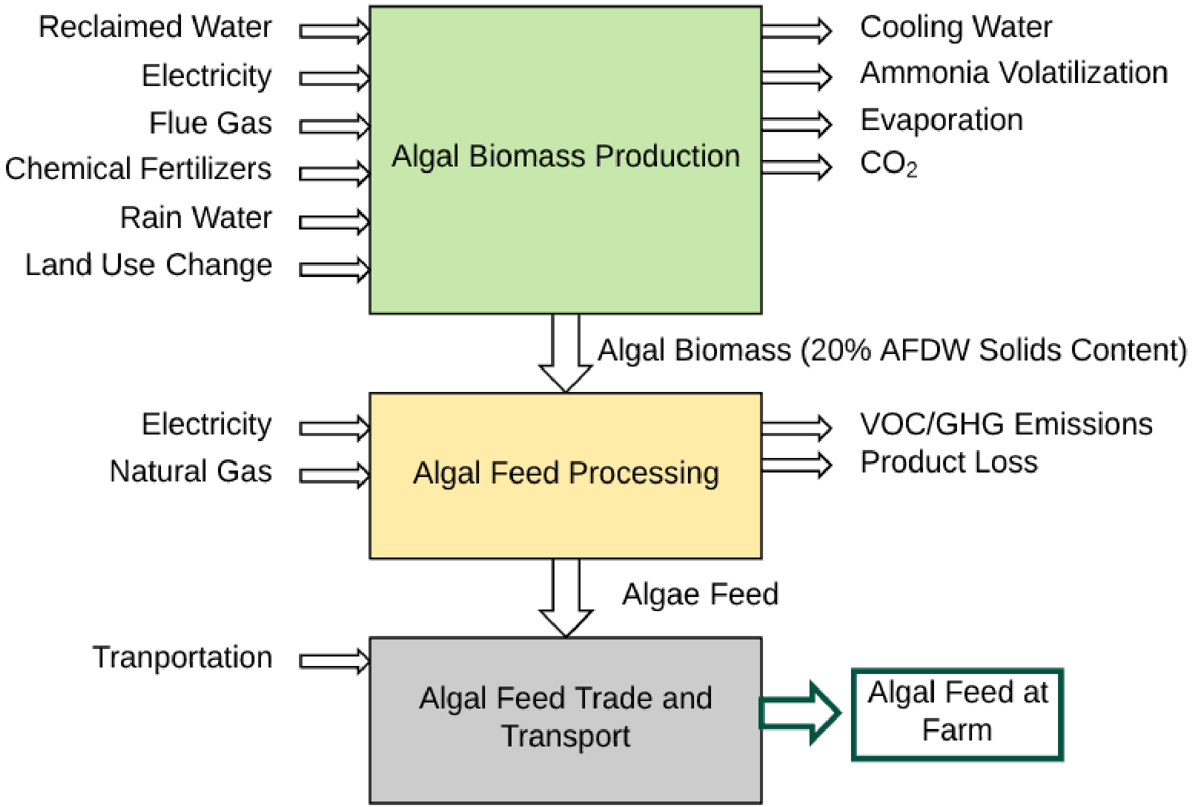
LCIA Method: US EPA TRACI v2.1

Modeling Software: openLCA

Data Sources:

- OUC-SEC specific flue gas characteristics
- Orange County reclaimed water characteristics
- Mass balance of algae, MBE ESPE model
- Ecoinvent US regional utilities (electricity, natural gas)

LCA (life Cycle Assessment) for Animal Feeds



LCA Model Type: Long-term Consequential (Co-products)

LCIA Method: US EPA TRACI v2.1

Modeling Software: openLCA

Data Inputs:

- OUC-SEC flue gas composition
- WWT Plant reclaimed water
- MicroBio Engineering Inc. TEA Algae TEA /Engineering Model
- Ecoinvent US regional utilities (electricity, natural gas)

Animal Feed Carbon Utilization Summary

Description	Value	Units
Global Warming Potential of Algae Feed	-0.473	kg CO2-eq/kg
Fraction of Carbon in Algal Biomass	47%	
Mass of Algal Feed Produced	26,300	mt/yr
CO2 Captured in Feed	45,300	mt/yr
OUC-SEC CO2 Annual Emissions	4,200,000	mt/yr
Percent of CO2 Utilized	1.1%	

Conclusions

- **Electricity generation from biogas produced from algal biomass is the simplest scenario, but is also the most expensive**
- **Biogas production using municipal wastewaters for production of RNG could be economically viable but requires large wastewater flows and would have modest requirements for CO_2**
- **Animal feeds offer the greater CO_2 flue gas utilization and mitigation potential and could be profitable based on feed value of biomass.**
- **Flue Gas CO_2 transport (pipeline) is only feasible to a maximum of 10km**
- **Will require CO_2 capture and compression, to greatly expands the utilization potential of algal products**

Future Developments in Microalgae CO_2 Utilization

- Technological advances required to achieve projected low CAPEX/OPEX
- Select/ improve algal strains for productivity, stability, composition, etc.
- Develop Wastewater/Flue gas CO_2 Utilization/ Biogas to RNG Process
- Valorize algal nutritional components for higher value animal feeds.
- Commercialization in niche markets (biofertilizers, specialty feeds, etc.)

PROPOSED NEXT OUC-MBE PROJECT PHASE:

Expand ponds at OUC-SEC to four x 43 m2

Scale-up of filamentous algae at OUC-SEC

<u>Flue gas CO_2 utilization for algal animal feed</u>

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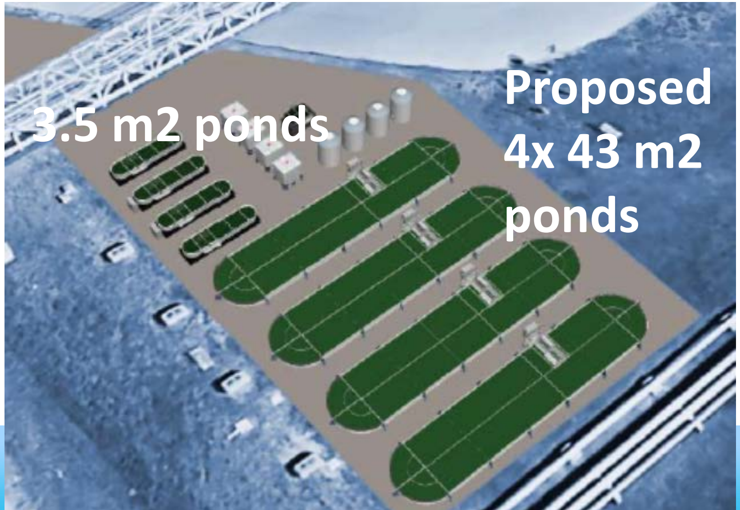

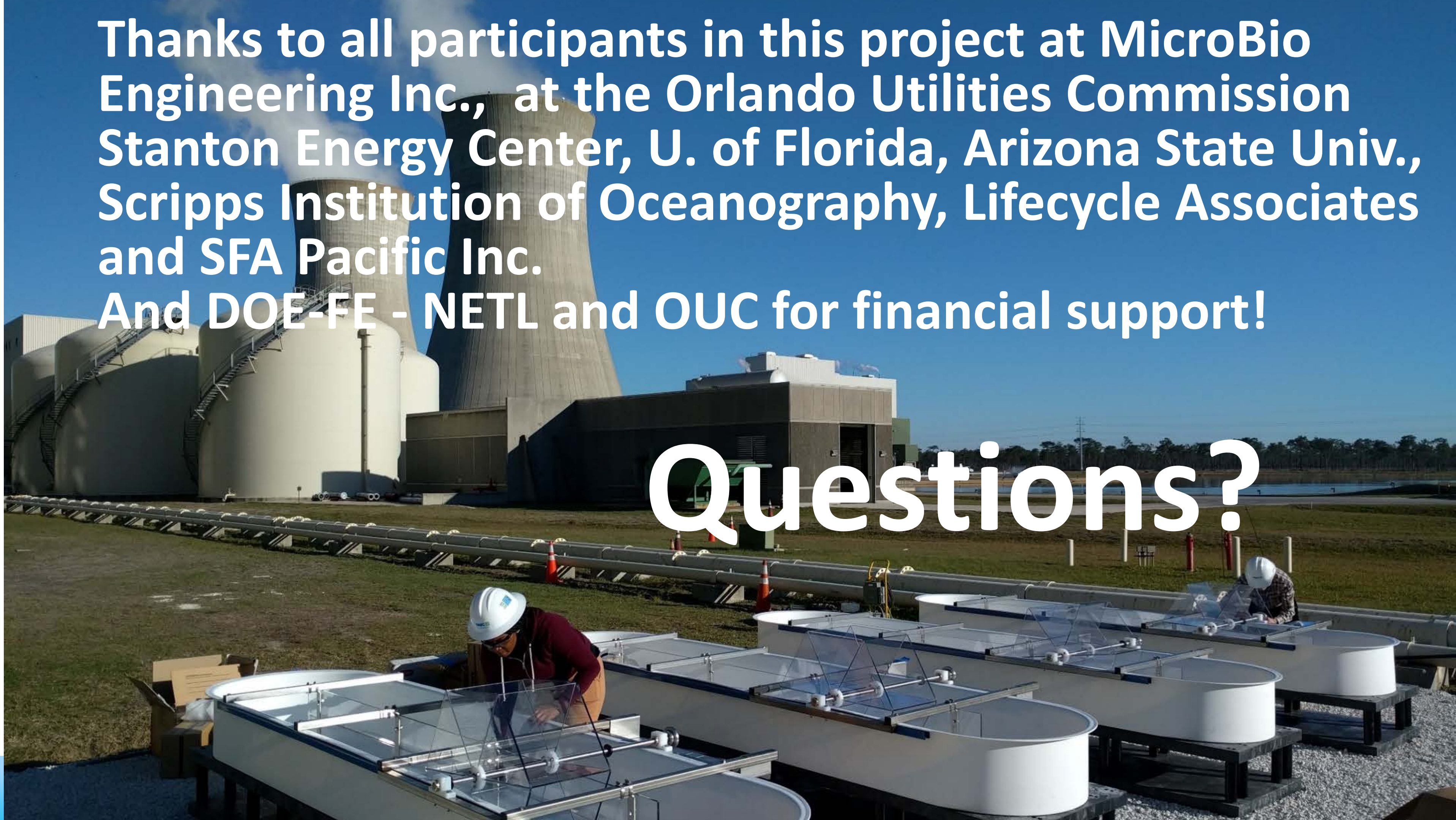
Thanks to all participants in this project at MicroBio Engineering Inc., at the Orlando Utilities Commission Stanton Energy Center, U. of Florida, Arizona State Univ., Scripps Institution of Oceanography, Lifecycle Associates and SFA Pacific Inc.
And DOE-FE - NETL and OUC for financial support!
Questions?