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2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

An Innovative Approach for Optimization of Annual Productivities using State-of-the-Art Climate-Simulation Ponds by Matching Microalgae Strains to the Most Suitable Geographic/Climatic Region

DATE: MAY 21, 2013
TECHNOLOGY AREA REVIEW: ALGAE

PRINCIPAL INVESTIGATOR: MICHAEL HUESEMANN
PACIFIC NORTHWEST NATIONAL LABORATORY

Goal Statement

Maximize the annual biomass productivity for LANL *Picochlorum sp.* wild type and lipid-hyperaccumulator (High4) strain by identifying the best geographic location for outdoor pond culturing and then verifying the strains' performance under climate-simulated conditions for that optimal location.

Alignment with Goals of DOE BETO

- **Achieve annual productivity of 20 g/m^2 -day by 2014 (equivalent to 1500 gallons per acre per year)***
- **Achieve annual productivity of 25 g/m^2 -day by 2018 (equivalent to 2500 gallons per acre per year)***

*Source: Biomass Multi-Year Program Plan (November 2012), p. 2-15.

Quad Chart Overview

Timeline

- Start date: 10-1-2012
- End date: 9-30-2017
- Percent Complete: 10%

Barriers

- Barriers addressed:
  - Ft-B. Sustainable Production
  - Ft-C. Feedstock Genetics and Development
  - Ft-G. Feed Quality and Monitoring

Budget

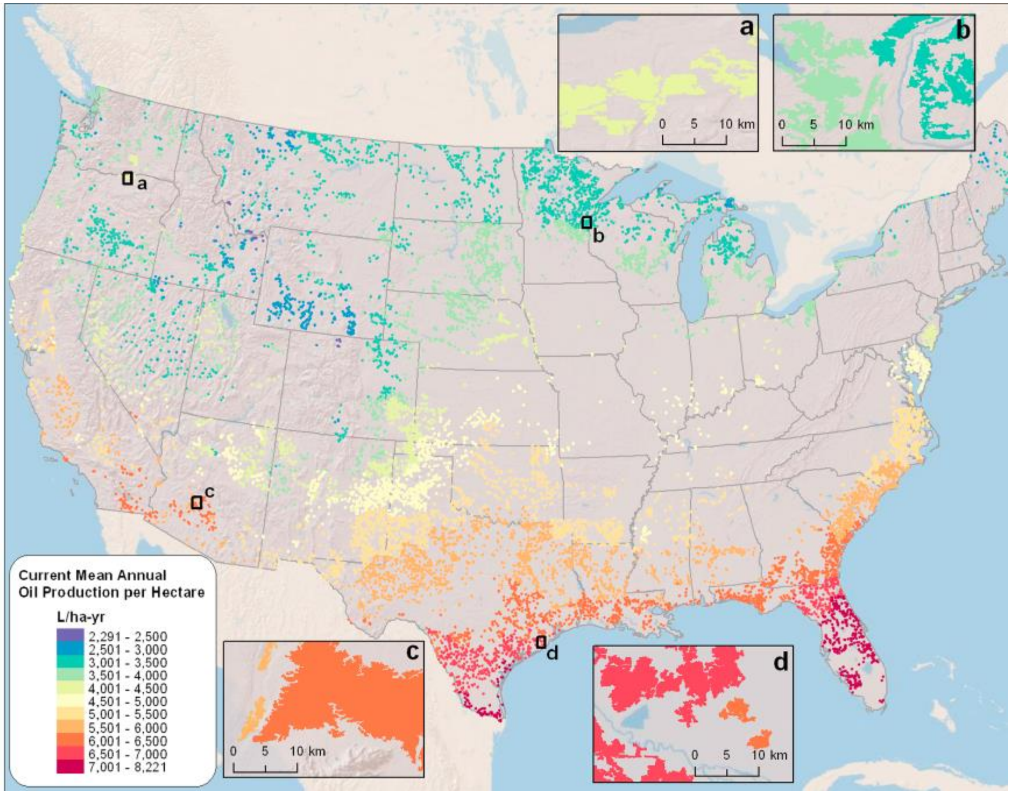
- Total Funding: $200K
- FY13 Funding: $200K

Partners

- LANL (Dr. Taraka Dale)
- Project Management by monthly telephone conference calls

The Importance of Climate on Biomass Productivity in Ponds

- **Biomass productivity = f (temperature, light, pH, salinity, nutrients, mixing, pond design)**
- **Water temperature and light can only be indirectly controlled by selecting pond location**
- **Optimize biomass productivity by matching strain characteristics to climatic conditions**



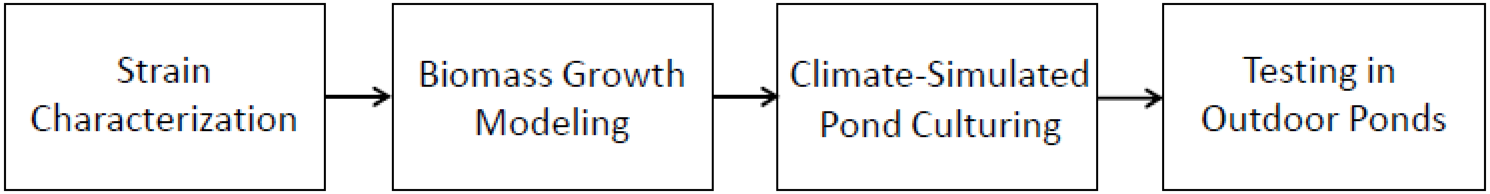
Project Overview and Objectives

The Challenge

- **How to determine which laboratory strains should be selected for outdoor pond cultivation, i.e., exhibit high enough annual biomass productivity to meet DOE's targets?**
- **How to determine the best match between strain and pond culture location, with the goal of optimizing productivity?**

The Solution

- **Integrated low-risk approach to predict real-world performance of novel promising strains at optimal pond location**



Overall Technical Approach

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$\mu = f(I,T)$

Light absorption coefficient (k_a)

Strain Characterization

Approved Project Management Plan

- Regular Milestones (1/Quarter) and Deliverables
- Go/No Go in Q3FY15 to asses the functionality of the validated growth models and advances in productivity

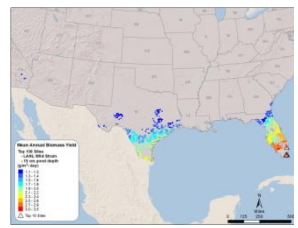
Biomass Growth Model

Biomass growth $= f(I, T, k_a, d, t)$

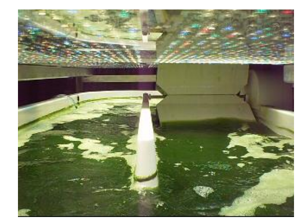
Location specific:
- Light scripts
- Temperature scripts
- Productivity

Biomass Assessment Tool (BAT)

Productivity Mapping



Climate-Simulated Culturing



BAT Inputs

Location specific:
(2600 stations)
- Land availability
- Resource availability
- Weather data

Technical metrics for measuring progress

- Annual biomass productivity
- Compare predicted vs. measured biomass productivities

Technical Progress - Overview

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Milestone	Planned Completion Date	Completion
Quantify the response of LANL's WT & lipid hyper-accumulating strain to temperature and light	Dec, 2012	✓
Identify geographic/climatic regions for optimal pond culture biomass productivity	Mar, 2013	✓
Provide annual biomass productivity map (U.S.) for model strain cultured in hypothetical ponds	Jun, 2013	✓
Measure biomass and lipid productivity in climate-simulation raceways	Sep, 2013	On schedule
Complete draft manuscript of biomass and lipid productivity in climate simulation cultures for subsequent submission to peer reviewed journal	Sep, 2013	On schedule

Technical Accomplishments (1Q ML)

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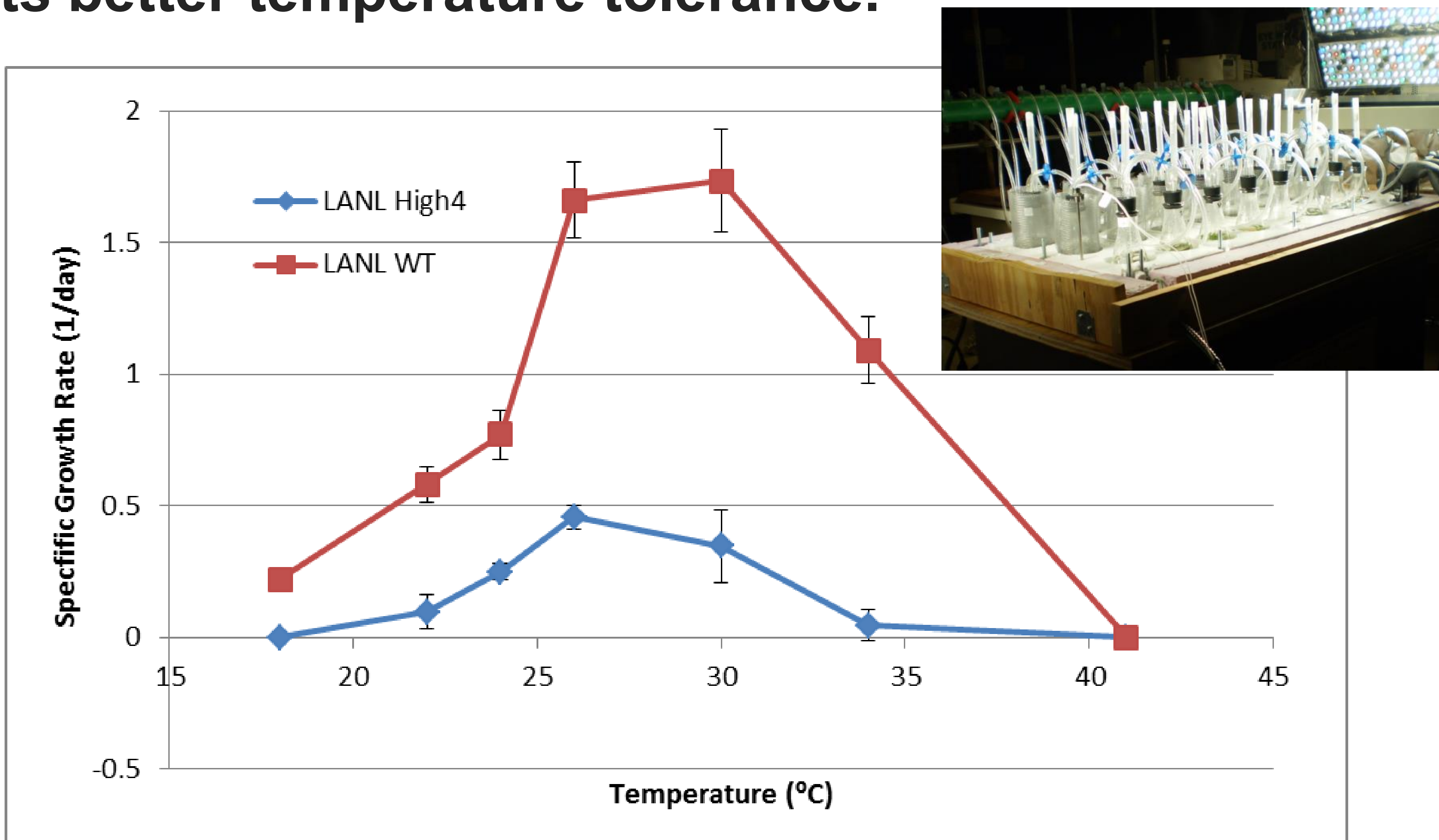
Measure the specific growth rate of both LANL strains as a function of temperature: WT grows faster than High4 and exhibits better temperature tolerance.



Technical Accomplishment (1Q ML)

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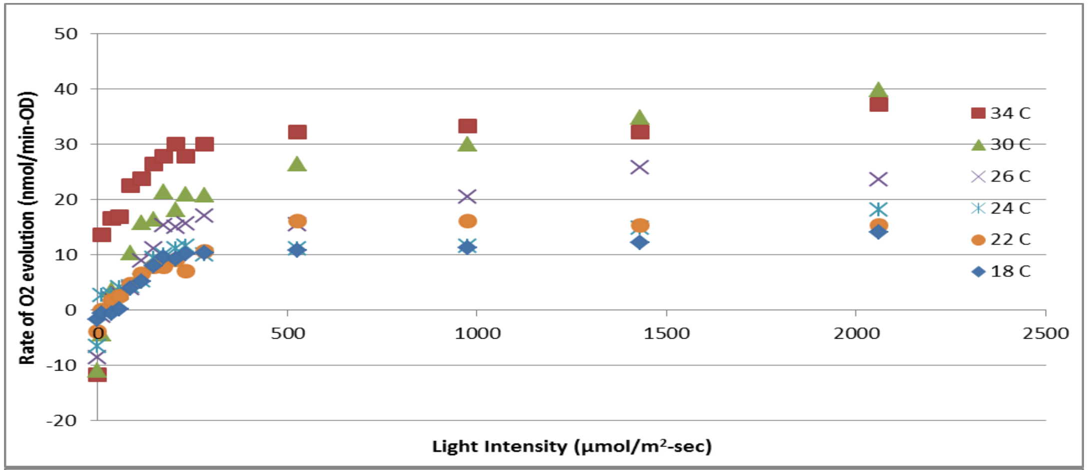
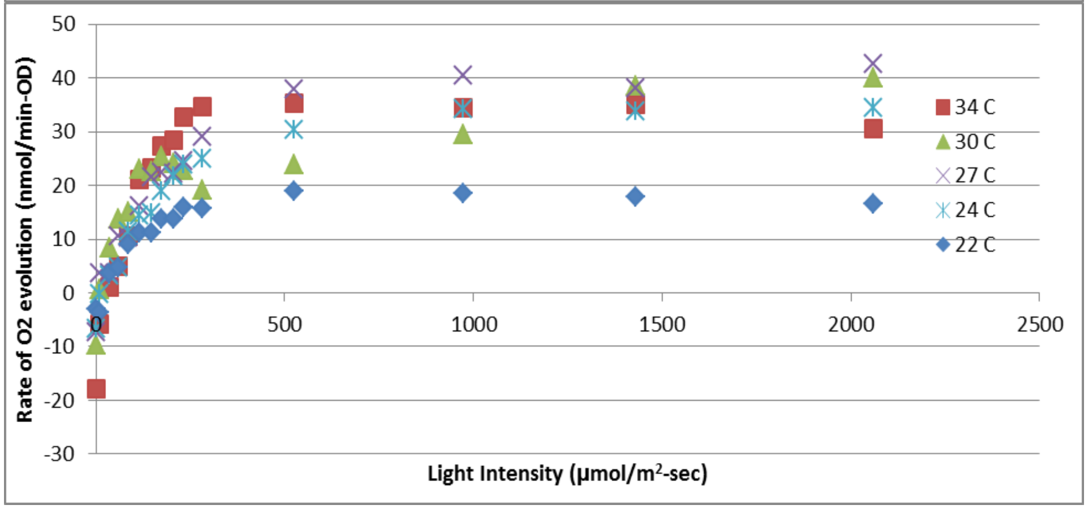
Measure photosynthetic O_2 evolution as a function of light intensity at different temperatures: Both strains have a saturating light intensity of about 250 µmoles/m²-sec .

Wild Type



High4



Technical Accomplishments (1Q ML)

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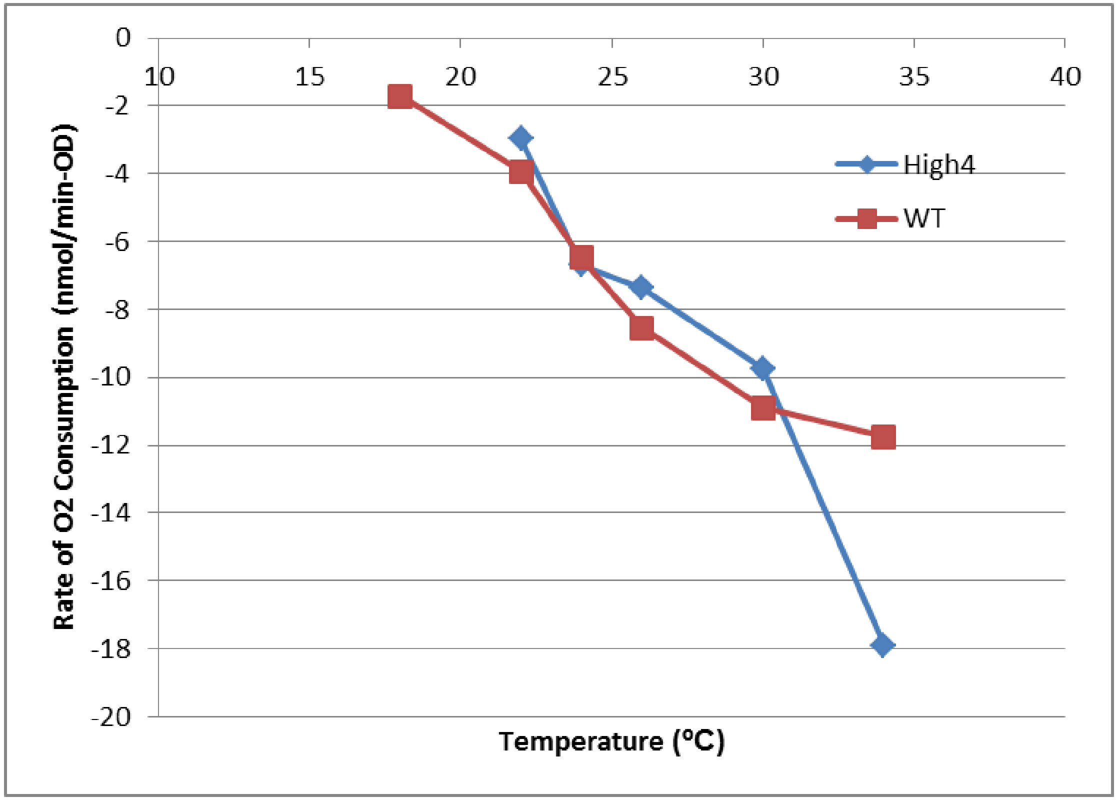
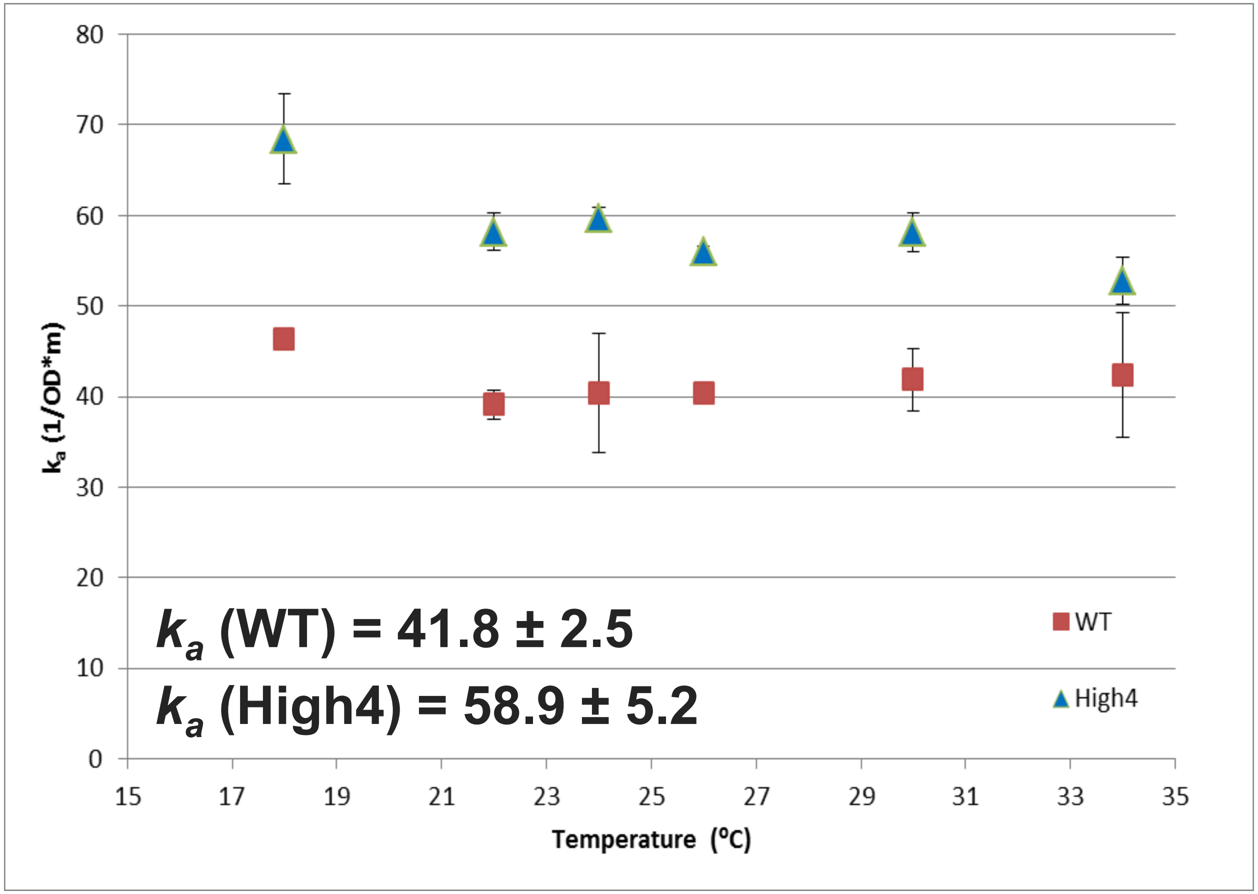
Measure the rate of O_2 consumption due to dark respiration as a function of temperature: Both strains exhibit a similar increase in dark respiration rate with temperature.



Technical Accomplishment (1Q ML)

Measure the biomass light absorption coefficient (k_a) as a function of temperature: WT is less pigmented which should translate into higher biomass productivity.



Technical Accomplishments (2Q ML)

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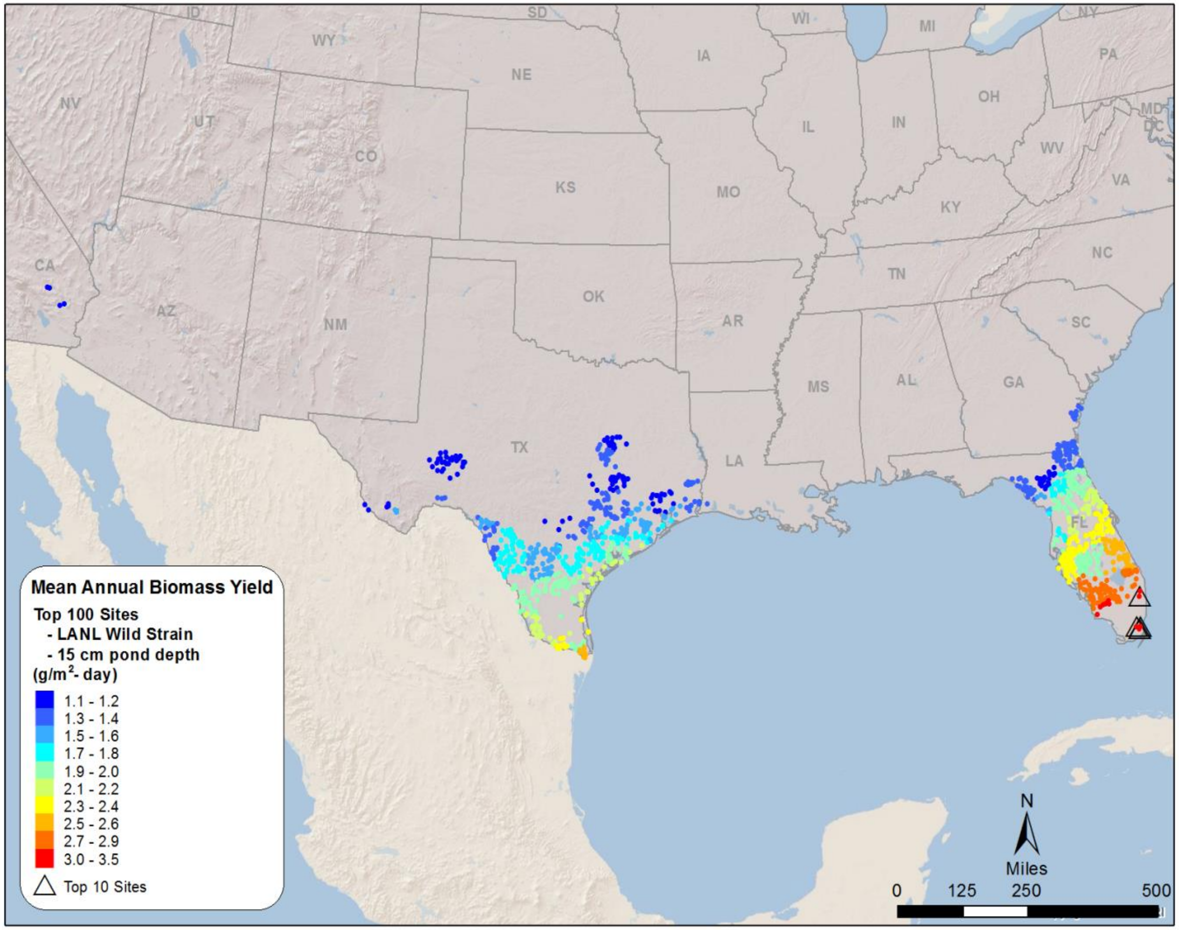
Identify geographic locations (U.S.) of optimal annual biomass productivity of WT in outdoor pond cultures: Top 10 production sites are located in Southern Florida.



Technical Accomplishments (2Q ML)

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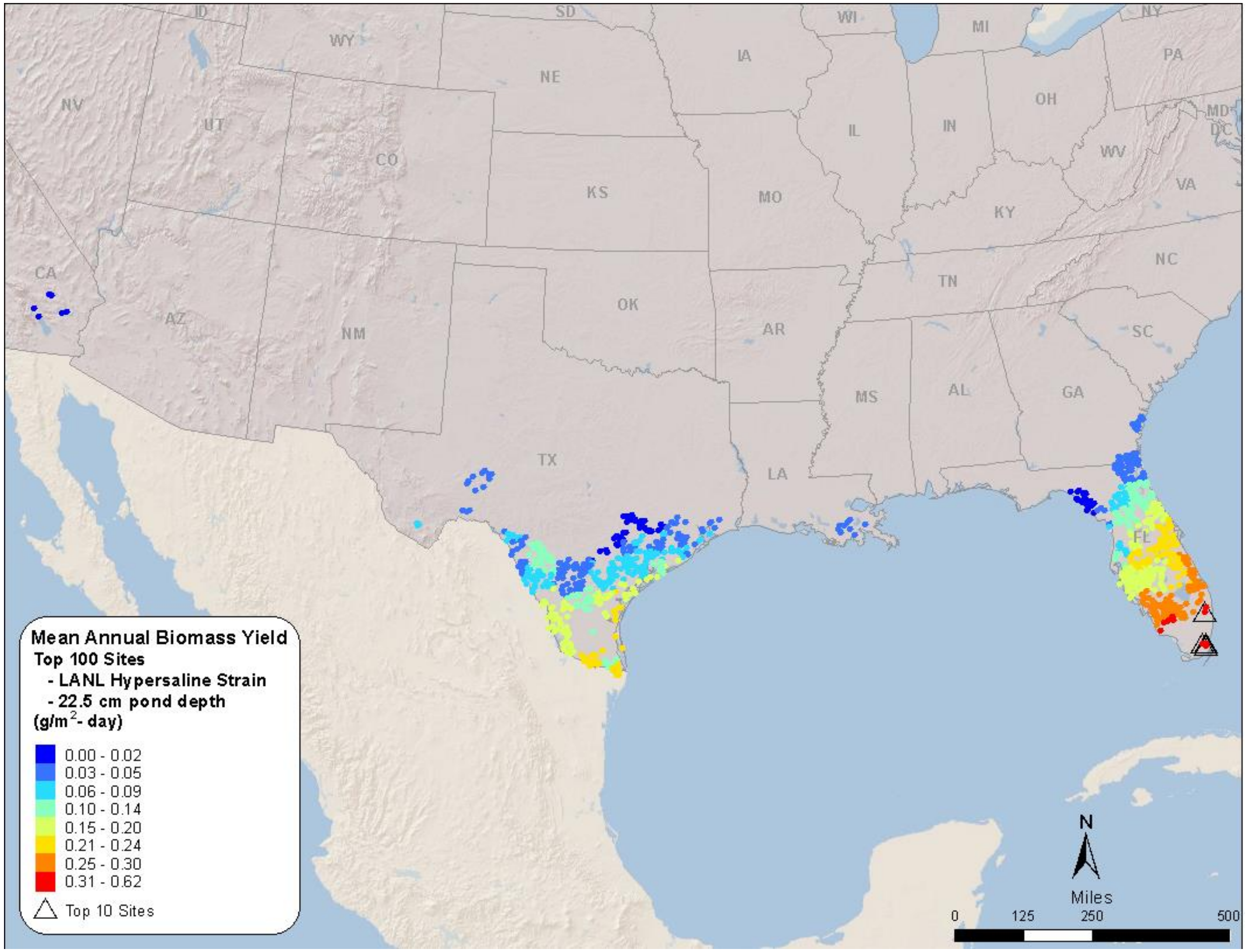
Identify geographic locations (U.S.) of optimal annual biomass productivity of High4 in outdoor pond cultures: Top 10 production sites are located in Southern Florida.



Technical Accomplishments (2Q ML)

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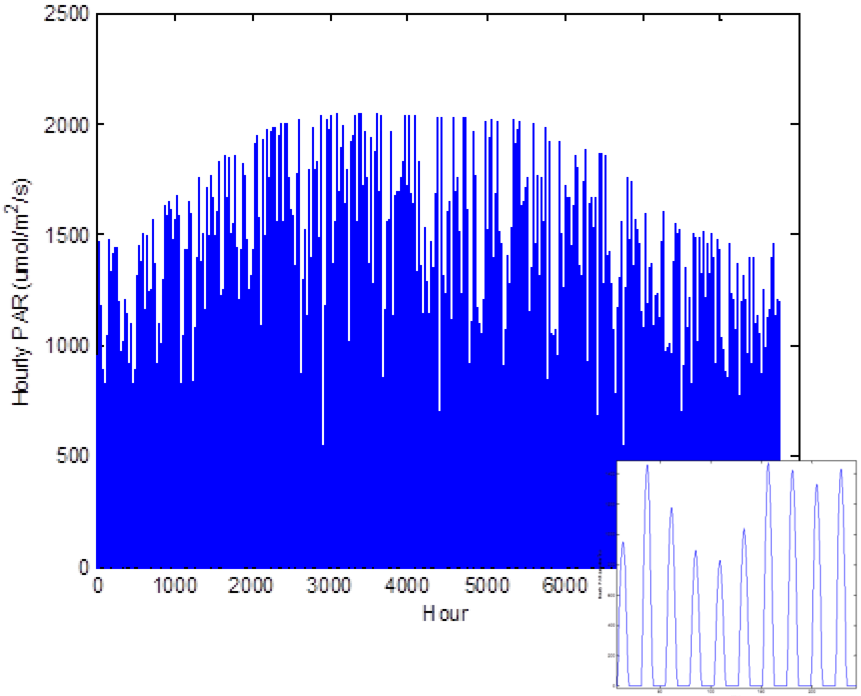
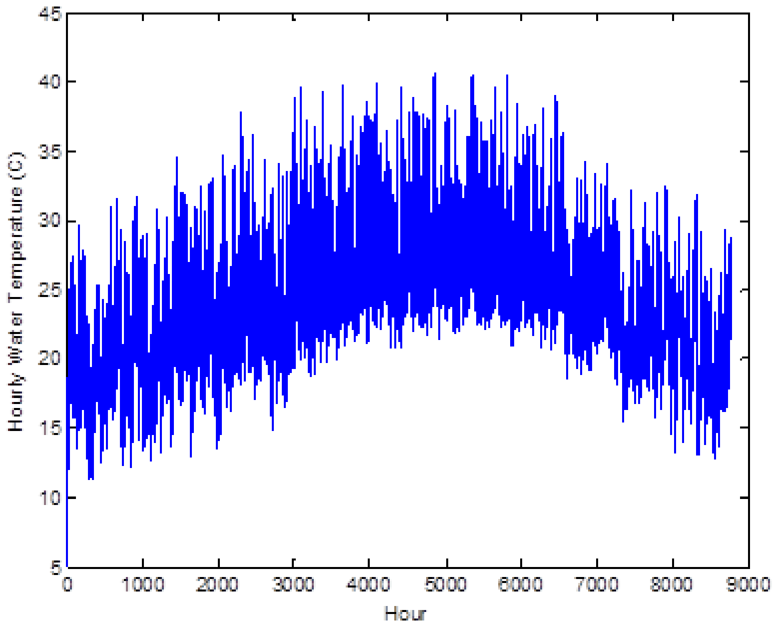
Generate light intensity and water temperature scripts (time series) for ponds at optimal location: Scripts will be used to operate climate-simulation ponds in Q3+Q4.

Light Intensity

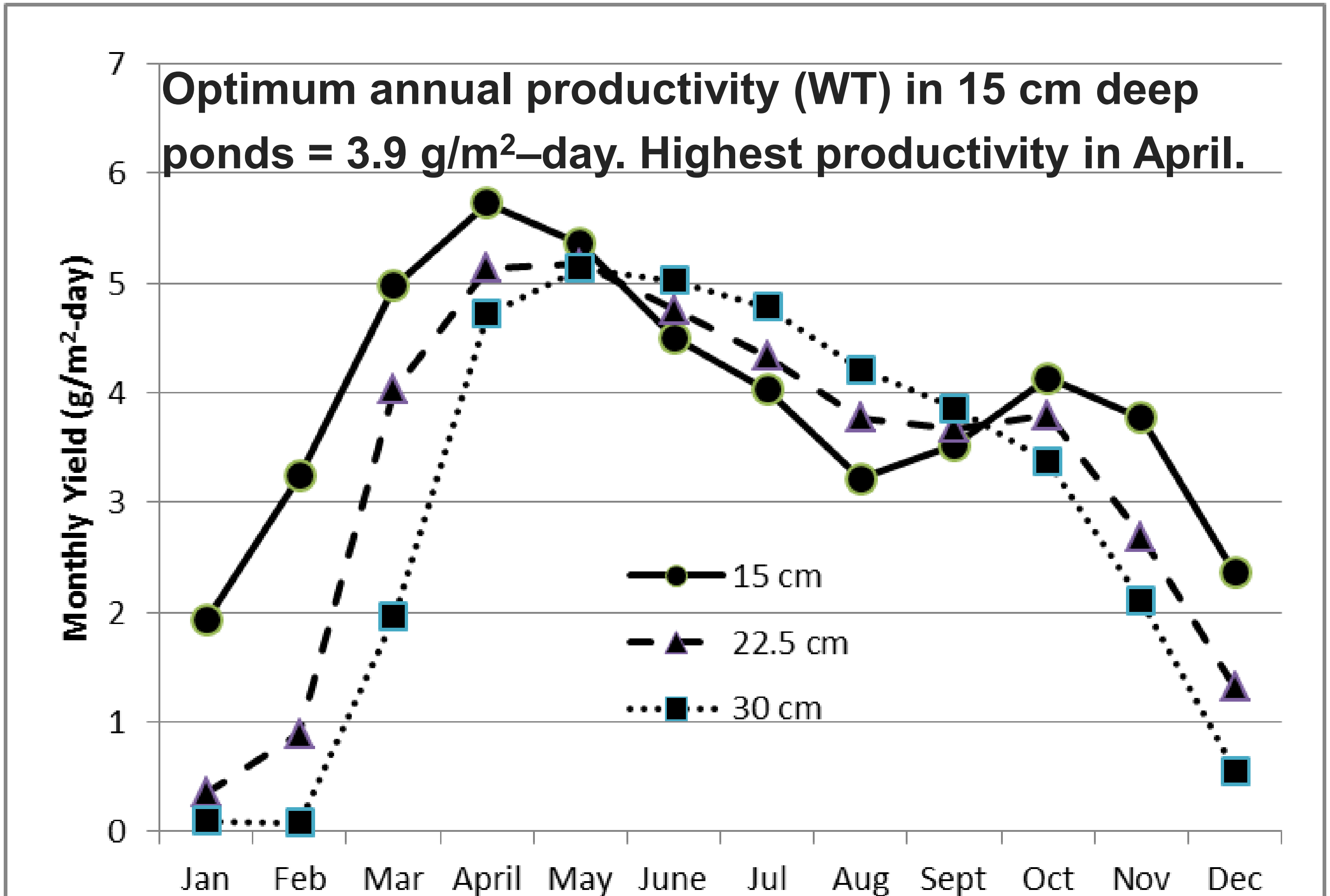


Water Temperature



Technical Accomplishments (2Q ML)

Predict monthly and annual biomass productivity for ponds at best location operated at optimal dilution rate (0.25/day).



Relevance

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- Achieving DOE's cost targets for algae oil requires significant increases in algae productivity, from 13.2 g/m^2- day (2010) to 30 g/m^2- day (2022).

  MYPP Barriers addressed:

  Ft-B. Sustainable Production
  Ft-C. Feedstock Genetics and Development
  Ft-G. Feedstock Quality and Monitoring

Table B-4: Open Pond Algae Feedstock Supply and Logistics Key Process and Cost Metrics*

Process Concept: Open Pond, wet solvent-based lipid extraction	Metric	2010 SOT	2014 Projection		2018 Projection	2022 Projection
Total Algal Feedstock Cost	$ / GGE Algal Oil	$18.22	$13.13		$6.30	$3.27
Production Cost	$ / GGE Algal Oil	$15.60	$11.18		$5.17	$2.63
Harvest Cost	$ / GGE Algal Oil	$2.99	$2.52		$1.65	$0.67
Preprocessing Cost	$ / GGE Algal Oil	$1.72	$1.56		$1.11	$0.77
Recycle Credit	$ /GGE Algal Oil	-$2.08	-$2.14		-$1.63	-$0.80
Production						
Total Cost Contribution	$/AFDW Ton	$916.2	$656.47		$384.48	$343.19
Capital Cost Contribution	$/AFDW Ton	$650.8	$436.34		$207.46	$174.54
Operating Cost Contribution	$/AFDW Ton	$265.3	$220.13		$177.02	$168.65
Algal productivity	g/m2/day	13.2	20		25	30

- This project provides an effective and low risk approach to predict and quantify the maximum achievable annual productivity of promising strains cultured at the optimal geographic location.

- PNNL is working with various industrial partners to apply the climate simulation and growth model tools to their specific algal feedstocks.

Critical Success Factors

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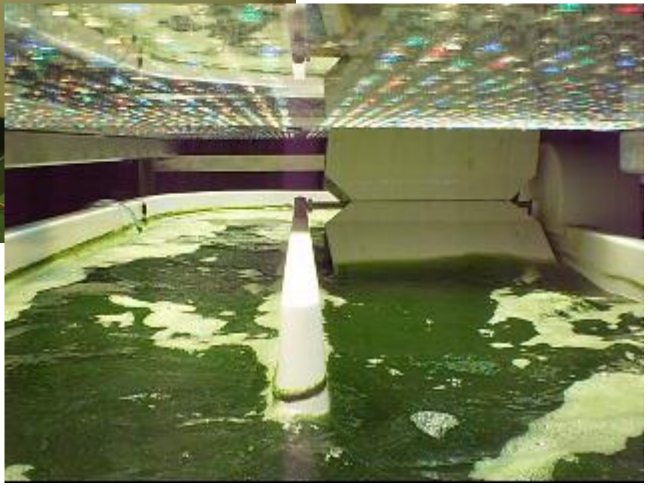
- Critical Success Factors
  - Steady stream of promising strains for testing
  - Validated biomass growth model and BAT
  - Validated climate-simulation concept
- Top Technical Challenges for Project Success
  - Generation/identification of high productivity strains
  - Additional validation of the biomass growth model and BAT
  - Additional validation of the climate-simulation concept
  - Refinement of biomass growth model (effects of pH, salinity, etc.)
- Project is advancing the state of technology and is positively impacting commercial viability of microalgae biofuels by accelerating the identification of high productivity strains and reducing the risk of scale-up and relocation.

Future Work (Q3+Q4)

Validation of predicted maximum biomass productivities in climate-simulation LED-lighted raceway ponds.



Future Work (Q3+Q4)

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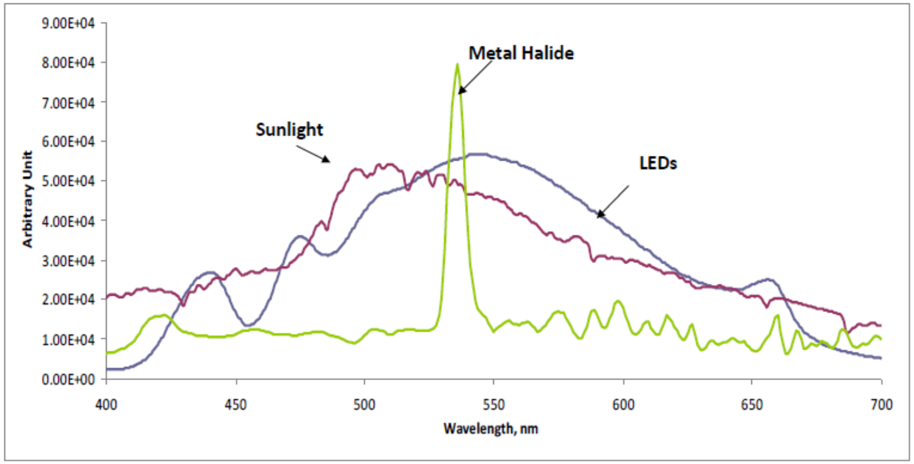
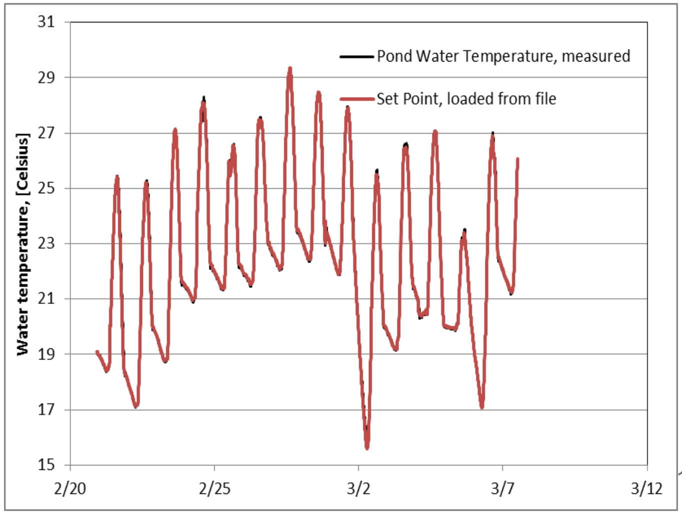
Culturing in climate-simulation ponds:

- Light intensity can be increased up to 2700 µmoles/m^2-sec.
- The LED spectrum (4500 LEDs) is very similar to that of sunlight.
- Pond water temperature controllable from ca. 6 to 48 °C.
- Simulate daily light and water temperature fluctuations of hypothetical outdoor ponds at any geographic location and season of choice.





Future Work (Q3+Q4)

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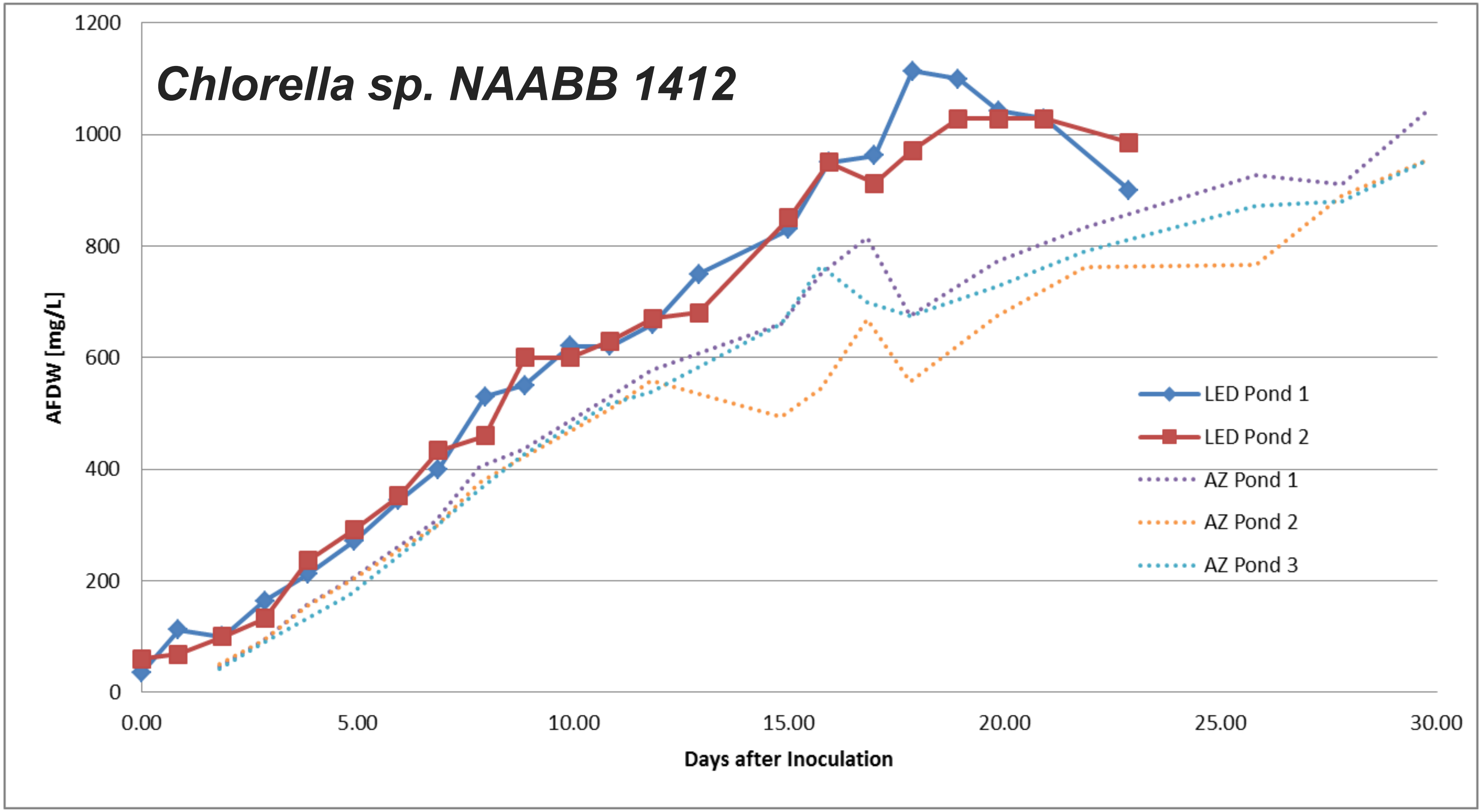
Culturing of LANL strains in climate-simulation ponds.

Already demonstrated successful simulation of *Chlorella* sp. 1412 biomass growth in outdoor AZ ponds.



Future Work (FY14)

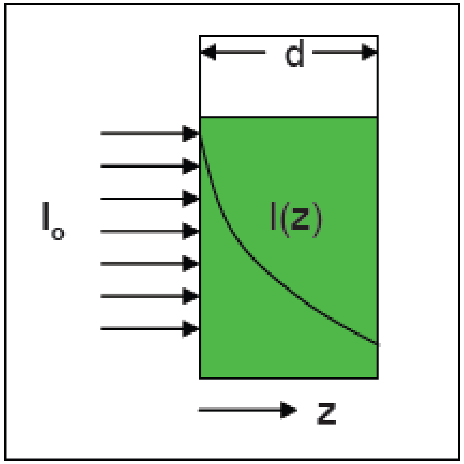
ML or DL or Go/No Go	Description	FY13 Q3	FY13 Q4	FY14 Q1	FY14 Q2	FY14 Q3	FY14 Q4
ML	**Provide annual productivity maps**	■					
ML	**Measure biomass & lipid productivity in climate-simulation ponds**		■				
DL	**Complete draft manuscript**		■				
ML	**Modify model/BAT for pH + salinity**			■			
ML	**Characterize new LANL strain**				■		
ML	**Generate productivity map**					■	
ML	**Measure prod. in climate-sim. ponds**					■	■
DL	**Complete draft manuscript**						■
Go/No Go	**Decision made by 6-30-15**						

Summary

- **Relevance:** The project contributes to meeting the goals and objectives of the Algae Conversion Technology Area.
- **Approach:** The project provides an effective and low risk approach to predict and quantify the maximum achievable annual productivity at best location and generates robust inputs to techno-economic models.
- **Technical Accomplishments:** The project has leveraged process data from NAABB to build initial models, completes Tech Memo, and provides critical inputs to the algae model harmonization group.
- **Future Work:** The project will conduct targeted research in FY14-15 to optimize biomass productivities and pond culturing conditions. This data will be used to update the growth model and the BAT.
- **Success Factors and Challenges**: The critical success factors and challenges for the project have been identified and can be managed.
- **Technology Transfer**: The project will support technology transfer to industry by providing validated process model and economics.

Additional Slides

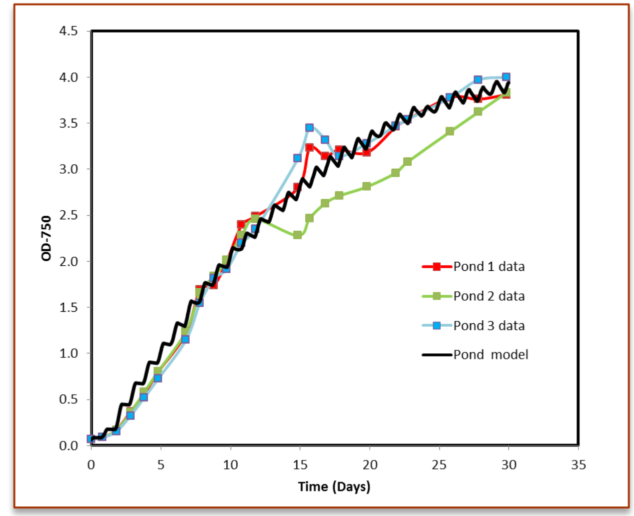
Validated Biomass Growth Model



$$I(z) = I_o \cdot e^{-k_a B z}$$

$$\mu = \mu_{max} \cdot f(I, T)$$

$$B(t + \Delta t) = B(t) \cdot e^{\mu \cdot \Delta t}$$



- **Physical Input Parameters**
  - **Incident light intensity (*I_o*) as a function of time**
  - **Water temperature (*T*) as a function of time**
  - **Culture depth (*d*)**
- **Biological Species-Specific Input Parameters**
  - **Maximum specific growth rate (*μ*) as a function of light**
  - ***μ* as a function of temperature**
  - **Biomass light absorption coefficient**

ARTICLE

BIOTECHNOLOGY and BIOENGINEERING

A Screening Model to Predict Microalgae Biomass Growth in Photobioreactors and Raceway Ponds

M. H. Huesemann, J. Van Wagenen, T. Miller, A. Chavis, S. Hobbs, B. Crowe

PNNL Water Temperature Model

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Use validated hydrodynamic thermal energy transport model to predict T_{pond}:

$$h_1 h_2 \frac{\partial(dT)}{\partial t} + \frac{\partial(h_2 dUT)}{\partial \xi} + \frac{\partial(h_1 dVT)}{\partial \eta} = \frac{\partial}{\partial \xi}\left(h_2 \frac{\varepsilon_1}{h_1}\frac{\partial T}{\partial \xi}\right) + \frac{\partial}{\partial \eta}\left(h_1 \frac{\varepsilon_2}{h_2}\frac{\partial T}{\partial \eta}\right) + \frac{h_1 h_2 H}{\rho c_v}$$

$$\frac{\delta(dT)}{\delta t} = \frac{H}{\rho c_v}$$

$$H = H_{sn} + H_a - (H_b + H_e + H_c)$$

Model Input Parameters:

- precipitation
- min + max temperature
- dew point
- wind speed
- solar radiation

T = pond water temperature

d = pond depth

ρ = water density

c_v = specific heat of water

H = heat exchange at water surface

H_{sn} = net solar shortwave radiation

H_a = net atmospheric longwave radiation

H_b = longwave back radiation

H_e = heat flux due to evaporation

H_c = heat flux due to conduction

WATER RESOURCES RESEARCH, VOL. 47, W00H04, doi:10.1029/2010WR009966, 2011

National microalgae biofuel production potential and resource demand

Mark S. Wigmosta,[1] André M. Coleman,[1] Richard J. Skaggs,[1] Michael H. Huesemann,[2] and Leonard J. Lane[3]