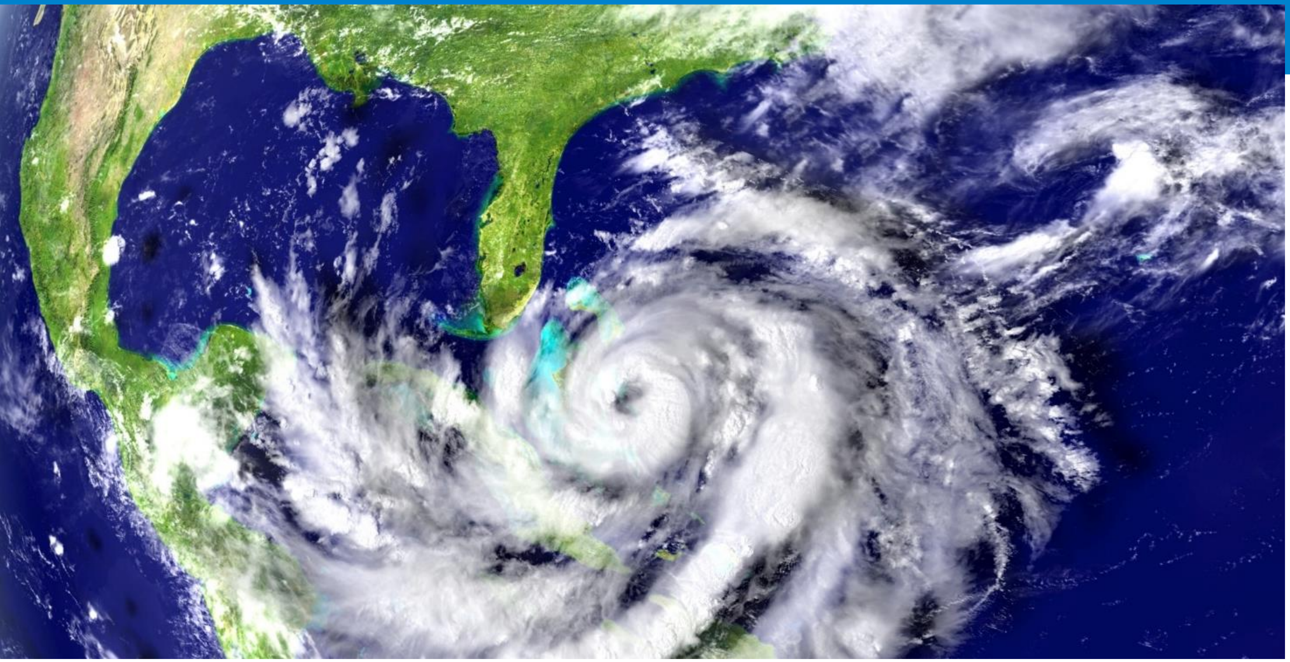

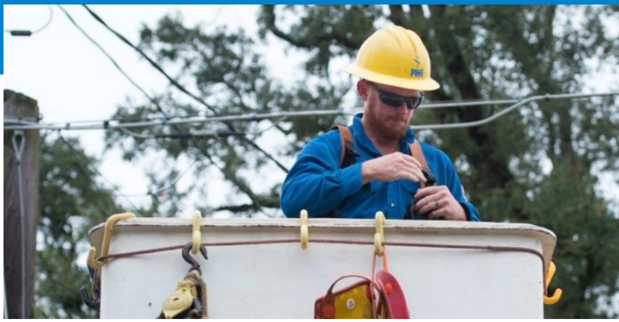

Orlando Utilities Commission Algae Cultivation for Carbon Dioxide Utilization

Rob Teegarden, Water Policy and Research Officer
Orlando Utilities Commission

Bioeconomy 2017: Domestic Resources for a Vibrant Future - Carbon Capture Strategies for Algae Cultivation

July 11, 2017

Interpreting the Arrows, Learning from Our Failures, & Recycling Carbon

Where do the opportunities exist to implement large scale co-production of algal biomass in a bio refinery context?

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Orlando Utilities Commission’s 1940-MW Coal & and Gas-Fired - *Stanton Energy Center*

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

Microalgae Commodities from Coal Plant Flue Gas CO_2

Cooperative Agreement DE-FE0026490, 10/1/15 - 09/30/17

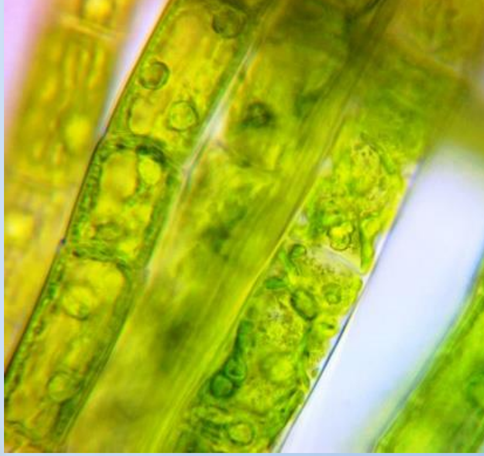
MicroBio Engineering Inc. (MBE)

John Benemann, Principal Investigator, Tryg Lundquist Co-P.I.

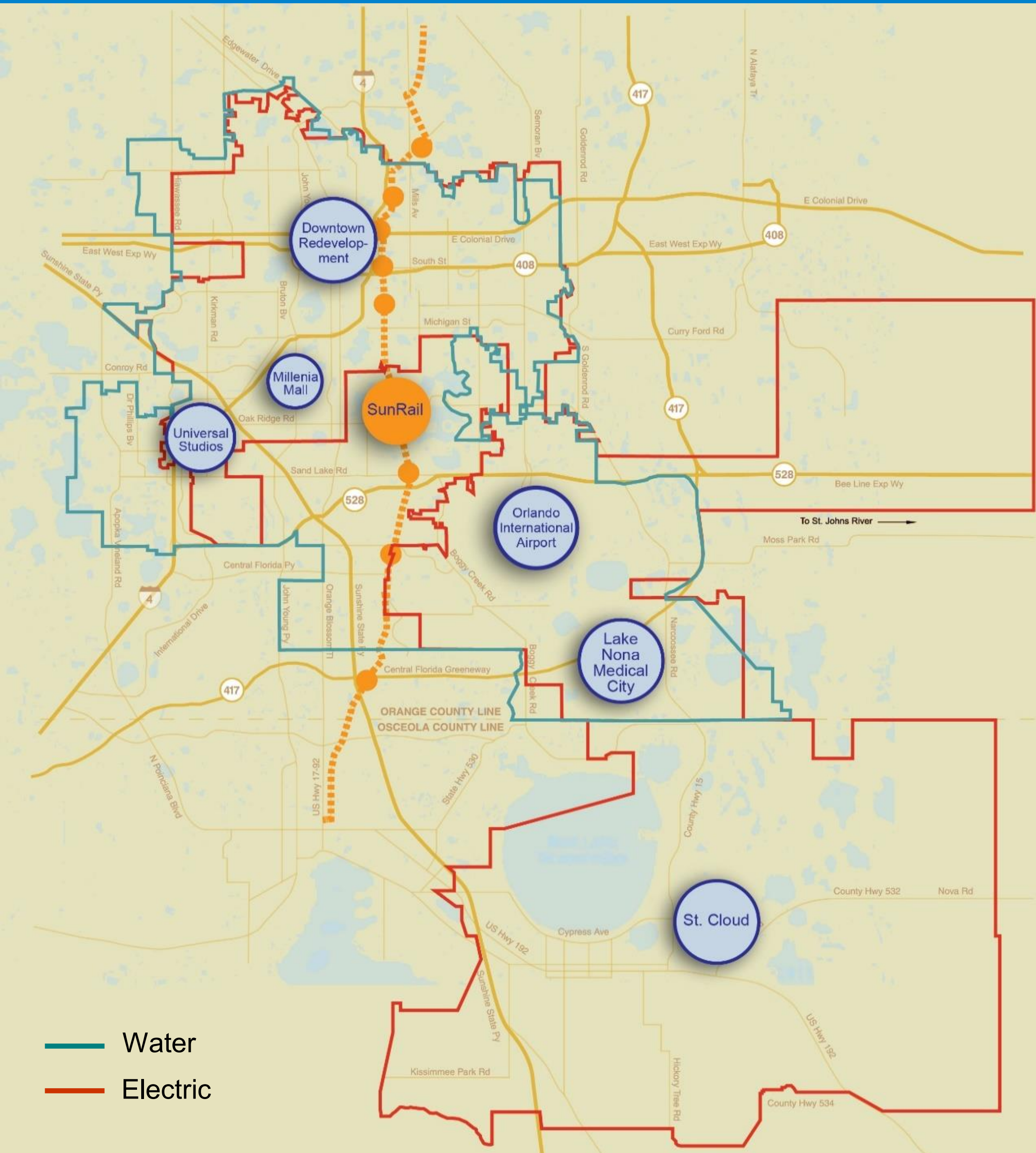
Agenda

- OUC Background
- Carbon Utilization Experiments & Results
- TEA / LCA Results
- Recommendations & Future Work

OUC Service Territory & Stanton Energy Center (SEC)



OUC Electric & Water Service Territory



Electric

- Service area
  - Orlando: 244 sq mi
  - St. Cloud: 150 sq mi
- Number of meters
  - Orlando: 180,000
  - St. Cloud: 30,000

Water

- Service area
  - 200 sq mi
- Number meters
  - 135,000

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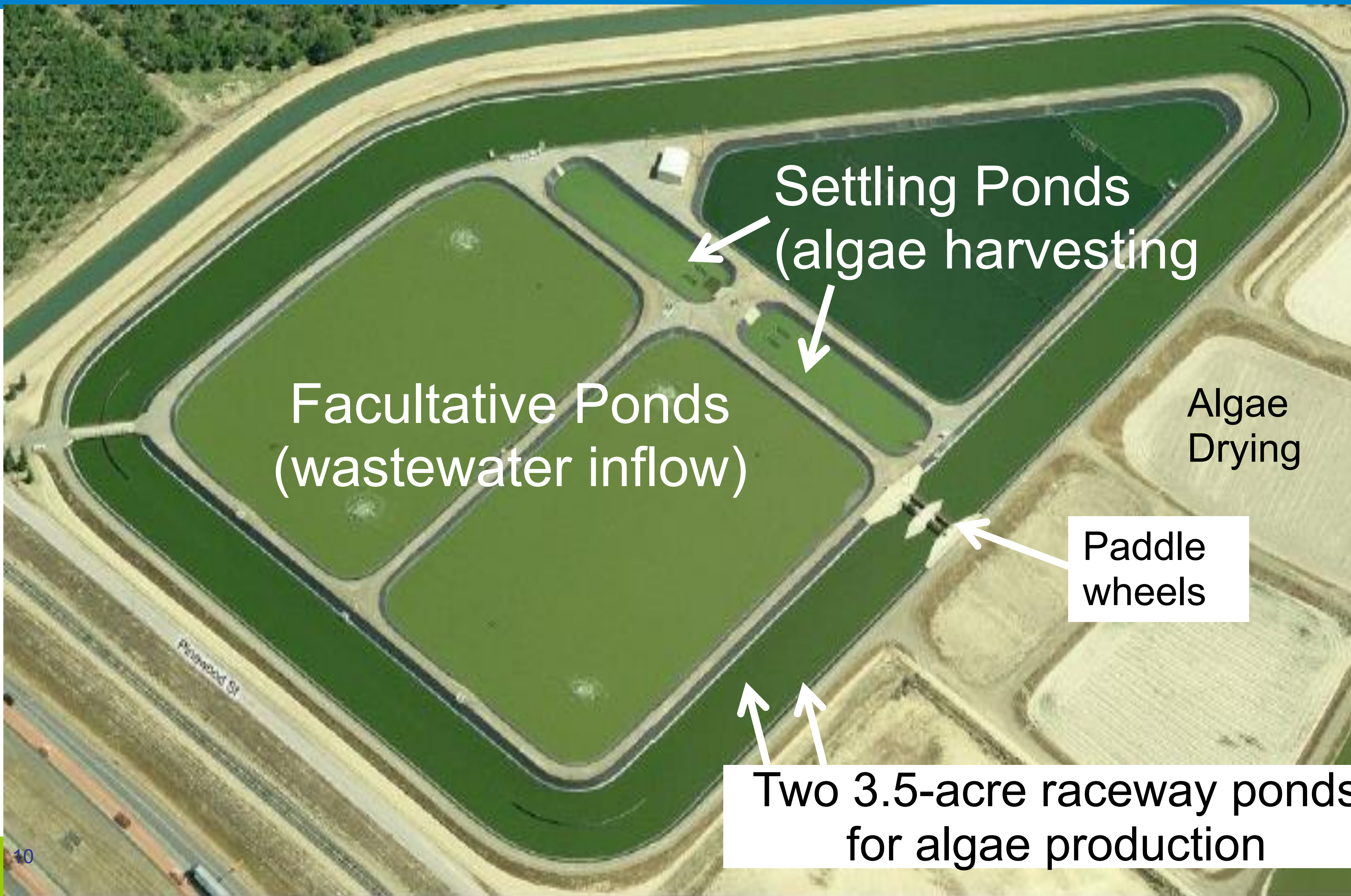
Chilled Water, Lighting and Other Energy Business Services

Full-scale algae California plant treating wastewater. Site DOE BETO funded MBE biofuel R&D project



NETL Project Goal: Make profitable products using flue gas CO_2

How much CO_2 can be used? What is cost? LCA?

Two Scenarios for CO2 Utilization

- **Biogas / Renewable natural gas production for maximum CO_2 utilization**

- **Commodity animal feeds production for maximum economic benefit**

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Research Objectives

Primary Objective

Techno-economic and life cycle assessments specifically for OUC's coal-fired power plant with two product scenarios:

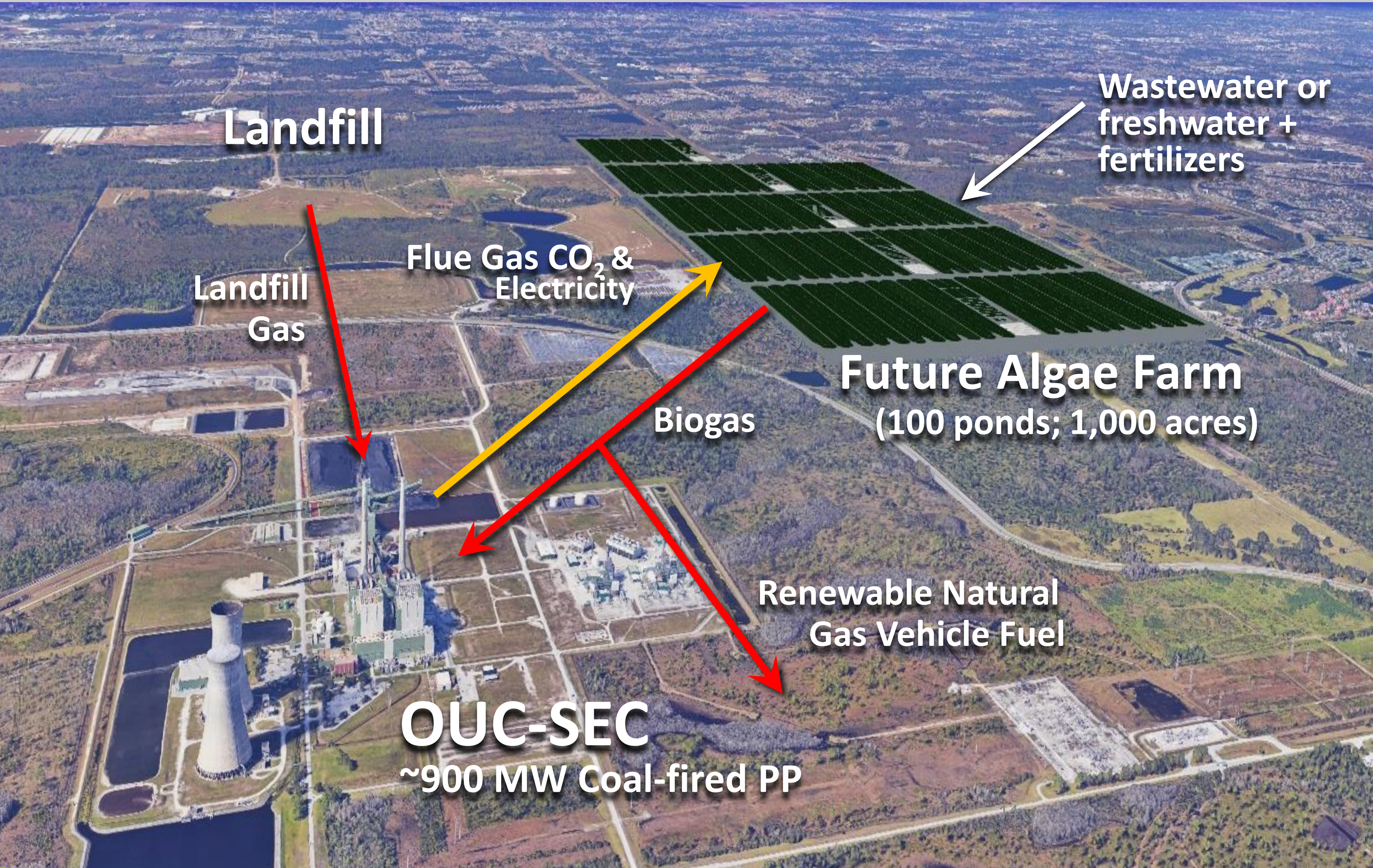
- Biogas / Renewable Natural Gas
- Animal feeds

Secondary Objective

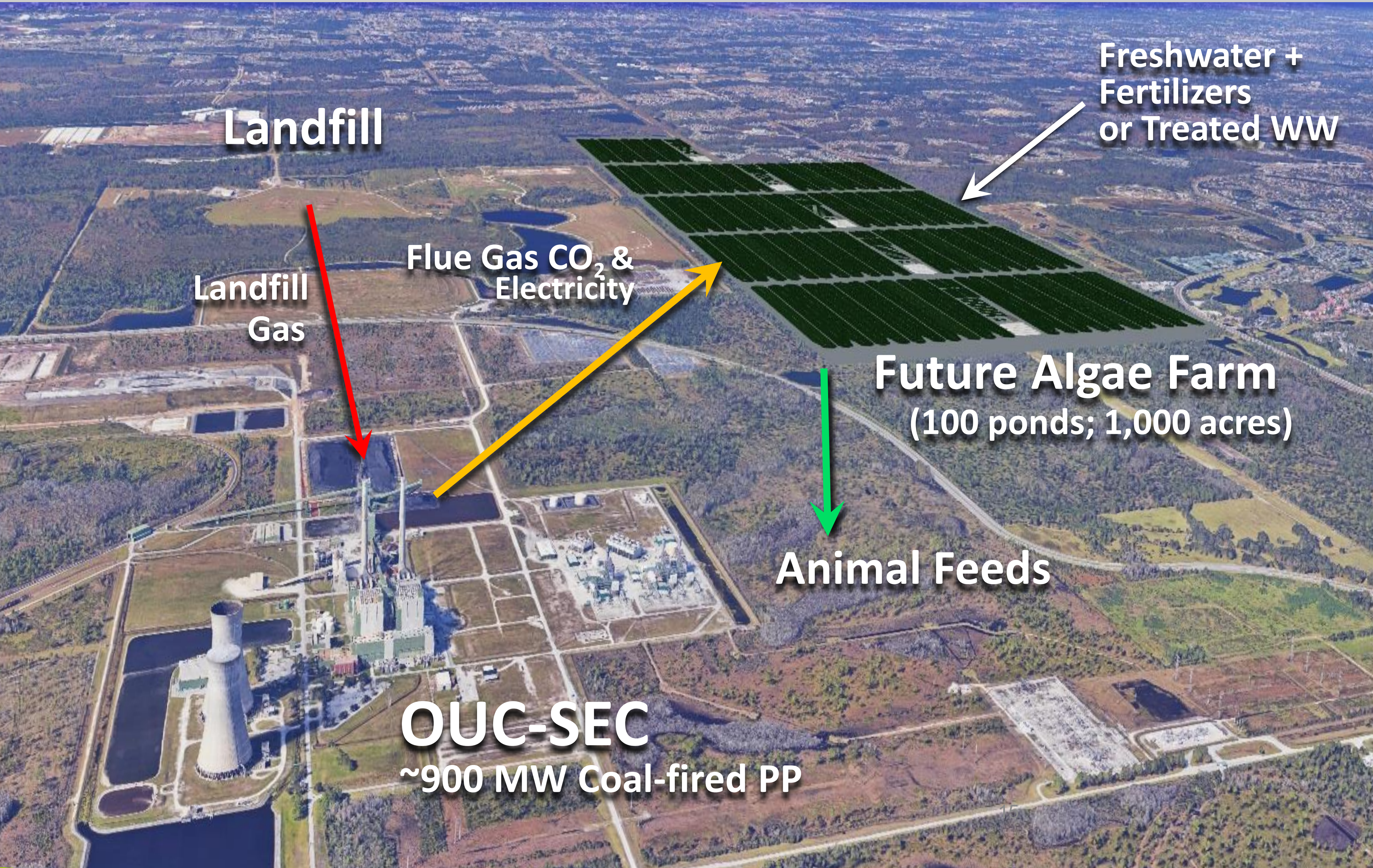
Demonstrate algae biomass production using OUC flue gas with native algae.

- Algae conversion to biogas
- Evaluate suitability as animal feed

1. Algae → biogas for power generation or/and renewable natural gas production (1st Year)



2. Algae → animal feed production (this year)



Experimental work with microalgae raceways ponds at OUC and University of Florida

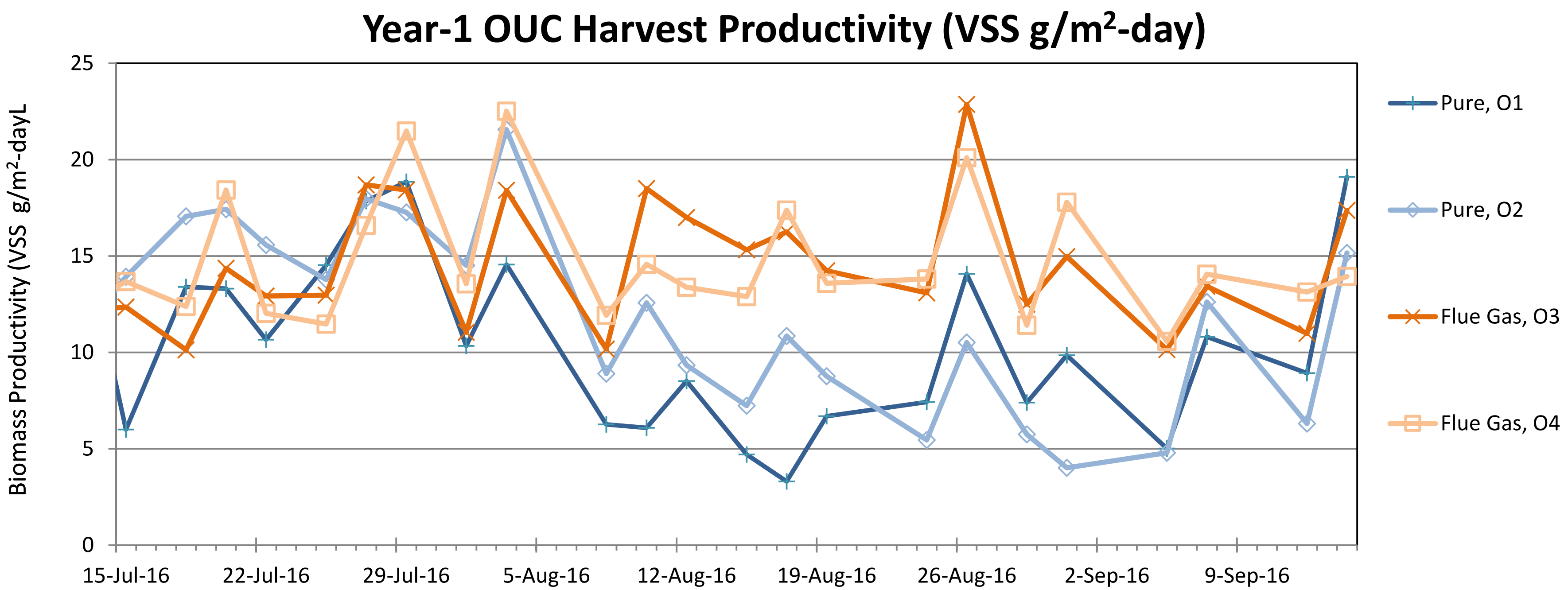
- Four 3.5-m^2 raceways at each site (supplied by MBE)
- Determine productivities in each season.
- Optimize hydraulic residence times.
- Measure biochemical composition and metals.
- Compare flue gas to pure CO_2
- Determine methane yields

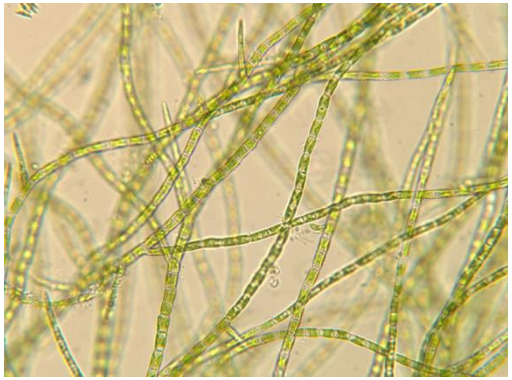
Ponds at OUC (above) and UF (Below)

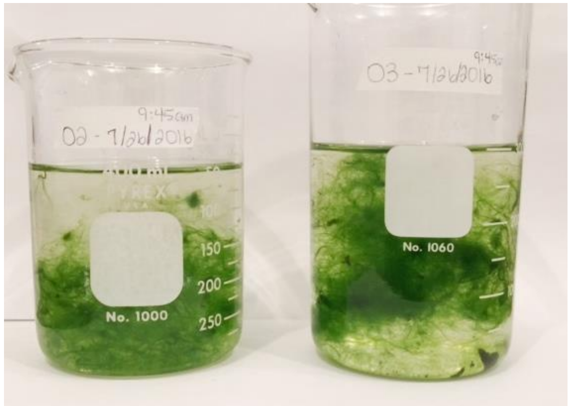
OUC-SEC: Flue gas from scrubbers to condensate traps pumped to 3.5-m^2 ponds.

CO_2 promotes growth.

Initial trend of growing the Flue gas algae cultures was more productive than pure CO2 cultures (trend diminished) . Successfully growing filamentous, easily harvested algae cultures at OUC







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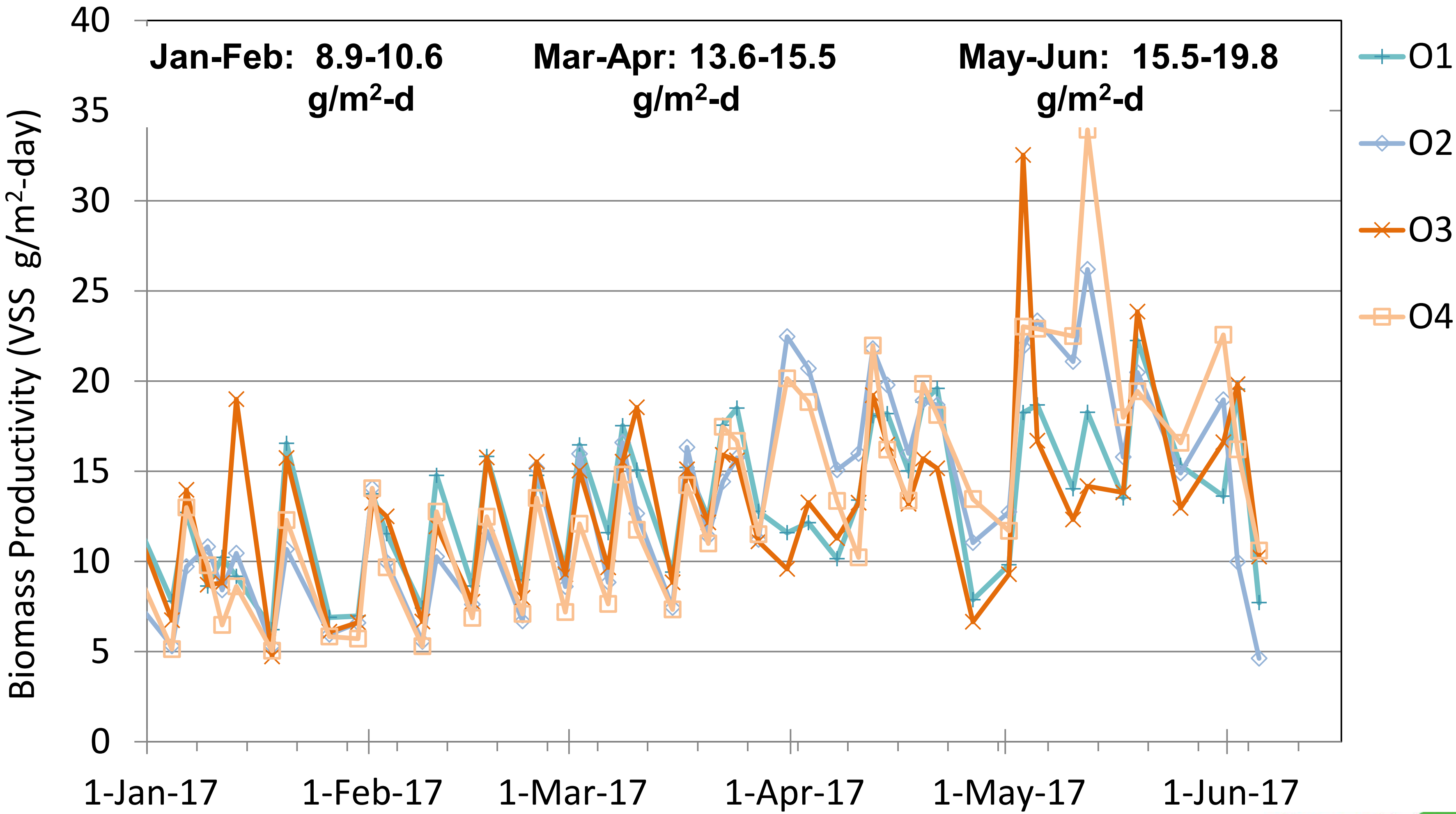
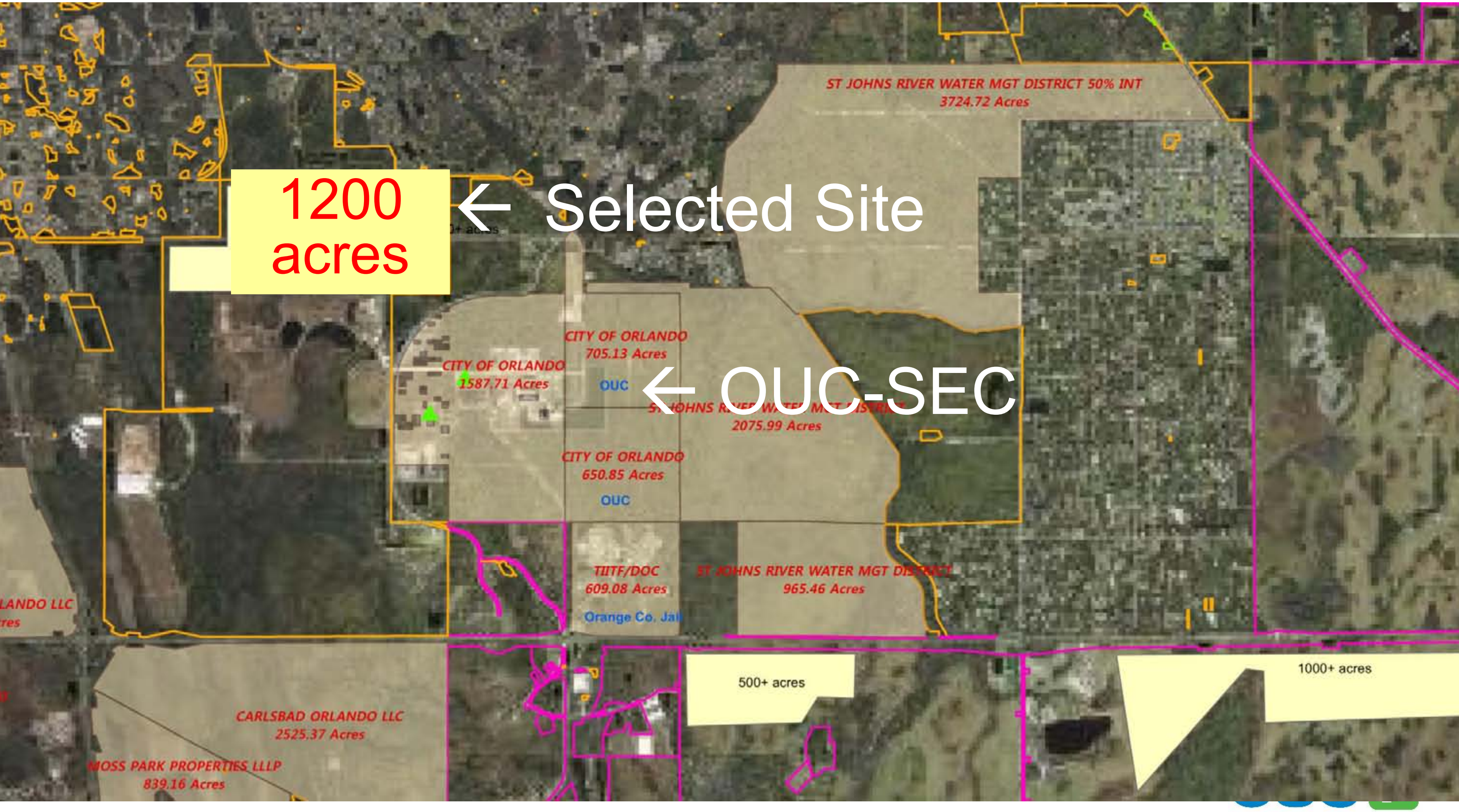
Jan-Jun 2017 productivity averaged 14 g/m²-d at OUC. Weeks of rain were the major detriment.



Site Selection for TEA/LCA of biofuels and feeds



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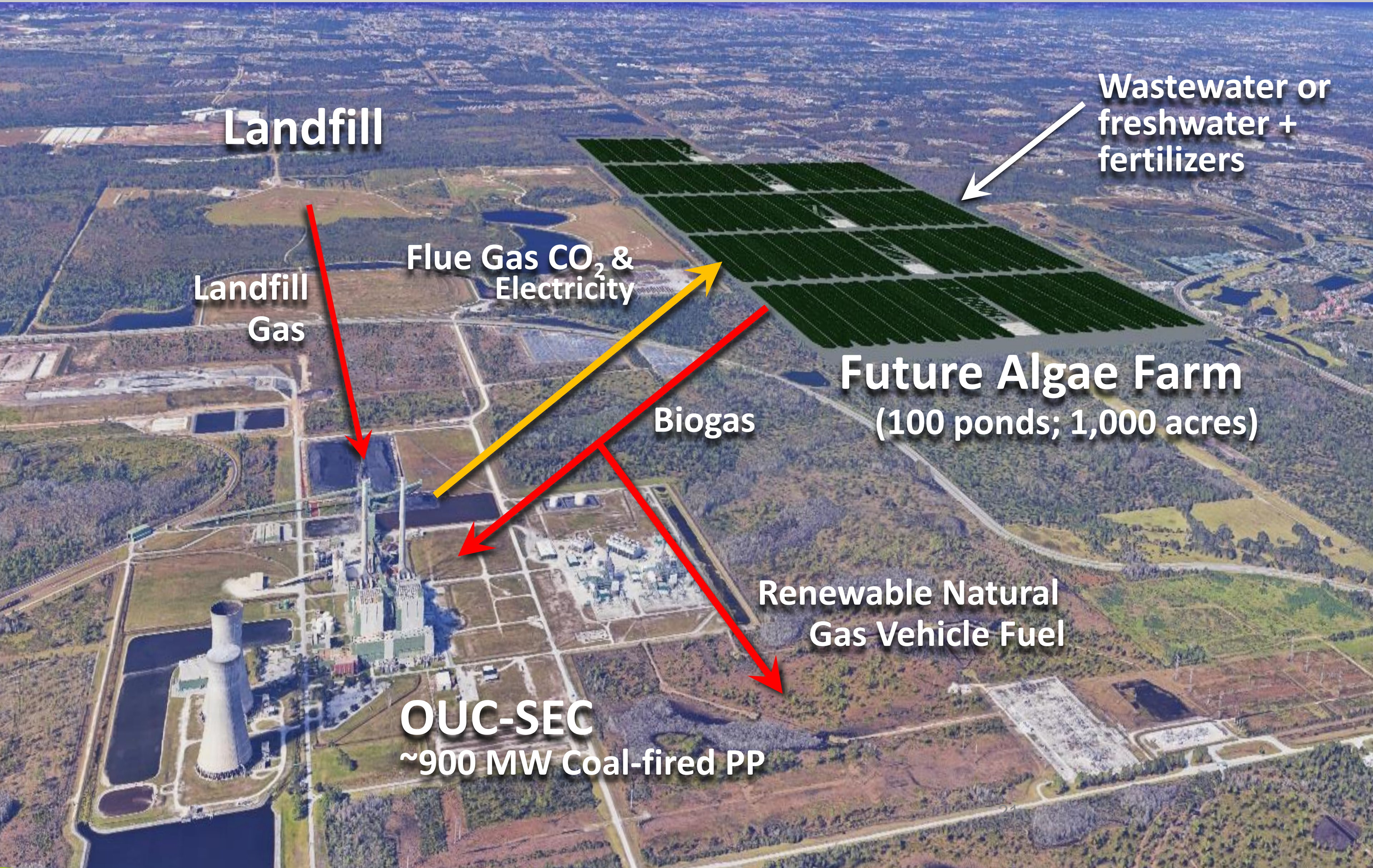
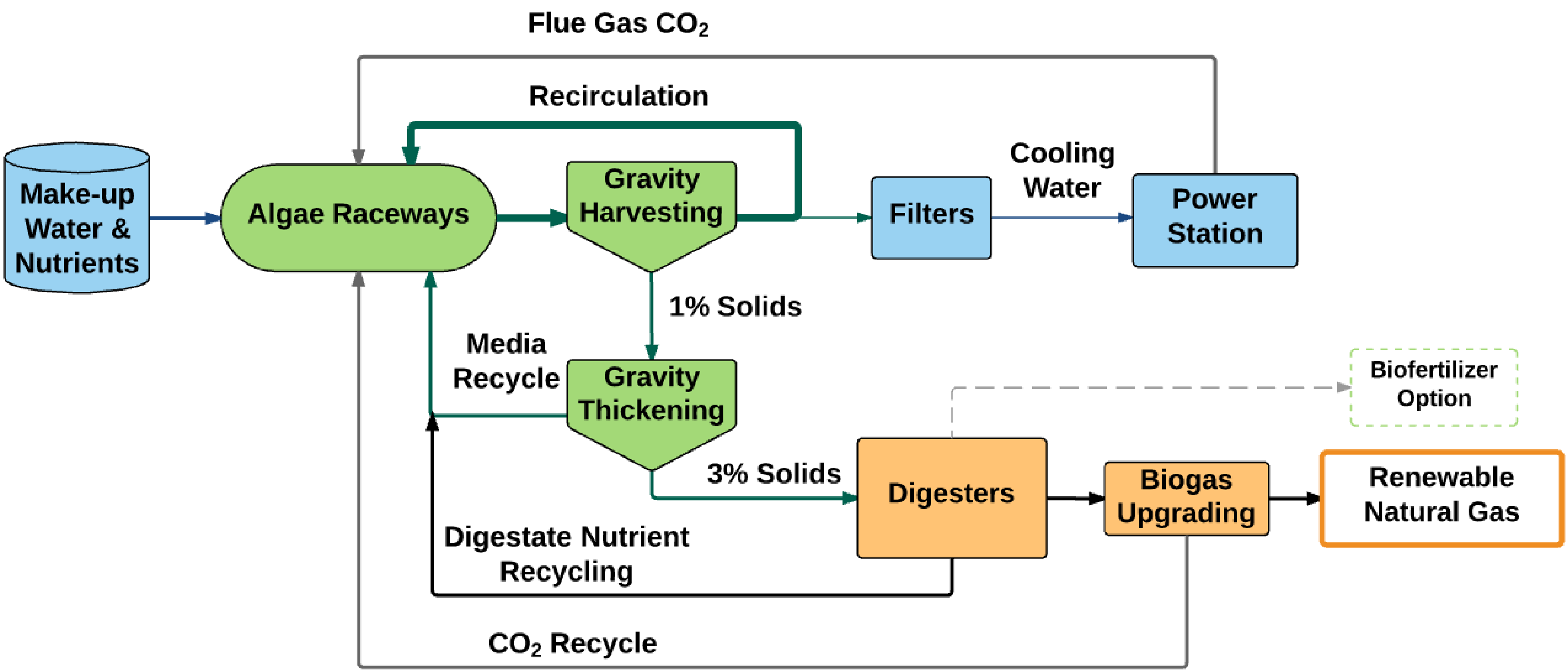
Proposed 1,000 acre algae farm (100 x 10 acre raceway ponds) 1st Year: Biogas/RNG case



Biogas/ Renewable natural gas (RNG) production from algae uses wastewater for nutrients, treatment credits

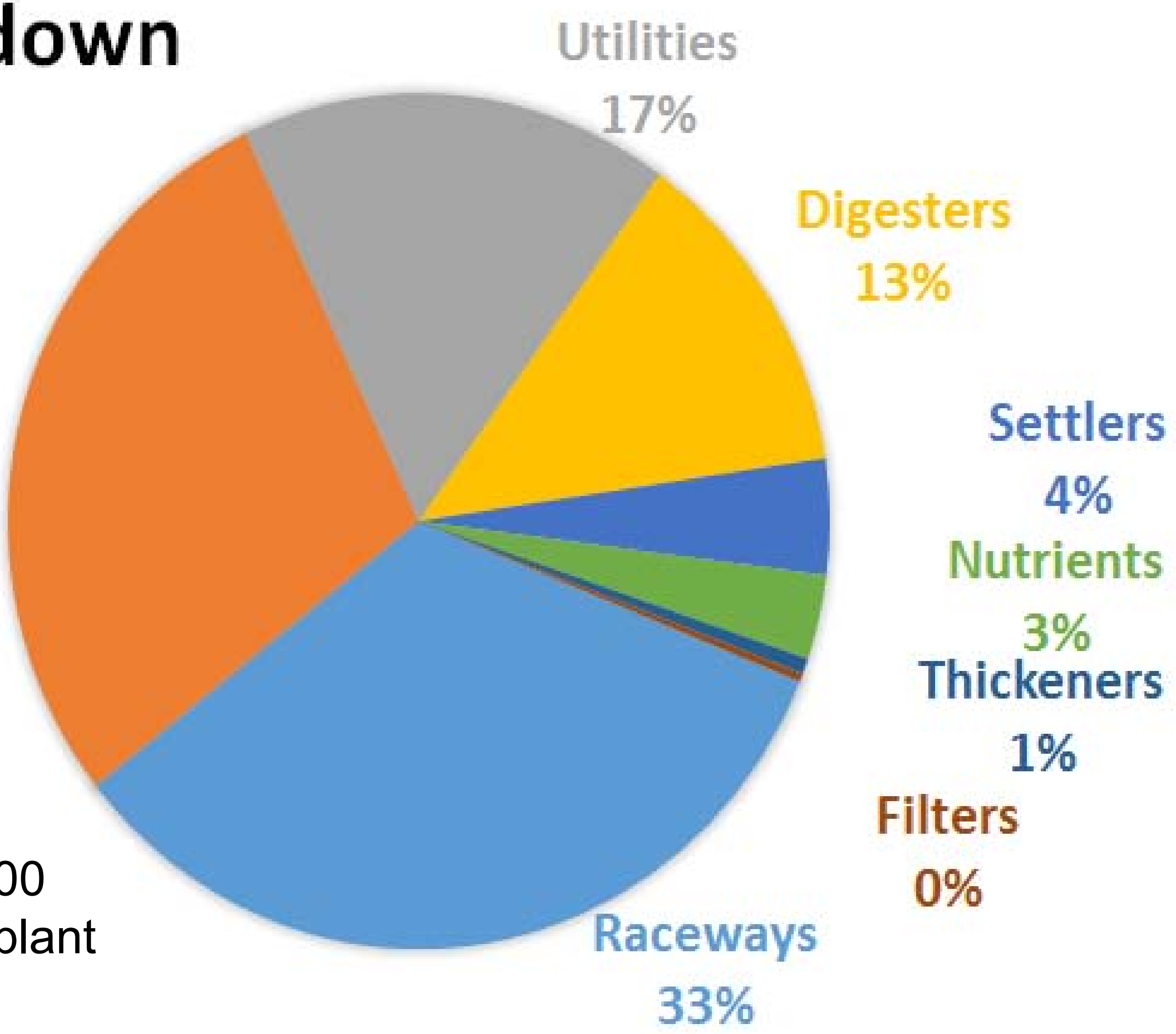


12 MGD (45,500 m^3/d) of wastewater to make-up evaporation

TEA/LCA Assumptions for Biogas /RNG Case

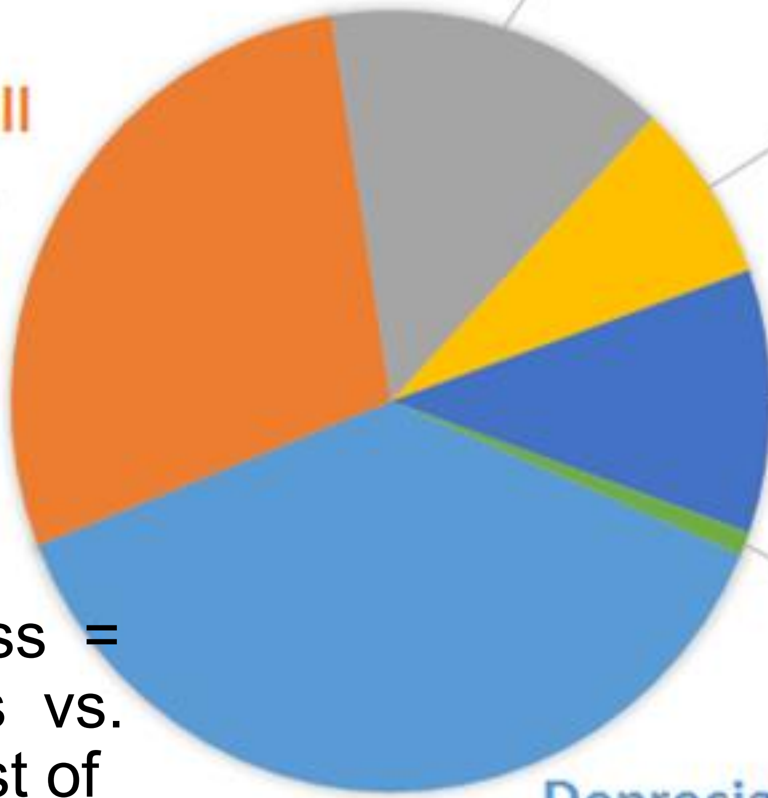
- Annual average productivity: 33 g/m^2-d
  - 15 g/m^2-d: autotrophic growth on flue gas CO_2
  - 18 g/m^2-d: mixo-/hetero-trophic growth on organic C from recycle of whole anaerobic digestate to raceways
  - 4.5 g/m^2-hr: Peak summer productivity on flue gas CO_2
- 45% Overall loss factor in flue gas 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

CAPEX Breakdown



Preliminary Capex: $100 million, for a 1000 acre plant ($100K/ac), rounded

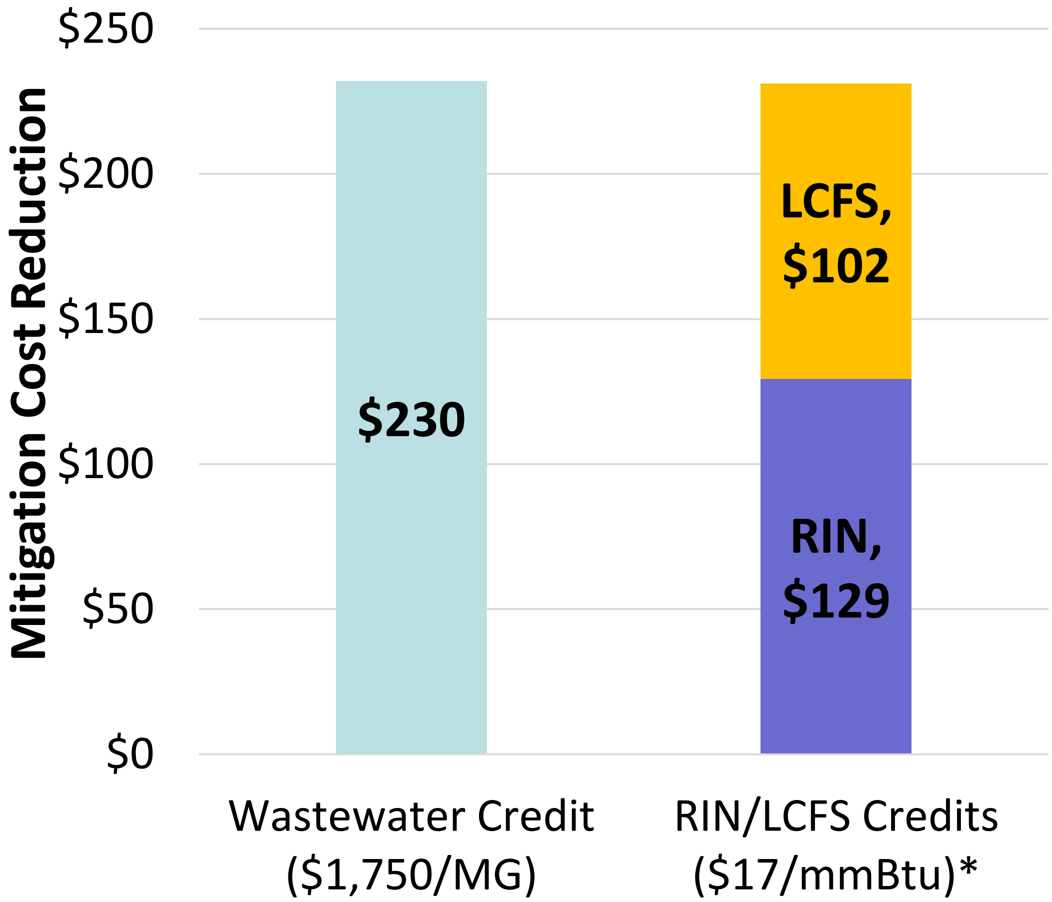
OPEX ~ $10 M/yr,
~50,000 mt/year biomass
(preliminary estimated numbers)



= $200/mt biomass
+ $200/mt CAPEX (annualized)
⁂⁂$400/mt biomass = $40/MMBTU biogas vs. $2 /MMBTU for cost of natural gas

CONCLUSION: Biogas replacing coal is not economically feasible

Wastewater treatment and upgrading biogas for vehicular fuels or RNG (pipeline) provide sufficient potential revenues



Cost - Revenue

$816/mt (without co-products)

-$230/mt (WWT credit)

-$102/mt (LCFS credit)

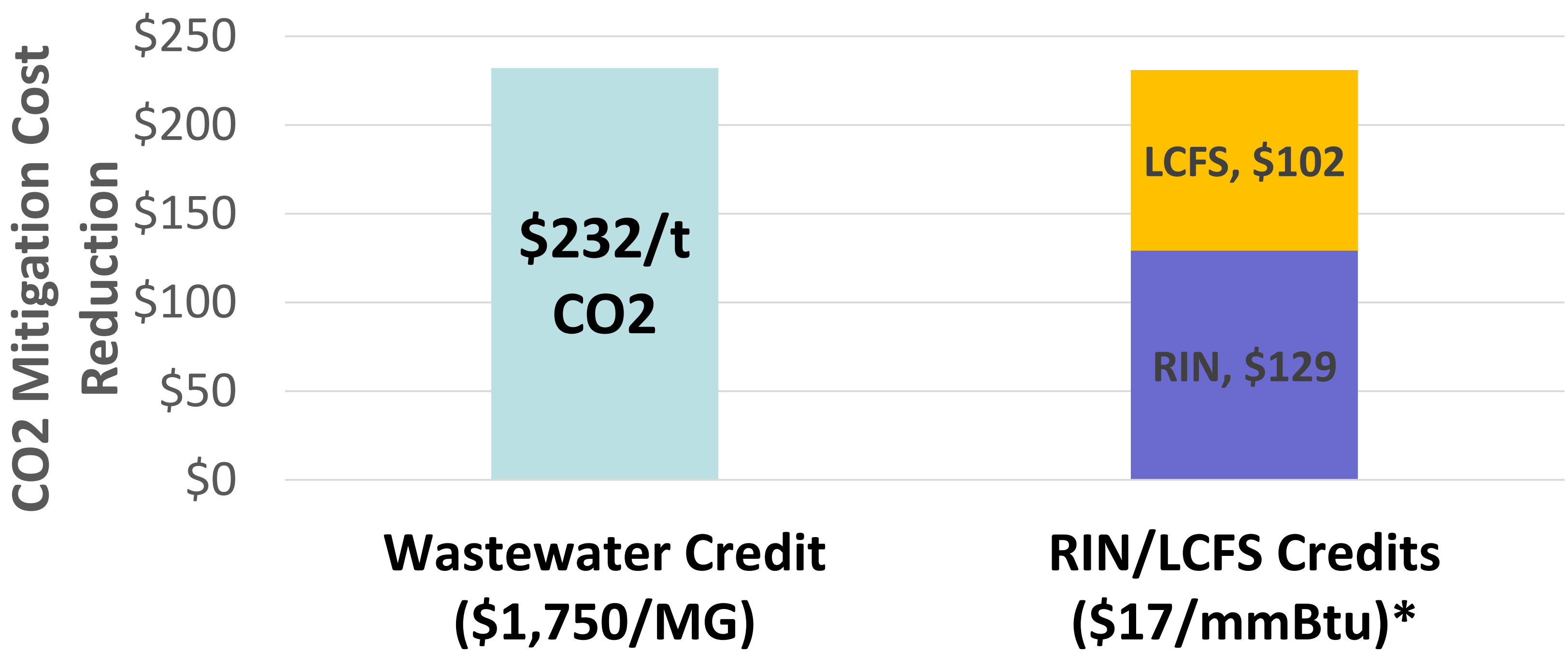
-$129/mt (RIN credit)

$355 /mt CO_2 (Sum)

(with value of biogas as vehicular fuel or RNG would cover costs of production

Preliminary

Alternative Scenario: Combine microalgae CO_2 utilization with wastewater treatment and biogas upgrading to'renewable natural gas'(RNG, for transportation fuels or pipelines). Wastewater treatment, RIN and LCFS credits make process economically feasible.



*Assumes treating 12 MGD, ~120,00 people equivalent. Much larger flows available at site. Nutrient removal alone would justify process. → economically attractive with lower or even no RIN/LCFS credits.

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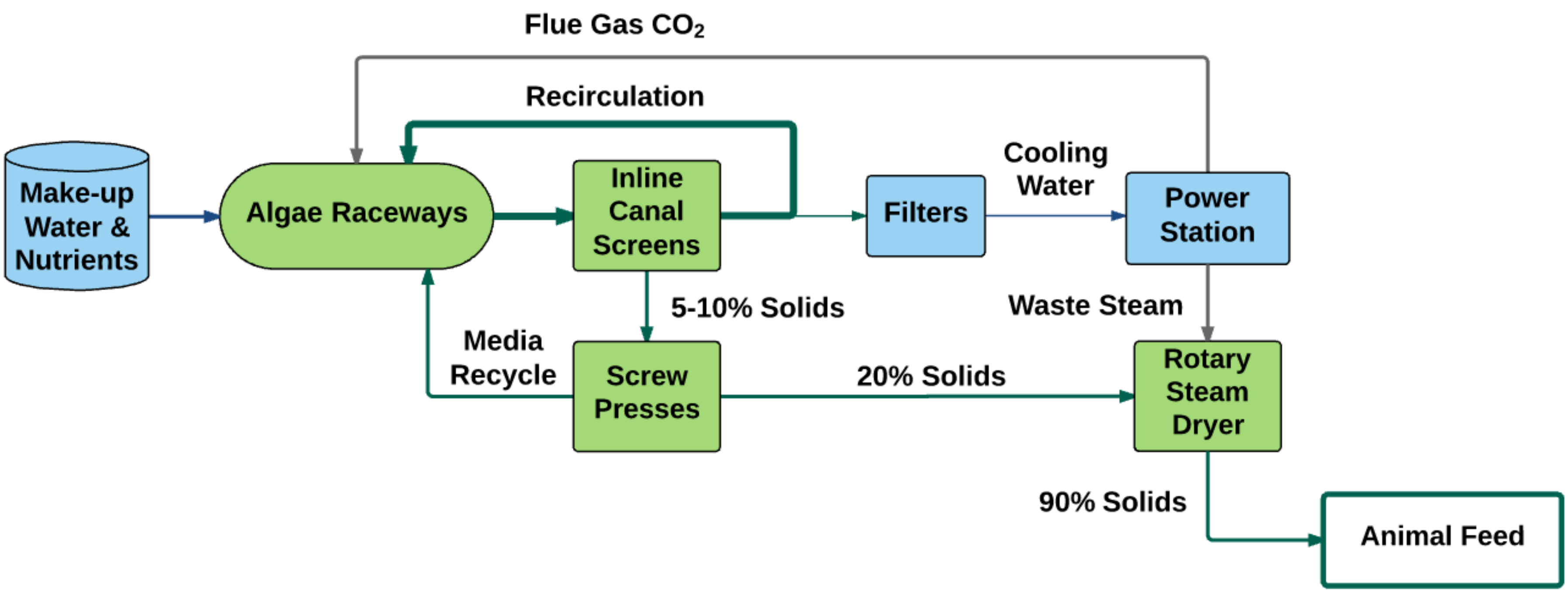
Animal feed case: uses clean water and agricultural fertilizer.



Cost per ton animal feed produced – work in progress

Initial Project Conclusions

Economical CO_2 utilization for Biogas/RNL cases will require a combination of:

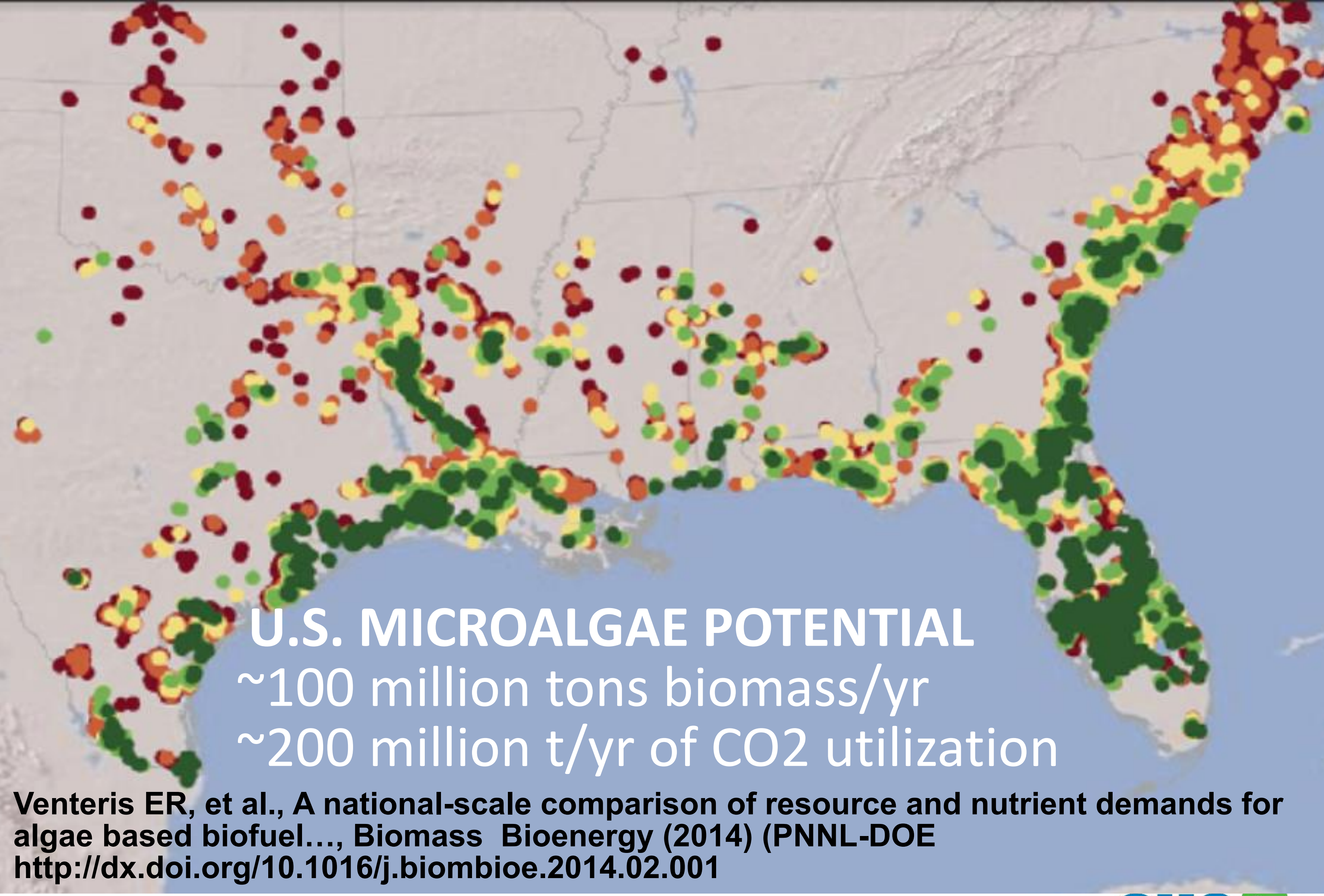
- Wastewater treatment credits
- RIN and LCFS credits
- Further cost cutting/process improvements

1,000 acre microalgae farm only utilizes about 1% of SEC CO_2 emissions.

- >10,000 acres of flat land available near plant Requires novel flue gas CO_2 transport technology. A future objective for this project.

CONCLUSION –Opportunities exist for beneficial Carbon Utilization.

- Requires Multi-disciplinary approach
- Must advance, demonstrate and integrate technology for microalgae cultivation
- Scale, Scale, & Scale
- Next steps: Demonstrate algae cultivation process for RNG at 10X current scale at OUC SEC



U.S. MICROALGAE POTENTIAL

~100 million tons biomass/yr

~200 million t/yr of CO_2 utilization

Venteris ER, et al., A national-scale comparison of resource and nutrient demands for algae based biofuel…, Biomass Bioenergy (2014) (PNNL-DOE http://dx.doi.org/10.1016/j.biombioe.2014.02.001

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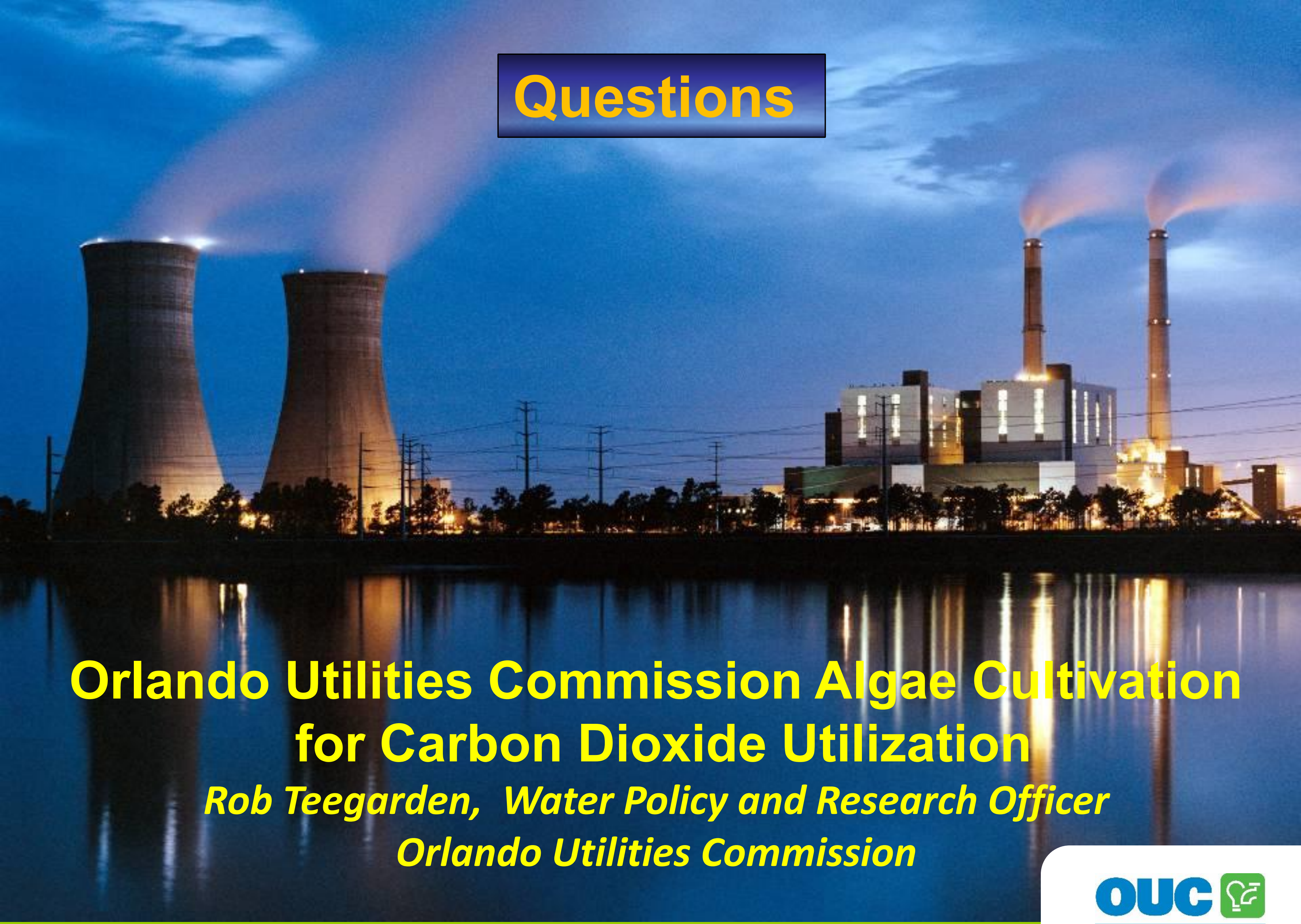

Questions

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Multi Disciplinary Approaches – Leadership and Advocacy for a sustainability master plan