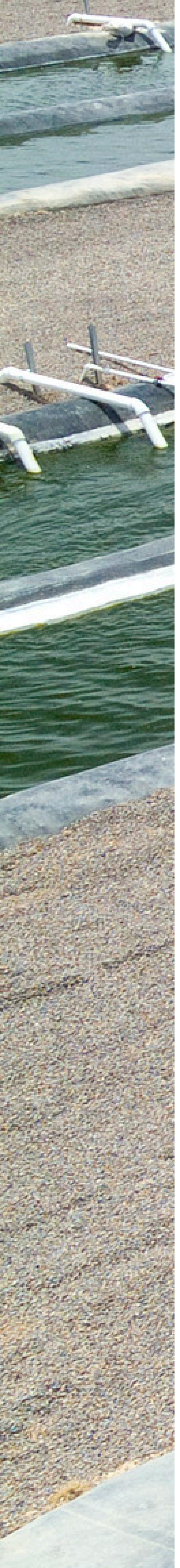


# 1.3.5.203 Microalgae Analysis

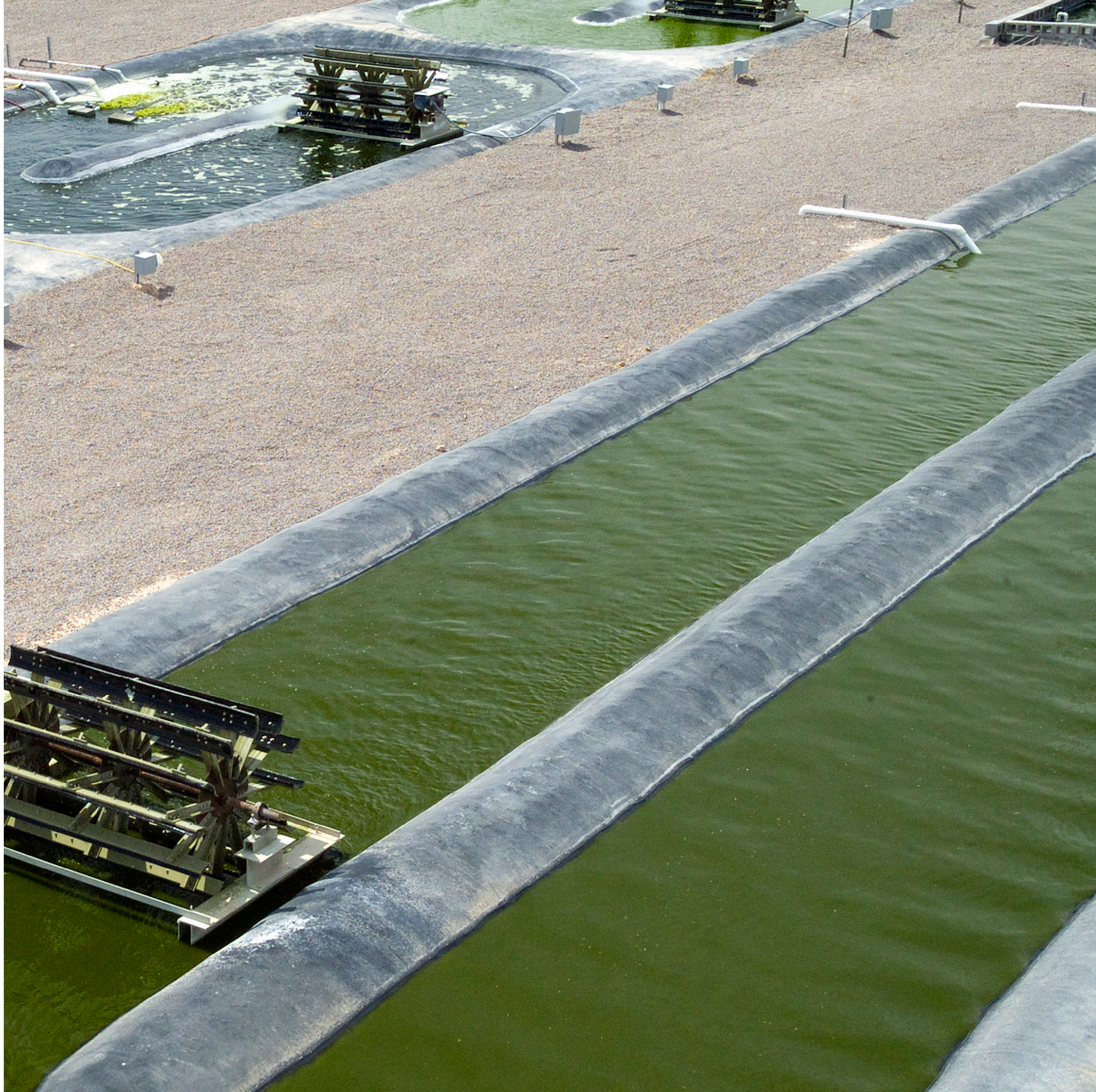
March 11, 2021

Advanced Algal Systems Program

**Mark Wigmosta**

PNNL is operated by Battelle for the U.S. Department of Energy





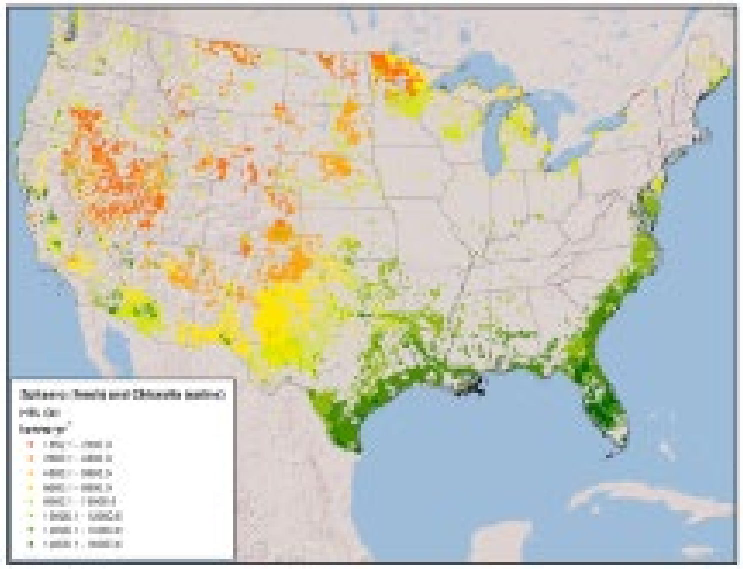
# Project Overview: Challenge, Goal and Objectives

**Challenge:** Development of an algal biofuel industry requires scaling-up from hundreds of acres currently in domestic algae cultivation, to millions of acres. Algae resource assessment includes identifying potential geographic locations for algae farms based on land characteristics, resource availability and access, estimating costs for current and future resources, and assessing the environmental sustainability of the use of these resources. (BETO 2016 Multi-Year Program Plan)

**Goal:** Provide BETO and industry a national assessment capability focused on fundamental questions of where production can occur, how much nutrient, land and water resource is required, how much biomass/energy is produced, and what interactions/trade-offs exist between technologies

**Technical Objectives:** Enhancement and application of the **PNNL Biomass Assessment Tool (BAT)** to evaluate alternative algal feedstock production strategies that will yield the highest sustainable fuel production potential as a function of unit cost and resource use efficiency

- Multi-scale: site → national
- ~89,000 unit farms with site specific climate, resource supply/demand
- Appropriate algal strains for location and season (freshwater & saline)
- Best growth media/operations
- Conversion technology and up & downstream logistics



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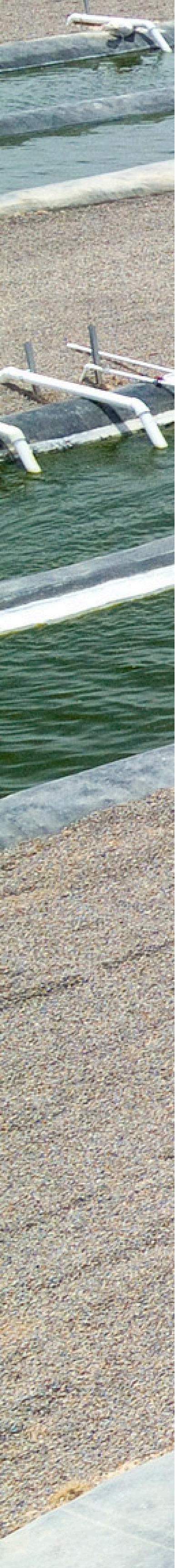
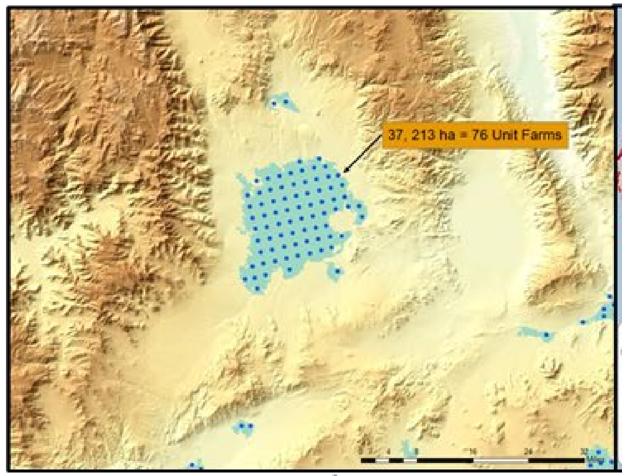
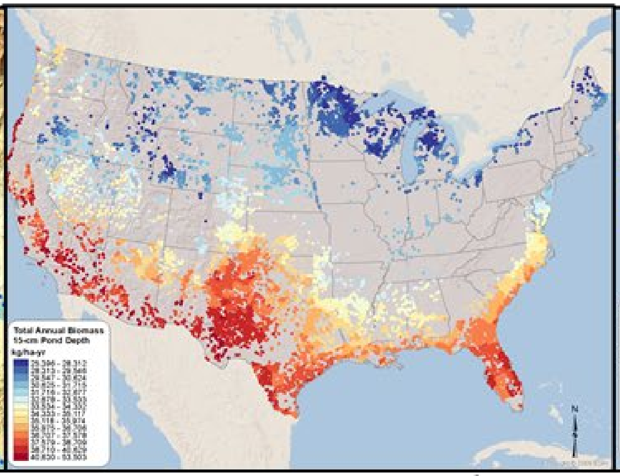


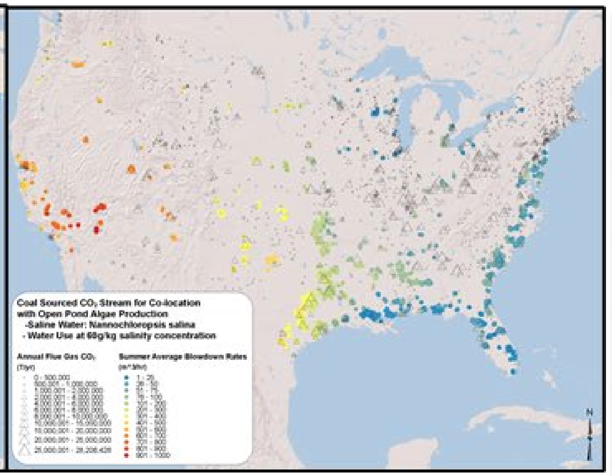
# Overview:
# BAT Integrates Detailed Spatiotemporal Data with Biophysical & Geospatial Models for Multi-Scale Analysis



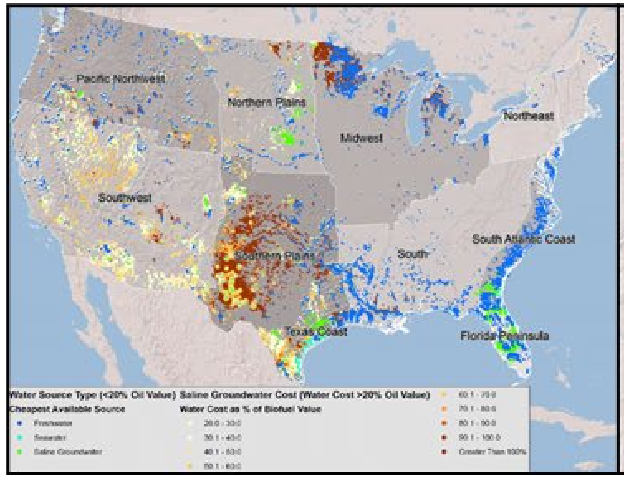

Site Selection



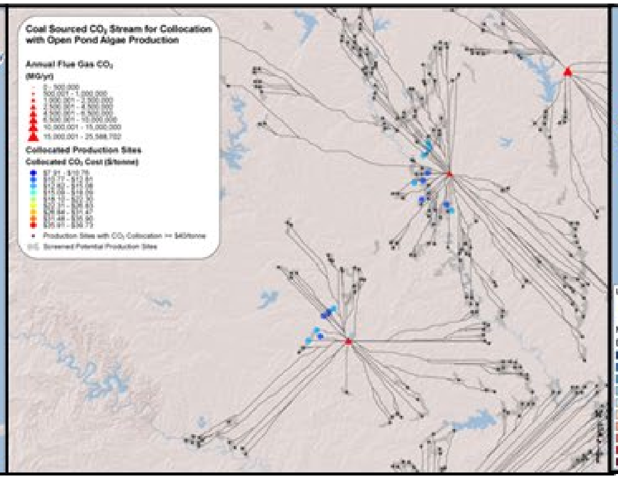
Biomass Growth



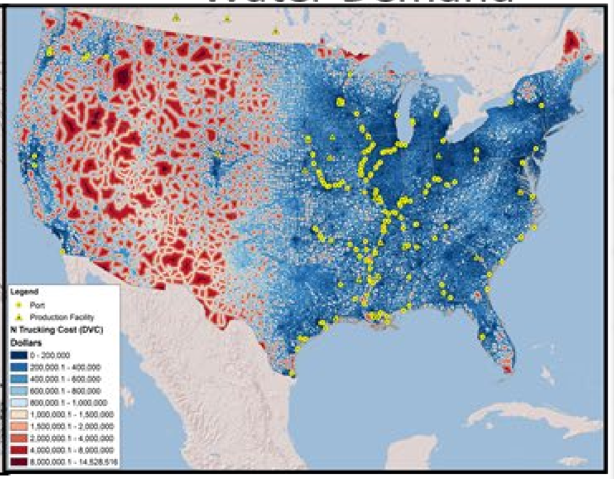
Water Demand




Water Supply



$CO_2$ Co-Location



Transport Costs

**BAT**

- Meteorology
- Site Selection
- Open Pond Temp. Model
- Closed Pond Model
- PBR Model
- Growth Model
- Nutrient Demands
- Water Supply/Use
- Least-Cost Route Models
- Co-Location Model
- Alt. Nutrient Resources
- Risk Assessment
- Land Value
- Tradeoff Models
- Conversion Pathways
- Infiltration Model
- Land Leveling Model

**Multiple criteria must be considered, and the highest biomass production site might not be the "best" site due to lack of infrastructure or other resource constraints**

# 1 – Management: Structure and Reporting

- Following BETO project management protocols
  - Annual Operating Plan (AOP)
  - Quarterly Progress Reports to BETO
- Quarterly Progress Reports to BETO
  - Progress against milestone
  - Actual costs against PMP planned spend rate
  - Discussion on any variances and plans for next quarter
- Project Communications
  - Weekly planning with PNNL staff
  - Regular conference calls with external partners
  - Regular conference calls with BETO Project Officer to discuss progress, project direction, and BETO analysis needs
  - Outreach: publications, press releases, and other related projects

    (e.g., 1.3.1.501 DISCOVR , ANL 1.3.5.204 – Life Cycle Analysis of Advanced Algal Systems)
- Risks
  - Timely access to experimental results and data
  - Change in schedule impacting coordination with external collaborators

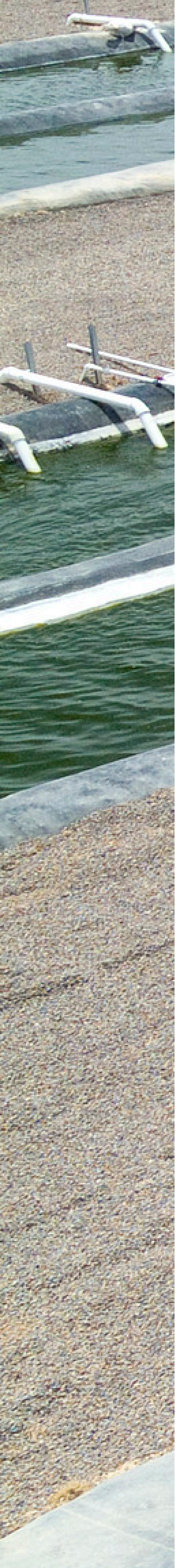
PI/PM Wigmosta

Project Coordinator: Burns

| Task | Lead |
|---|---|
| **SOT Support** | Yan |
| **Water Sustainability** | Coleman |
| **$CO_2$ -Wastewater Co-Location** | Coleman |
| **Enhanced High-Rate Pond Model** | Wigmosta |
| **Multiscale Land Screening** | Coleman |
| **Probabilistic Analysis** | Wigmosta |
| **2021 Peer Review** | Wigmosta |

# 1 – Management: Risk Mitigation

| Name | Status | Target Completion Date | Severity | Response | Description |
|---|---|---|---|---|---|
| **Modification to project scope and schedule** | Known | 9/30/2022 | Medium | Active oversight by the Project Coordinator and regular communication with BETO and discussion of schedule/scope changes in advance | This project has ongoing interaction with other research organizations (ANL, ASU, DISCOVR Consortium, BETO). A change of scope or schedule among any of the participants can impact current project scope and schedule |
| **Lack of data** | Known | 9/30/2022 | Low | Regular communication with BETO and discussion of alternatives to achieve completion | Lack of certain data or inputs |





# Application of BAT to Evaluate Innovative Algal Feedstock Strategies to Improve Production, Cost, and Resource Use Efficiency

BAT links the latest research in cultivation and conversion with biophysical process models and spatiotemporal information to quantify interactions between resource availability and costs, biomass production, and biomass to biofuel conversion technology across a range of scales.

- **Technical Success**: Identify and assess impacts of design and operational constraints and risks for algal biofuel feedstock production
  - Ongoing process incorporating best available process modules (Huesemann growth model, HTL conversion) and databases (DISCOVR) into the BAT
  - Coordination with DISCOVR and BETO Waste-to-Energy
  - Dissemination of study results through peer-reviewed publications, conferences and workshops, university and other national lab collaborations
- **Key challenges**:
  - Limited, but increasing, experimental/observational data to support model parameterization and validation – updating, formatting, data gaps
  - Seasonality and climate change in biomass production
  - Sustainability: economic and resource
- **Go/No-Go**:
  - If the total potential from co-location with wastewater facilities exceeds 5% of the BETO MYPP 2030 target of 5 BGY GGE, we will continue to evaluate wastewater co-location with a more refined modeling approach and cost considerations (3/31/2021) – on track for a go decision.

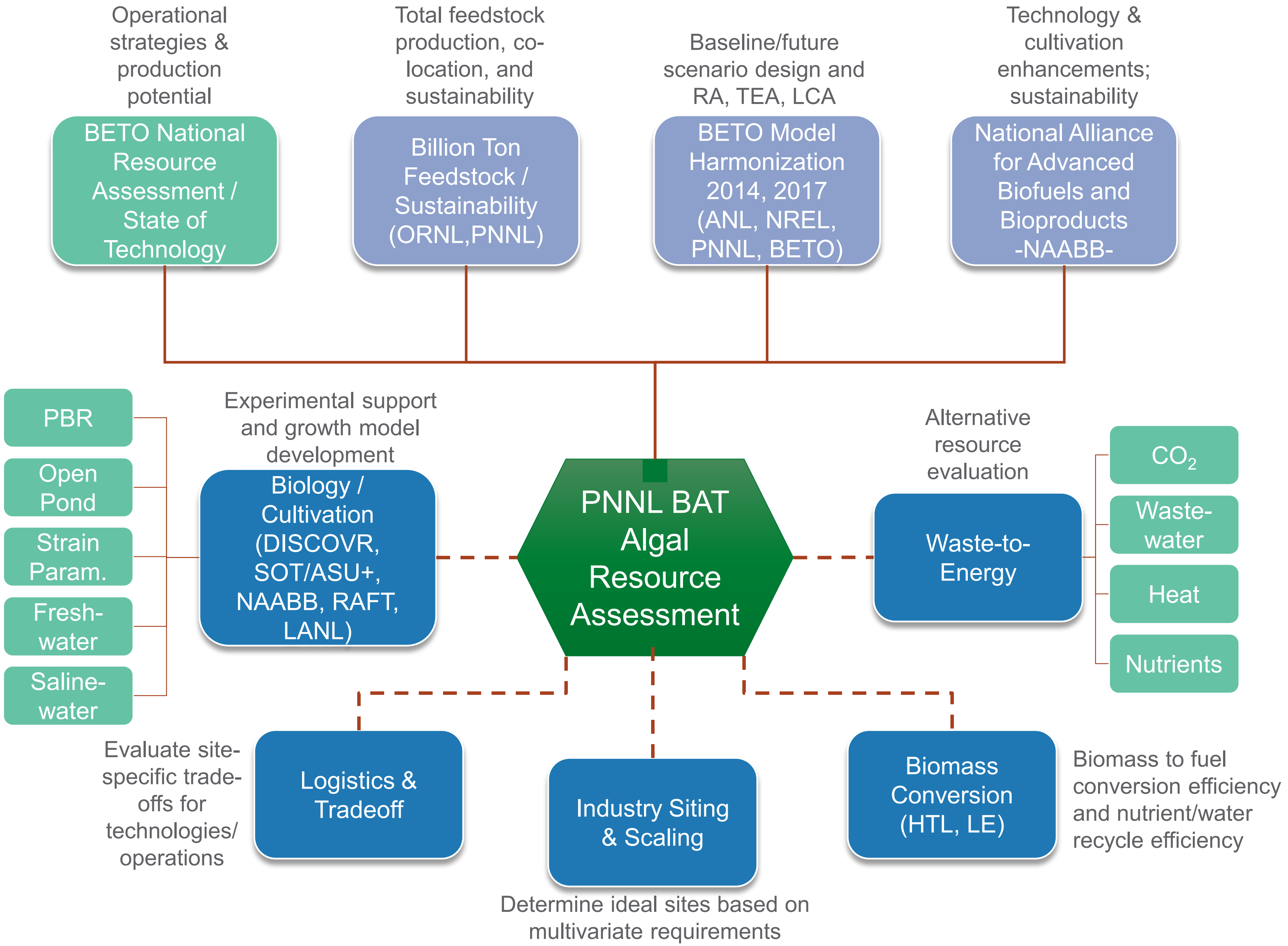
# 3 – Approach

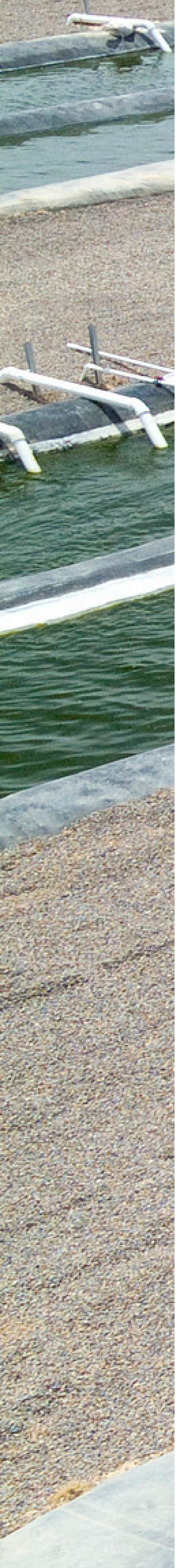
Topic areas

Past efforts

Current efforts

**The BAT provides a biophysics-based analysis framework for linking key BETO & industry research activities to achieve high-impact objectives for multiple feedstocks**

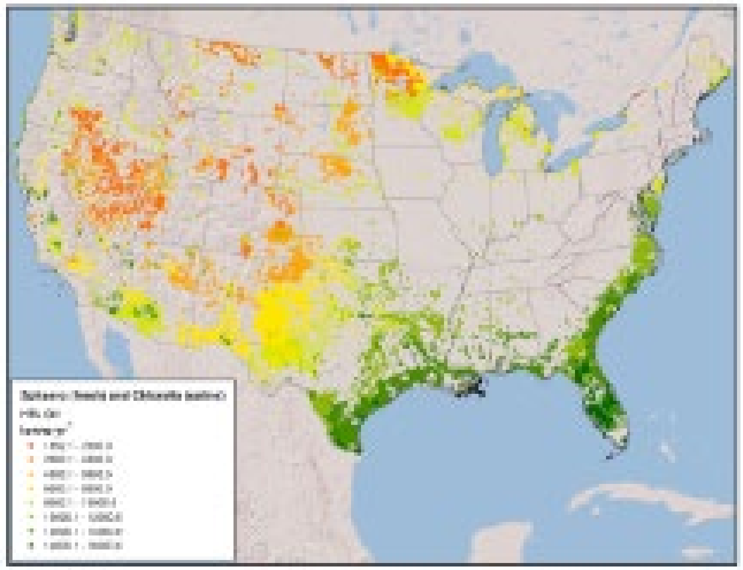




# 3 – Impact

**Advancing the state of technology by evaluating alternative algal feedstock site locations, algal strains, growth media, operations, and process technology to yield the highest sustainable fuel production potential per unit cost and resource use efficiency**

- **Aggressive technology transfer**
  - Numerous workshops and conferences
  - Direct collaboration with industry
  - Experimental Support (BETO State of Technology, DISCOVR, RAFT)
  - BETO Waste-to-Energy, Forest Restoration, and Waterborne Plastics
  - Small Business Support
  - Aviation Biofuels

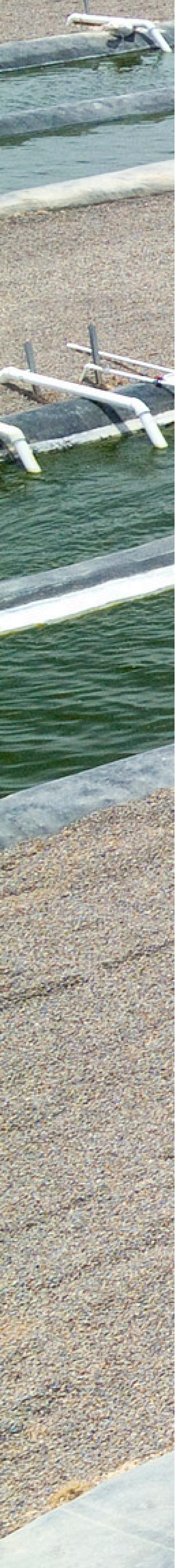


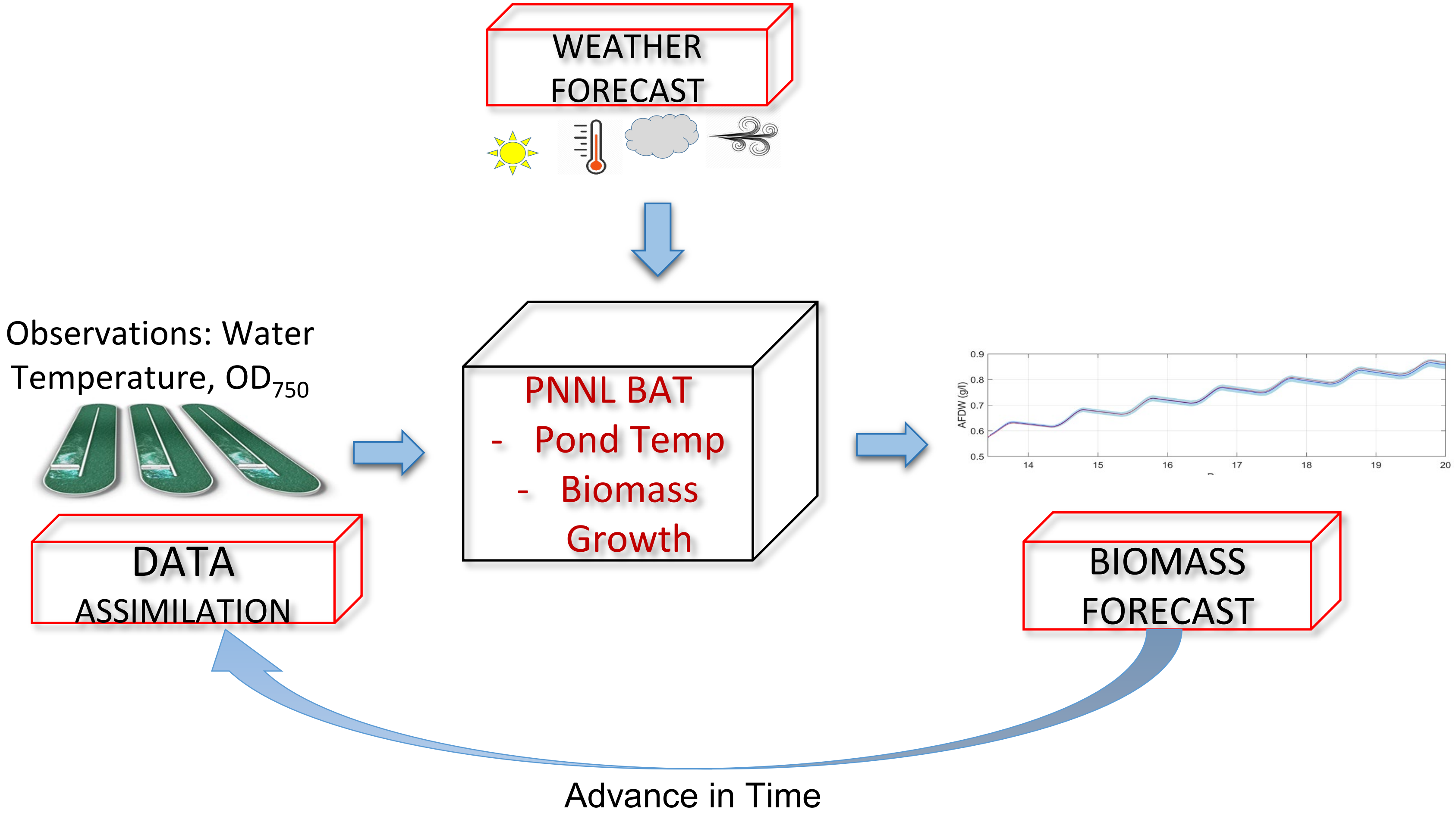
- **Analyses are directly focused on BETO MYPP targets:**
  - By 2022, model the sustainable supply of 20 million metric tons AFDW cultivated algal biomass
- **Peer Reviewed Publications**
  - 22 total since 2011 (**4 > 120 citations; 7 > 60 citations**; 11 > 27 citations; 16 > 12 citations)
  - 4 published since last review - in addition, 1 in review and 4 in preparation

2019 Peer Review Panel Comments: “BAT (Biomass Assessment Tool) is an incredibly useful analysis relevant across the AAS portfolio. The tool strives to simplify the complexity associated with considering more than 15 factors that directly impacts the cost of converting algae to biofuels”.

## 4 – Progress and Outcomes

# Framework for Operational Biomass Forecasting to Optimize Pond Operations



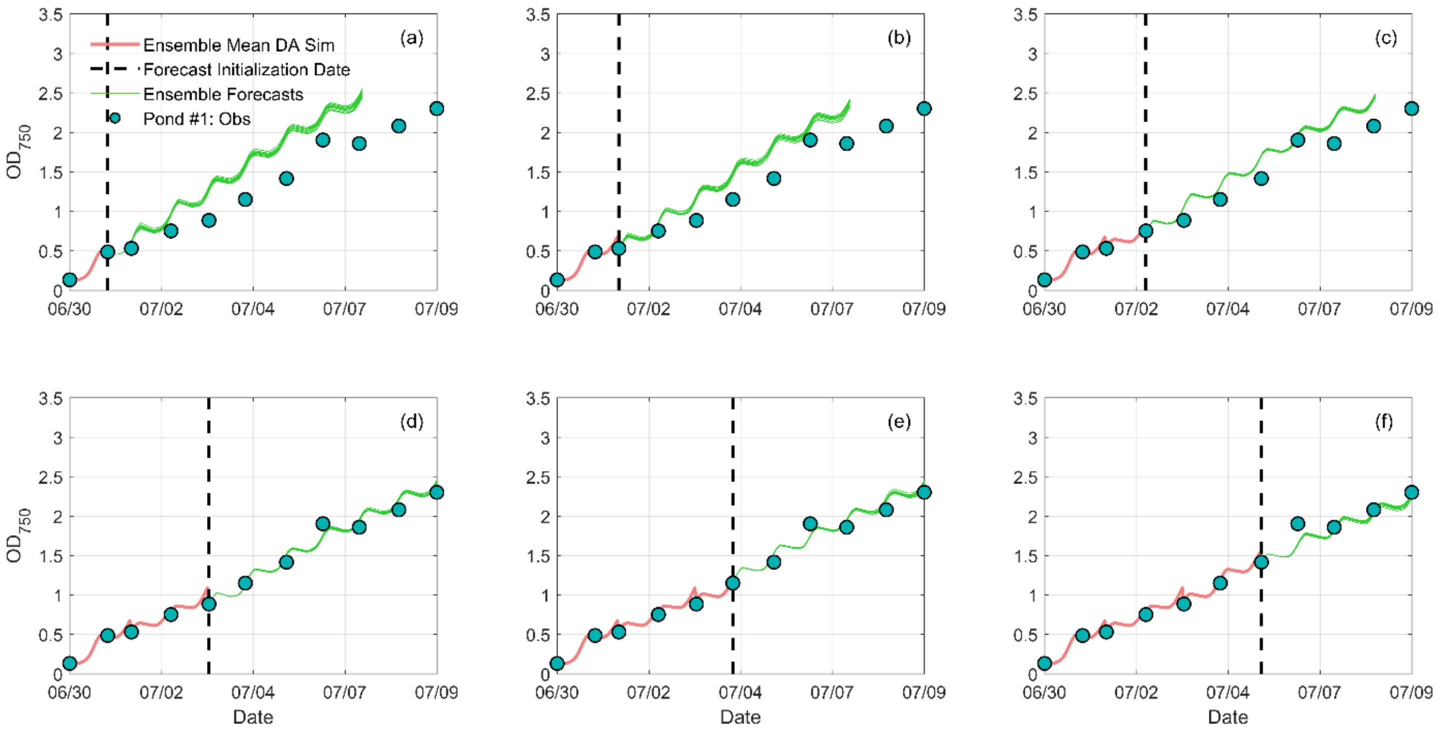



**Real-time, 7-day forecast of biomass growth to guide pond operations and maximize growth**

Yan H, Wigmosta MS, Sun N, Huesemann MH, Gao S. Real-time ensemble microalgae growth forecasting with data assimilation. *Biotechnology and Bioengineering*. 2021;1–6. https://doi.org/10.1002/bit.27663

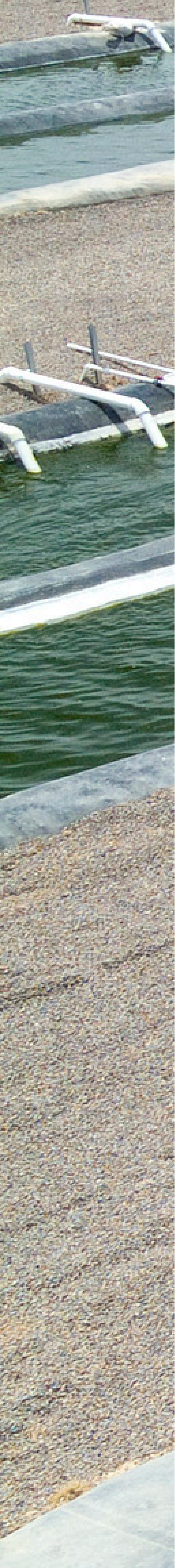
## 4 – Progress and Outcomes

# Retrospective Analysis of Forecast Accuracy




- 3 Ponds in Delhi, California
  - *Chlorella sorokiniana* (USDOE 1412)
- Archived 7-day Global Ensemble Forecast System (GEFS) weather forecasts were used to drive the pond temperature and biomass growth models
  - 1° × 1° grid cell
  - 11 ensemble members
  - air temperature, wind speed, specific humidity, air pressure, and shortwave radiation

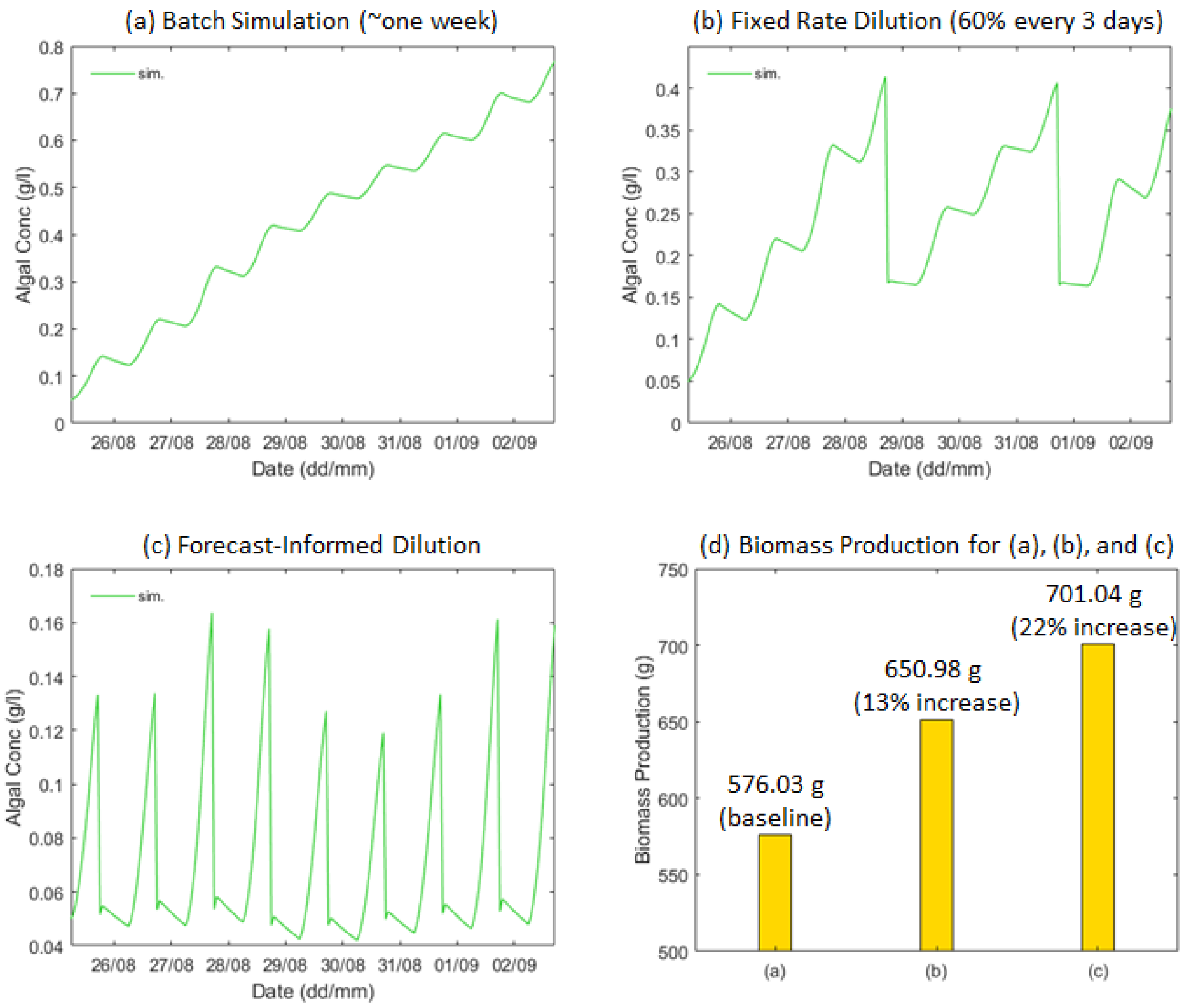
**Particle Filtering based data assimilation with bias correction (PF-BC) improved forecasted biomass yield by ~ 60% over direct model application without PF-BC**



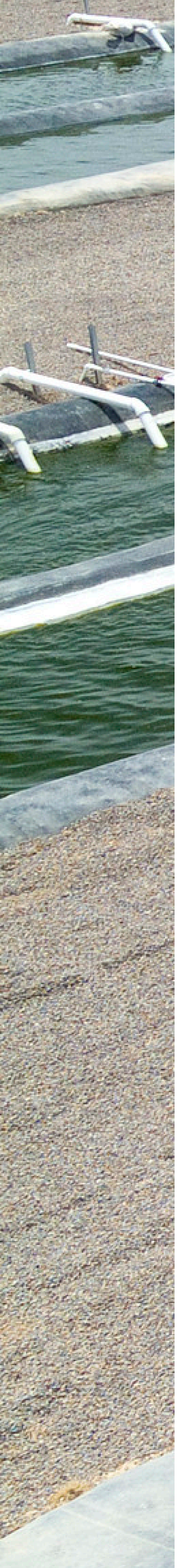
## 4 – Progress and Outcomes

# Experimental Design to Test Forecast System in Real Time

- 3 scenarios using the Laboratory Environmental Algae Pond Simulator (LEAPS)
  - *Chlorella sorokiniana* (USDOE 1412)
- (a) Baseline – large dilution every 7 days
- (b) Fixed dilution rate of 60-80% every 2-4 days
- (c) Dilution determined by forecasting system to maximize biomass production




**Forecasted-based dilution could improve biomass yield by 22% over baseline**



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## 4 – Progress and Outcomes

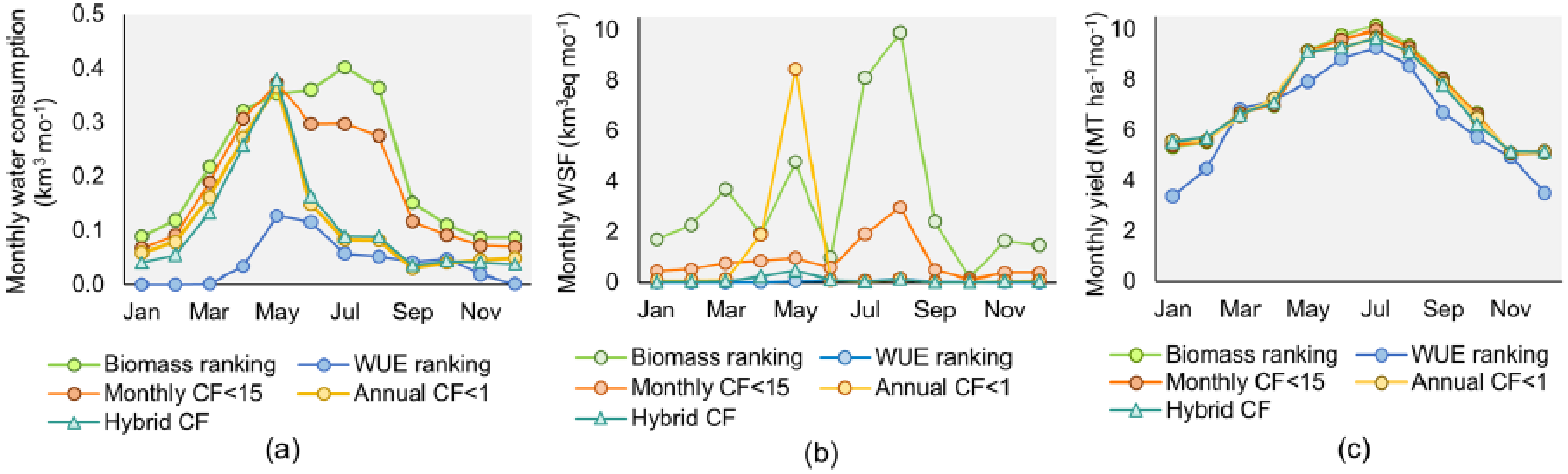
# Sustainable Use of Freshwater

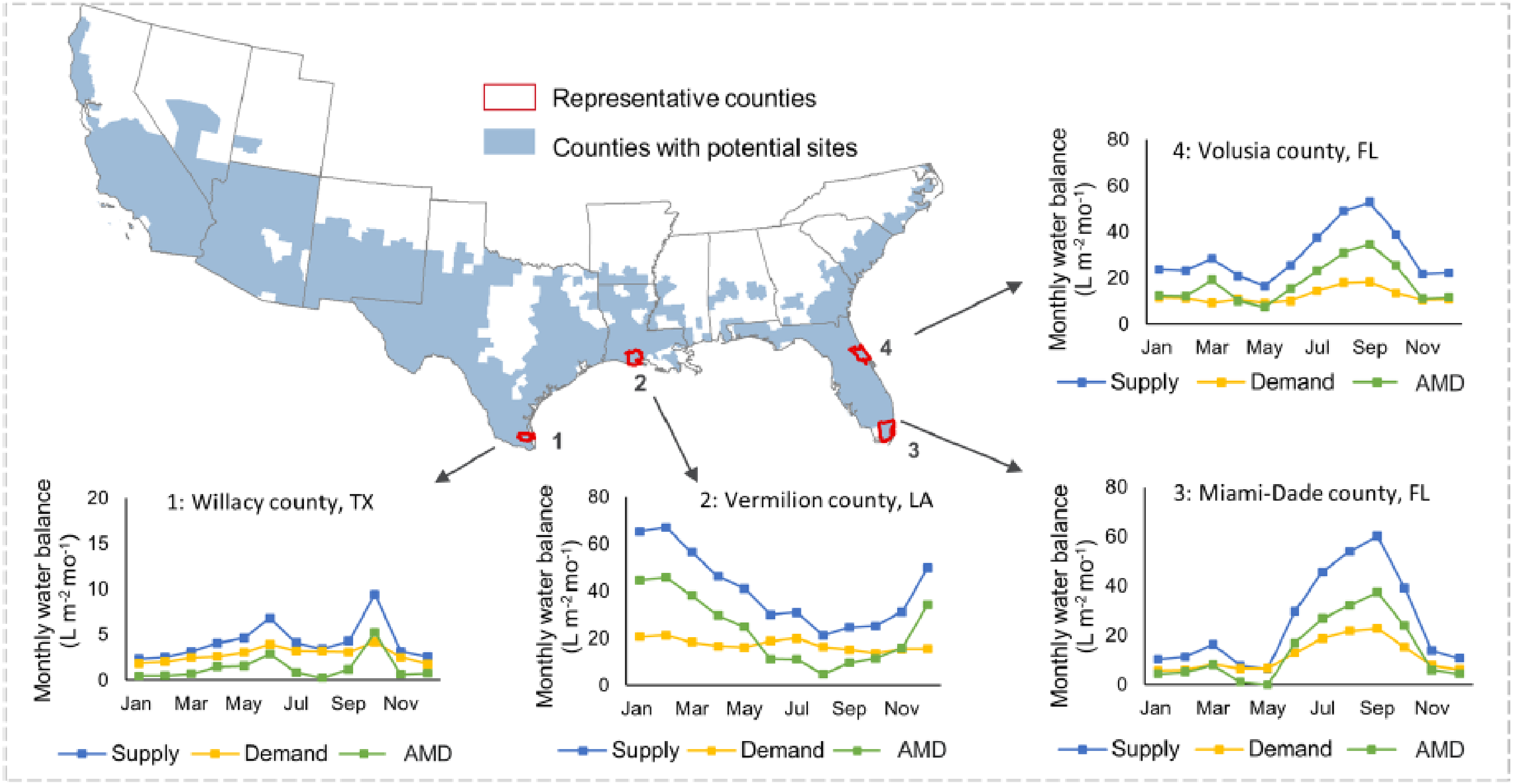
- Joint ANL/PNNL study implementing the BAT+AWARE-U.S. model
  - Evaluation of spatiotemporal water scarcity with freshwater and freshwater+saline mixes
  - Accounts for seasonality in supply and demand
- Identification and ranking of sites that enhance biomass productivity while reducing water impact

**Adding water stress constraints to site-ranking reduces water-stress impact by 97%, water consumption by 50%, with only a 1.7% average loss in biomass production**

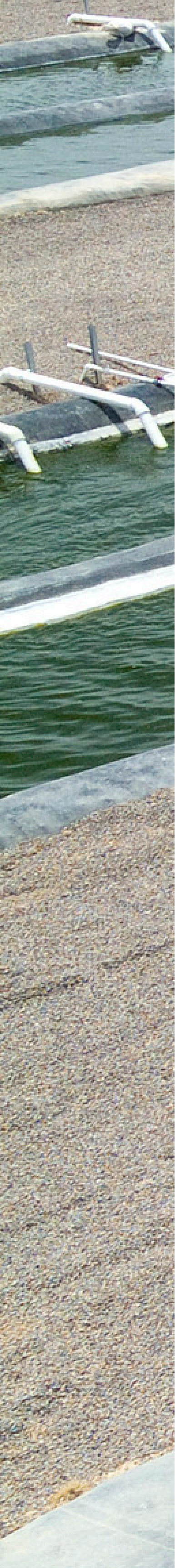

Xu, H, U Lee, AM Coleman, MS Wigmosta, N Sun, T Hawkins, and M Wang. 2020. Balancing water sustainability and productivity objectives in microalgae cultivation: siting open ponds by considering seasonal water-stress impact using AWARE-US, Environmental Science & Technology, 54 (4), 2091-2102, 10.1021/acs.est.9b05347.

Xu, H, U Lee, AM Coleman, MS Wigmosta, M Wang. 2019. Assessment of algal biofuel resource potential in the United States with consideration of regional water stress, *Algal Research*, 37:30-39, 10.1016/j.algal.2018.11.002.


CF = water stress characterization factor; WUE = water use efficiency
AMD = water supply – water demand



## 4 – Progress and Outcomes

# $CO_2$ Co-Location

- CONUS-wide, site-specific simulation of $CO_2$ co-location potential for algae production in fresh and/or saline water open ponds

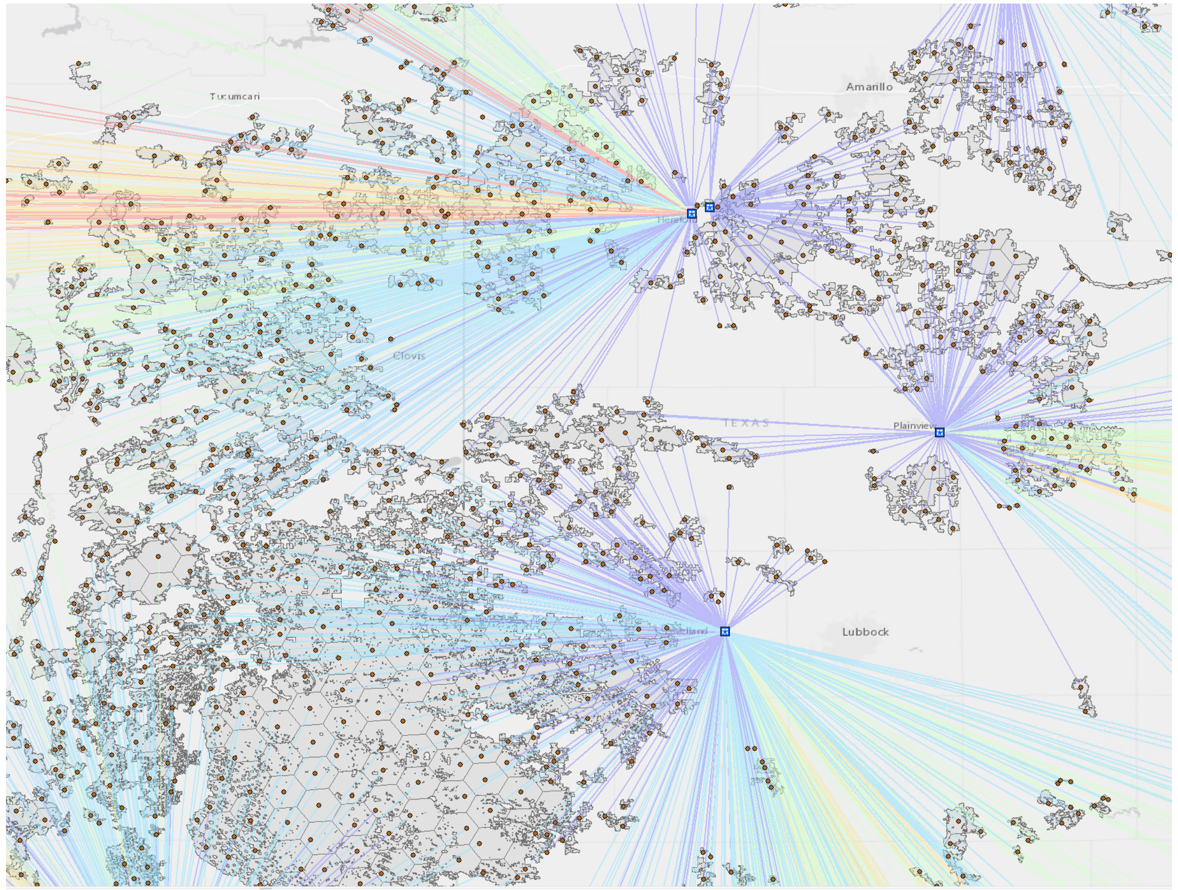
- $CO_2$ supplied via carbon capture from existing, non-competitive, stationary waste sources modeled at an hourly time-step

- Site-specific algal growth model provides hourly carbon demand accounting

- Provides a comprehensive $CO_2$ utilization system that can be assessed under varying scenarios and technology pathways

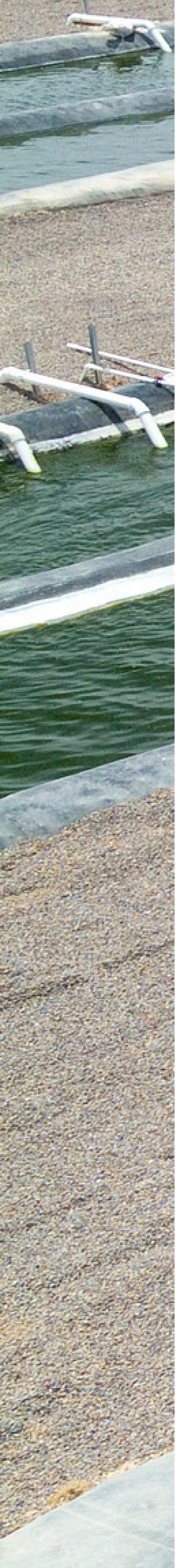
**1.49 billion tonnes per year $CO_2$** (31% of U.S. $CO_2$ output in 2019) economically co-located to sustainable freshwater sites with productivity ≥ 20 $g/m^2$-day to produce 442.5 million tonnes per year biomass AFDW

Note: Pipeline distance shown as straight-line distances; actual distance calculations follow existing right-of-ways where possible.




<u>Location-Allocation Model</u>

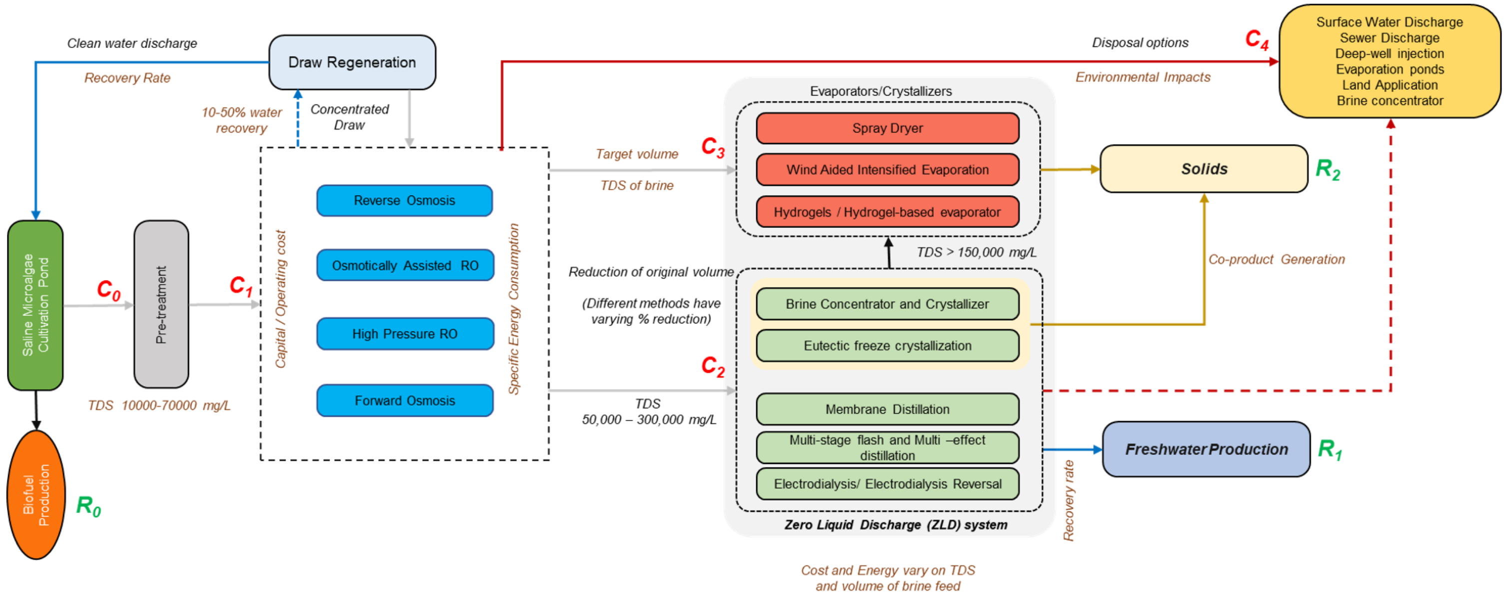
- Co-located $CO_2$ supply
- Algal carbon demand
- Pipeline routing
- Pipeline sizing & annualized cost
- Carbon capture cost by source

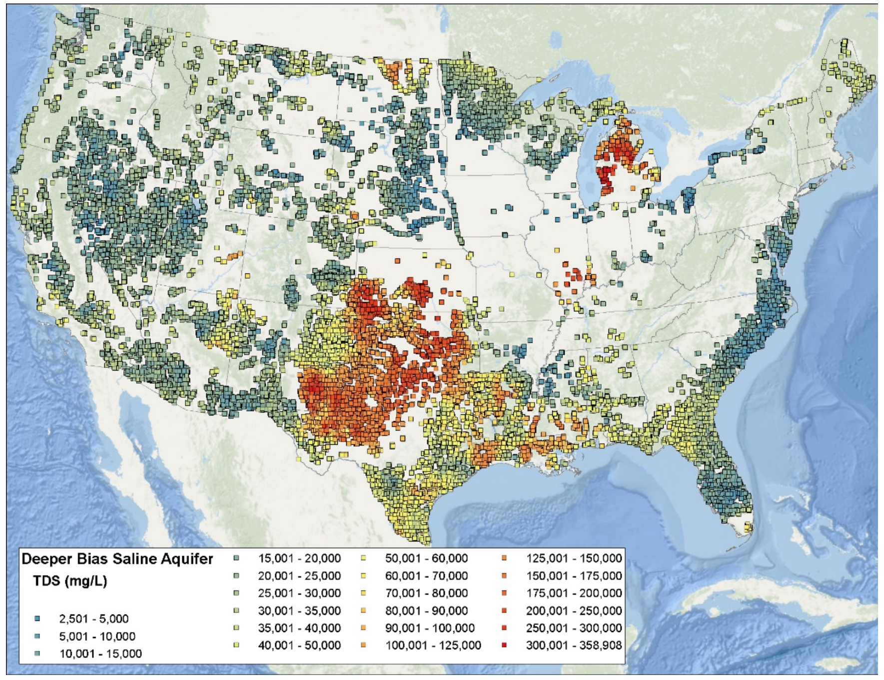


## 4 – Progress and Outcomes
# Brine Management

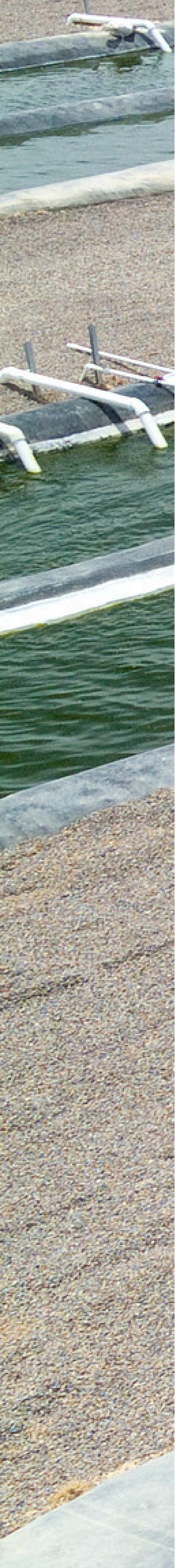
- **Objective**: Evaluate the potential of 15 technologies to reduce the volume of site-specific brine for disposal based on salinity limits, costs, energy demand, and freshwater recovery
- Our previous work estimates the potential for 235 million tonnes/yr biomass using saline water at sites ≥ 5,000 acres + ≥ 20 g/m$^2$-day productivity + economic $CO_2$ co-location (<$55/tonne)

| Method | OpEx ($/m3) | Energy (kWh/m$^3$) | Freshwater Recovery (%) |
|---|---|---|---|
| Deep Well Injection | $0.33-2.64 | 3-10 | 0% |
| Evaporation Ponds | $1.18-10.04 | ~3 | 0% |
| **Fwd. Osmosis** | **$0.10** | **3-8** | **98%** |
| Membrane Crystallization | $1.24 | 39-73 | 90% |
| Membrane Distillation | $0.64-1.23 | 23 | 93% |
| Electrodialysis | $0.6-10.05 | 7-15 | 92% |
| High Pressure Rvrs Osmosis | $0.8 | 4-16 | 50% |




**Forward osmosis demonstrates good potential to reduce the volume of brine interims of operating cost, energy demand, and freshwater recovery**



## 4 – Progress and Outcomes
# Wastewater Co-Location

- CONUS assessment of 14,920 municipal wastewater treatment plants for their potential to support algae biomass production in high-rate algae ponds
- Total N, P, and water supply modeled at various wastewater treatment phases including influent, primary clarifier sludge, secondary clarifier sludge, treated biosolids, and facility effluent
- Supply/demand accounting model factors input nutrient loss due to oxidation or volatilization, algae utilization efficiencies, and nutrient recycle from the HTL aqueous phase media

Minimum Scenario = plant self-sustains with all N, P, and water requirements

Maximum Scenario = either N or P cannot fully meet demand & requires external input

Algal biomass and renewable diesel (RD) production potential within CONUS using waste resource from different treatment phases

| Scenario | Biomass (Mt/yr) | RD (HTL) (Mgal/yr) |
|---|---|---|
| **Minimum:** Primary/Final Clarifier Phase | 1.453 | 265.5 |
| **Minimum:** Biosolids Phase | 1.869 | 341.6 |
| | | |
| **Maximum:** Primary/Final Clarifier Phase | 2.091 | 382.2 |
| **Maximum:** Biosolids Phase | 2.745 | 501.6 |

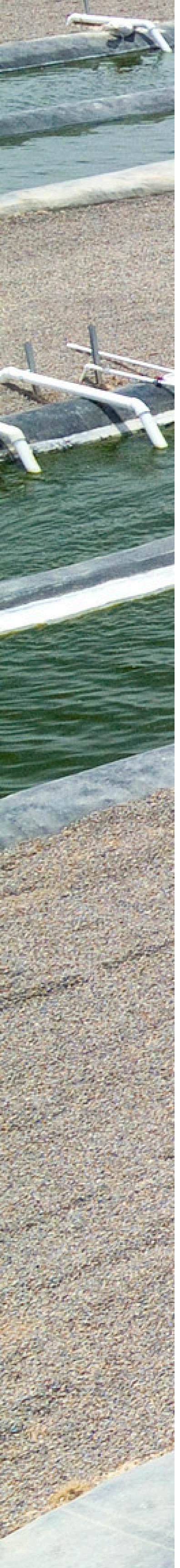
**Significant production potential when the plant self-sustains with all N, P, and water requirements:**

- **1.5 million tonnes of biomass per year**
- **266 – 342 million gallons per year (Mgal/yr) of renewable diesel**

**Comparable with the Go/No-Go target of 250 Mgal/yr GGE**

# Summary

- **Overview:** This project provides BETO and industry a national assessment capability focused on fundamental questions of where production can occur, how much nutrient, land and water resource is required, how much biomass/energy is produced, and what interactions/trade-offs exist between technologies
- **Management:** Task-driven approach following BETO management protocols
- **Approach:** Enhancement and application of the PNNL Biomass Assessment Tool (BAT) to evaluate alternative algal feedstock production strategies that will yield the highest sustainable fuel production potential as a function of unit cost and resource use efficiency
- **Impact:** The BAT provides a biophysics-based analysis framework for linking key BETO & industry research activities to achieve high-impact objectives for multiple feedstocks
  - BETO MYPP, model harmonization, Billion Ton Study, State of Technology, DISCOVER
  - 22 peer reviewed publications with 4 since the last review, 1 in review, and 4 in preparation
- **Progress & Outcomes:** Demonstrated biomass forecasting system, evaluation of spatiotemporal water scarcity with freshwater and freshwater + saline mixes, evaluated brine management options, and estimated biomass potential through co-location with $CO_2$ and wastewater treatment facilities
- **Future Work:**
  - Utilize BAT in a probabilistic based approach to evaluate the likelihood of achieving local and national production targets
  - Evaluate tradeoffs in alternative technology pathways to achieve the MYPP 2022 target to model the sustainable supply of 20 million metric tons AFDW cultivated algal biomass



# Quad Chart Overview

## Timeline
- Project start date: 10/01/2020
- Project end date: 09/30/2022

| | FY20 | Active Project |
|---|---|---|
| **DOE Funding** | $575,000 | $1,725,000 |

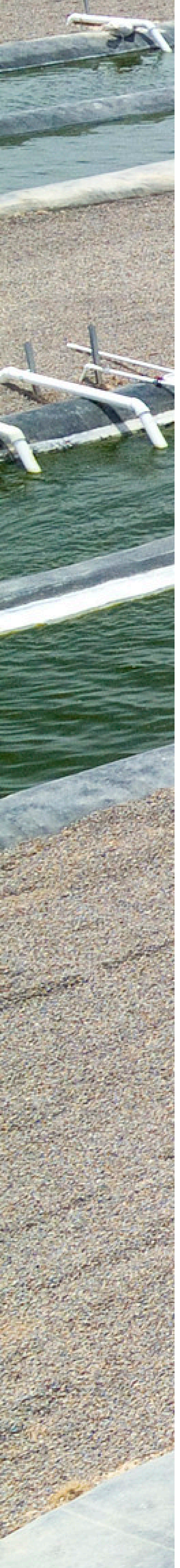
## Project Partners
- Partner 1: ANL
- Partner 2: NREL
- Partner 3: BETO DISCOVR Team
- Partner 4: BETO Waste-to-Energy Team

## Barriers Addressed
- Aft-B. Sustainable Algae Production
- Aft-H. Overall Integration and Scale-Up
- Aft-J. Resource Recapture and Recycle

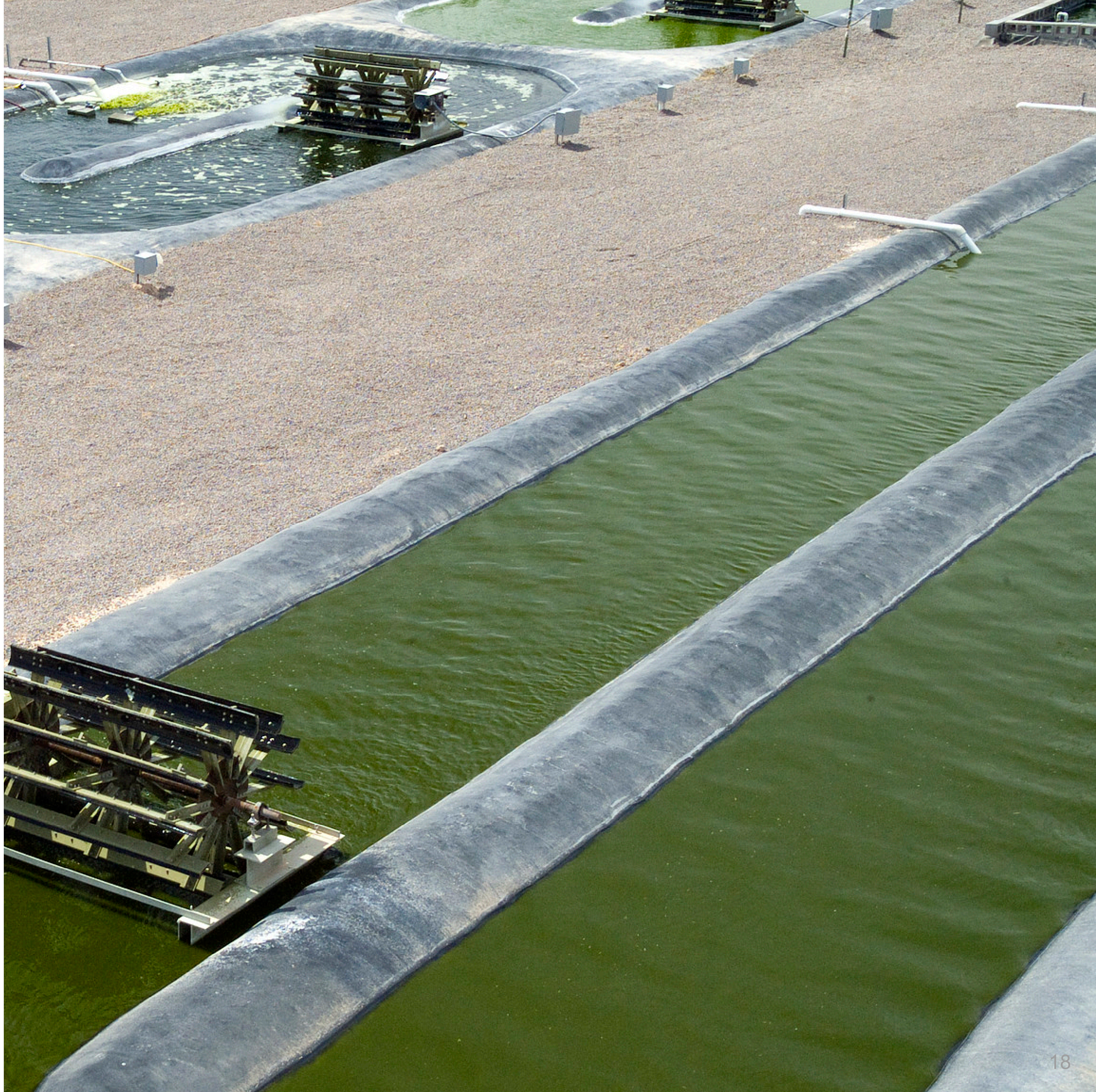
## Project Goal
Model the sustainable supply of cultivated algal biomass to achieve 5 billion GGE per year by employing open ponds, PBRs, saline water, $CO_2$ co-location, and alternative nutrient sources by September 2022

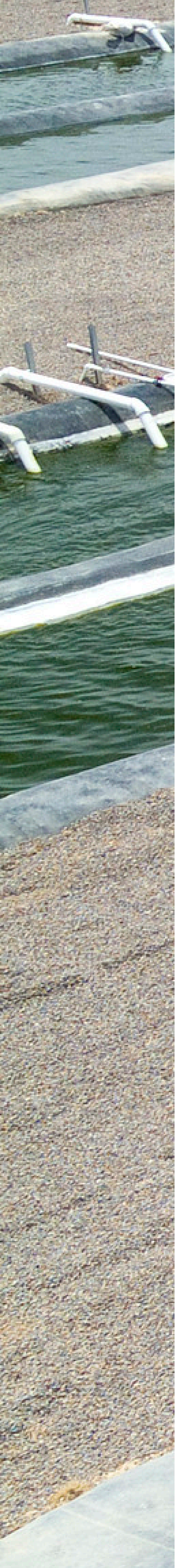
## End of Project Milestone
Through collaboration with the DISCOVR project, make enhancements to the BAT and growth model parameterization library to include additional fresh and saline, cold- and heat-tolerant algal strains, model maximized production operations, and evaluate tradeoffs in alternative technology pathways to achieve the MYPP 2030 target to model the sustainable supply of cultivated algal biomass to achieve 5 billion GGE per year

## Funding Mechanism
BETO Lab Call for FY20



# Additional Slides





# Responses to Previous Reviewers' Comments

**Comments:**

- Continued focus on integration of observational data to support model parameterization and validation
- Additional work needs to be done on seasonality of water availability versus algae productivity
- Additional work is needed on future sustainability especially when considering the trend of agriculture shifting to saline tolerant strains as well and how that will impact the model's projections in the future

**Response:**

We continue to integrate the latest observational data to support model parameterization and validation, most recently through close collaboration with the multi-laboratory/University DISCOVR project. In a joint study with Argonne National Laboratory, we are implementing the BAT+AWARE-US model to evaluate spatio-temporal water scarcity with freshwater and freshwater+saline mixes. This effort accounts for seasonality in supply and demand to identify and rank sites that enhance biomass productivity while reducing water impact. We continue our research on saline water sources, with a recent focus on potential technologies to reduce the volume of brine for disposal using site-specific input salinity, pond operations/blowdown, salinity thresholds, capital and operation costs, and energy demand.

# Publications, Patents, Presentations, Awards, and Commercialization

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## Peer Reviewed Publications Since Last Review

- Yan H, Wigmosta MS, Sun N, Huesemann MH, Gao S. Real-time ensemble microalgae growth forecasting with data assimilation. Biotechnology and Bioengineering. 2021;1–6. https://doi.org/10.1002/bit.27663.
- Xu, H., Lee, U., Coleman, A.M., Wigmosta, M., Sun, N., Hawkins, T.R., Wang, M.Q. (2020), Balancing water sustainability and productivity objectives in microalgae cultivation: Siting open ponds by considering seasonal water-stress impact using AWARE-US, Environmental Science & Technology, DOI: 0.1021/acs.est.9b05347.
- Khawam, G., P Waller, S. Gao, S. Edmundson, M. Wigmosta, and K. Ogden (2019), Model of temperature, evaporation, and productivity in elevated experimental algae raceways and comparison with commercial raceways, Algal Research, 39, DOI: 10.1016/j.algal.2019.101448.
- Hui, X., Lee, U., Coleman, A.M., Wang, M. Wigmosta, M., Wang, M. 2019. Assessment of algal biofuel resource potential in the United States with consideration of regional water stress, Algal Research 37:30-39.

## In Review

- Ou, Longwen; B, S; Xu, H Coleman, A; Cai, H; Lee, U; Wigmosta, M; Hawkins, T In Review. Utilizing High-purity CO2 Sources for Algae Cultivation and Biofuel Production in the United States: Opportunities and Challenges, Environmental Science & Technology.

## In Preparation

- Hongxiang, Y, M. Wigmosta, M. Huesemann, N. Sun, and S. Gao, Integrated Ensemble Data Assimilation Modeling System for Operational Outdoor Microalgae Growth Forecasting.
- Hongxiang, Y, M. Wigmosta, M. Huesemann, N. Sun, and S. Gao, Real-Time Microalgae Growth Forecasting to Enhance Biomass Production.
- Coleman, Wigmosta, Sun, Yan, The Use of Saline Groundwater Resources for Microalgae Production in the Conterminous U.S.
- Coleman, Parajuli, Yan, Wigmosta, Evaluation of Brine Management Options for Saline Microalgae Cultivation

# Publications, Patents, Presentations, Awards, and Commercialization

Prior Peer Reviewed Publications


- Huesemann M H, Chavis A R, Edmundson S J, Rye D K, Hobbs S J, Sun N ,Wigmosta M S. 2018. Climate-Simulated Raceway Pond Culturing: Quantifying the Maximum Achievable Annual Biomass Productivity of Chlorella sorokiniana in the Contiguous USA, Journal of Applied Phycology 30(1):287-298. 10.1007/s10811-017-1256-6
- Huesemann M H, Dale T ,Chavis A R, Crowe B J, Twary S ,Barry A ,Valentine D C, Yoshida R,Wigmosta M S, Cullinan V I 2017. "Simulation of outdoor pond cultures using indoor LED-lighted and temperature-controlled raceway ponds and Phenometrics photobioreactors" Algal Research 21():178-190. 10.1016/j.algal.2016.11.016
- Wigmosta MS, A Coleman, E Venteris, and R Skaggs. 2017. "Microalgae Feedstocks for Aviation Fuels." Chapter 11 in Green Aviation: Reduction of Environmental Impact Through Aircraft Technology and Alternative Fuels, ed. ES Nelson and DR Reddy. CRC Press, BOCA RATON, FL.
- Huesemann MH, BJ Crowe, P Waller, AR Chavis, SJ Hobbs, SJ Edmundson, and MS Wigmosta. 2016. A Validated Model to Predict Microalgae Growth in Outdoor Pond Cultures Subjected to Fluctuating Light Intensities and Water Temperatures. Algal Research 13:195-206. doi:10.1016/j.algal.2015.11.008.
- Huesemann, MH, T. Dale, A. Chavis, B. Crowe, S. Twary, A. Barry, D. Valentine, R. Yoshida, M.Wigmosta, V. Cullinan. 2016. Simulation of outdoor pond cultures using indoor LED-lighted and temperature-controlled raceway ponds and Phenometrics photobioreactors, Algal Research 21:178-190, doi.org/10.1016/j.algal.2016.11.016.
- Huesemann, M.H., M. Wigmosta, B. Crowe, P. Waller, A. Chavis, S. Hobbs, B. Chubukov, V.J. Tocco, and A. Coleman. 2016. Estimating the maximum achievable productivity in outdoor ponds: Microalgae biomass growth modeling and climate-simulated culturing, In: Micro-Algal Production for Biomass and High-Value Products, Dr. Stephen P. Slocombe and Dr. John R. Benemann (Eds.), CRC Press, Taylor and Francis, LLC, ISBN 9781482219708.

# Publications, Patents, Presentations, Awards, and Commercialization

Prior Peer Reviewed Publications (continued)


- Langholtz M, AM Coleman, LM Eaton, MS Wigmosta, CM Hellwinckel, and CC Brandt. 2016. Potential Land Competition Between Open-Pond Microalgae Production and Terrestrial Dedicated Feedstock Supply Systems in the U.S. Renewable Energy, 93:201-214. doi:10.1016/j.renene.2016.02.052.
- Moore, BC, AM Coleman, MS Wigmosta, RL Skaggs, and ER Venteris, 2015, A High Spatiotemporal Assessment of Consumptive Water Use and Water Scarcity in the Conterminous United States. Water Resource Management. DOI 10.1007/s11269-015-1112
- Venteris ER, MS Wigmosta, AM Coleman, and R Skaggs.  2014.  Strain selection, biomass to biofuel conversion, and resource colocation have strong impacts on the economic performance of algae cultivation sites.  *Frontiers in Energy Research*, August 2014, doi: 10.3389/fenrg.2014.00037
- Coleman AM, JM Abodeely, RL Skaggs, WA Moeglein, DT Newby, ER Venteris, MS Wigmosta, 2014, An integrated assessment of location-dependent scaling for microalgae biofuel production facilities, *Algal Research* 5:79-94. doi: 10.1016/j.algal.2014.05.008
- Abodeely J, AM Coleman, DM Stevens, AE Ray, and DT Newby. 2014. Assessment of Algal Farm Designs using a Dynamic Modular Approach. *Algal Research*, 5:264-273 doi: 10.1016/j.algal.2014.03.004
- Davis RE, DB Fishman, ED Frank, MC Johnson, SB Jones, CM Kinchin, RL Skaggs, ER Venteris, and MS Wigmosta, 2014, Integrated Evaluation of Cost, Emissions, and Resource Potential for Algal Biofuels at the National Scale, *Environmental Science & Technology*, available online, http://pubs.acs.org/doi/abs/10.1021/es4055719.

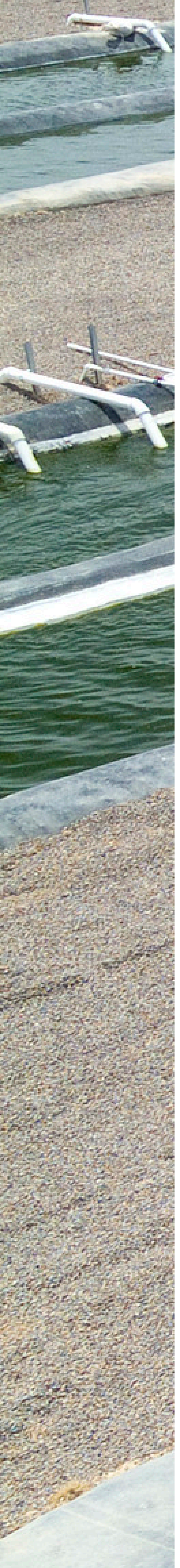
# Publications, Patents, Presentations, Awards, and Commercialization

Prior Peer Reviewed Publications (continued)


- Venteris ER, R Skaggs, AM Coleman, and MS Wigmosta, 2012, An Assessment of Land Availability and Price in the Coterminous United States for Conversion to Algal Biofuel Production. *Biomass & Bioenergy*, 47:483-497. doi:10.1016/j.biombioe.2012.09.060
- Venteris ER, RL Skaggs, MS Wigmosta, AM Coleman, 2014, Regional algal biofuel production potential in the coterminous United States as affected by resource availability trade-offs, *Algal Research*, 5:215-225. doi: 10.1016/j.algal.2014.02.002
- Venteris ER, R McBride, AM Coleman, R Skaggs, and MS Wigmosta, 2014, Siting algae cultivation facilities for biofuel production in the United States: trade-offs between growth rate, site constructability, water availability, and infrastructure, *Environmental Science & Technology,* 48(6):3559-3566. doi:10.1021/es4045488
- Venteris ER, R Skaggs, MS Wigmosta, and AM Coleman, 2014, A National-Scale Comparison of Resource and Nutrient Demands for Algae-Based Biofuel Production by Lipid Extraction and Hydrothermal Liquefaction, *Biomass & Bioenergy* 64:276-290. doi:http://dx.doi.org/10.1016/j.biombioe.2014.02.001
- Venteris ER , RL Skaggs, AM Coleman, and MS Wigmosta, 2013, A GIS model to assess the availability of freshwater, seawater, and saline groundwater for algal biofuel production in the United States, *Environmental Science & Technology*, 47(9):4840 4849. doi:10.1021/es304135b
- Wigmosta MS, AM Coleman, RL Skaggs, MH Huesemann, and LJ Lane, 2011, National microalgae biofuel production potential and resource demand, *Water Resour. Res.*, 47, W00H04, doi:10.1029/2010WR009966

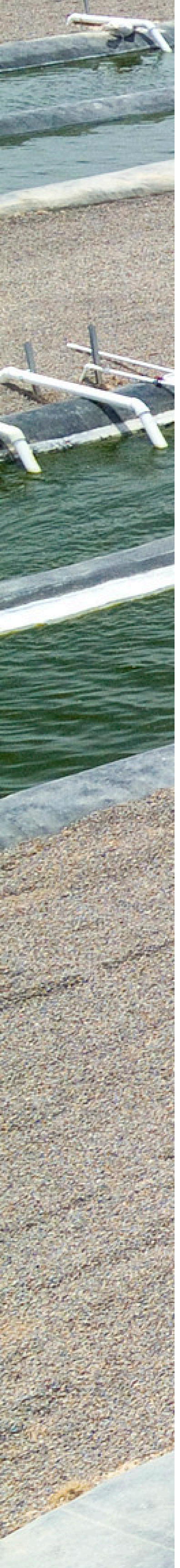
# Key Assumptions

- Current biomass growth simulations assume optimal pH and nutrients
- Assumes 100% water and nutrient recycle during harvest
- $CO_2$ co-location analysis
  - only utilizes sites where $CO_2$ can be captured and delivered at ≤$55/T ($CO_2$ source specific)
  - uses disaggregated annual data to get to general seasonal and diurnal patterns (currently working to go to hourly basis across CONUS)
- Where deep saline groundwater supply exists, available volume is considered large enough that it will not be resource-constrained. Constraints are placed on salinity levels and depth of extraction (and in cases constituents). No explicit consideration of other users.
- Currently, shallower brackish-saline groundwater does not consider potential impacts to overlying freshwater aquifers
- New generation brine disposal technology that is assessed is assumed to be available at scale
- We do not currently integrate freshwater returns from brine disposal technology back to ponds (salinity maintenance → reduced groundwater pumping), but rather assess a revenue for $H_2O$



## 2 – Approach
# Go/No-Go Decision

| Name | Description | Criteria | Date |
|---|---|---|---|
| **Continued evaluation of co-location with wastewater treatment facilities for alternative sources of water and nutrients** | We will evaluate the total annual algal biomass production potential using water and nutrients from over 15,000 inventoried wastewater treatment facilities. | If the total potential from co-location with wastewater facilities exceeds 5% of the BETO MYPP 2030 target of 5 BGY GGE, we will continue to evaluate wastewater co-location with a more refined modeling approach and cost considerations. | 3/31/2021 |



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# 3 – Impact

- 2019 Peer Review Panel Comments
  - "BAT (Biomass Assessment Tool) is an incredibly useful analysis relevant across the AAS portfolio.  The tool strives to simplify the complexity associated with considering more than 15 factors that directly impacts the cost of converting algae to biofuels".
  - "The project is considering multiple important criteria that falls outside some other models currently being developed but that have great impact on deployment and environmental sensitivities such as water demand, biomass growth, water supply, CO2-co location. Detailed input of ground water availability in addition to integration of reduction of water stress is a big step in the right direction. Incorporation of actual ground water salinity data and depth to salinity groundwater is a great tool for any future algae farm".

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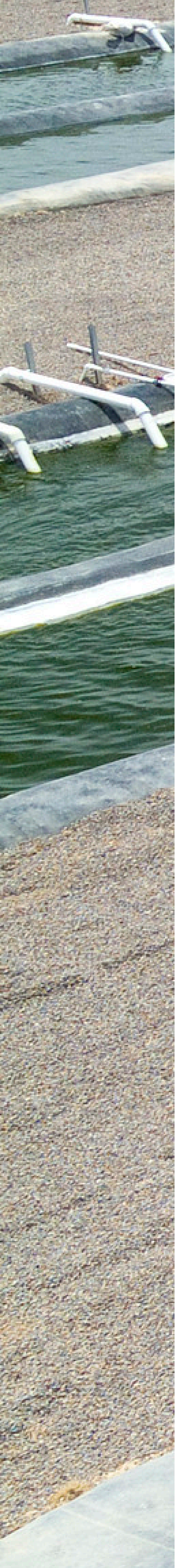

# Thank you