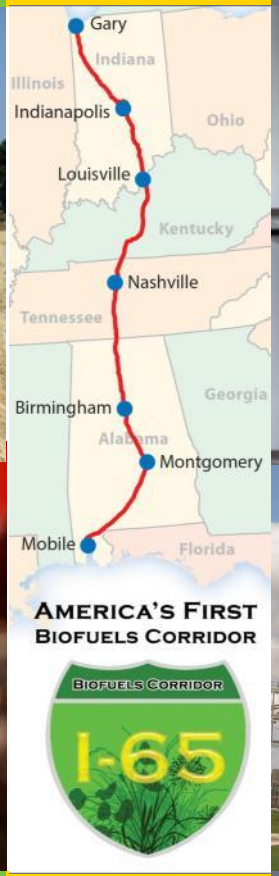
2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Title: Algae Resource Assessment

May 20, 2013

Principal Investigator: Mark Wigmosta

Technology Area Review: Analysis & Sustainability

Organization: PNNL

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Goal Statement

BETO launched an initiative to obtain consistent quantitative metrics for algal biofuel production in order to establish an "integrated baseline" production scenario by harmonizing and combining the Program's National Resource Assessment , Life-Cycle Analysis and Techno-Economic Analysis

Goal 1: In collaboration with ANL and NREL, develop a harmonized near-term production scenario with freshwater microalgae growth, extraction of lipids, and conversion via hydroprocessing to produce renewable diesel (RD). Use the PNNL Biomass Assessment Tool to prioritize and select the most favorable consortium of sites that supports production of 5 billion gallons per year of RD.

The DOE Billion-Ton study focused on terrestrial biomass resources and does not include potential algal feedstocks.

Goal 2: In collaboration with ORNL, conduct an integrated biomass assessment that 1) includes both terrestrial and algal feedstocks, 2) accounts for potential land competition between the two feedstock types, and 3) identifies areas where algal and terrestrial feedstocks have opportunities for production with a minimum of competition for available land resources.

Quad Chart Overview

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Timeline

- Project start date: October 2011
- Project end date: September 2012
- Percent complete: 100%

Budget

- Funding for FY11: 0
- Funding for FY12: $184K
- Funding for FY13: 0*

* Project tasks transitioned to 9.6.1.2 in FY13

Barriers

- Ft-A. Feedstock Availability and Cost
- Ft-B. Sustainable Production
- St-A. Scientific Consensus on Bioenergy Sustainability
- St-B. Consistent, Defensible Message on Bioenergy Sustainability
- At-C. Inaccessibility and Unavailability of Data

Partners

- ANL, DOE-BETO, NREL
- ORNL

Project Overview

Strategic application of the Biomass Assessment Tool (BAT), which provides spatially-explicit estimates of open pond microalgae production potential and resource demands for the conterminous United States:

- High spatial resolution
  - "farm scale": 100 10-ac ponds plus 200 ac infrastructure (1,200 ac)
- Fine temporal scales (hourly)
  - Account for critical threshold events (wind, temperate, precipitation)
  - Capture non-linear dynamics (sensible/latent heat transfer)
  - Antecedent conditions
- Upscale high resolution results as necessary
  - Summaries by county, state, or region
  - Monthly or annual rates
- Web-based, Biomass Assessment Tool
  - Spatially optimized locations based on multi-criteria analysis
  - Production rates and resource demand
- Integration with Bioenergy Knowledge Discovery Framework

1 - Approach

Biomass Assessment Tool

National Resource Database

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Land Constraints: Open Pond

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Climate Constraints: Open Pond

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Biofuel Production: Open Pond Land & Water Demand

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Freshwater Supply

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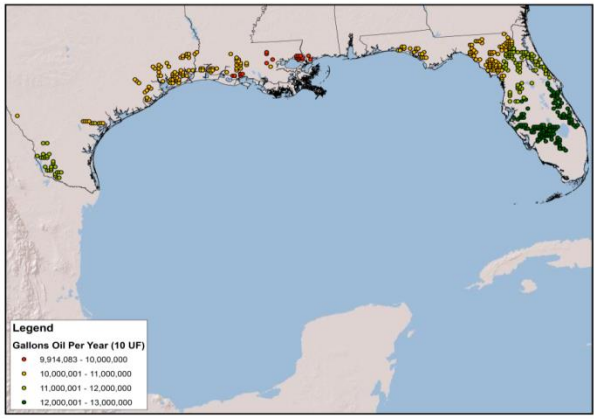
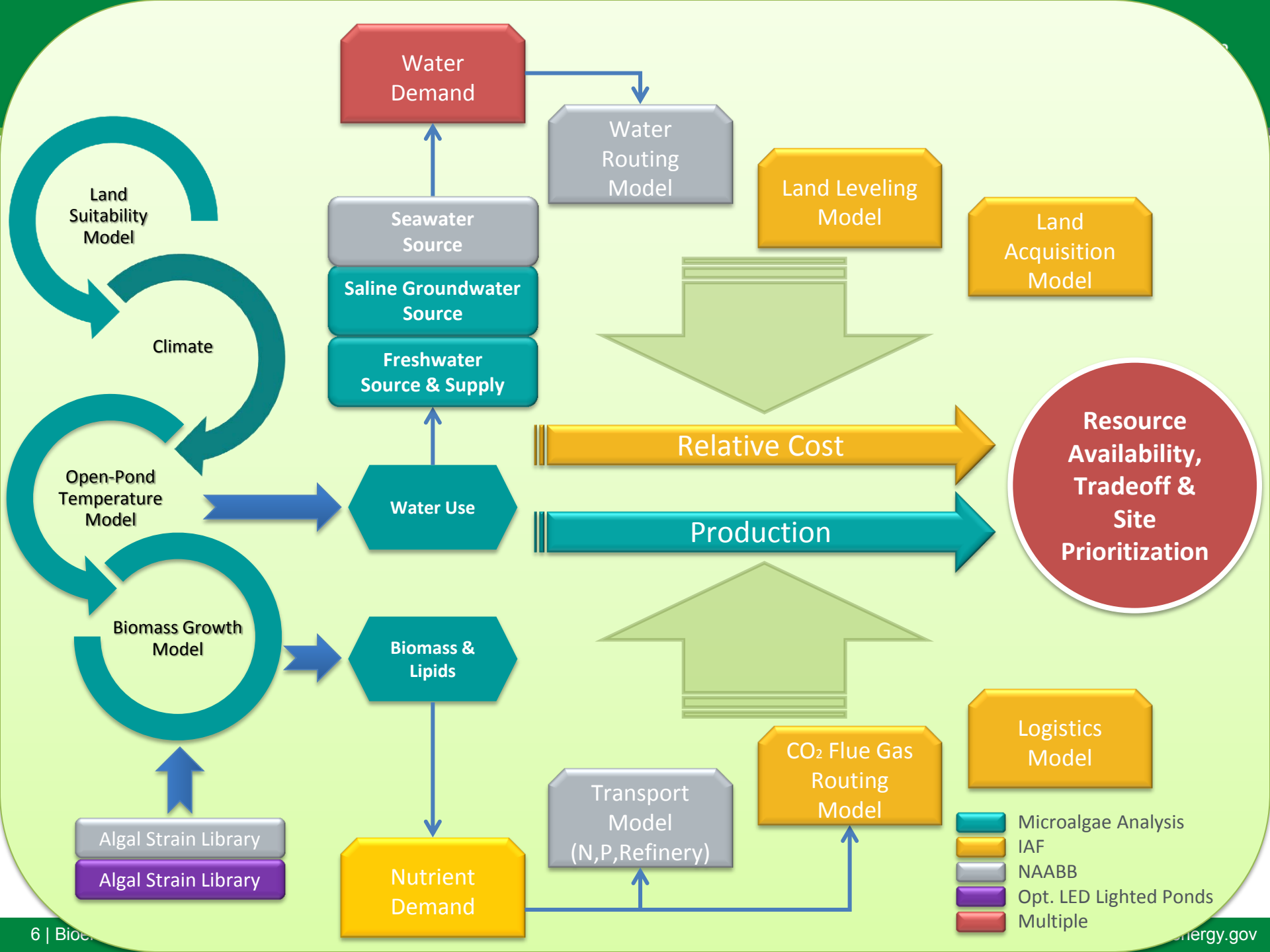
Goal 1: Model Harmonization and 5 BGY Down-Select

→ Goal 2:Terrestrial / Algal Integration

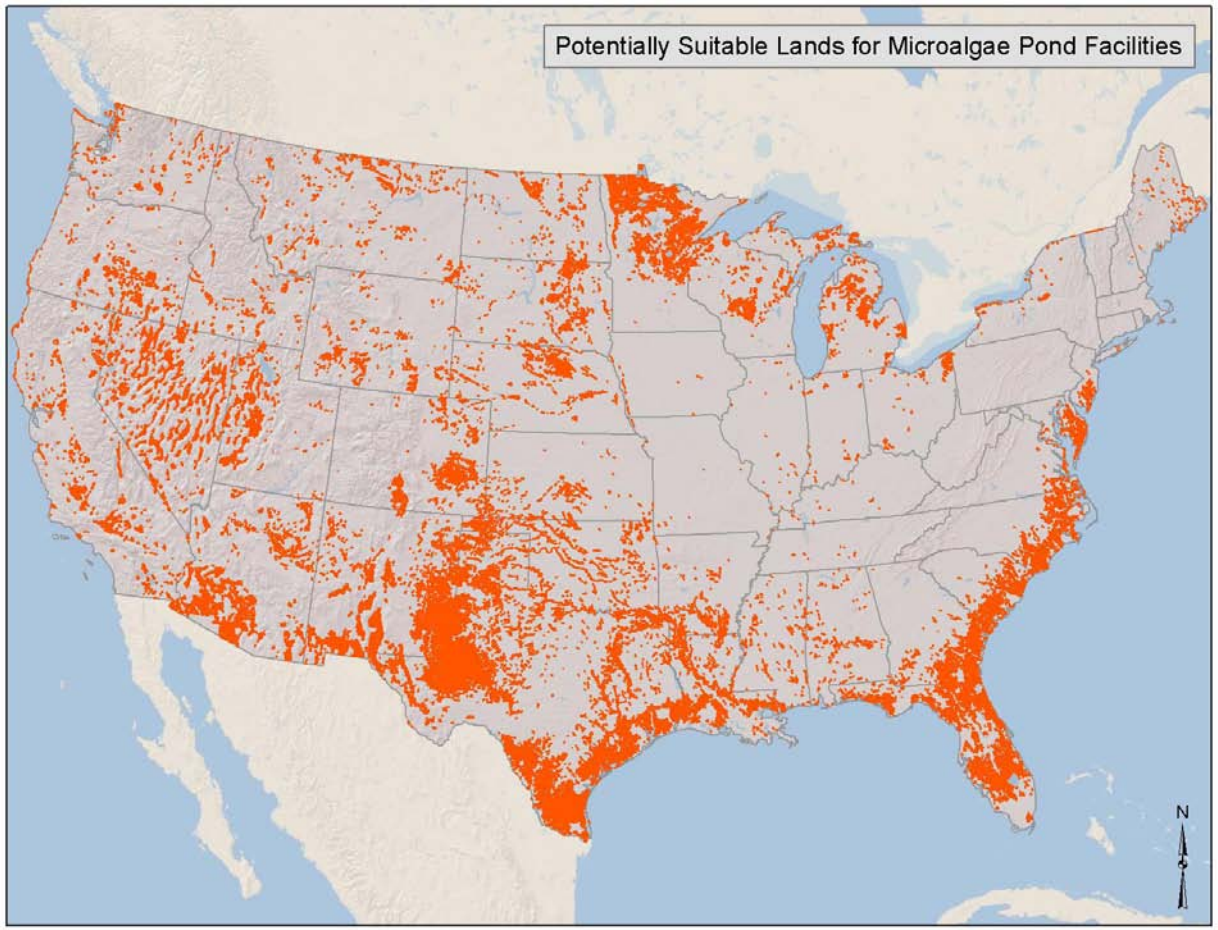
MANAGEMENT APPROACH

- Project management plans
  - SOW and how it relates to DOE goals
  - Quarterly milestones
- Frequent project communications
  - Bi-weekly conference calls with off-site project team members
  - Quarterly formal reporting to HQ
  - Participate in monthly Analysis & Sustainability conference call reviews




Water Demand
Water Routing Model
Land Leveling Model
Land Acquisition Model
Land Suitability Model
Seawater Source
Saline Groundwater Source
Freshwater Source & Supply
Climate
Open-Pond Temperature Model
Water Use
Relative Cost
Production
Resource Availability, Tradeoff & Site Prioritization
Biomass Growth Model
Biomass & Lipids
Logistics Model
CO2 Flue Gas Routing Model
Transport Model (N,P,Refinery)
Algal Strain Library
Algal Strain Library
Nutrient Demand
Microalgae Analysis
IAF
NAABB
Opt. LED Lighted Ponds
Multiple

2 – Technical Accomplishments / Suitable Land



485 ha unit farm

Slope

Exclude

- Cultivated Lands
- Protected Lands
- Waterbodies
- Airports
- Urban / Developed
- Environmental Sensitive Lands
- Wetland / Riparian

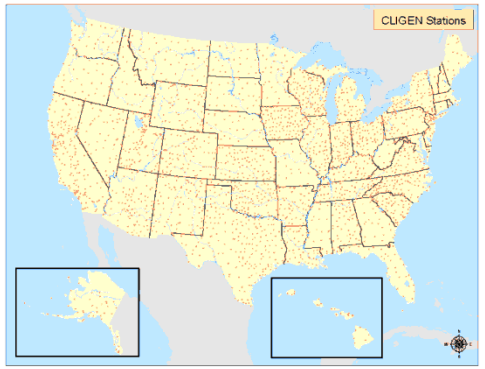
- Potential: 89,756 areas (> 1,200 ac) suitable for open ponds
  - 430,830 km^2 of the conterminous U.S.
  - 5.5% of the conterminous U.S.

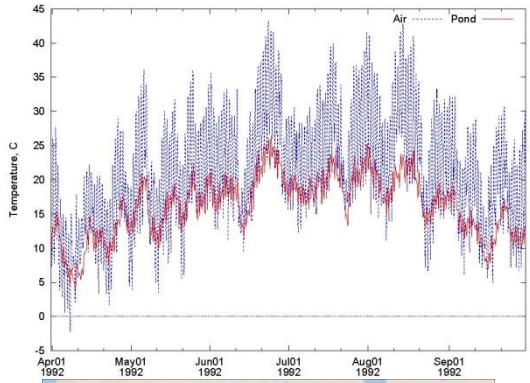
2 – Technical Accomplishments / Production Potential / Water Demand

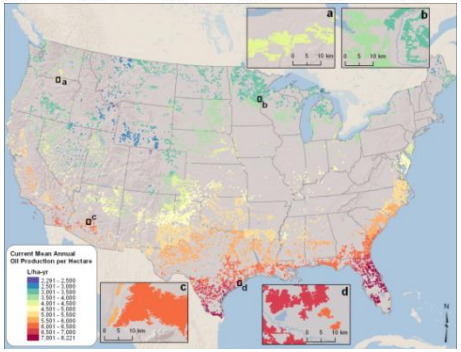
- 30 Years of Hourly Meteorology at 2600 stations
  - Air temperature, precipitation, wind speed, solar radiation, and humidity

- Two-dimensional Hydrodynamic Pond Model
  - Estimate water temperature and evaporative loss at each unit farm

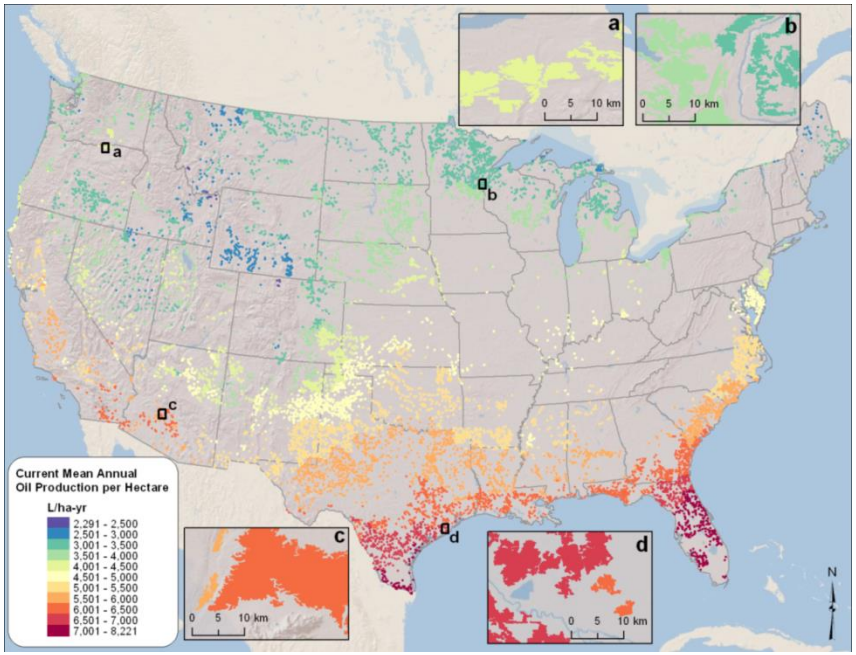
- Biophysical Pond Growth Model
  - Hourly biomass production (solar radiation, light intensity, water temperature)

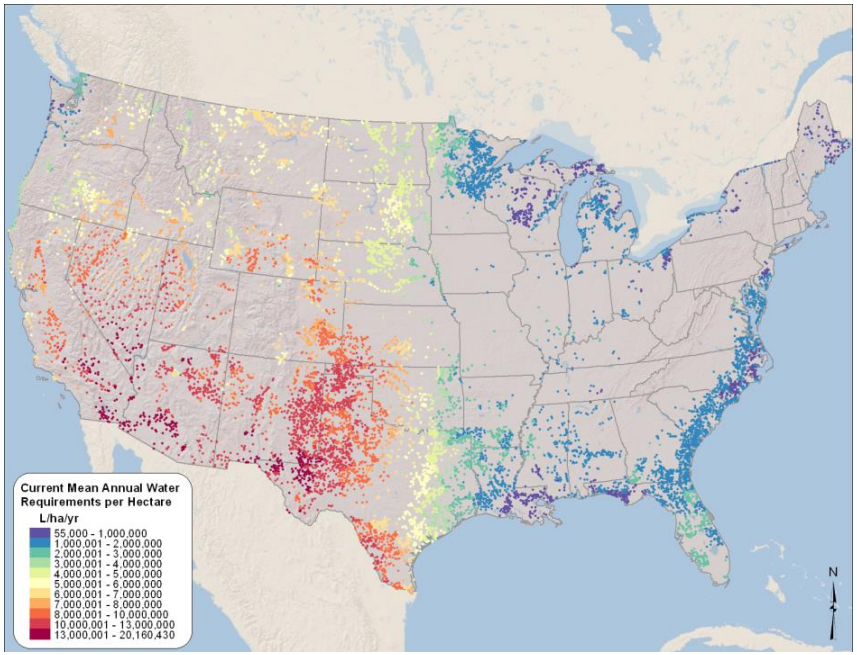






2 – Technical Accomplishments / Production Potential / Water Demand





Wigmosta, M. S., A. M. Coleman, R. J. Skaggs, M. H. Huesemann, and L. J. Lane, 2011, National microalgae biofuel production potential and resource demand, Water Resour. Res., 47, W00H04, doi:10.1029/2010WR009966

- Generic algal strain
- Potential: 220 billion liters per year of biofuel production
- Freshwater demand for all potentially suitable areas is 300% of current consumptive use for irrigation

2 – Technical Accomplishments / DOE Model Harmonization

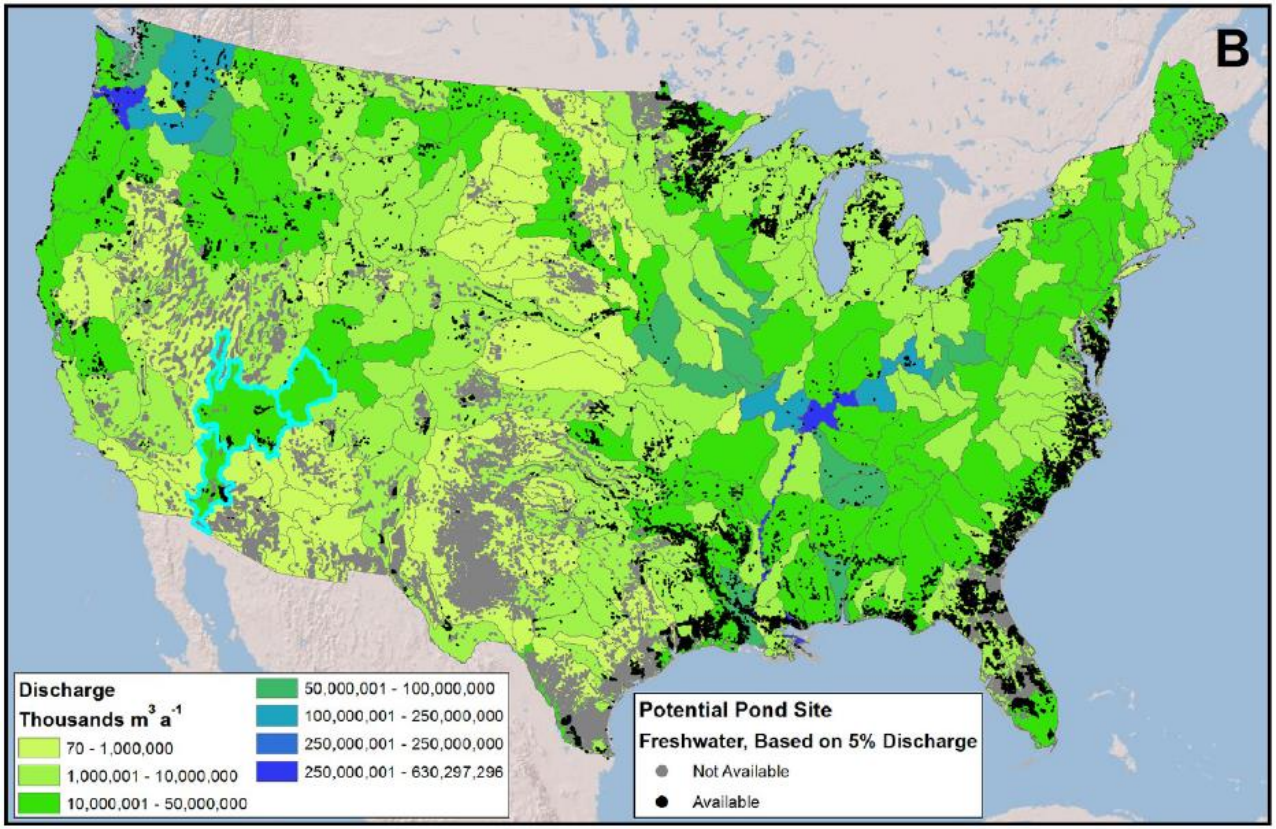
- The U.S. Department of Energy's Biomass Program launched an initiative to obtain consistent quantitative metrics for algal biofuel production in order to establish an "integrated baseline" by harmonizing and combining the Program's
  - National Resource Assessment (RA) - PNNL BAT
  - Life-Cycle Analysis (LCA) - ANL
  - Techno-Economic Analysis (TEA) - NREL

- The harmonized baseline represents a plausible near-term production scenario with freshwater microalgae growth, extraction of lipids, and conversion via hydroprocessing to produce a renewable diesel (RD) blendstock

- Differences in the prior models were reconciled (harmonized) and the BAT was used to prioritize and select the most favorable consortium of sites that supports production of 5 billion gallons per year (BGY) of RD
  - Seasonal biomass/oil production
  - Seasonal water demand

2 – Technical Accomplishments / DOE Model Harmonization

Freshwater constraints on feedstock locations

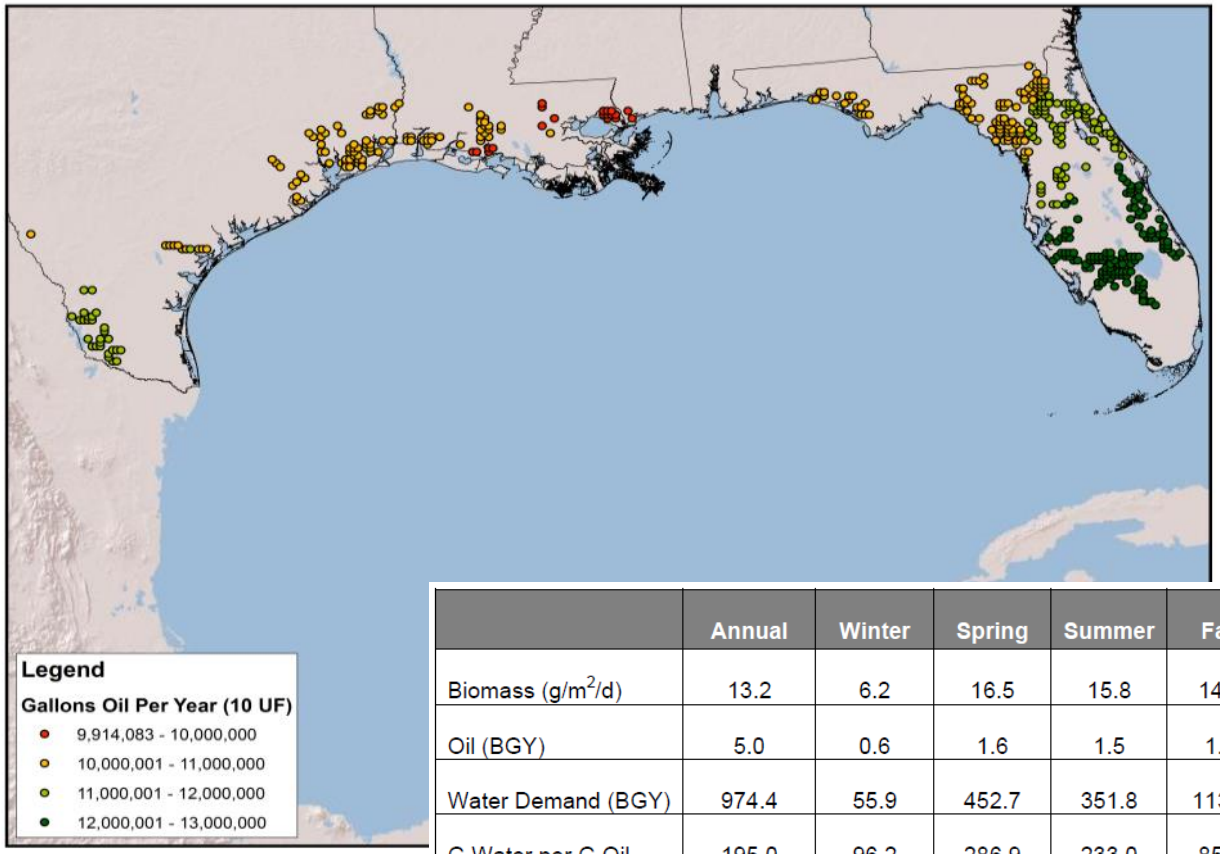


Venteris, E.R. , R.L. Skaggs, A.M. Coleman, and M.S. Wigmosta, A GIS model to assess the availability of freshwater, seawater, and saline groundwater for algal biofuel production in the United States, Environmental Science & Technology, 2013

- Includes downstream flow accumulation and consumptive use
- 5% withdrawal limit
- Does not consider water rights, compacts, or local regulations
- Freshwater mainly limited by availability

- Water supply limits potential for freshwater algal strains in the southwestern U.S.

2 – Technical Accomplishments / DOE Model Harmonization (cont.)



	Annual	Winter	Spring	Summer	Fall
Biomass ($g/m^2/d$)	13.2	6.2	16.5	15.8	14.1
Oil (BGY)	5.0	0.6	1.6	1.5	1.3
Water Demand (BGY)	974.4	55.9	452.7	351.8	113.9
G Water per G Oil	195.0	96.2	286.9	233.0	85.8

Prioritize on:

- Biomass production
- Freshwater availability and pumping costs
- Lipid transport

- Gulf coast identified as most favorable region to meet 5 BGY target
- Freshwater availability was the most important constraint
- Seasonality is potentially key to processing facility scale and operation

2 – Technical Accomplishments DOE Model Harmonization (cont.)

Key Findings

An integrated cost, emissions, and resource potential baseline was created for algae that identifies key knowledge gaps and sensitivity drivers and can serve as a metric for assessing algae technologies

- BAT production estimates showed strong seasonality, while previous TEA and LCA analysis were based on estimated mean annual biomass production
- The relationship between performance (cost and emissions) was found to be non-linear, especially at lower values
  - i.e., performance is season-dependent and caused over-sizing of facility capacity for portions of the year, increasing costs
  - TEA modeling showed it is always economically advantageous to operate the facility, even at low productivities
  - LCA studies showed that, unless power consumption is reduced, periods of low production could result in emissions that would not meet reduction targets
  - Site and strain selection must place a high priority on minimizing seasonal fluctuations, and productivity increases should be pursued
- This baseline study demonstrates that performance based on annual average productivity are inaccurate and suggest temporally and spatially explicit computations allow for more rigorous analysis of these dynamic systems

2 – Technical Accomplishments Terrestrial / Algal Integration

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- National biomass feedstock assessments (Perlack et al., 2005; DOE, 2011) have focused on terrestrial biomass resources, and have not included potential algal feedstocks.

- Recent research (Wigmosta et al., 2011) provides spatially-explicit information on potential algal biomass and oil yields, water use, and facility locations.

- ORNL and PNNL have begun an integrated biomass resource assessment that
  - includes both terrestrial and algal feedstocks
  - accounts for potential land competition between the two feedstock types
  - identifies areas where algal and terrestrial feedstocks have opportunities for production with a minimum of competition for available resources

2 – Technical Accomplishments
Terrestrial / Algal Integration (cont.)

Terrestrial Feedstocks

- DOE (2011) is a terrestrial biomass resource assessment, with simulations derived from the Policy Analysis System (POLYSYS)
  - POLYSYS is a linear program run at the county level, which allocates land as reported from the USDA Census of Agriculture.
  - In this study, approximately one billion dry tons/year of terrestrial feedstocks (herbaceous and woody, residues and dedicated) are identified as potentially available, and are reported by price, year, and scenario at www.bioenergykdf.net .

- DOE (2011) allows for conversion of some private pasture east of the 100th meridian, which in some cases can compete for pasture land allocated to algae production in Wigmosta et al. (2011)

2 – Technical Accomplishments
Terrestrial / Algal Integration (cont.)

High-Production Scenario

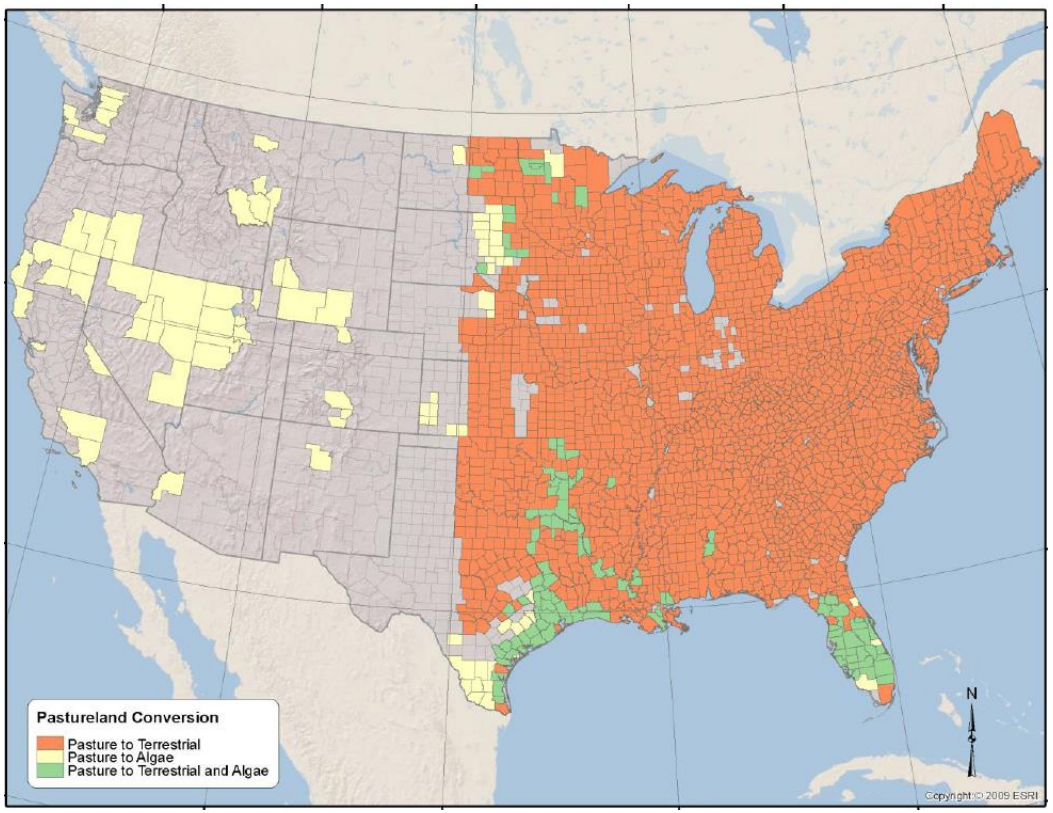
- Terrestrial
  - Mean annual production at the county scale
  - NASS County scale land cover
  - POLYSYS simulation assuming farmgate price of $66 per dry Mg
  - 29.5 billion liters of biofuel in 2022 from feedstock production on private pastureland east of the 100th meridian

- Algae
  - Hourly production at the “unit pond farm” scale – 1,200 ac
  - CDL 30-m land cover
  - 12 billion liters of biofuel from feedstock production on private pastureland from Wigmosta et al. (2011)

- Algal results were aggregated to the county scale
- Significant effort to reconcile differences in county level land use data between terrestrial and algae resulting from differences in NASS and CDL scale and land classifications

2 – Technical Accomplishments
Terrestrial / Algal Integration (cont.)

Conversion of Private Pastureland



Non-Competitive Terrestrial
- 1,897 US counties
- 12.3 million ha

Non-Competitive Algae
- 251 counties
- 0.2 million ha

Both Feedstocks
- 110 counties
- 1.7 million ha terrestrial
- 1.0 million ha algae

Summary and Key Findings

- Due to basic assumptions in Wigmosta at al. (2011) and DOE (2011) private pasture east of the 100th Meridian is the most likely land for completion between algal and terrestrial feedstock production
- We evaluate a high-production scenario in which 41.5 billion liters of second-generation biofuels are produced on private pasture land
  - Algae: 1.2 million hectares
  - Terrestrial: 14 million hectares
- In the high-production scenario, 110 counties in 11 states contain private pasture land that could be exposed to competition
  - Algae: 1 million hectares
  - Terrestrial: 1.7 million hectares
  - 38 to 59 counties could experience competition for over 40% of its private pastureland
  - The combined 2.7 million hectares represents only 2 – 5% to the total pastureland in the US
- Land competition is less likely in 3,000 of the 3,110 US counties under the production scenario presented

Milestones/Metrics and Progress:

Title/Description	Due Date	Completed
RA, TEA, LCA Harmonization		
Harmonization workshop	Dec-11	✓
Establish 5 BGY scenario	Mar-12	✓
Draft multi-lab White Paper for review	Jun-12	✓
Final multi-lab White Paper	Sep -12	✓
Algae/Terrestrial Integration		
Kickoff meeting and revised AOP	Dec-11	✓
County level microalgae data	Mar-12	✓
Algae and terrestrial competition	Jun-12	✓
Progress report (ORNL/PNNL co-authored manuscript submitted)	Sep -12	✓

3 - Relevance

- As requested by BETO, this project directly supports the DOE goals and objectives in the Biomass Program Multi-Year Program Plan (updated November, 2012) by providing 1) a harmonized algal baseline assessment, and 2) conducting an integrated biomass assessment that includes both terrestrial and algal feedstocks
  - Resource assessment goal to compile "current and future projections of the geographic location, price, quality, and environmental sustainability of accessing existing and potential future feedstock resources."
  - By 2013, "establish feedstock resource assessment models with geographic, economic, quality, and environmental criteria under which algal resource supply can be identified to support cultivation of 1 million metric tons ash free dry weight algae biomass by 2017 and 20 million metric tons ash free dry weight (AFDW) by 2022."
  - By 2016, "produce a fully integrated assessment of potentially available feedstock supplies under specified criteria and conditions."
  - By 2017, "evaluate and compare the sustainability of biofuels produced from agricultural residues, energy crops, forest resources, and algae."
  - By 2017, "establish geographic, economic, quality, and environmental criteria under which 155 million dry tons (DT) per year would be feasible".

4 - Critical Success Factors

- Technical Success: identification of the geographic location, price, and environmental sustainability of accessing existing and potential future feedstock resource, as well as projecting future supply availability and prices
  - Integrated (with LCA & TEA), harmonized baseline 5 BGY production scenario
  - Integrated algal/terrestrial biomass feedstock assessment
- Technical Challenge: how to best incorporate scientific data for better model predictions
  - Dynamic nature of Biomass Assessment Tool allows rapid assimilation of scientific advances
  - Since last review we have integrated NAABB derived products, Huesemann growth model, and NWIS water resource database
- Technical Challenge: allow integration of research into full TEA and LCA
  - Collaboration with ANL, NREL, and BETO on model harmonization effort
- Technical Challenge: how to integrate algal and terrestrial feedstock production
  - Collaboration with ORNL on Billion-Ton integration
- Market
  - Strategic partnerships with industry - Sapphire
  - Dissemination of study results through peer-reviewed publications, web-based Biomass Assessment Tool, and integration with Bioenergy Knowledge Discovery Framework
    - AGU WRR Editor's Choice Award (Wigmosta et al., 2011), Venteris et al. (2013), Biomass and Bioenergy paper, numerous presentations

5. Future Work
Plan through September 30, 2014

Related Tasks under 9.6.1.2 for DOE Model Harmonization

- FY13: Complete harmonized 5 BGY freshwater HTL scenario site selection
  - Biomass yield
  - Water demand
- FY13: Complete multi-laboratory technical report documenting 5 BGY results
- FY14: Tentative
  - Comparison of harmonized 5 BGY lipid extraction and HTL scenarios
  - Harmonized HTL scenario with both freshwater and saline water sources
  - Complete harmonized CO_2 flue gas transport model
  - Harmonized HTL scenario with commercial and/or flue gas CO_2

Related Tasks under 9.6.1.2 for Integrated Terrestrial and Algal Feedstocks

- FY13: Complete low/high production scenarios
  - Biomass yield
  - Cost
- FY13: Complete multi-laboratory white paper report documenting integrated results
- FY14 (tentative): Draft manuscript analyzing potential competition for water and nutrient resources between algae and terrestrial feedstocks

Summary

- ***Relevance:*** This study provides DOE and industry with a spatially-explicit estimate of open pond microalgae production potential and resource demands for the conterminous United States. It directly supports program goals to "produce a fully integrated assessment of potentially available feedstock supplies under specified criteria and conditions."
- ***Approach:*** A systematic biophysical evaluation of resource demands and constraints on microalgae biofuel production, integration with terrestrial feedstock production estimates, integration with algal TEA and LCA analysis.
- ***Technical accomplishments:*** 1) An integrated biomass assessment that includes both algal and terrestrial feedstocks; 2) a harmonized 5 BGY baseline algal biofuel production scenario integrating resource assessment , TEA, and LCA.
- ***Success factors and challenges:*** Integrated assessment of on-site feedstock production, integration into full lifecycle and TEA analysis, integration with terrestrial feedstock analysis
- ***Technology transfer and future work:*** Integration of web-based Biomass Assessment Tool into Bioenergy Knowledge Discovery Framework, coordination with NAABB, collaboration with ANL, NREL, and ORNL.
  - AGU WRR Editor's Choice Award (Wigmosta et al., 2011), Venteris et al. (2013), Biomass and Bioenergy paper, numerous presentations

Responses to Previous Reviewers' Comments

- Project has not been reviewed

Publications, Presentations, and Commercialization

Publications

- Wigmosta, M. S., A. M. Coleman, R. J. Skaggs, M. H. Huesemann, and L. J. Lane, 2011, National microalgae biofuel production potential and resource demand, Water Resour. Res., 47, W00H04, doi:10.1029/2010WR009966
- Venteris, E.R. , R.L. Skaggs, A.M. Coleman, and M.S. Wigmosta, A GIS model to assess the availability of freshwater, seawater, and saline groundwater for algal biofuel production in the United States, Environmental Science & Technology, 2013.
- Davis, R., D,. Fishman, E.D. Frank, M.S. Wigmosta, A. Aden, A.M. Coleman, P.T. Pienkos, R.L. Skaggs, E.R. Venteris, M.Q. Wang, “Renewable diesel from algal lipids: An integrated baseline for costs, emissions, and resource potential from a harmonized model”, Technical Report ANL/ESD/12-4, NREL/TP-5100-55431, PNNL-21437, June 2012
- Langholtz, M.A., A.M. Coleman, L.M. Eaton, M.S. Wigmosta, C.M. Hellwinckel, and C. Brandt, Potential Land Competition Between Open-Pond Microalgae Production and Terrestrial Dedicated Feedstock Supply Systems in the U.S., Biomass and Bioenergy, in review.

County Private Pasture Competition Index

- PCI = (Ac + Tc) / Pt
  - PCI = land competition index for private pasture
  - Ac = conversion of private pasture to algae (ha)
  - Tc = conversion of private pasture to terrestrial (ha)
  - Pt = total private pasture in the county based on CDL or NASS land classification (ha)