DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

Scale-up of Algal Biofuel Production Using Waste Nutrients

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DOE Bioenergy Production Technologies Office
Algae R&D Activities Peer Review

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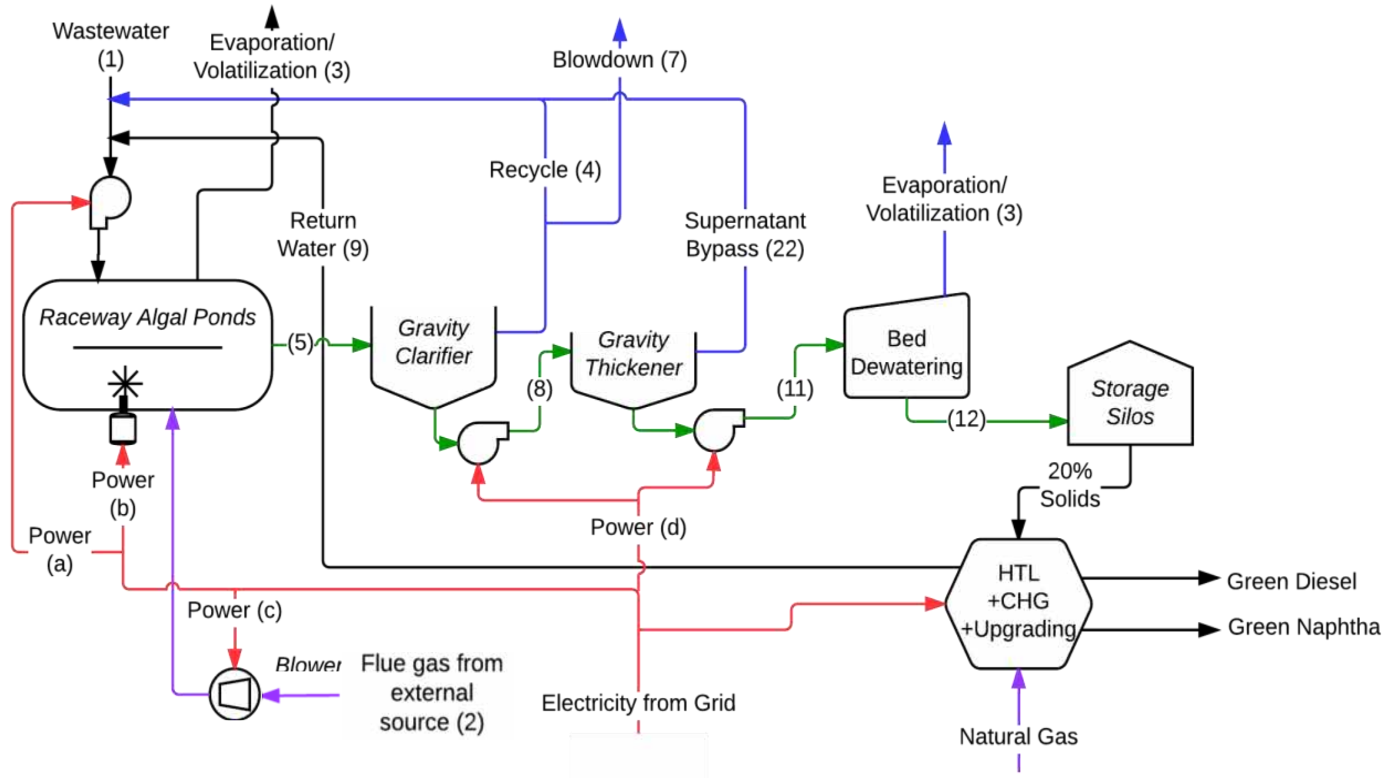
Phase 1 Goal Statement

- Develop the capability for 2500 gal/ac-yr of biofuel intermediates via HTL from microalgae grown at an existing raceway wastewater treatment facility in California's San Joaquin Valley.
- Determine productivity with CO_2 addition and demonstrate bioflocculation/settling harvesting.
- Model the process, TEA, and LCA.
- Plan for Phase 2 in collaboration with the facility owner.



What does it take to reach 2500 gal/ac-yr?

Two main unknowns are to be determined in field studies:

Biofuel Intermediate Goal:
2500 gal/ac-yr = 6.4 mL/m^2-d = 6 g oil/m^2-d

HTL Conversion:
?? g oil / g biomass

Productivity:
?? g biomass / m^2-day

What kind of productivity?
With wastewater, we have gross and net.

1 - Project Overview

- A Central Valley town (pop. 11,000) operates a 7-acre algal raceway facility for municipal wastewater treatment.
- Nine 3.5-m^2 raceways, settling units, and drying beds (below right) were installed to work on optimization of productivity and harvesting.

Scale-up of Algal Biofuel Production Using Waste Nutrients (EE0006317)

Timeline

- Started October 2013
- Ends June 2016
- 40% complete

Barriers

- Ft-A. Feedstock availability & cost
- Ft-D. Sustainable Harvesting
- Ft-N. Algal Feedstock Processing

Budget

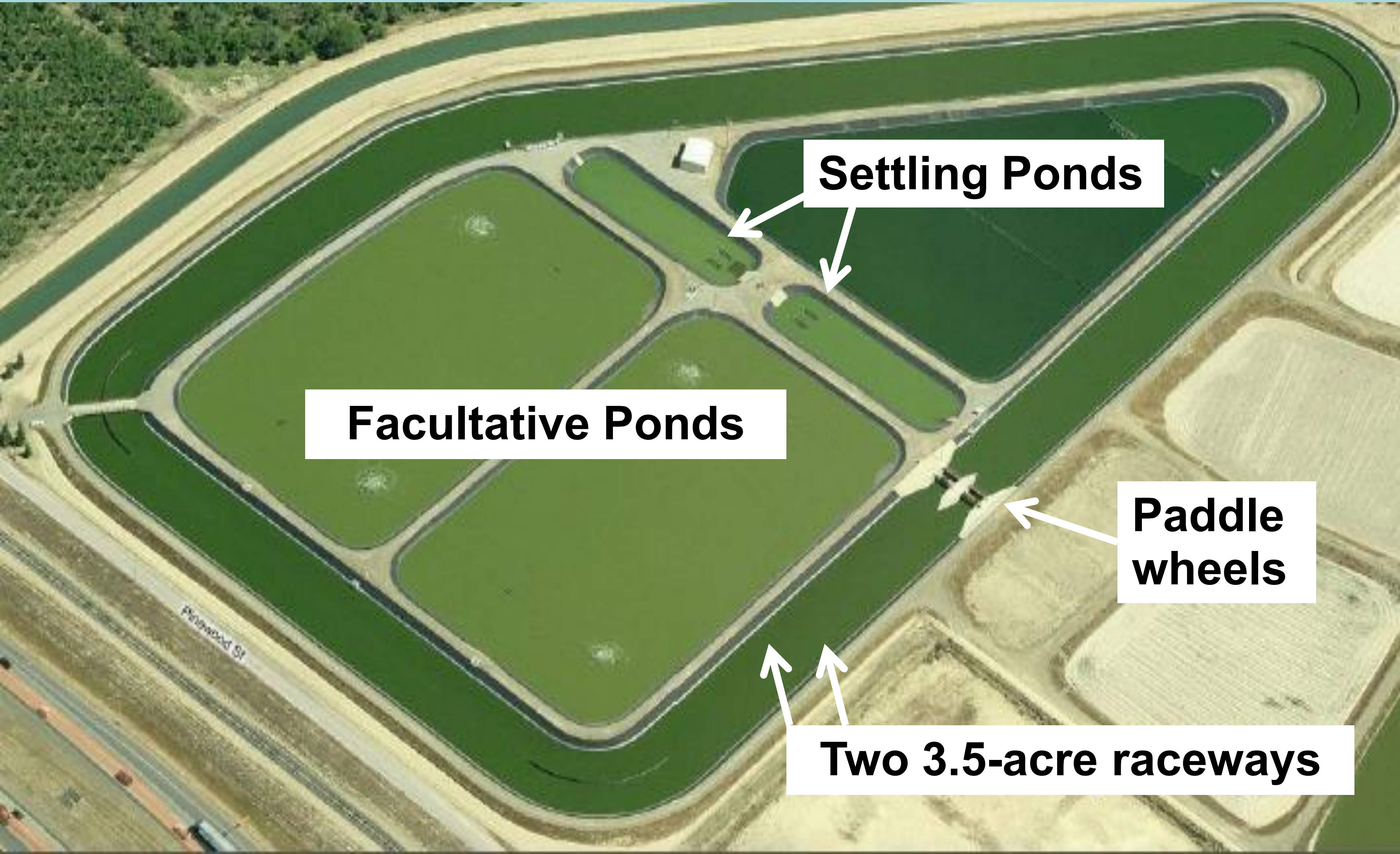
	Total Costs	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date
DOE Funded	$1.6m	0	683k	948k
Project Cost Share (Comp.)*	$0.5m	0	236k	259k

Partners

- Cal Poly, San Luis Obispo (62%)
- PNNL (22%)
- SNL (16%)
- MicroBio Engineering, Inc. (cost share)
- Delhi County Water District (site host)

Site of Cal Poly Algal Biomass Yield Project

Delhi, Calif. Algae Wastewater Treatment Plant



In Phase 2, the Delhi plant will be upgraded to reach DOE's initial 2,500 gallon per acre per year goal.

At full-scale, Delhi algae are coagulated, settled, and solar dried.

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

Solar dried algae

New concrete drying pad

2 – Approach (Technical)

TASK 0: Process and Data Validation
(Lead: Cal Poly)

TASK 1: Develop models to identify high-performance strains and culture methods
(Lead: M. Huesemann, PNNL)

TASK 2: Maximize algal productivity and harvesting efficiency in Delhi pilot ponds (Lead: Cal Poly and T. Lane, Sandia)

TASK 3: Full-scale raceway hydraulic characterization (Lead: Cal Poly and MicroBio Engineering)

TASK 4. Biomass processing to biofuel intermediates
(Lead: Doug Elliott, PNNL, and Cal Poly)

TASK 5. Scale-up engineering analysis, modeling, and planning
(Lead: MicroBio Engineering and Cal Poly)

TASK 6. Stage Gate Review and Preparations
(Lead: Cal Poly, with PNNL, SNL, and MicroBio Engineering)

2 – Approach (Management)

- **Critical success factors**
  - **Technical:** Achieving productivity, harvesting efficiency, and conversion to fuel sufficient to produce 2,500 gallons per acre per year, initially.
  - **Market & Business:** Achieving at least 25% lower cost than conventional wastewater treatment.

- **Top challenges:** Each of the technical success factors above require advancement.

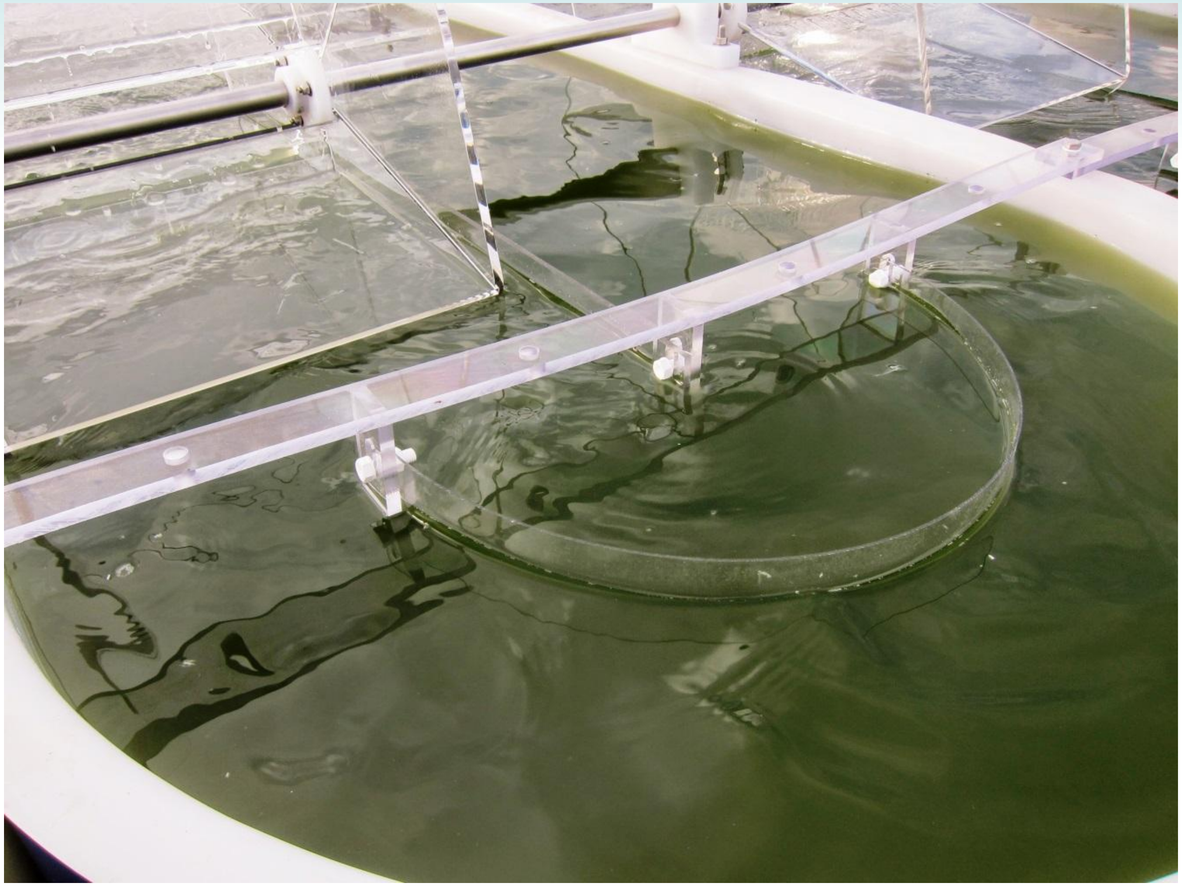
- **Management approach:**
  - 19 milestones and a Go/No-Go.
  - Knowledge integration and vigorous collaboration among partners on multiple DOE projects. Eyes open for more partners.
  - Research economy-of-scale at Cal Poly in ABY, ASAP, and ATP^3 projects.

3 – Technical Accomplishments

Pilot facility provided by MicroBio Engineering Inc.

Edge effects are minimized with transparent paddles and dividers.

Scale-up value is diminished by edge effects such as shading, wall growth, and heat transfer.



Remote control and data logging capabilities

Feed rates, CO_2 dosing, paddle speeds, etc. can be changed on timer basis or remotely.

Primary Clarifier
2-hour residence time

Pilot-Scale Raceways
2-5 day HRT

Algae Settlers
(2-3 hours)

Algae

Treated Wastewater

Algae Drying Beds & Screens

Algae Thickener

Supernatant Tank

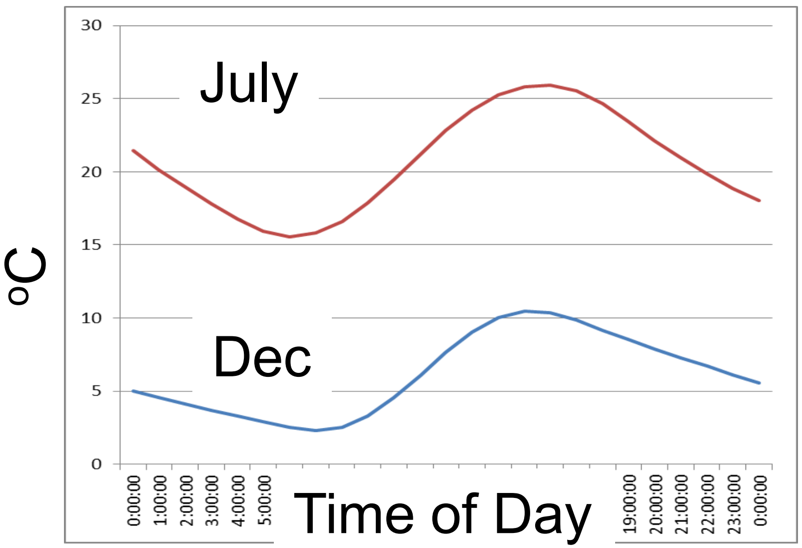
Task 1: Develop models to identify high-performance strains and culture methods

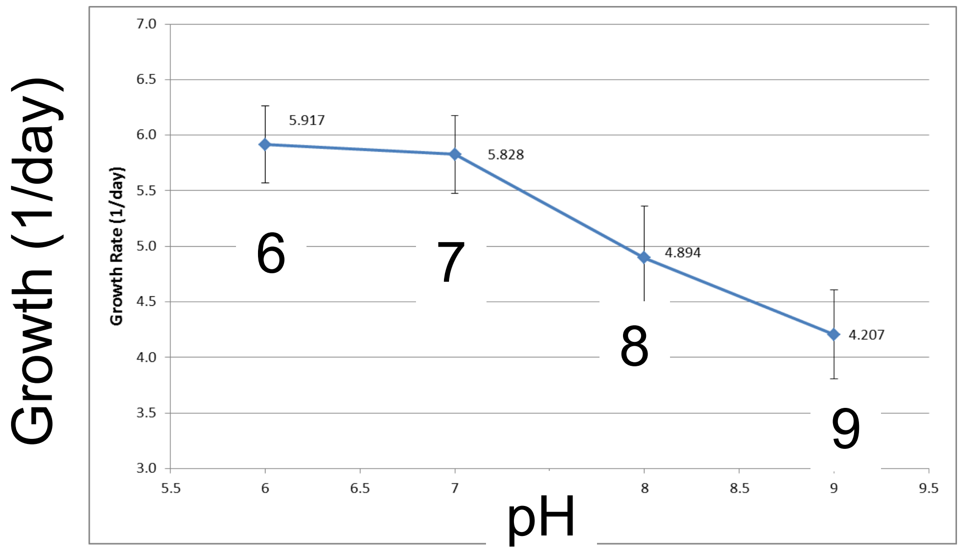
Goal: Identify pond operation conditions (pH, HRT) to maximize algal biomass productivity

Approach: Use PNNL’s Biomass Assessment Tool (BAT) to identify optimum pH and dilution rate for *Chlorella sorokiniana* (DOE 1412)

Step 1: Use climate model to generate light intensity and temperature scripts

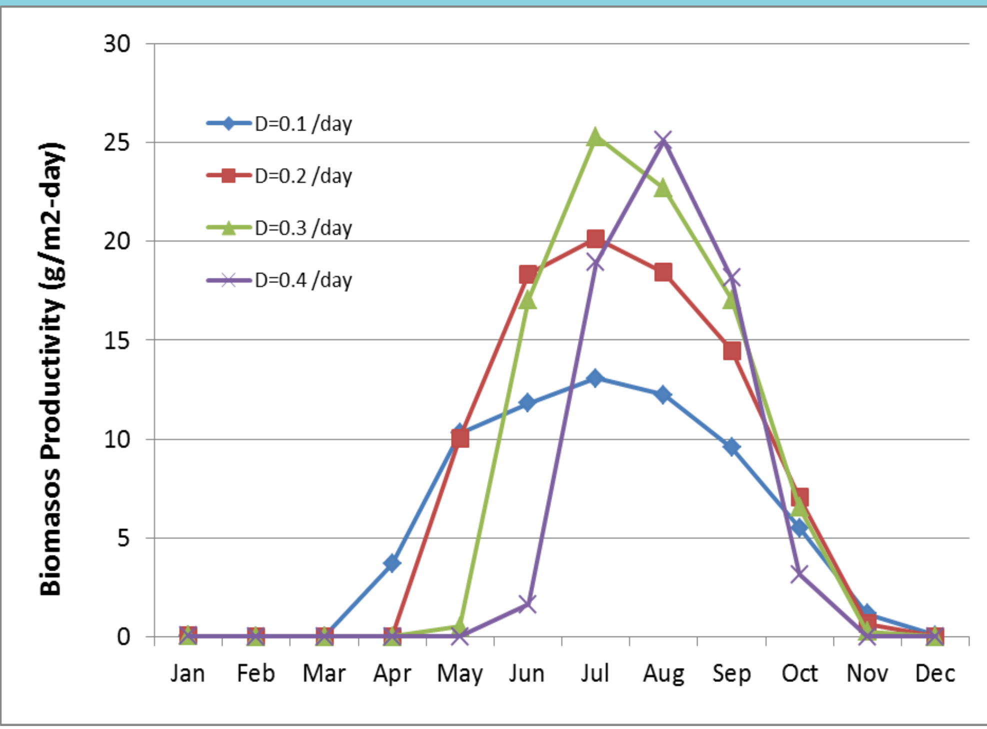
Step 2: Modify biomass growth model to include pH effects

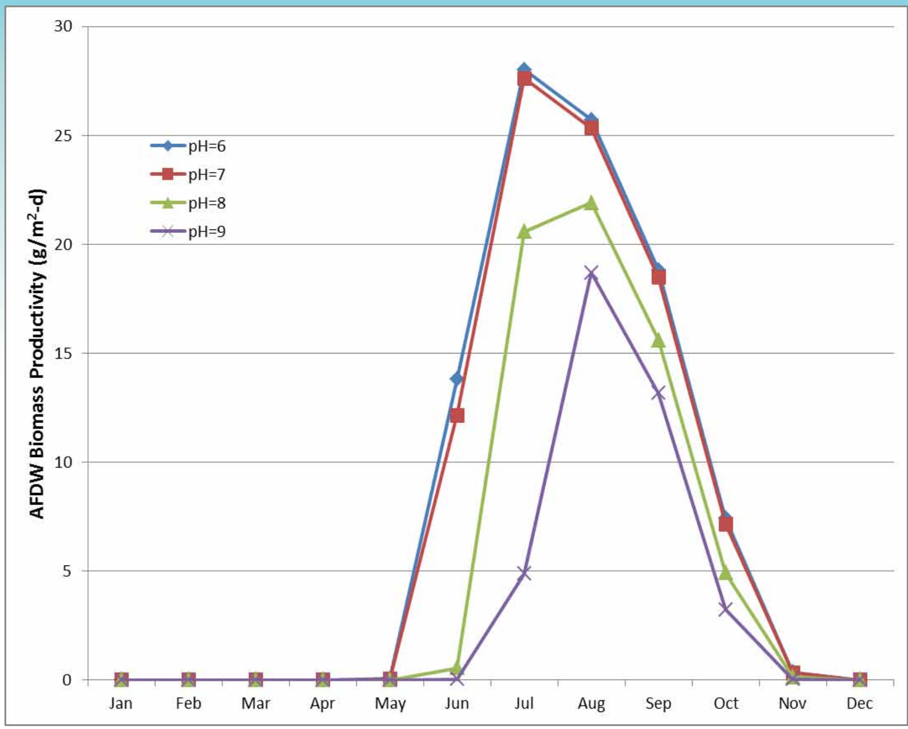




Step 3: Determine algal productivity at the Delhi site using the Biomass Growth Model (BGM) as a function of pH, season, and dilution rate

Chlorella DOE 1412 modeling for dilution & pH optimization, followed by field validation.





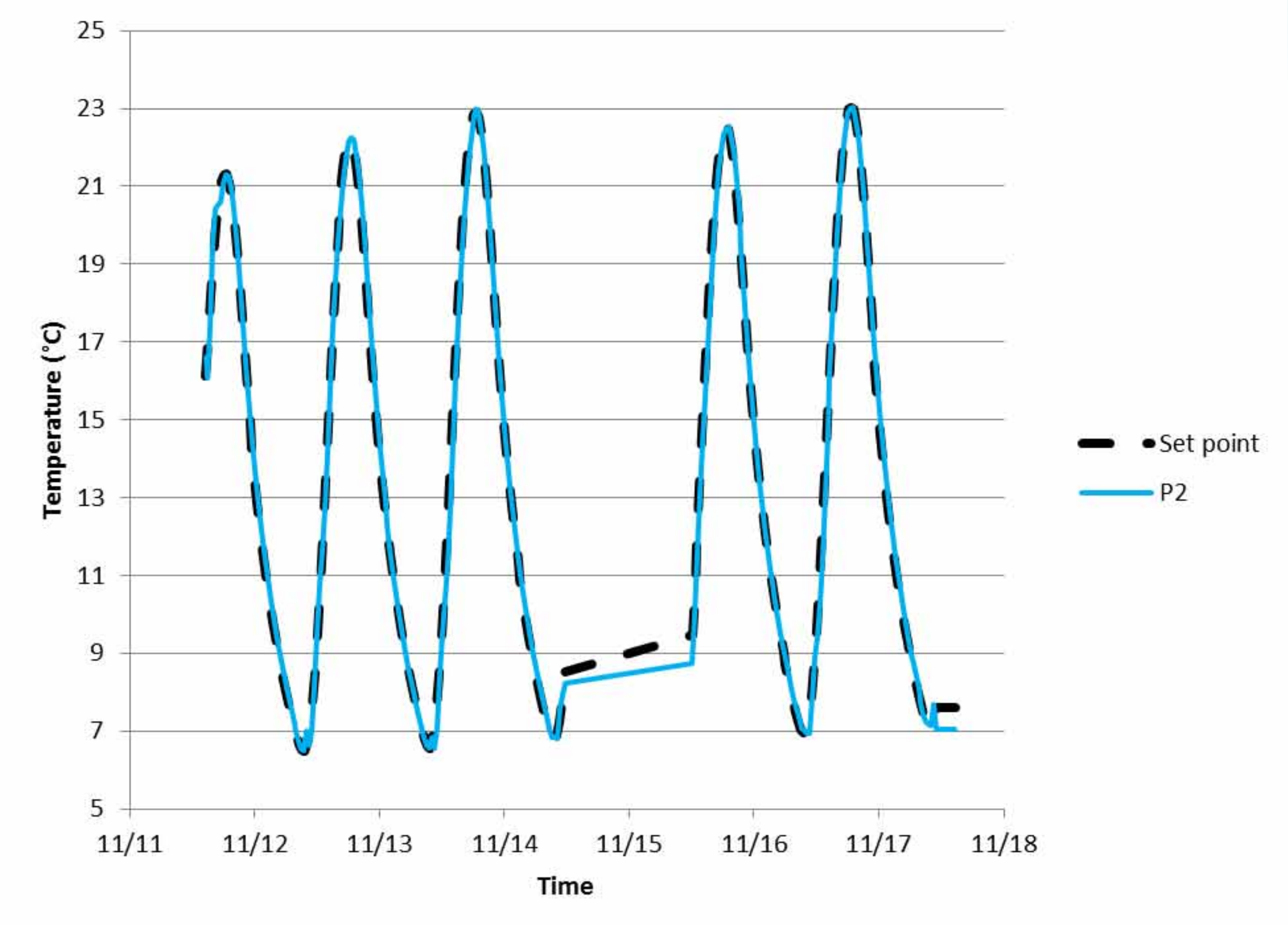
7.5 g/m^2-day annual average productivity at 0.2 and 0.3/day

- 30% increase over ~5.7 g/m^2-day productivity at 0.1 and 0.4/day
- 40% increase in annual average productivity at pH 7 versus pH 8 (7.6 vs. 5.4 g/m^2-day)
- DOE 1412 also being studied at LANL.

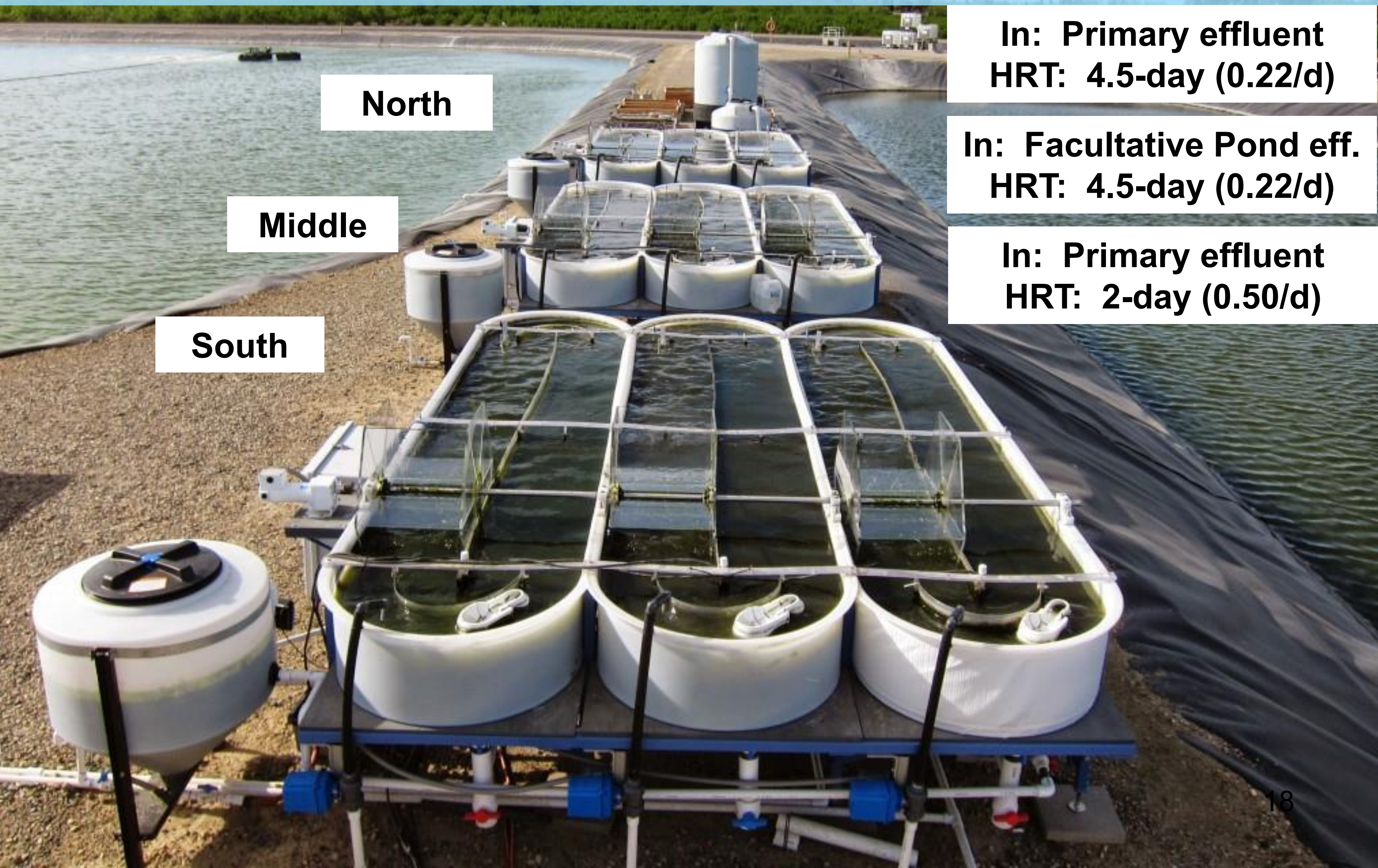
Bench-top pond simulator is under development to increase strain testing throughput.

Temperature and light control systems are working.

Next: Validate using outdoor pond cultivation data (northern AZ)

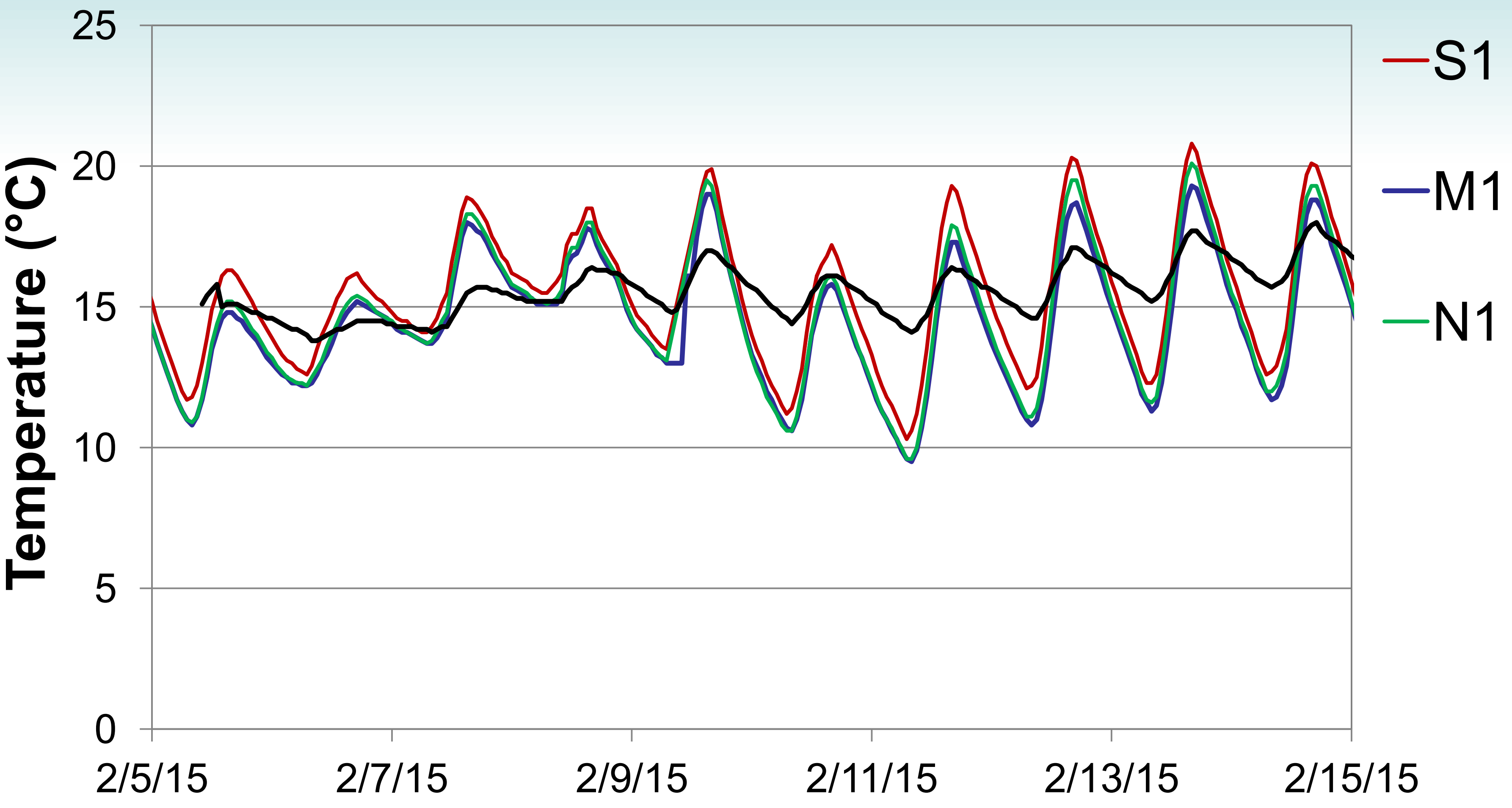


Task 2: We run three conditions in triplicate to maximize productivity. Current experiment:



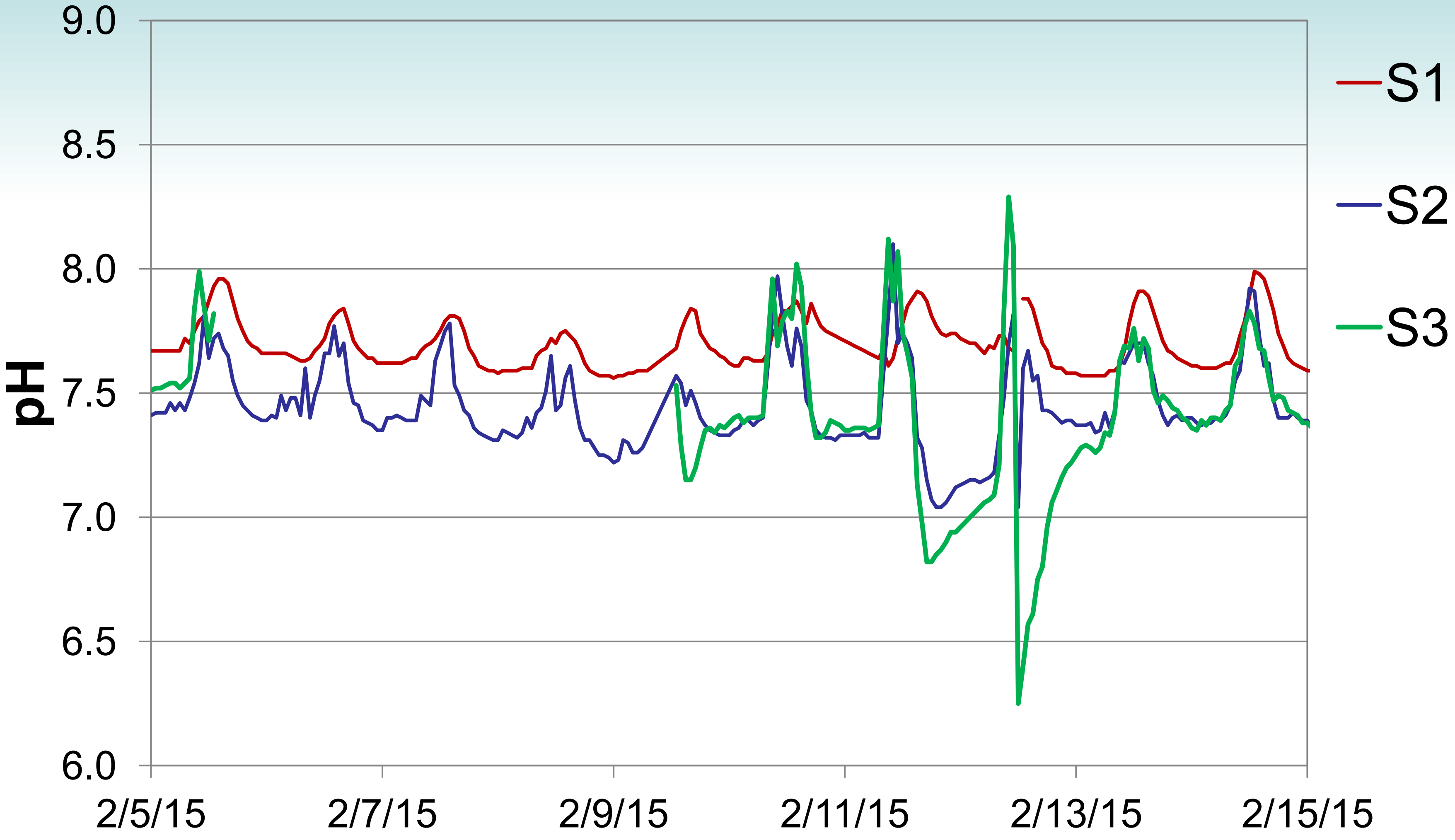
Water source also affects temperature.

Middle pond is fed from deep a Facultative pond with more stable temperatures.



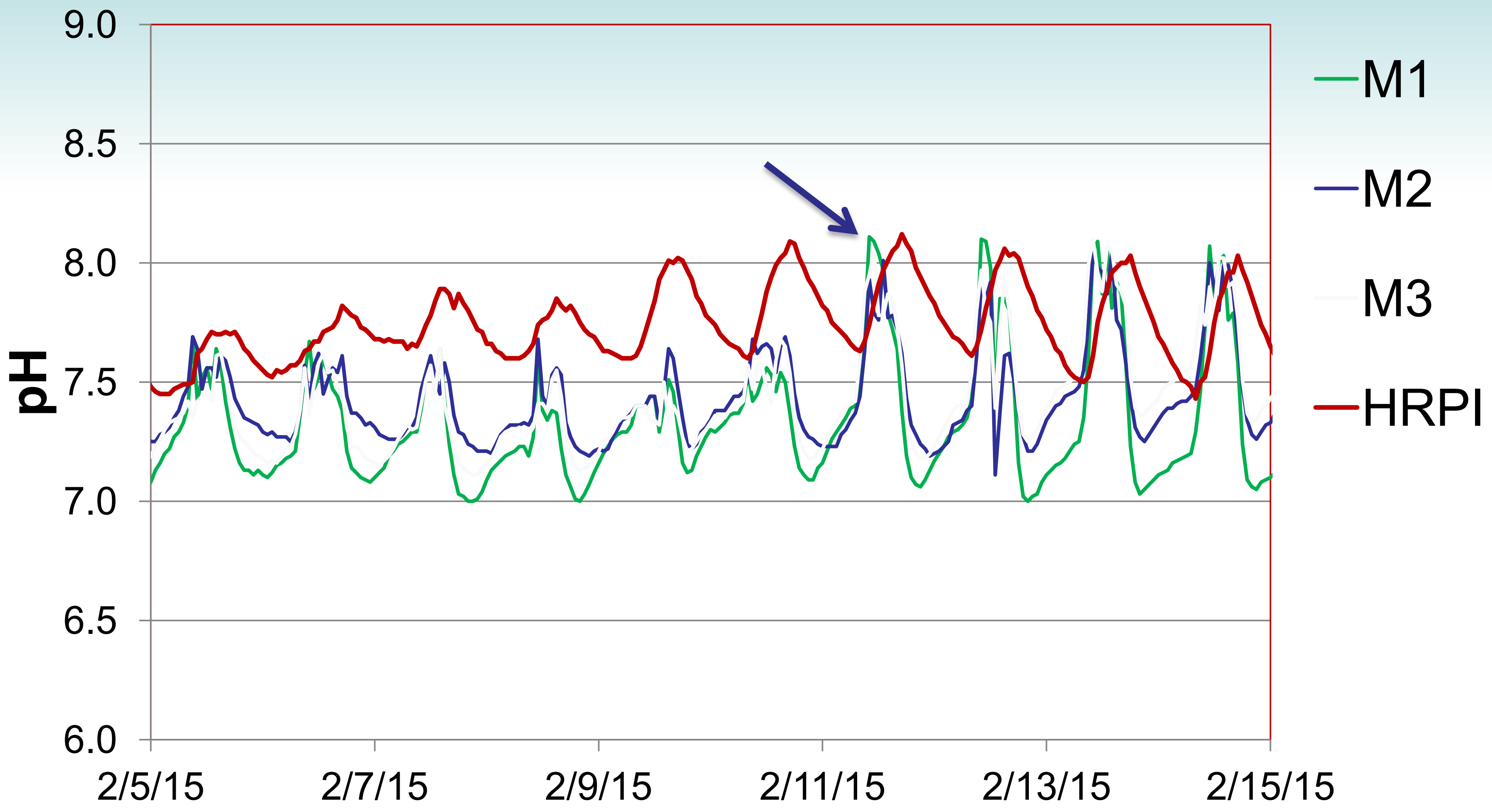
We are working to minimize differences with the triplicate ponds.

Twice-weekly calibration and independent checks.



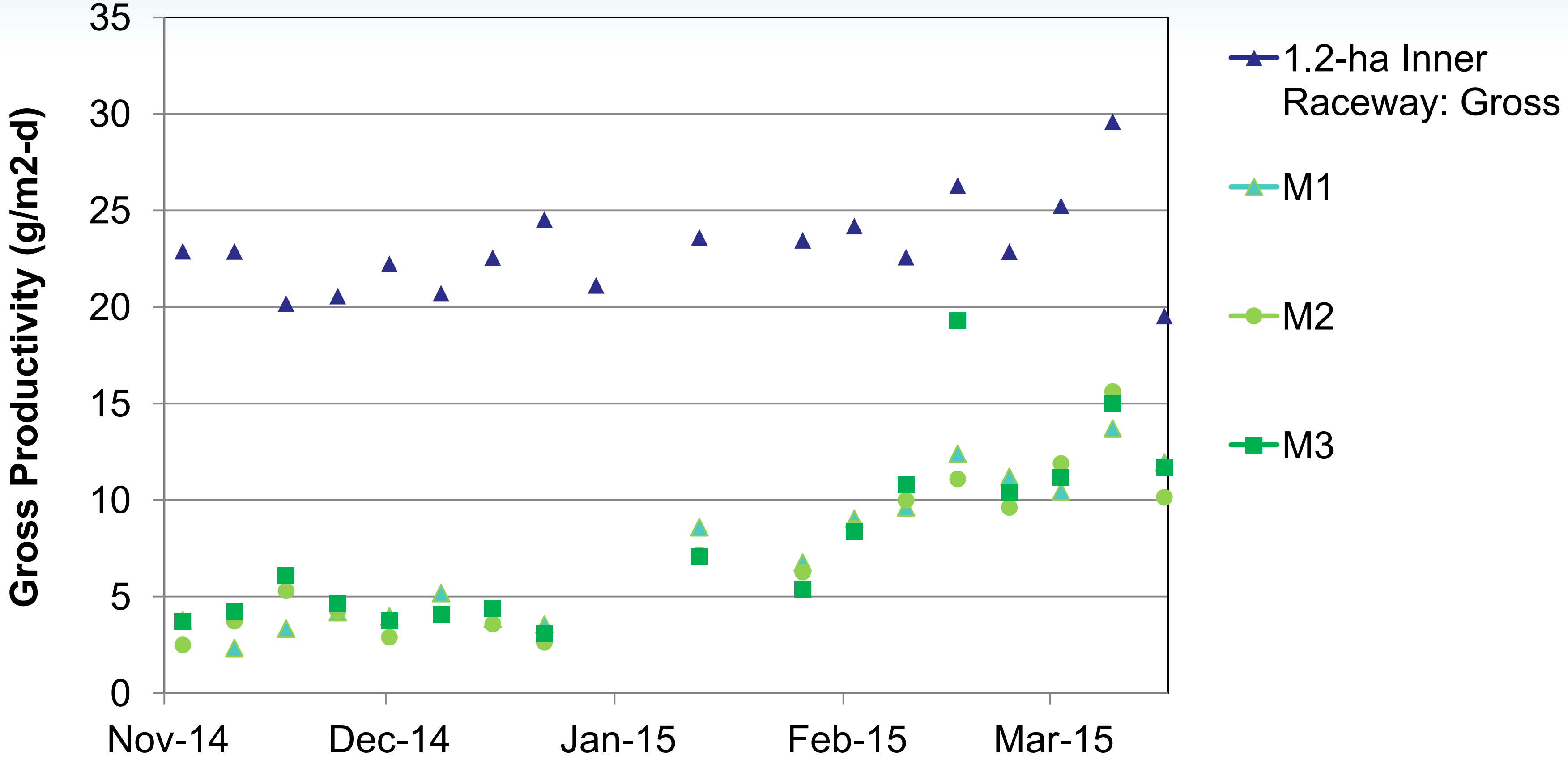
We are working to minimize differences between pilot and full-scale raceways.

Pilot pH setpoints were adjusted to match HRPI.



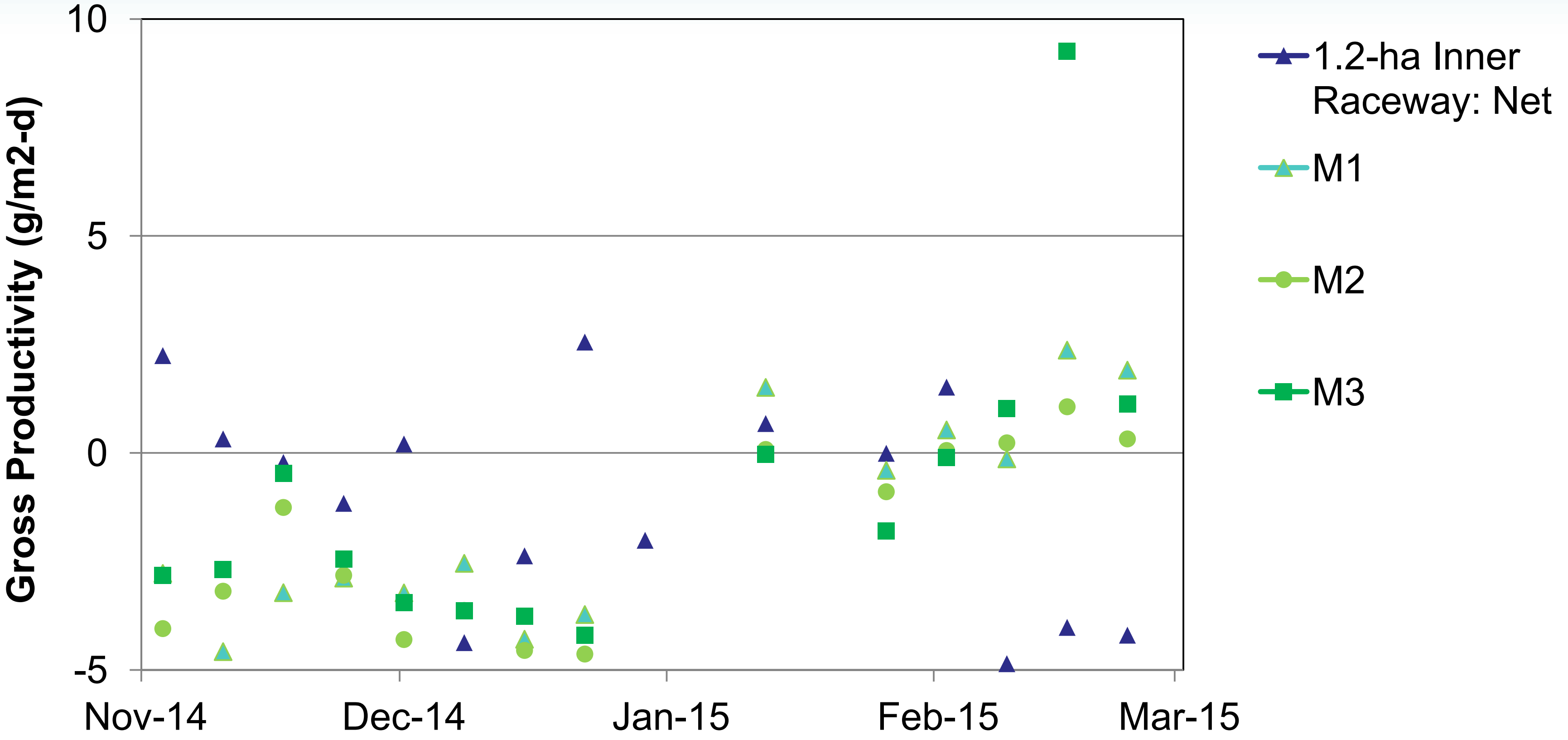
Pilot vs. full-scale: Gross productivities differed due to higher suspended solids in the full-scale pond.

1.2-ha Inner Raceway vs. triplicate "M" pilot raceways also fed Facultative Pond water.



Pilot vs. full-scale: Net productivities were similar until recently but mostly negative!

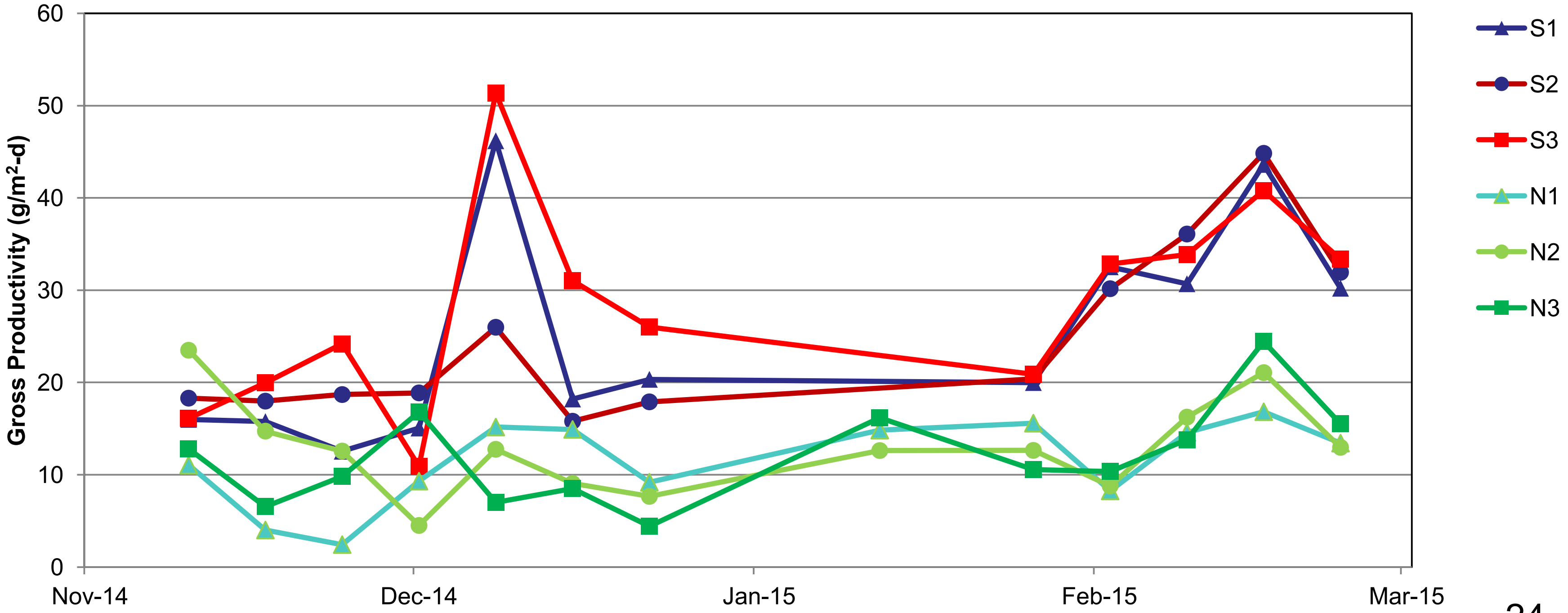
The spring and summer comparison should be telling.



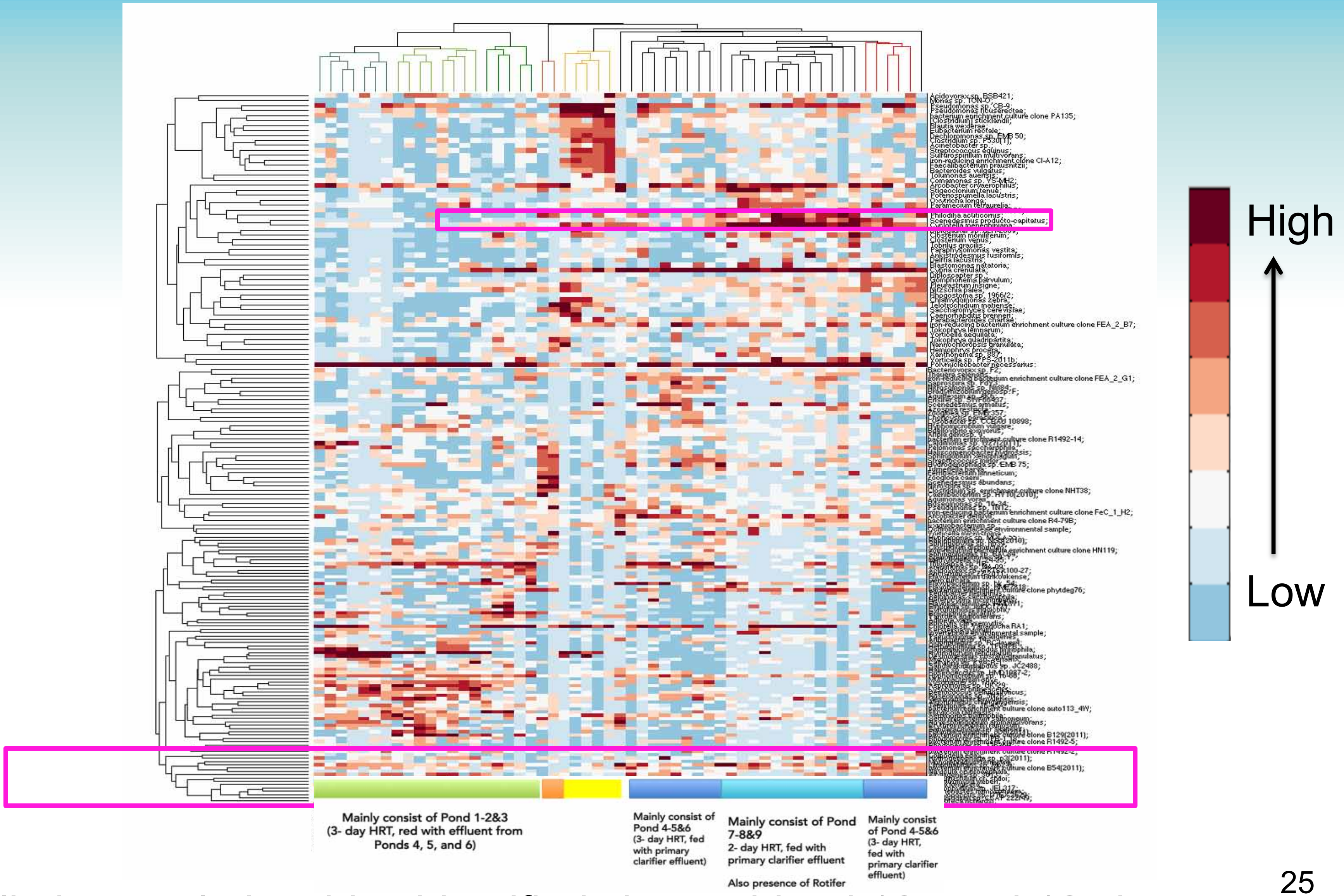
Gross productivity ranged 10-45 g/m²-day during Dec-Mar. Some growth is fueled by influent organic matter.

<u>Net productivity</u> 5 g/m²-d in Nov-Jan
20-25 g/m²-d in Feb.

Gross productivity of triplicate ponds: S = 2-day and N = 3-day hydraulic residence time

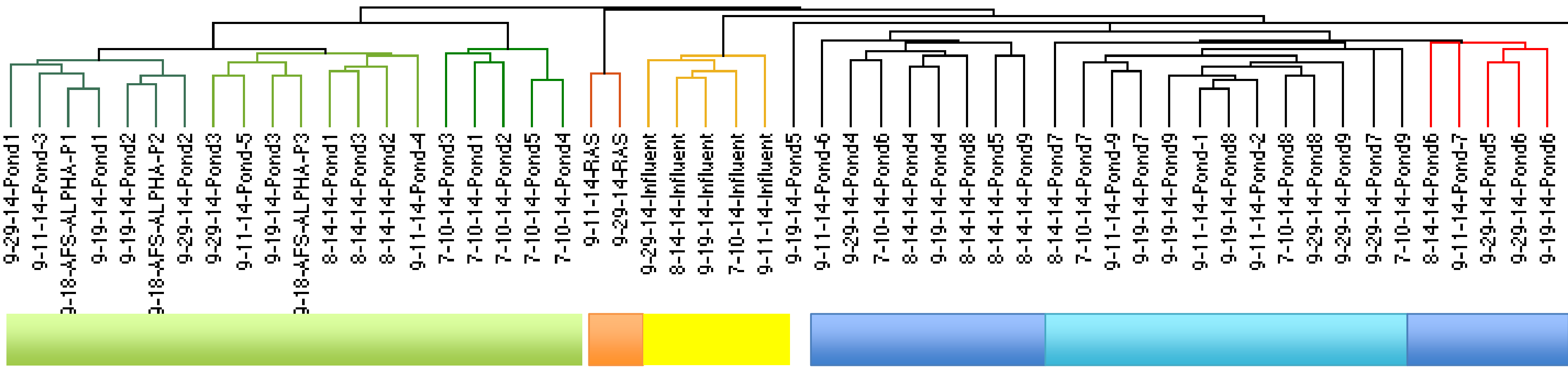


Community genetic data (Sandia) may lead to better control of productivity and bioflocculation



Preliminary relationships identified via combined 16s and 18s heat maps

Different operating conditions are producing distinct communities. More substantial insights are expected as data analysis proceeds.



Mainly consist of Pond 1-2&3 (3- day HRT, fed with effluent from Ponds 4, 5, and 6)

Mainly consist of Ponds 4, 5, & 6. (3- day HRT, fed with primary clarifier effluent)

Mainly consist of Pond 7, 8, & 9 (2- day HRT, fed with primary clarifier effluent)

Also presence of Rotifer

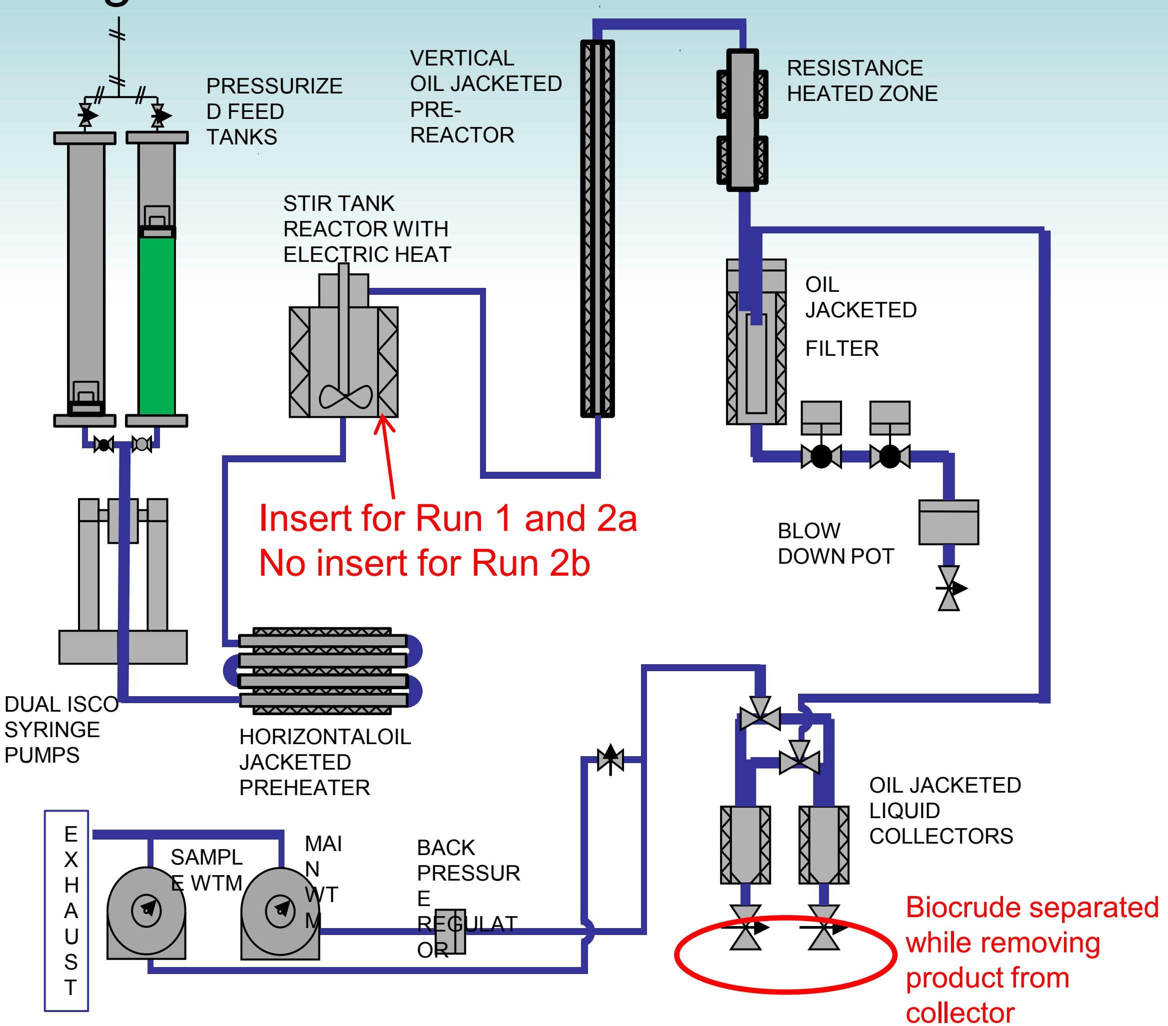
Mainly consist of Pond 4-5&6 (3- day HRT, fed with primary clarifier effluent)

"RAS" is return activated sludge for comparison.

No *Vampirovibrio* in Cal Poly wastewater ponds, but is present in some Cal Poly ATP^3 ponds. Not implicated in Cal Poly crashes.

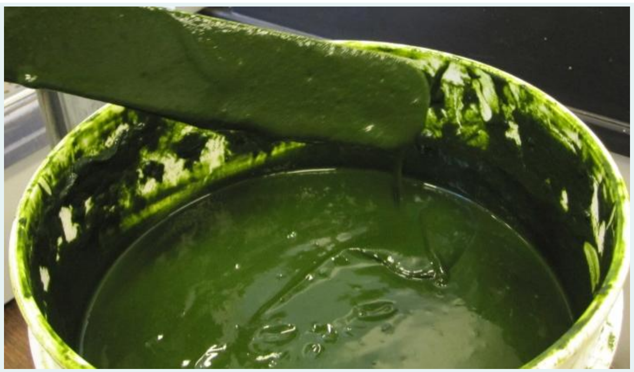
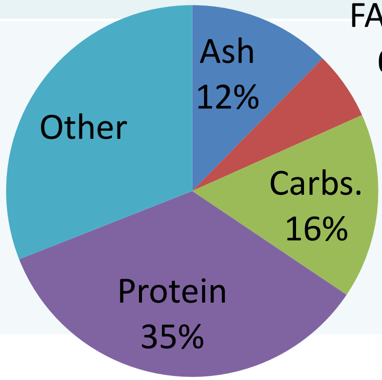
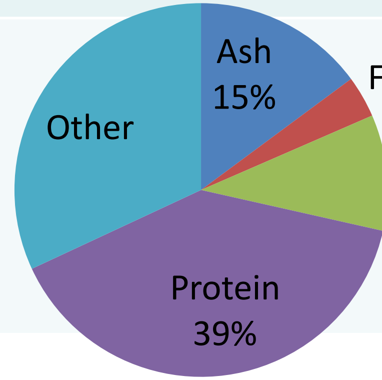
Task 3: Biomass processing to biofuel intermediates

HTL System Configuration:



Task 3: Biomass processing to biofuel intermediates

Demonstrate and optimize conversion of wastewater grown microalgae feedstock into a biofuel intermediate suitable for further upgrading

	Run 1: 10 wt% TS	**Run 2:** 18 wt% TS
Feedstock source, harvesting mechanism, photo	 Bioflocculated, then centrifuged thickened from CP WW ponds.	  Bio-flocculated, then solar-dried from CP WW ponds.
Biochemical characterization		

Task 3: Biomass processing to biofuel intermediates

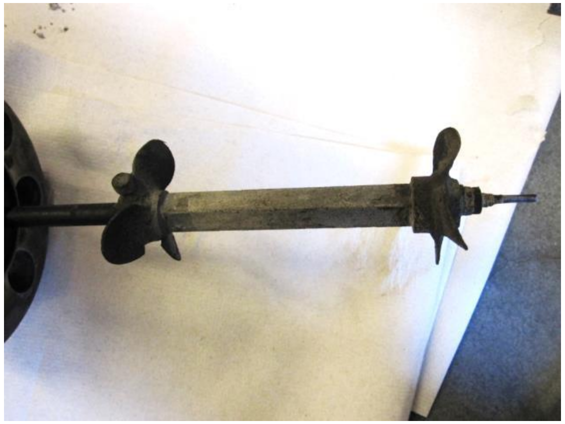
Feed preparation: Material caught by 20 mesh in-line strainer after homogenization

Task 3: Biomass processing to biofuel intermediates

Results: Run 2a and 2b operation summary

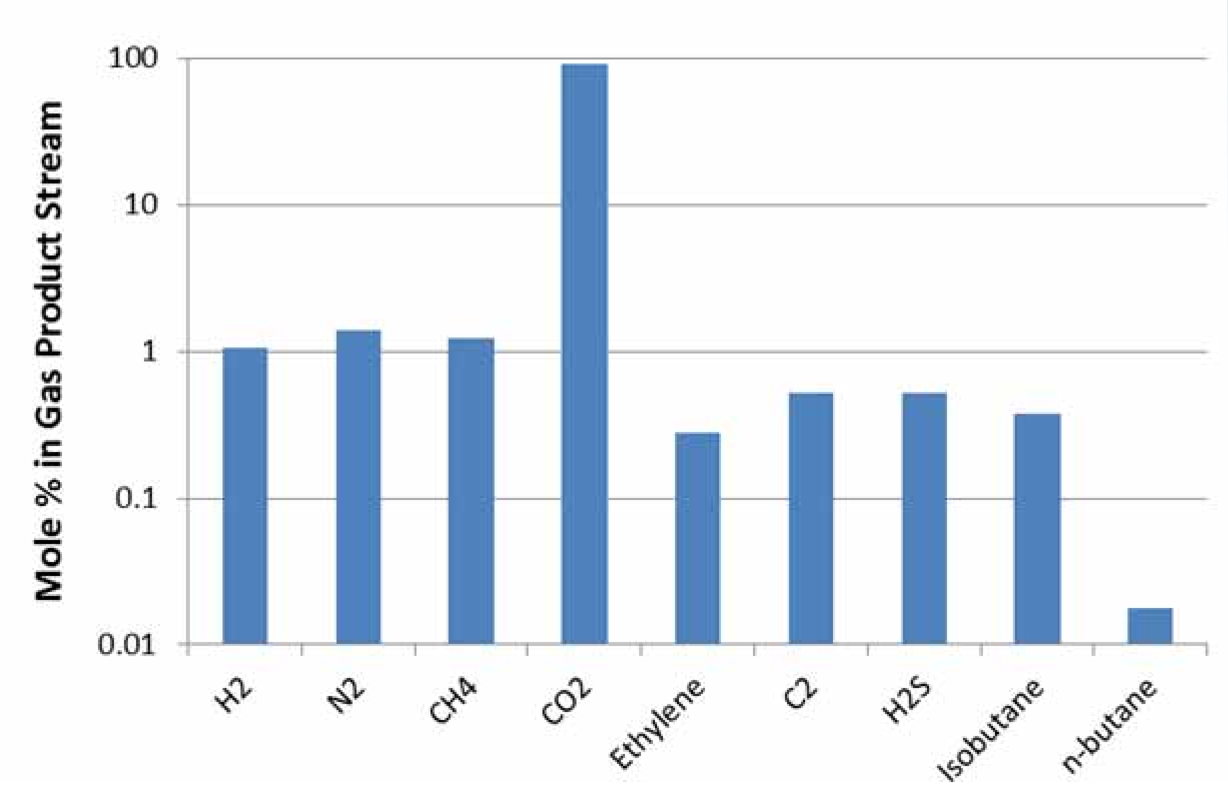
Run 2a terminated due to excessive solid accumulation in CSTR; relatively low solids accumulation in filter housing

CSTR insert removed in Run 2b, yields clean impeller and solids in filter



Task 3: Biomass processing to biofuel intermediates

Gaseous emissions characterized for air permitting



Gas is predominantly CO_2

Unlikely to trigger air-pollution controls

Task 3: Biomass processing to biofuel intermediates

Mass Yields (Dry, Ash Free, Normalized):

Parameter	Unit	Run 1	Run 2a	Run 2b
Mass Balance	%	98%	99%	100%
Oil Yield, Mass (N)	g_{oil}/g_{fd}	15%	35%	36%
Solid Yield, Mass (N)	g_{solid}/g_{fd}	5%	3%	4%
Gas Yield, Mass (N)	g_{gas}/g_{fd}	2%	6%	5%
Aq. Yield, Mass (N)	g_{aq}/g_{fd}	78%	56%	55%

What does it take to reach 2500 gal/ac-yr?

Two main unknowns are to be determined in field studies. Below are PRELIMINARY results.

Biofuel Intermediate Goal:

2500 gal/ac-yr = 6.4 mL/m^2-d = 6 g oil/m^2-d

HTL Conversion:

0.35 g oil / g biomass

Productivity Need:

17 g biomass / m^2-day

If harvesting - dewatering efficiency is 85%:

20 g biomass / m^2-day

5 – Future Work

TASK 1: Develop models to identify best strains and culture methods

* Validate new Climate Simulating Photobioreactor with climate scripts against pond data.
* Validate Biomass Growth Model predictions with pond data.

TASK 2: Maximize algal productivity and harvesting in pilot ponds

* Evaluate effect of dilution rate and feed water source on productivity and harvesting
* Generate biomass for HTL runs.

TASK 3: Full-scale raceway hydraulic characterization - Underway

TASK 4. Biomass processing to biofuel intermediates
* To continue with quarterly runs

TASK 5. Scale-up engineering analysis, modeling, and planning
* Incorporate productivities, harvesting efficiencies, and HTL results into a process model to be used in planning Phase 2.
* Update TEA and LCA results

Acknowledgments

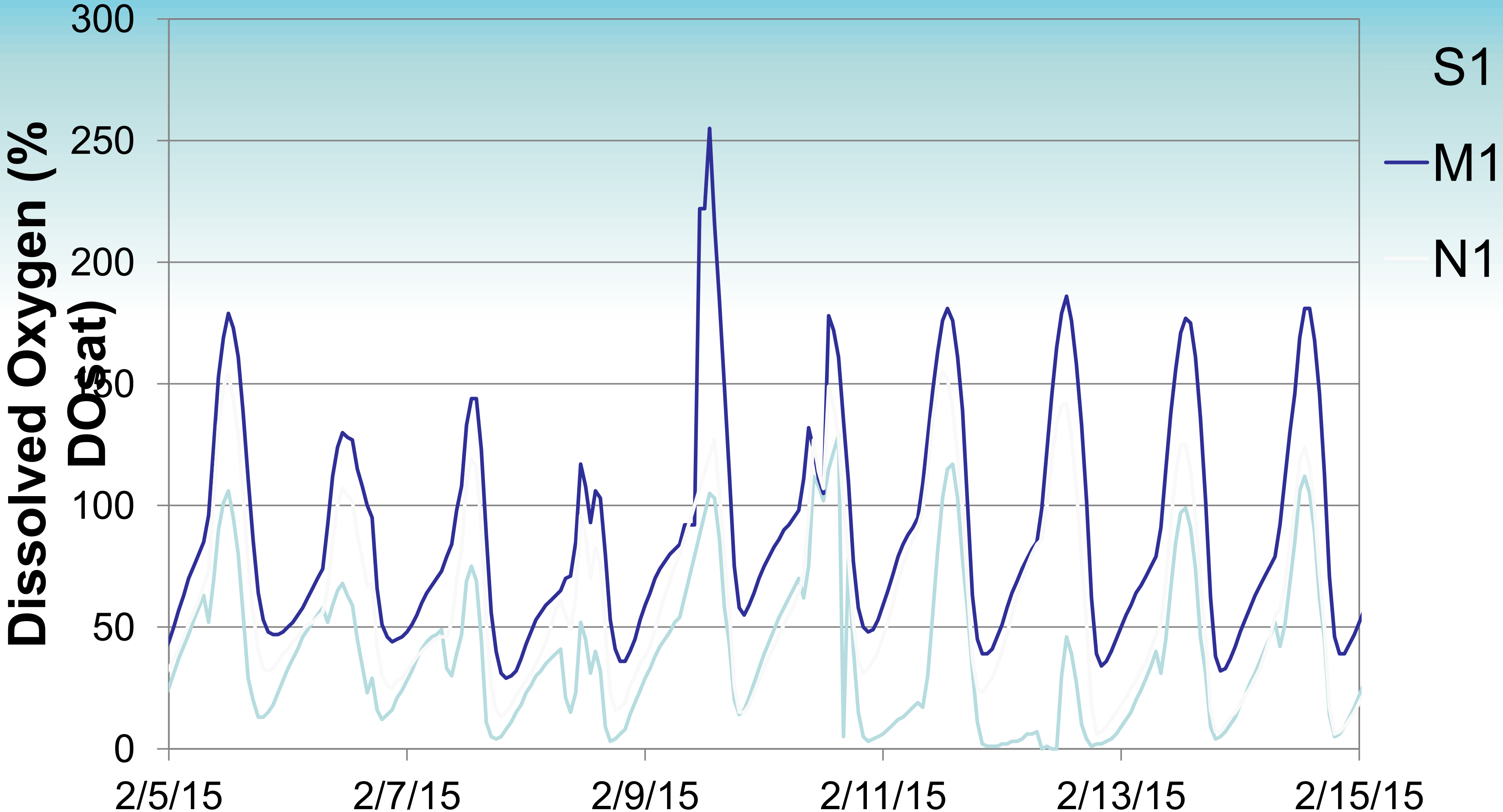
- U.S. Department of Energy
  - Dan Fishman (project monitor)
  - Evan Mueller (contractor)
  - Christine English (validation task)
  - Josh Gesick (validation task)

- Review
  - Colleen Ruddick

- Project Execution
  - Michael Huesemann & team, PNNL
  - Doug Elliott and team, PNNL
  - Todd Lane and Kunal Poorey
  - Staff and students at Cal Poly
  - MicroBio Engineering staff

- Other Helpful Colleagues
  - ATP^3 network, now extending to NM RAFT
  - Juergen Polle, Brooklyn College

Thank you


Dissolved Oxygen (% DOsat)
300
250
200
150
100
50
0
2/5/15
2/7/15
2/9/15
2/11/15
2/13/15
2/15/15
S1
M1
N1

Task 3: Biomass processing to biofuel intermediates

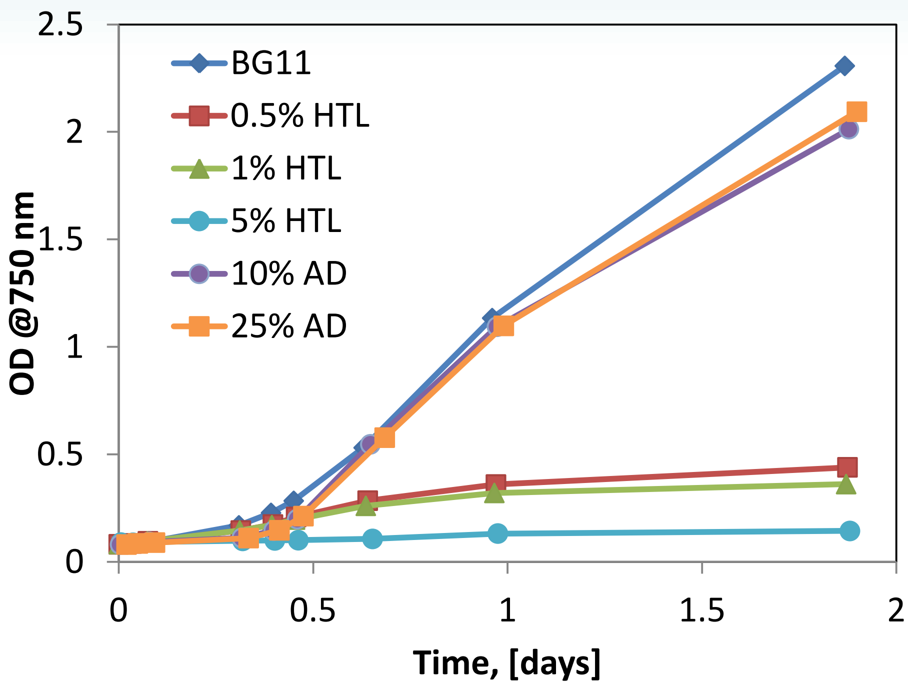
Results: Run 1 operation summary

Oil-water phase separation difficult due to low initial solids concentration

Task 3: Biomass processing to biofuel intermediates

Utilization of Aqueous Phase (AP) nutrients for algal regrowth attempted:

- HTL AP was 0.2 um filtered
- Metals added (Mg, K, P…) to avoid nutrient limitation



Growth reduced in HTL cultures even with a 100 fold dilution, at saturating nutrient concentrations

Aqueous phase characterization:		
Nitrogen	wt%	0.62%
NH3	wt%	0.41%
Total Carbon	wt%	1.8%
Total Organic Carbon	wt%	1.7%
COD	mgO/L	54,200
Acetic acid	wt%	0.29%
Propanoic acid	wt%	0.15%
Methanol	wt%	0.79%
Ethanol	wt%	0.07%
Butanoic Acid	wt%	0.17%
Chloride	ppm	–
Sulfur	ppm	83
pH	pH unit	8.0

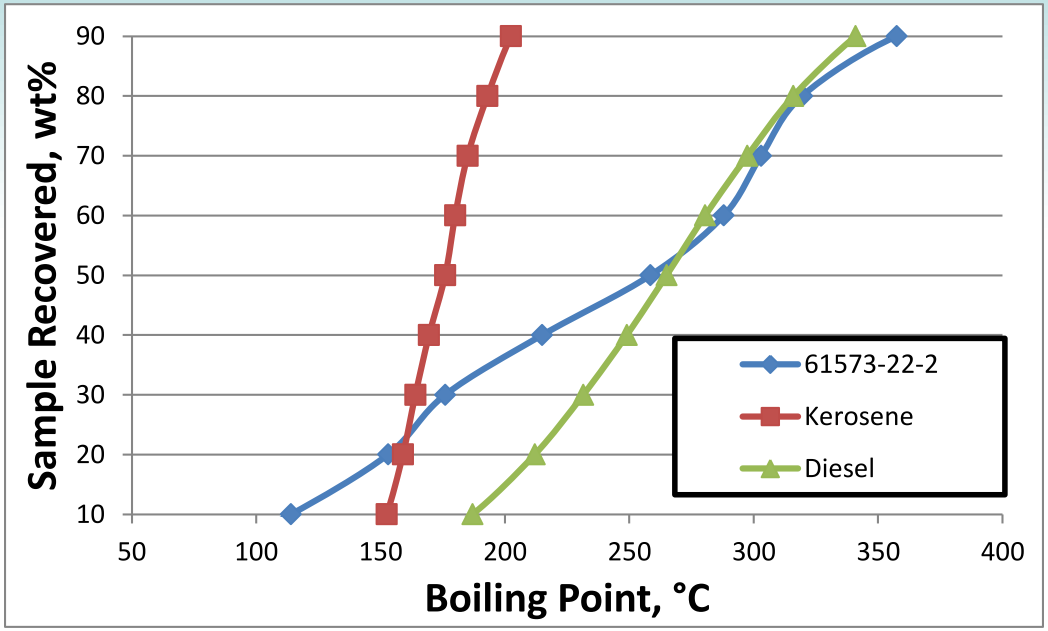
Task 3: Biomass processing to biofuel intermediates

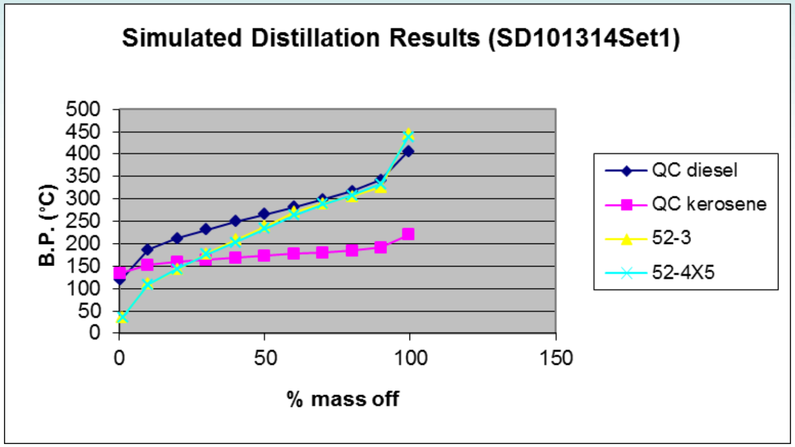
Biofuel intermediate characterization (dry basis):

Parameter	Unit	Run 1	Run 2a
Carbon, wt%	wt%	83%	78.9%
Hydrogen, wt%	wt%	9.1%	10.2%
H:C, mol ratio	ratio	1.31	1.53
Oxygen	wt%	1.3%	3.6%
Nitrogen	wt%	5.2%	5.4%
Sulfur	wt%	0.6%	1.2%
TAN	mg_{KOH}/g_{oil}	47	38
Density	g/mL	0.98	0.98
Viscosity	cSt@40°C	725	320
Moisture	wt%	n/a	10.2
Ash	wt%	0.78%	0.75%
Filterable Solids	wt%	1.19%	0.72%

Task 3: Biomass processing to biofuel intermediates

Biofuel intermediate characterization: Simulated distillation





HT bed plugged with black, high molecular weight substance

High yield of distillate range hydrocarbons