Recycling of Nutrients and Water in Algal Biofuels Production

Thursday, May 23, 2013
DOE Bioenergy Production Technologies Office
Algae R&D Activities Peer Review

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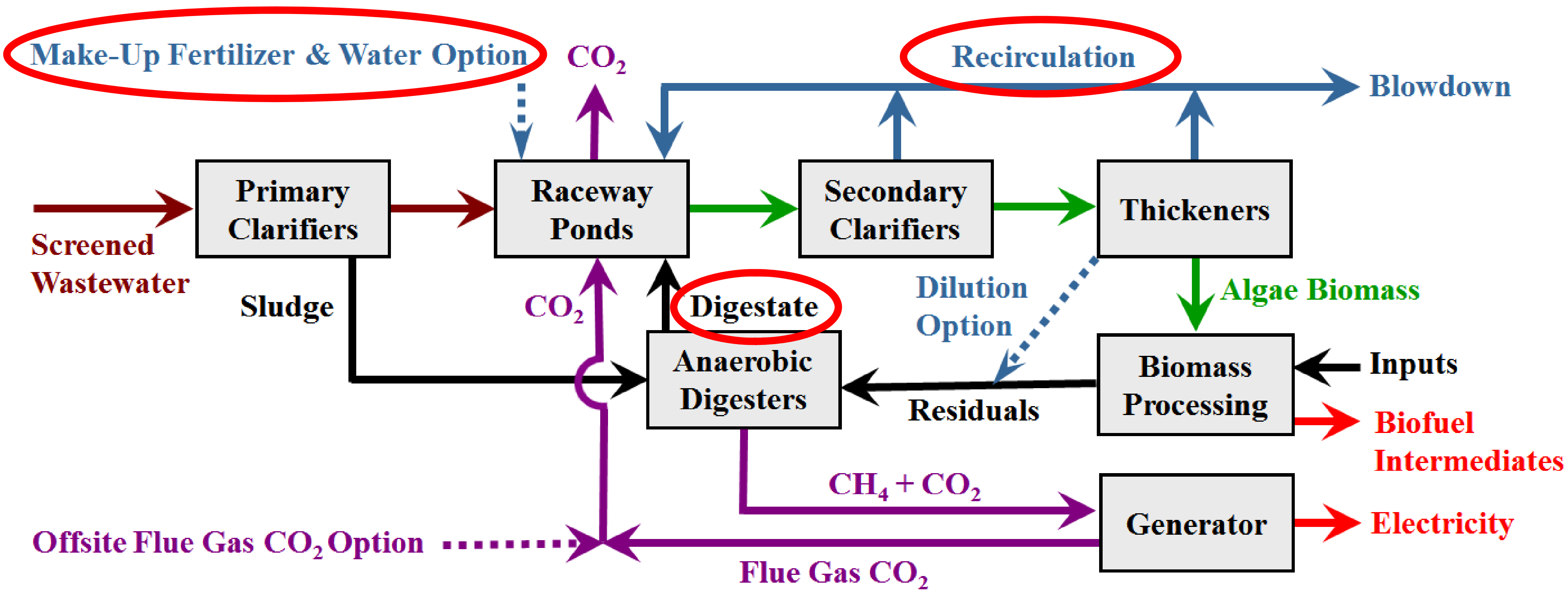
Goal Statement

- Improve the sustainability of algae biofuels by developing and demonstrating efficient recycling of water, nutrients, & some carbon.
- Without significant loss in culture stability and productivity, achieve at least 75% recycle efficiency of:
  - The water recovered after harvesting the biomass
  - The nutrients added (N, P, K and minor nutrients)
- Water and nutrient recycle rates of up to 90% will be tested.



Quad Chart Overview

Timeline

- Started February 2013
- Ends February 2016
- 5% complete

Barriers

- Ft-N Algal Feedstock Processing
  - Recovery and recycling of nutrients and water

Budget

- Total: $1,678,070
  - DOE share: $1,306,070
  - Contractor share: $372,000
- DOE Funding FY13: $290,237
- ARRA Funding: None

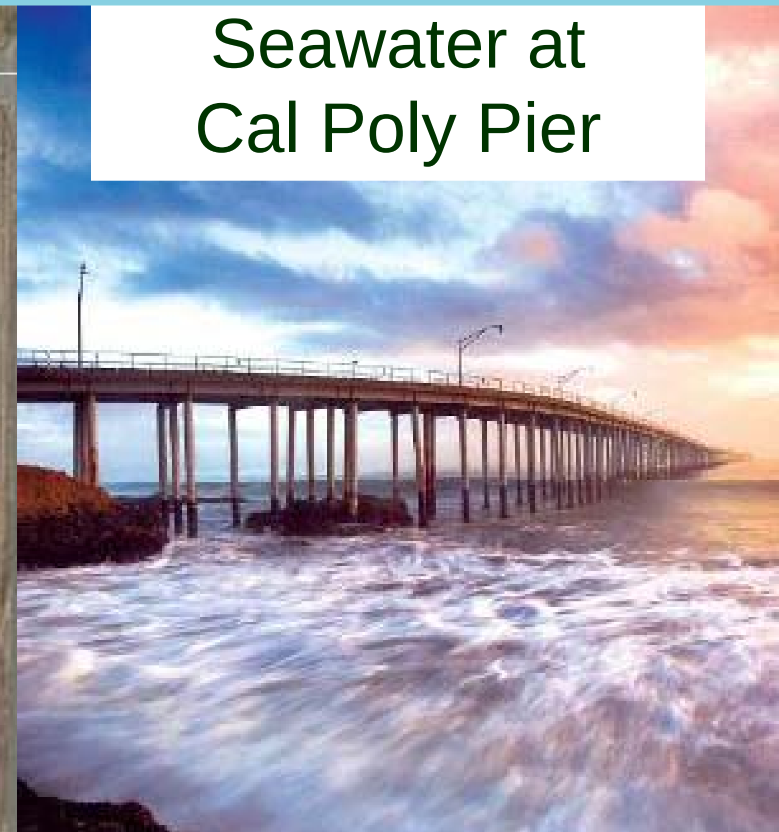
Partners

- Cal Poly
- City of San Luis Obispo
- MicroBio Engineering, Inc.

Cal Poly is also an ATP^3 site

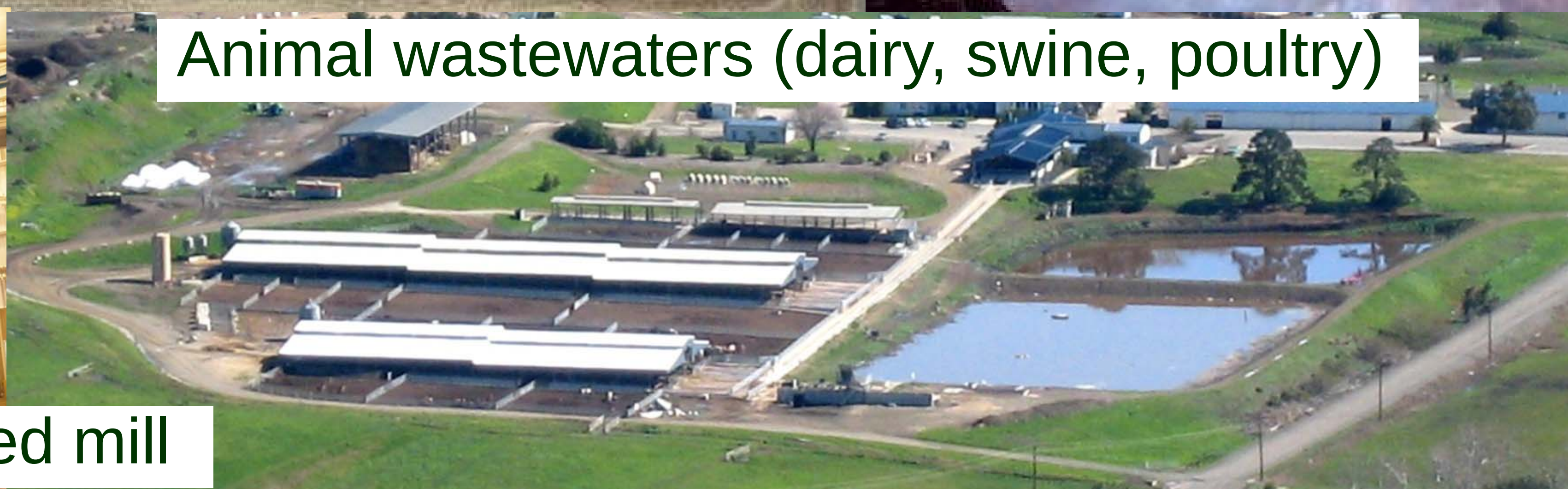
Cal Poly has access to….

3-acre raceways with settling basins & drying beds



Seawater at Cal Poly Pier

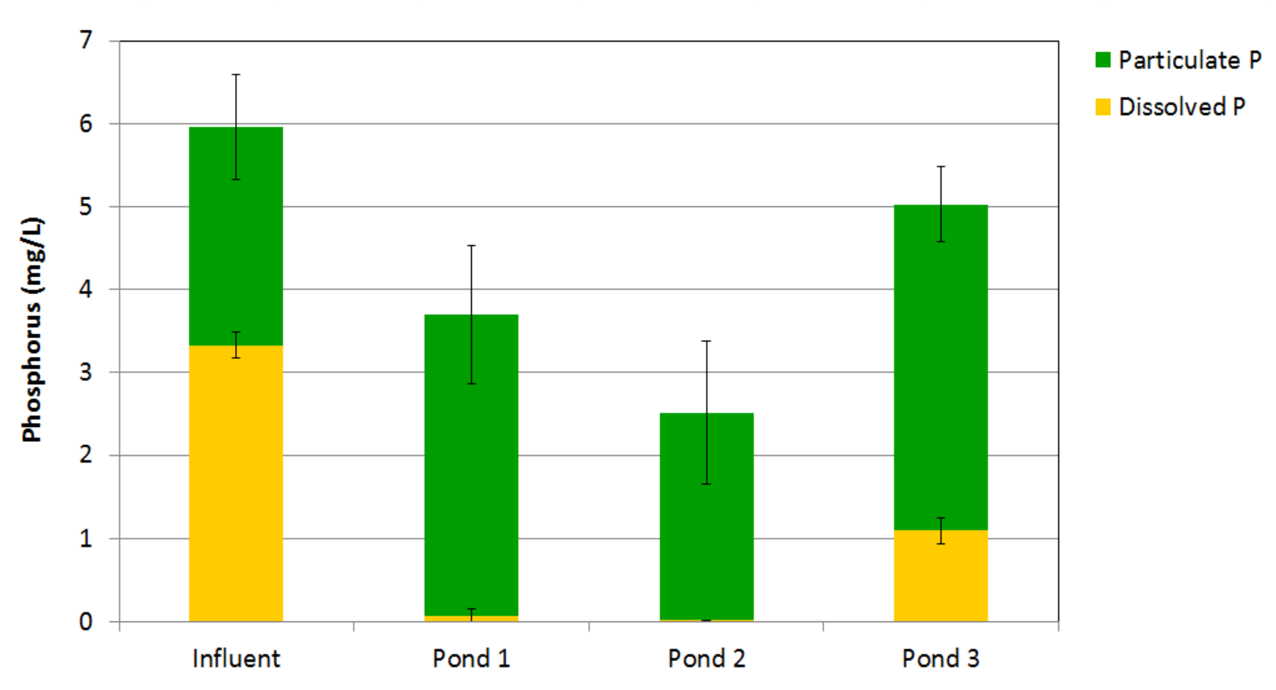
Research feed mill



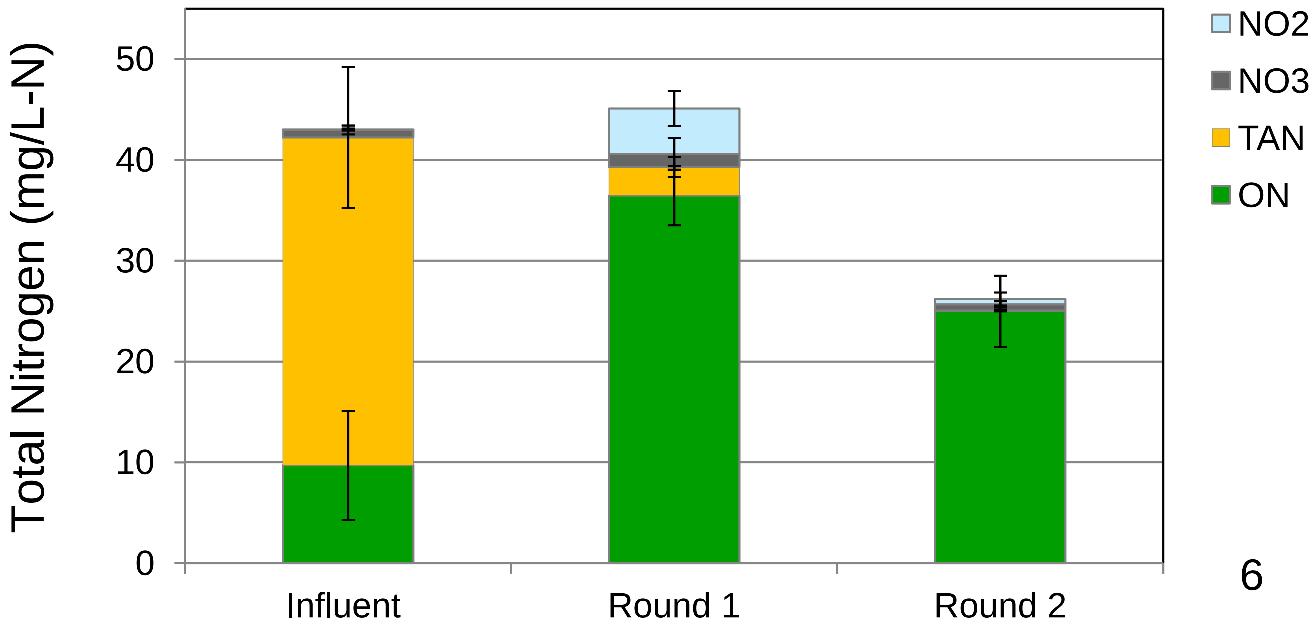
Animal wastewaters (dairy, swine, poultry)

Nutrient transformations to be studied

Phosphorus

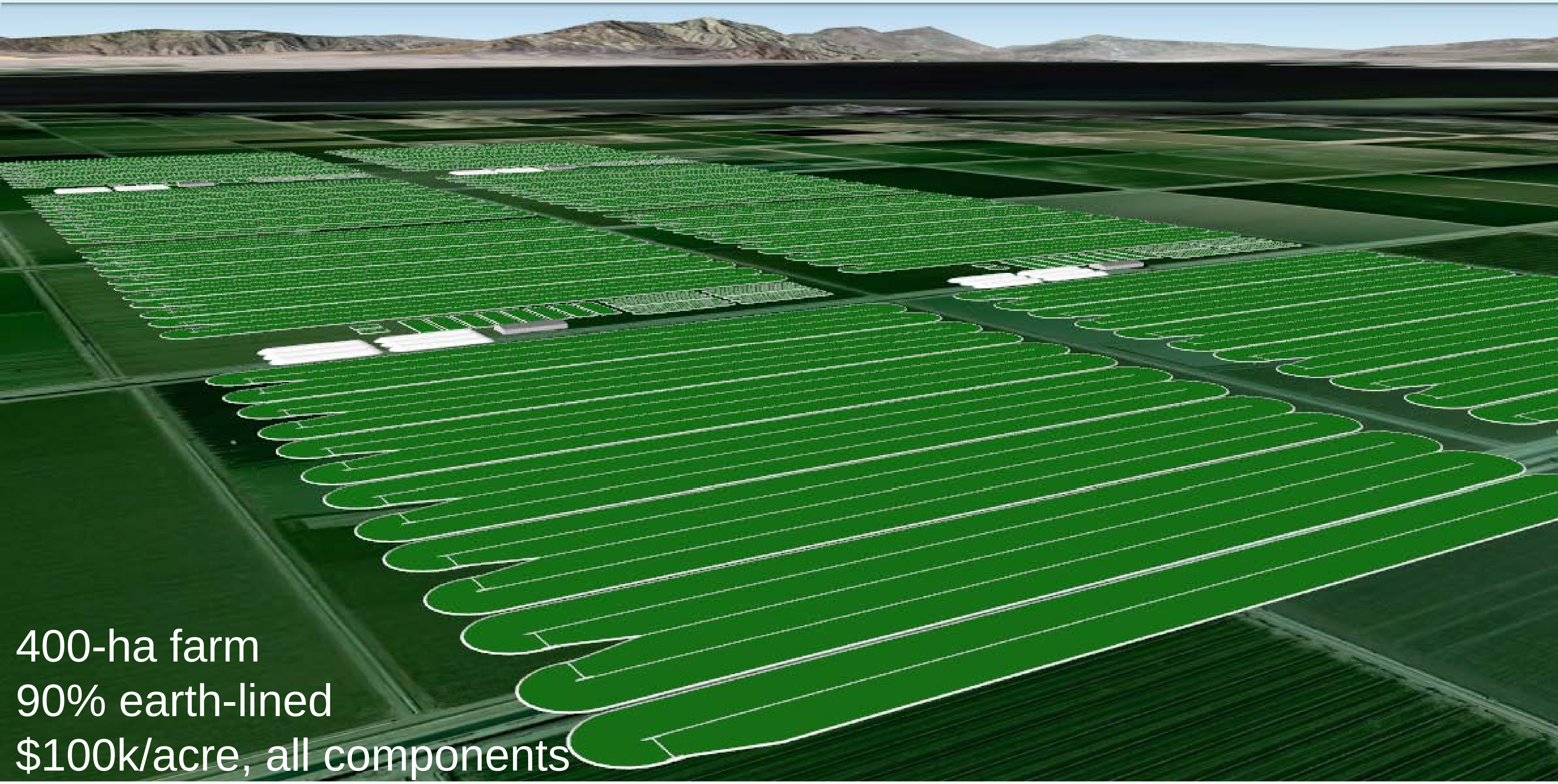


Nitrogen



TEA & LCA models to be updated

- Basis will be ***Realistic Assessment*** report, Lundquist, Woertz, Benemann et al. 2010
  - Similarly based on 1980s – 1990s reports of Benemann, Weissman, et al.
- Participated in Harmonization effort (ongoing: informal and via ATP^3)



Nutrient and water recycling is assumed in 2010 TEA. Now we test the assumptions.

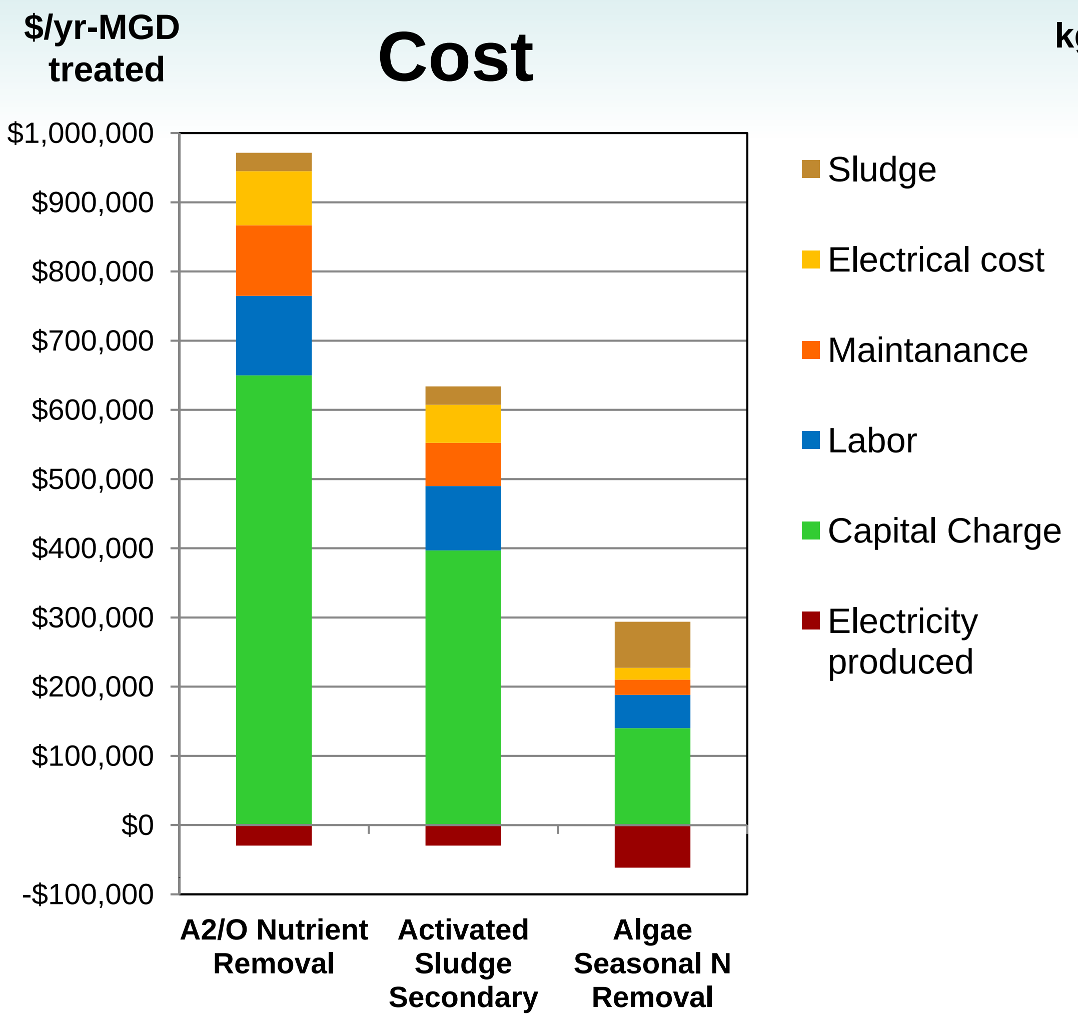
System Goal	Break-even without WWT credit	Break-even with WWT credit
Treatment (100 ha)	--	$28 /bbl
Oil (400 ha)	$300 /bbl	$240 /bbl

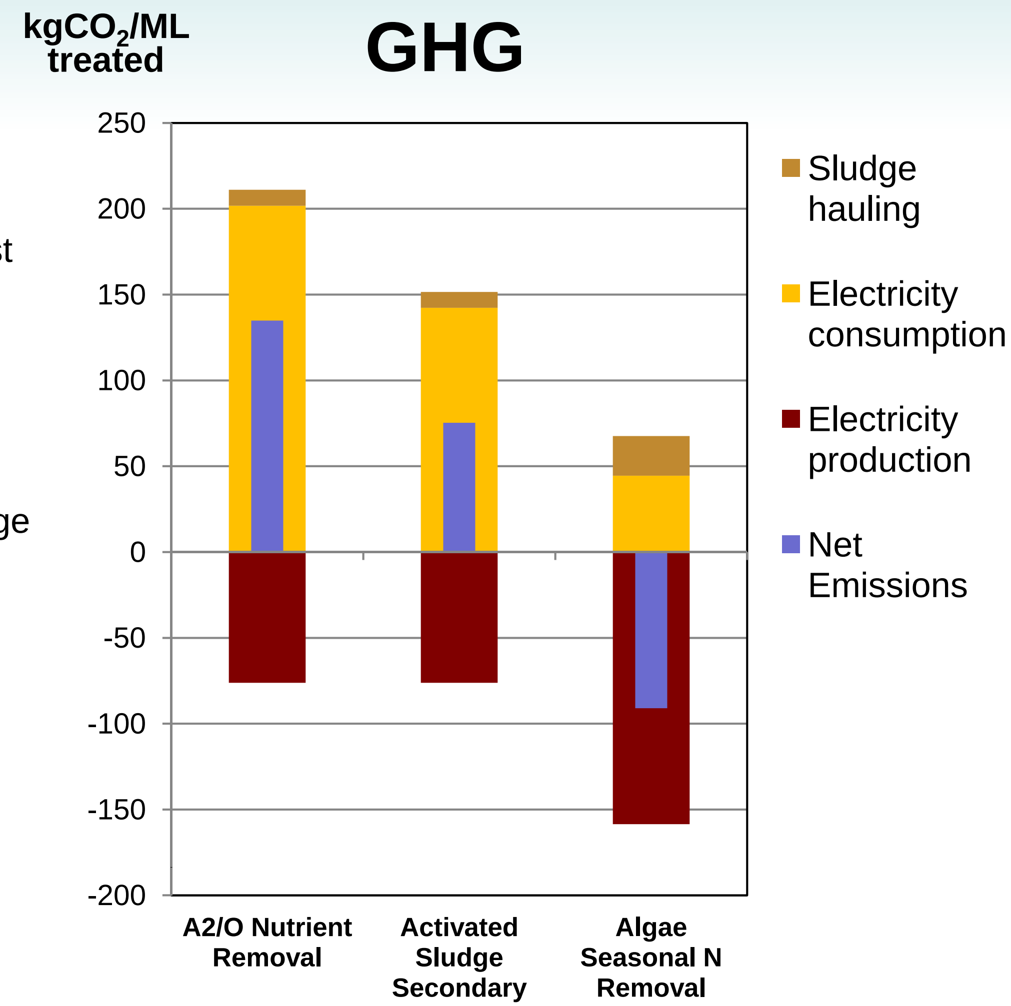
Treatment revenue lowers cost to $28/bbl, but national scale would be small.

“<$200/bbl possible with great R&D success for the non-treatment cases.”

First co-product commercialized is reclaimed water — An early win on road to biofuel.

Algae wastewater treatment is low cost and energy efficient.
Builds algae capacity. But nutrient removal unproven.





Project Overview

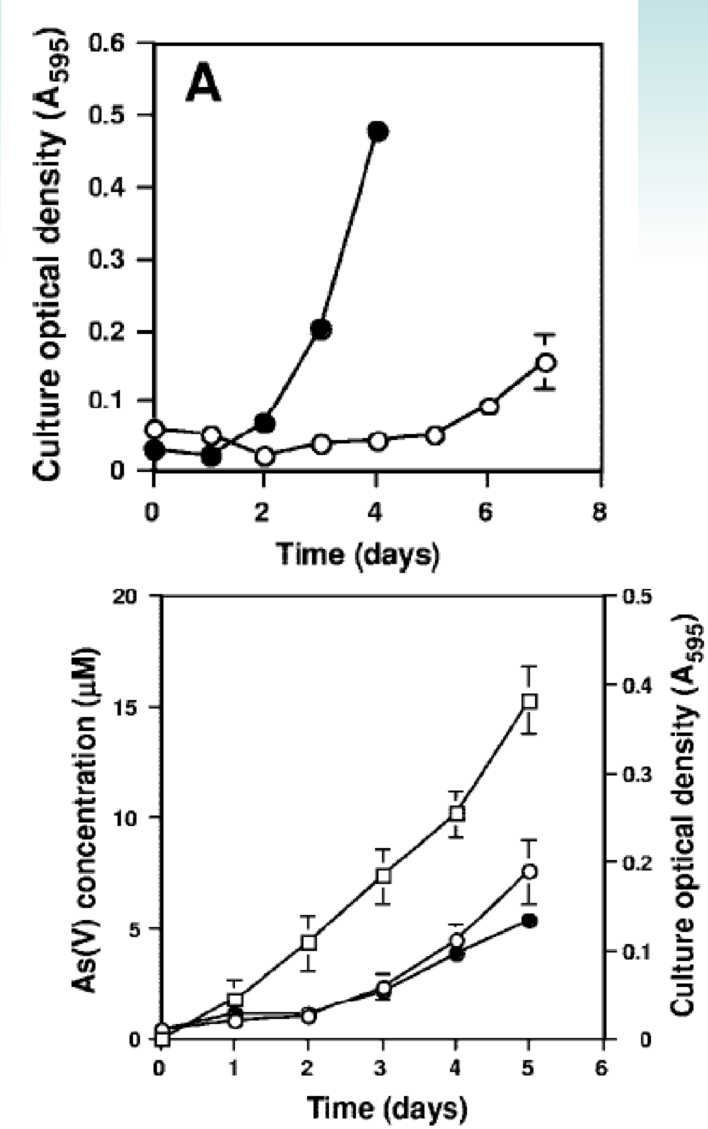
- Cal Poly operates an algae production pilot facility at a municipal wastewater treatment plant. Nine raceways @ 33 m^2 (10 m^3).
- Nutrients and carbon will be re-solubilized using anaerobic digestion, with digestate fed to the raceways.
- Recycled water will be monitored for build-up of inhibitory compounds and removal methods tested.
- Model recycling: processes, lifecycle, techno-economics.

1 – Approach [Milestones]

- Lab studies will establish the methods and initial modeling [Select a scalable cell lysing method; Determine biomass degradation parameters; Characterize inhibitory compounds from algae production].
- Pilot experiments will each be operated continuously over several months, in replicate and with controls. Cells will be lysed prior to digestion. [Measure productivity with 50% and 75% recycling of water or nutrients; Determine degradation parameters; Characterize inhibitory compounds].
- Algal biomass will be harvested by bioflocculation, with centrifugation as needed [95% harvesting efficiency achieved].
- ***Go–No Go at end of Year 2: Was pilot plant performance measured with separate nutrient and water recycling, compared to controls? If yes: Proceed with integrated nutrient & water recycling pilot studies.***
- Up to 90% water recycling will be tested [Measure productivity; Characterize inhibitory compounds].
- Lifecycle and cost assessment studies based on pilot data.

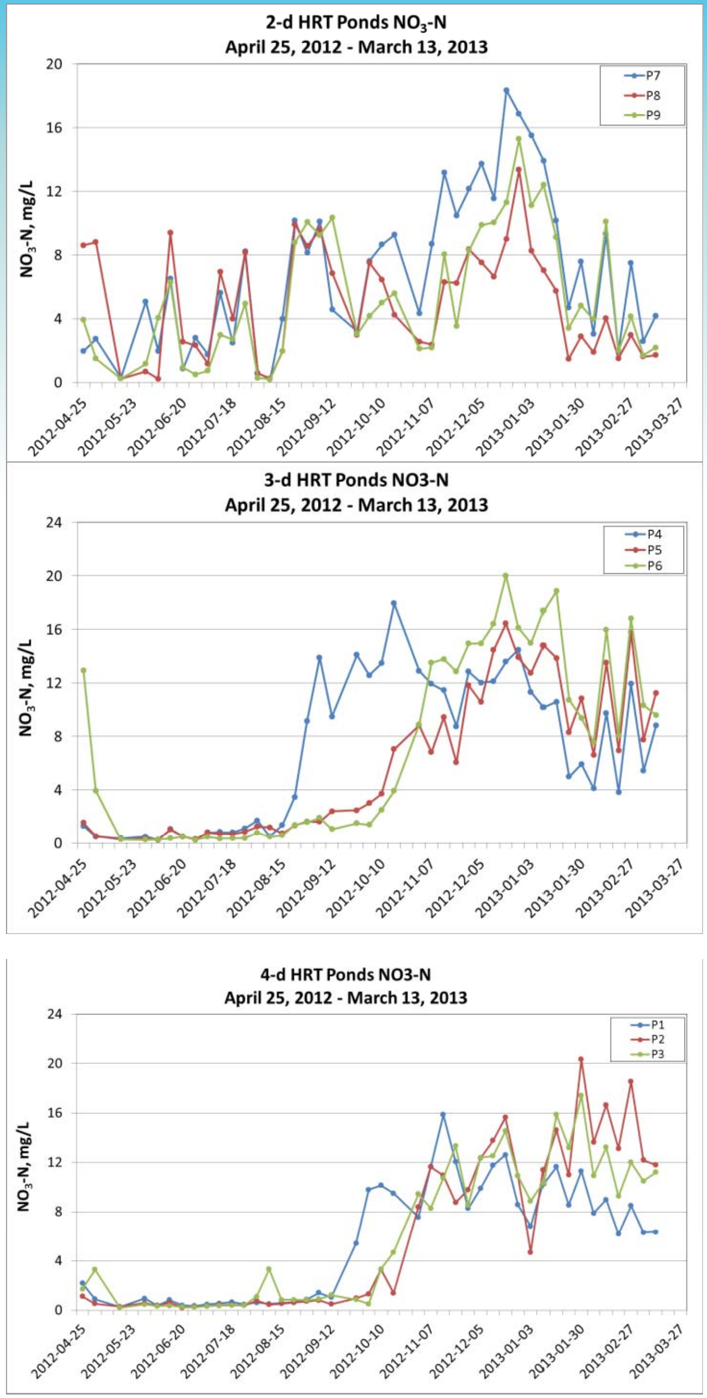
Approach to Statistical Uncertainty

Lab growth trials (examples)



72-hr incubation: Compare average specific growth rate & yield.

Triplicate ponds (NO3 example)



2 – Technical Progress

Personnel

- Trained technicians, graduate students, and undergraduates.

Instruments and Equipment

- Newly selected and installed: accelerated solvent extractor, freeze dryer, GC-MS/FID, biogas GC, light incubator, and field centrifuge.

Lab Studies

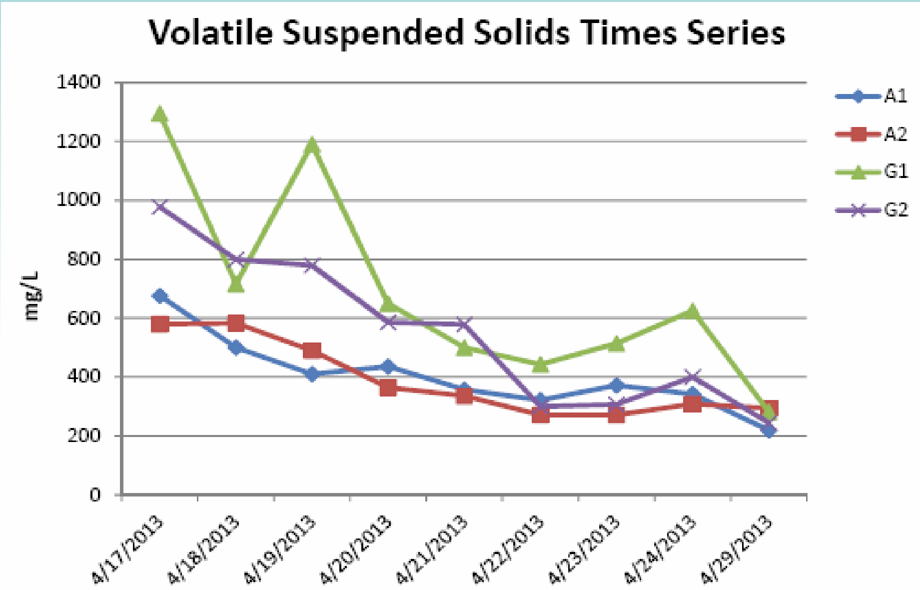
- Conducted initial test on nutrient release/transformation from algae during dark aerobic incubation (simulating solids decay in a pond).
- Conducted two lab algae culturing batches for training and setup.
- Conducted initial lab sonication study measuring the increase of soluble chemical oxygen demand concentration.

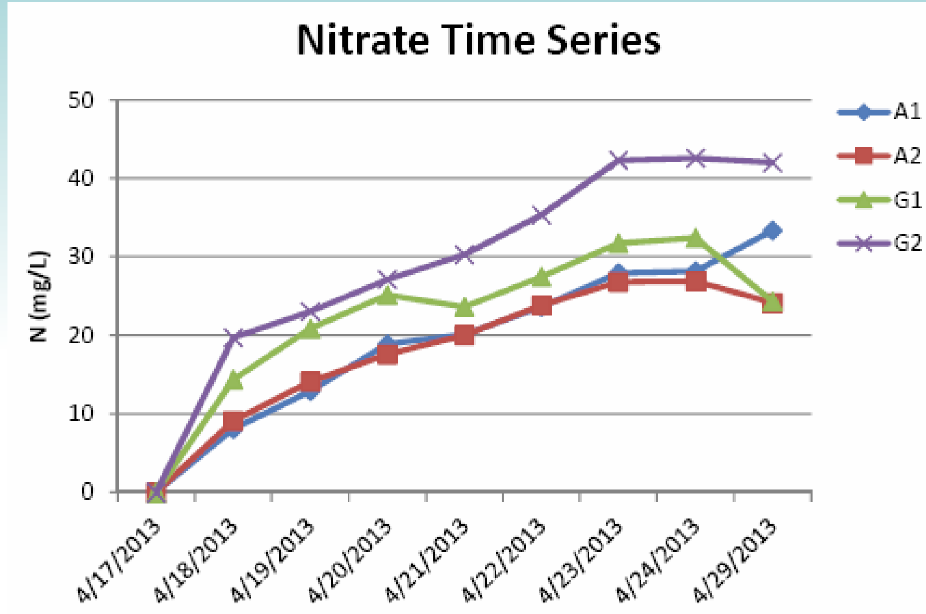
Pilot Plant Operation

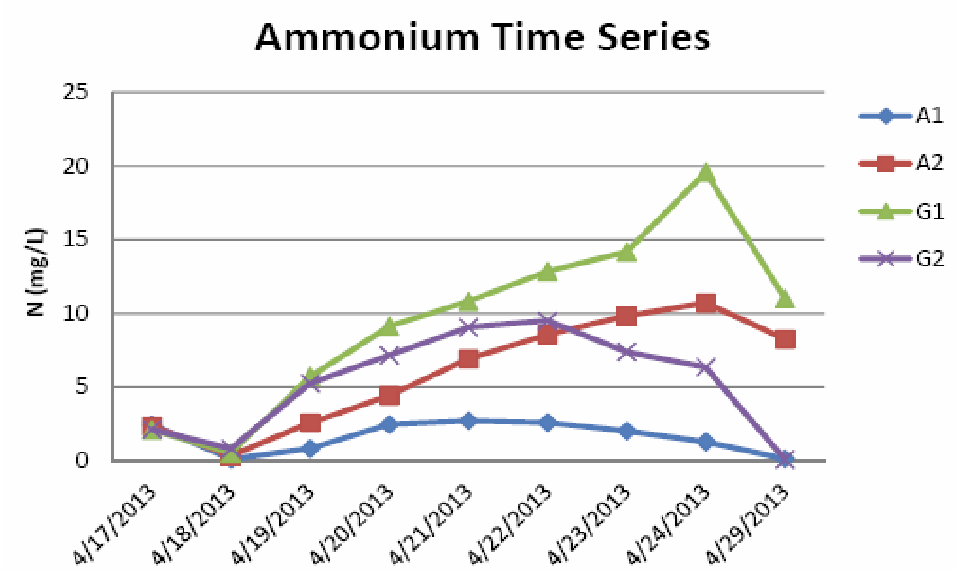
- Operating and sampling the nine 33-m^2 raceway ponds on weekly basis to obtain baseline performance and precision data.
- Testing a new rack design for the probes and effluent tubing to avoid fouling by filamentous algae.

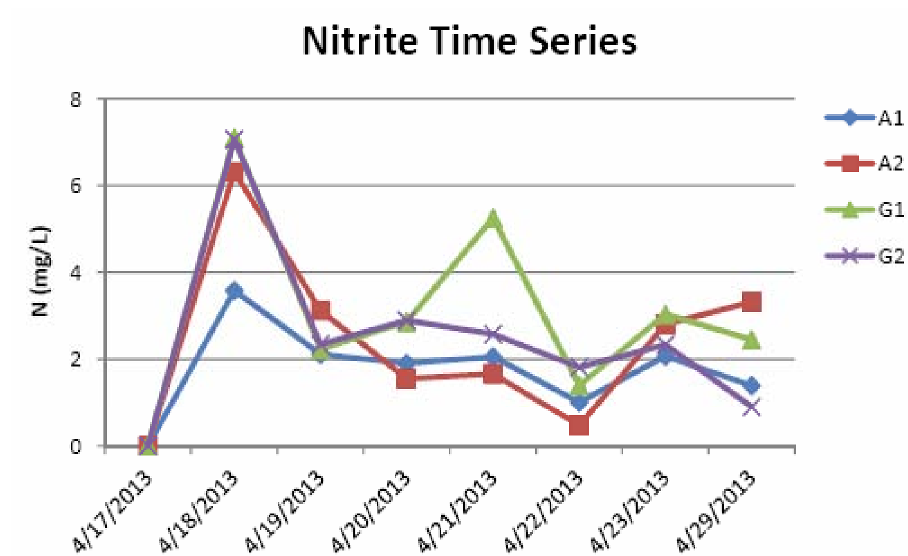
2 - Technical Progress (cont'd)

- *Aerobic solubilization of algal biomass and transformation of nitrogen*





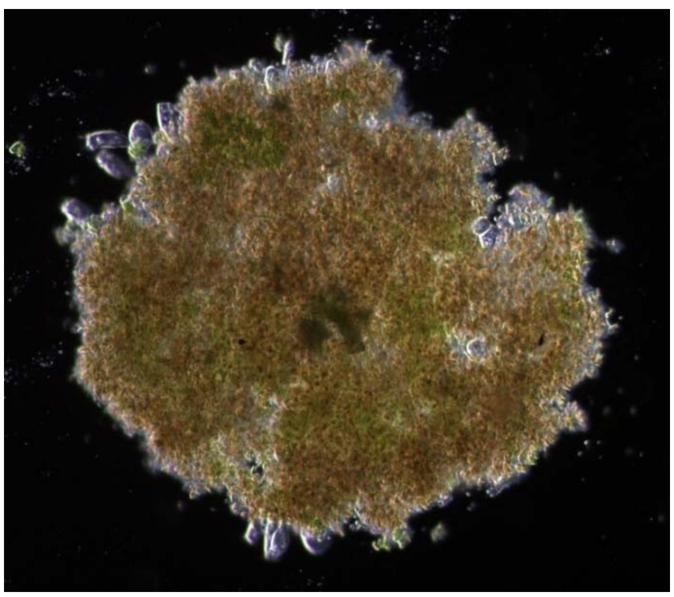


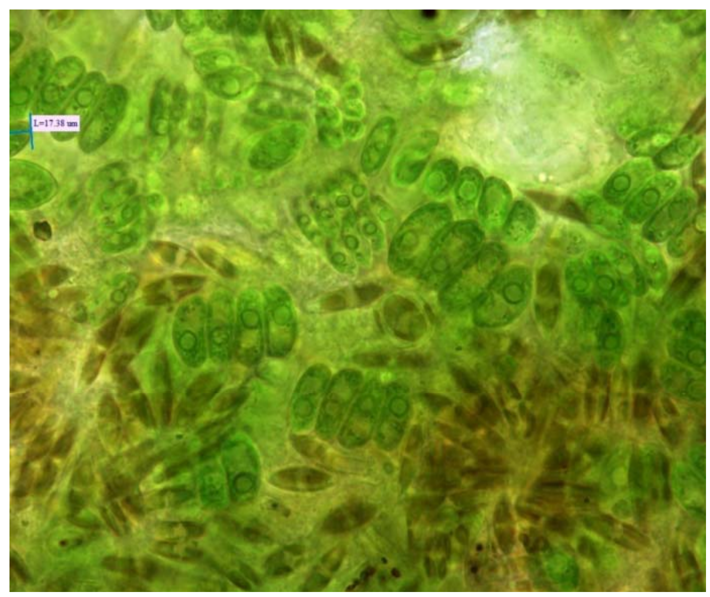


2 – Technical Results (cont'd)

- ***A key question is effect of recycling on simple bioflocculation harvesting process***

Primary Clarifier   Raceway Pond   Tube Settler

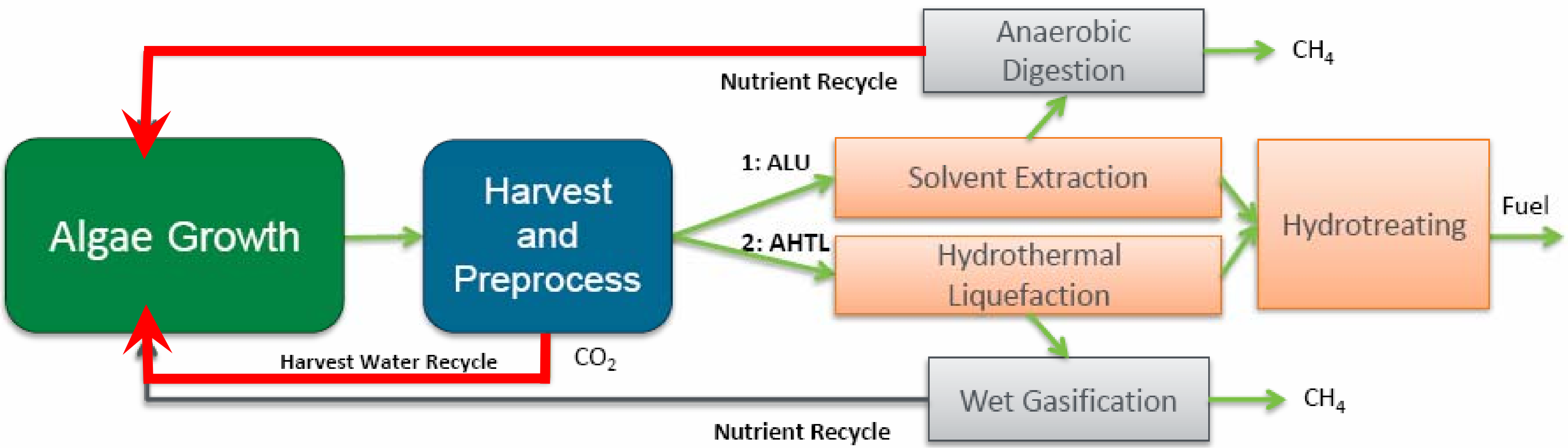




3 - Relevance

BETO Multi-Year Program Plan topics addressed:

- *R.9.2 Sustainability*
- *R.9.2.1 Pathway & Cross-Pathway Analysis*
- *R.9.2.1.1.8 Environmental - Algae*
- *R.9.2.1.3.8 Systemic Sustainability – Algae*
- *R.9.2.2 Sustainability Standards & Adoption*



Fishman, DOE, 2012

4 - Critical Success Factors

- ***We are attempting to demonstrate key technical and sustainability aspects of a common model of algae biofuel production.***
- ***Technical Challenges***
  - ***Achieving at least 75% water and nutrient recycling capability.***
  - ***Achieving rapid and extensive degradation of cell matter in digesters and raceway ponds to release nutrients.***
  - ***Overcoming inhibitors (free fatty acids, turbidity, etc.) with low cost methods.***
  - ***Maintaining low-cost bioflocculation harvesting during recycling.***
  - ***Variability among replicate ponds***

5. Future Work

Laboratory Studies – Water Recycling

- ***Optimize separately biomass and lipid productivity by mono- and poly-cultures.***
- ***Determine extent of productivity inhibition due to repeated water recycling.***
- ***Attempt to identify inhibitory compounds or deficient nutrients.***
- ***Attempt to rectify drags on productivity with cost-effective and sustainable methods.***

Laboratory Studies – Nutrient Recycling

- ***Determine aerobic and anaerobic nutrient (macro and micro) and carbon re-solubilization kinetics and ultimate extent for various pre-treatments.***
- ***Determine biogas methane productivity for biomass & pretreatments.***
- ***Determine re-growth kinetics on recycled nutrients and carbon.***
- ***Measure influence of recycled water and media on bioflocculation.***

5. Future Work

Field Studies – Water Recycling

- ***Demonstrate high biomass and lipid productivity by mono- and/or poly-cultures.***
- ***Confirm extent of productivity inhibition due to repeated water recycling.***
- ***Confirm identity of inhibitory compounds & deficient nutrients.***
- ***Implement any needed and appropriate methods to decrease inhibition due to recycling.***

Field Studies – Nutrient Recycling

- ***Confirm aerobic and anaerobic nutrient and carbon re-solubilization kinetics and ultimate extent for most practical pre-treatment.***
- ***Confirm biogas methane productivity for biomass.***
- ***Confirm re-growth kinetics on recycled nutrients and carbon.***
- ***Confirm influence of recycled water and media on bioflocculation***
- ***Demonstrate water and nutrient recycling independently and in integrated system.***

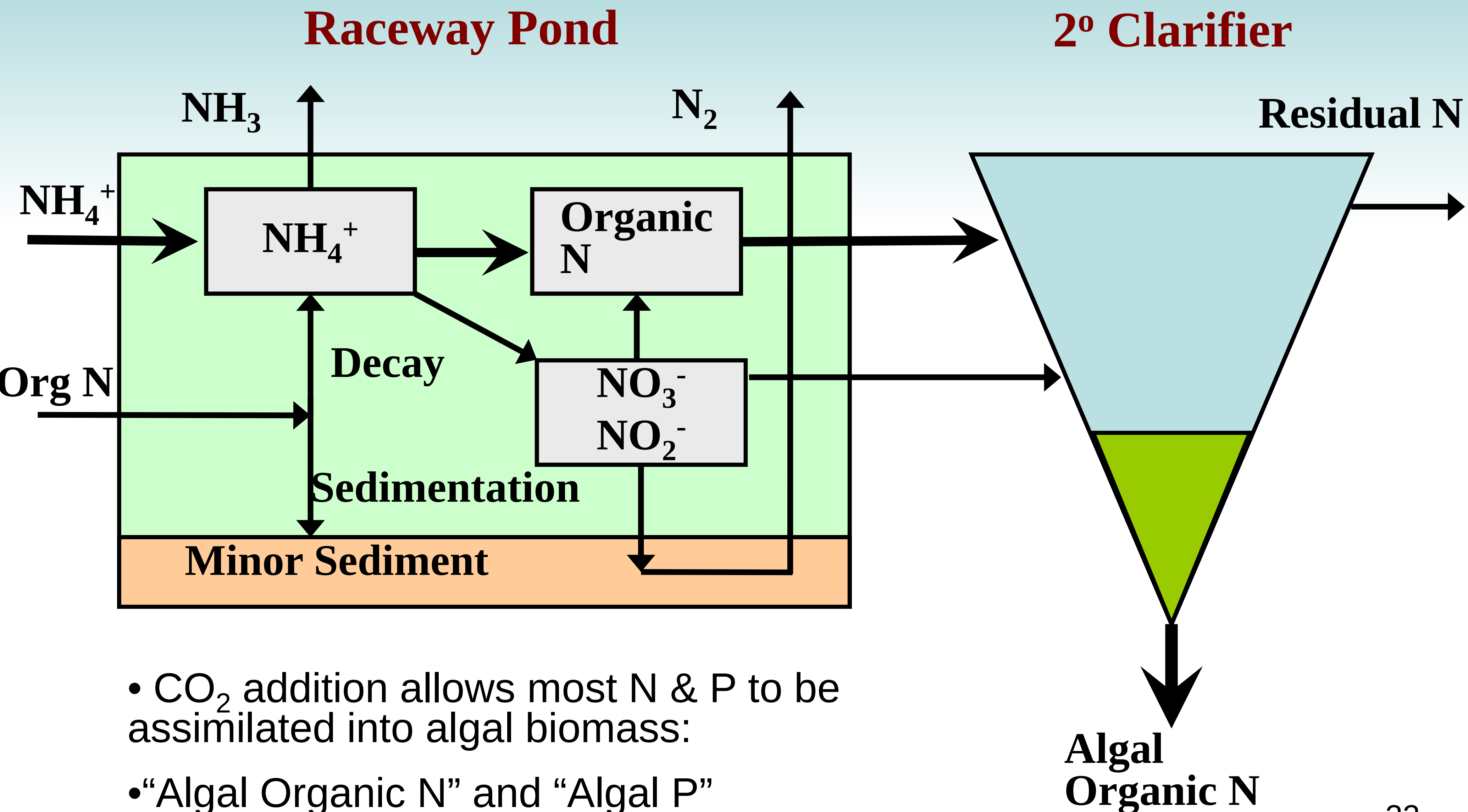
Summary

- Some key elements of sustainable algae biofuel production are the following:
  - Efficient recycling of water, nutrients, and carbon
  - Low-cost, low-input biofloccuation and sedimentation harvesting
  - Renewable electricity production from biogas to offset other GHG-generating inputs to the overall algae biofuel process.
- We will generate basic information and model parameter values and demonstrate integrated cultivation recycling in lab.
- We will attempt to recreate and confirm lab results in the pilot facility.
- LCA and TEA analyses will be updated based on the results.

Acknowledgments

- U.S. Department of Energy
  - Dan Fishman
  - Roxanne Dempsey
  - Christine English
- Review
  - Colleen Ruddick (contractor)
- AzCATI – ASU – ATP^3 team
- California Energy Commission

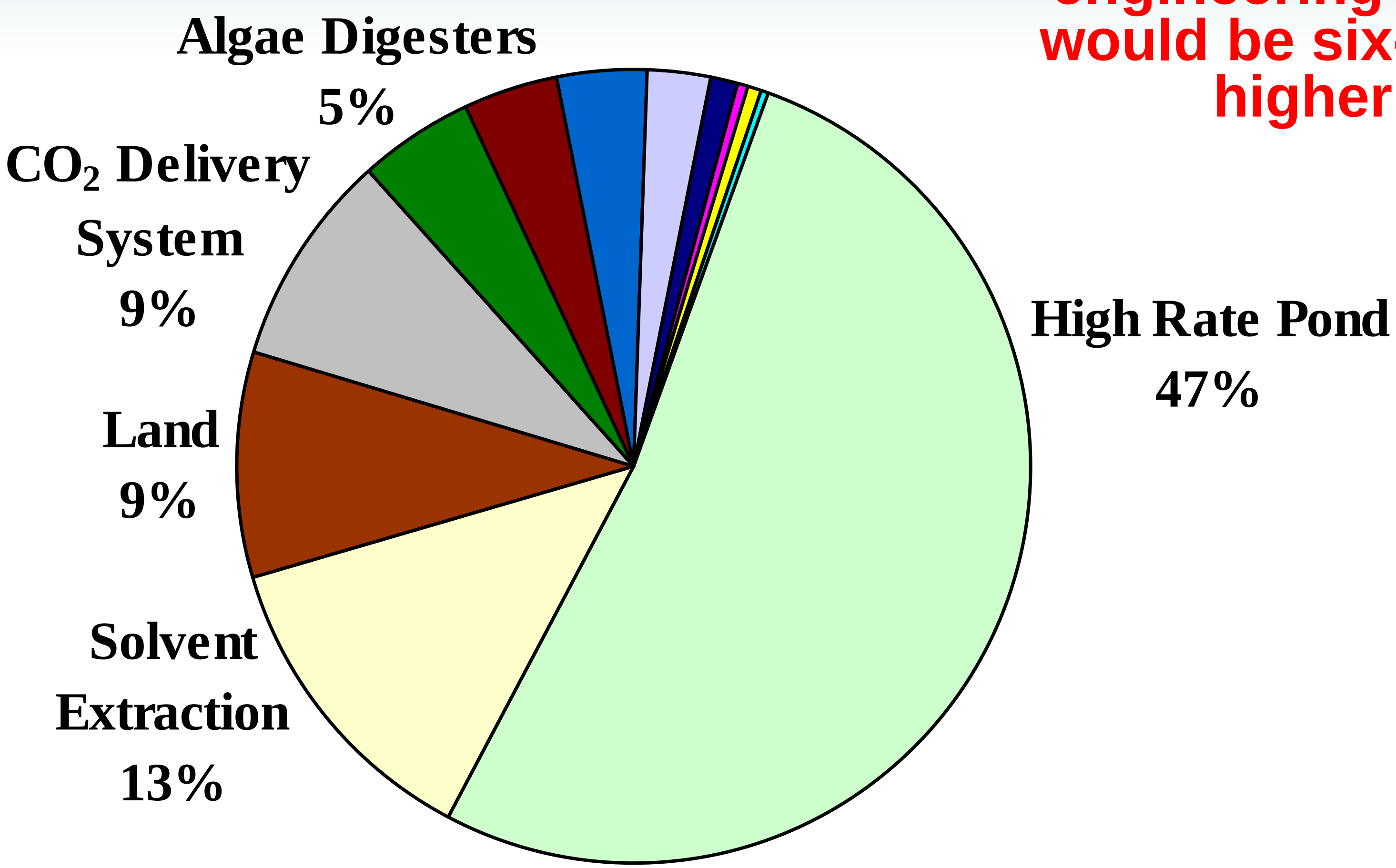
N & P are mostly assimilated in algae biomass, allowing nutrient recycling.



- CO_2 addition allows most N & P to be assimilated into algal biomass:
- "Algal Organic N" and "Algal P"

Capital costs were dominated by pond construction (clay lined).

100 ha, Oil+Biogas: Total capital = $31 million



Municipal engineering costs would be six-times higher