Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Collaborative: Algae-based biofuels integrated assessment framework development, evaluation, and demonstration (PNNL)

MAY 23, 2013
TECHNOLOGY AREA REVIEW: ALGAE

PRINCIPAL INVESTIGATOR: RICHARD SKAGGS
PACIFIC NORTHWEST NATIONAL LABORATORY

Goal Statement

Goal: This collaborative project couples PNNL's Biomass Assessment Tool (BAT) with the Algae Logistics Model (ALM) developed by Idaho National Laboratory (INL). The resultant toolset provides the DOE Bioenergy Technologies Office (BETO) with an analysis framework to holistically evaluate U.S. microalgae biofuel production potential, associated resource requirements, and production system design trade offs.

- This project directly aligns with BETO Multi-Year Program Plan (MYPP) feedstock and logistics strategic goal: *"The Feedstock Supply and Logistics strategic goal is to develop sustainable technologies to provide a secure, reliable, and affordable biomass feedstock supply for the U.S. bioenergy industry, in partnership with USDA and other key stakeholders"*

Quad Chart Overview

Timeline

- Project start date: Sept. 2010
- Project end date: July 2013
- Percent complete: 95%

Budget

- Total project funding: $700k
- DOE share: $700k
- Contractor share: $0k
  - Funding for FY10: $200k
  - Funding for FY11: $500k
  - Funding for FY12: $0k
  - Funding for FY13: $0k

Barriers

- Barriers addressed
  - Ft-A. Feedstock Availability & Cost
  - Ft-B. Sustainable Production
  - Ft-M. Overall Integration and Scale-Up

Partners

- Idaho National Laboratory
  - Joint deliverables/objectives
  - Coordinated through periodic workshops

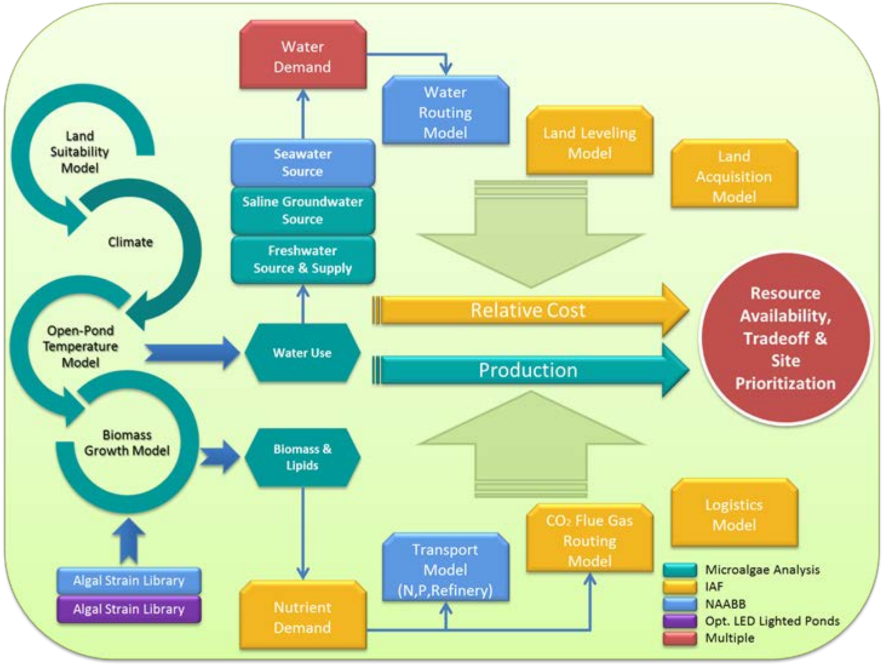
Project Overview

Objectives:

- Develop adaptive GIS-based Integrated Assessment Framework (IAF) for algae feedstock production systems
  - Add critical database and analytical elements to the Biomass Assessment Tool related to land valuation and nutrient demand
  - Design/develop architecture to integrate the BAT with INL's ALM
- Demonstrate IAF capabilities to address key questions of interdependence between spatial-temporal variability of production and process design capacity and costs at local/regional/national scales.
  - Optimal feedstock production and process alternative configurations, locations and scales
  - Infrastructure requirements
  - Regional/national production capabilities
  - Sustainability of potential microalgae biofuel production

1 - Approach

- Add critical database and analytical elements to the BAT
  - Build relative land value model and database
  - Enhance the algae growth model to estimate CO_2 and nutrient requirements
  - Build CO_2 and nutrient source data bases
- Develop IAF functionality design specifications and enabling architecture
- Integrate BAT and ALM
- Exercise the IAF to discover/evaluate important algal production system design tradeoffs



Management Approach

- Project management plans
  - SOW and how it relates to DOE goals
  - Quarterly milestones
- Frequent project communications
  - Regular conference calls with project team members
  - Quarterly formal reporting to HQ
  - Participate in monthly algae platform conference call reviews

2 - Technical Accomplishments/ Land Availability Assessment

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

- Challenge: Evaluate available land and its suitability for algal biofuel production
- Macroeconomic approach to answering two key questions:
  1. What would be the cost of acquiring large amounts of land not offered on the market?
  2. How much land is economically available to an algal biofuel industry or other land-intensive energy technology?

Definitions:

- Value (cost) – amount of money required to acquire land not currently offered for sale
- Availability – relative likelihood an algal biofuel entity could purchase land from the current owner based on land derived income versus sale value

2 - Technical Accomplishments/ Land Availability Assessment (cont.)

- Methodology: develop land availability index, where

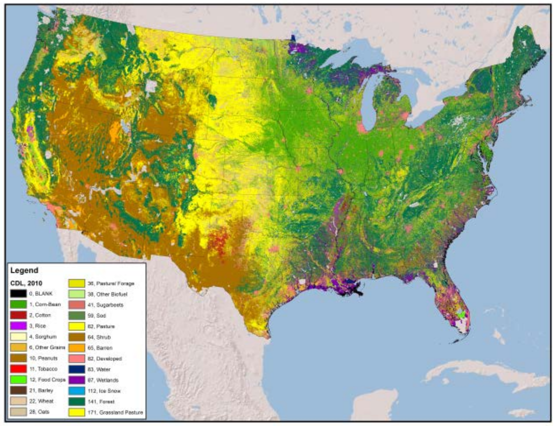
  a = (p+ I + r)/c

  p = average annual profit from sale of products

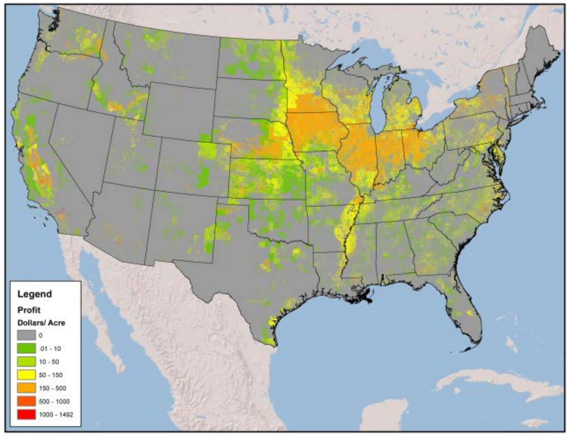
  I = annualized appreciation

  r = cash rent or other miscellaneous income streams

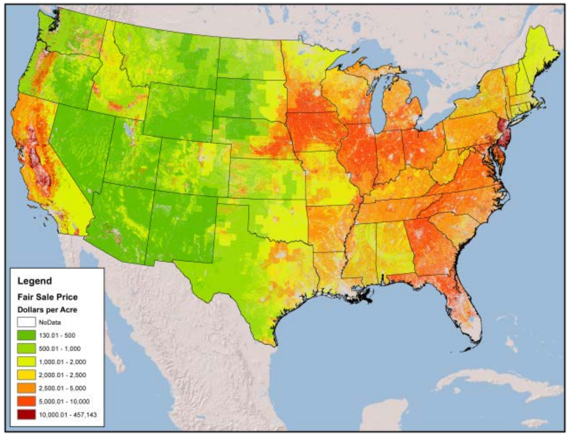
  c = annualized income from selling land and investing proceeds (T-bond)



Land use/ land cover (CDL, 2010)



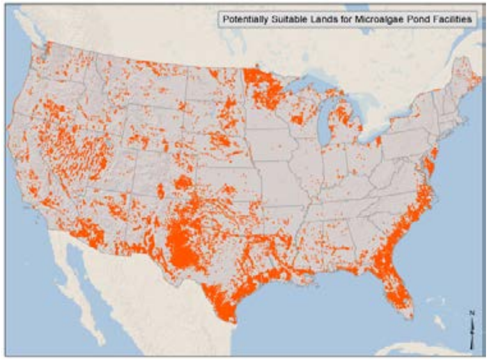
Profit $/acre/yr) (NASS + ERS)

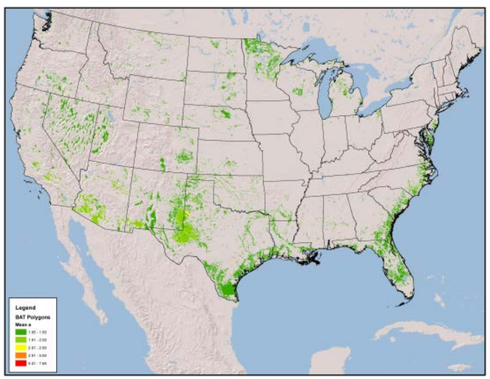


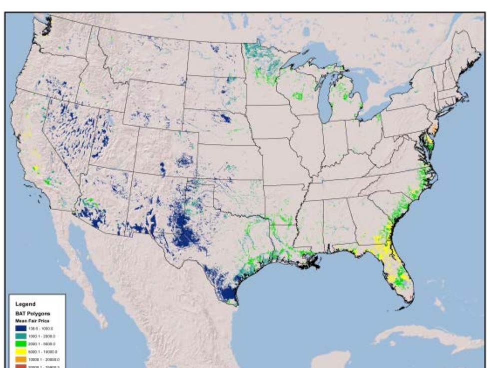
Fair sale price ($/acre) (NASS + ERS)

Availability index: relative measure of landowner's willingness to sell.

2 - Technical Accomplishments/ Land Availability Assessment (cont.)







- Potential: 89,756 areas (≥ 485 ha) suitable for open ponds
  - <1% slope, screened to eliminate crop lands, protected/sensitive areas, etc.
  - 430,830 km^2 (5.5%) of the coterminous United States
- > 1 million km^2 have low owner resistance to selling (a < 2.0), is not in protected land category, and has low slope
- Over half of the available land has a fair acquisition cost < $2500/ha

Venteris, E, R Skaggs, A Coleman, M Wigmosta. An assessment of land availability and price in the coterminous United States for conversion to algal biofuel. Biomass and Bioenergy 47 (2012).

2 - Technical Accomplishments/ Nutrient Resource Assessment

- Challenge: Evaluate impact of nutrient resources availability on algal biofuel production
- Premise: Nutrient demands (N, P, CO_2) and offsets from recycling are dependent on the conversion technology pathway
- Approach: Utilize the BAT to characterize geospatial and temporal distribution of potential biomass production and associated nutrient demand based on *Chlorella* growth model results
  1. Two water sources considered: freshwater limited by competitive demand and unlimited saline groundwater
  2. Compare net nutrient demand between lipid extraction (LE), and hydrothermal liquefaction (HTL), and recycling technologies (anaerobic digestion, catalytic hydrothermal gasification)

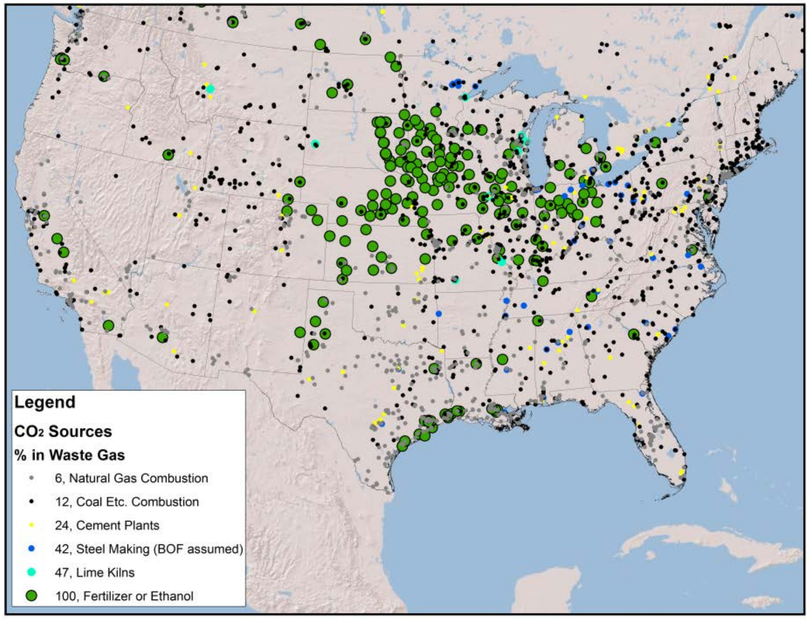
Integrates BAT resource assessment capabilities w/published models of LE (Davis et al. 2012) and HTL (Frank et al. 2013) bio oil yield and nutrient consumption.

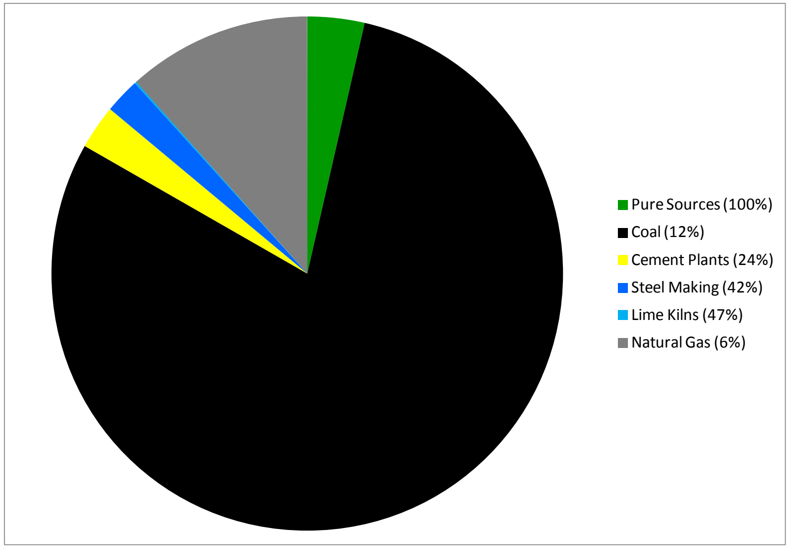
2 - Technical Accomplishments/ Nutrient Resource Assessment (cont.)

CO_2 Sources and Purity (Dilution):

- Key limitation in waste CO_2 usage is transport cost
- CO_2 concentration is critical – however, source characterization is limited
- Where flue gas is unavailable (supply and/ or cost) $40 tonne-1 (commercial) is used as a default.

Short distance pipe transport of CO_2 waste streams has potential sustainability and economic advantages





2 - Technical Accomplishments/ Nutrient Resource Assessment (cont.)

Concern: Impact of algal biofuels on U.S. food production:

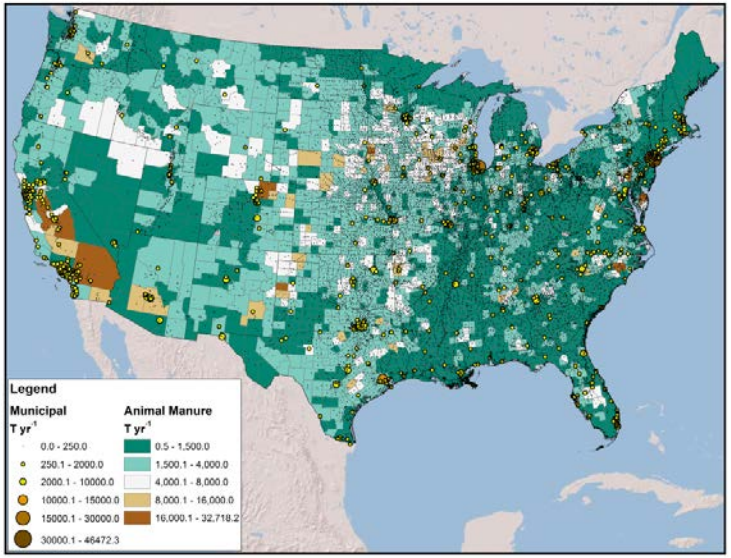
Average ag. consumption (2006 – 2010):

- N: ~ 11 M tonne/yr
- P: ~ 1.6 M tonne/yr

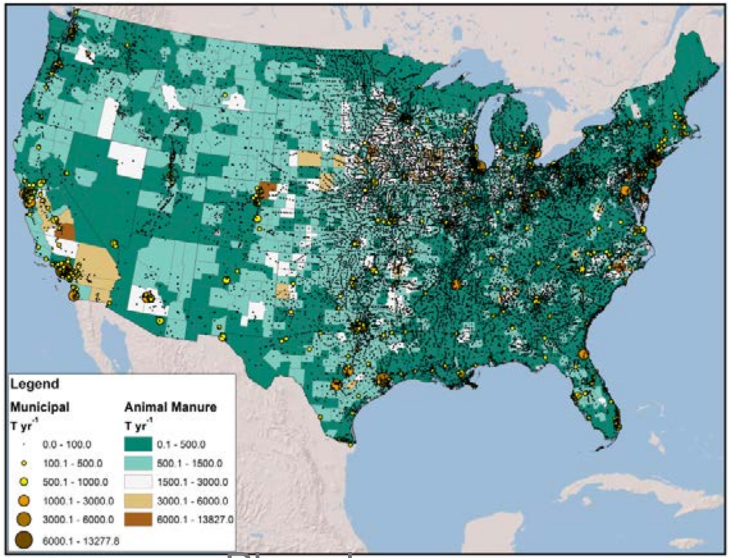
Estimated annual production from:

- Municipal waste: N: ~1.0 M tonne/yr
  P: ~1.9 M tonne/yr
- Animal waste: N: ~5.9 M tonne/yr
  P: ~1.9 M tonne/yr

Increased demand could be partially offset by municipal and animal waste.



Nitrogen



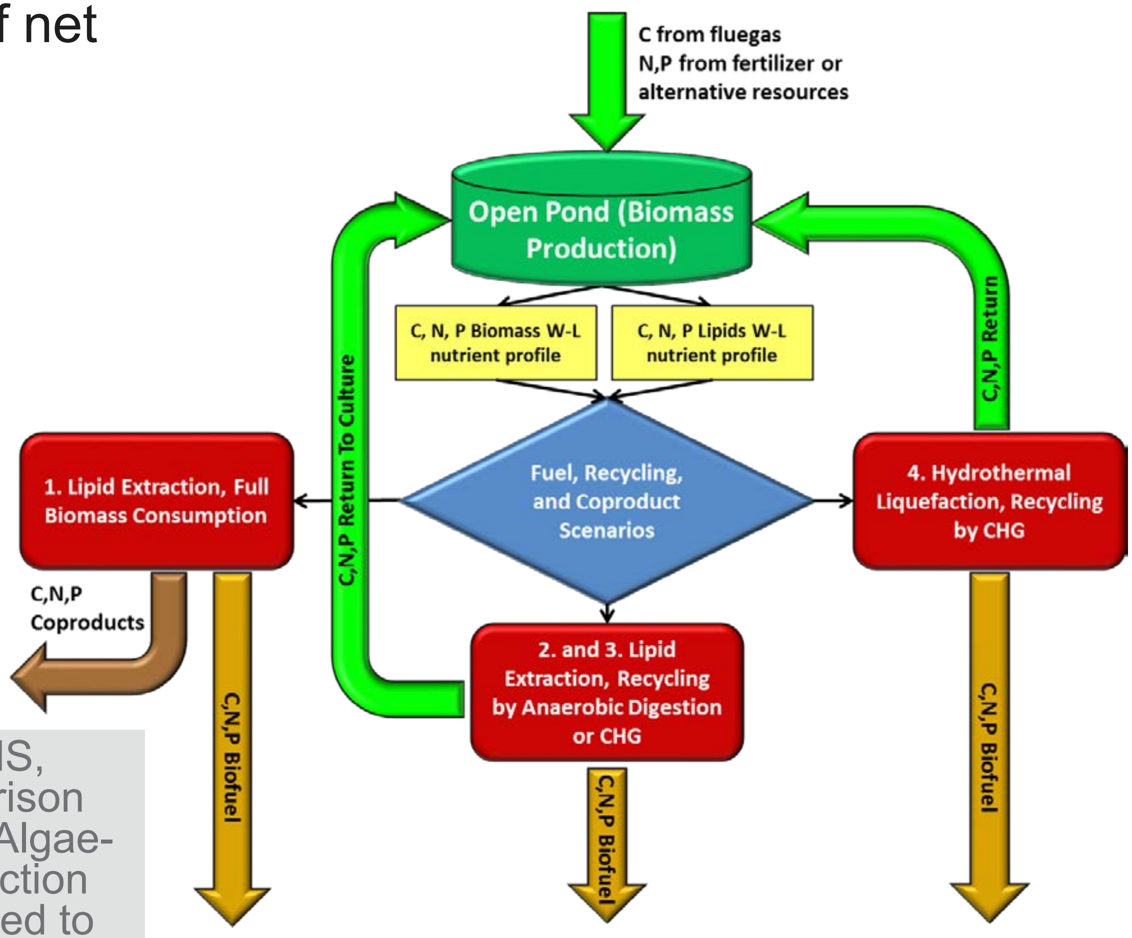
Phosphorous

2 - Technical Accomplishments/ Nutrient Resource Assessment (cont.)

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- 1st order nutrient mass balance
- Preliminary assessment of net nutrient demand for four scenarios.
  - LE w/o recycling
  - LE w/AD
  - LE + CHG
  - HTL + CHG

Process Diagram



Venteris, ER, Skaggs, RL, Wigmosta, MS, Coleman, AM. A National-Scale Comparison of Resource and Nutrient Demands for Algae-Based Biofuel Production by Lipid Extraction and Hydrothermal Liquefaction. Submitted to Biomass and Bioenergy, May 2, 2013.

2 - Technical Accomplishments/ Nutrient Resource Assessment (cont.)

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

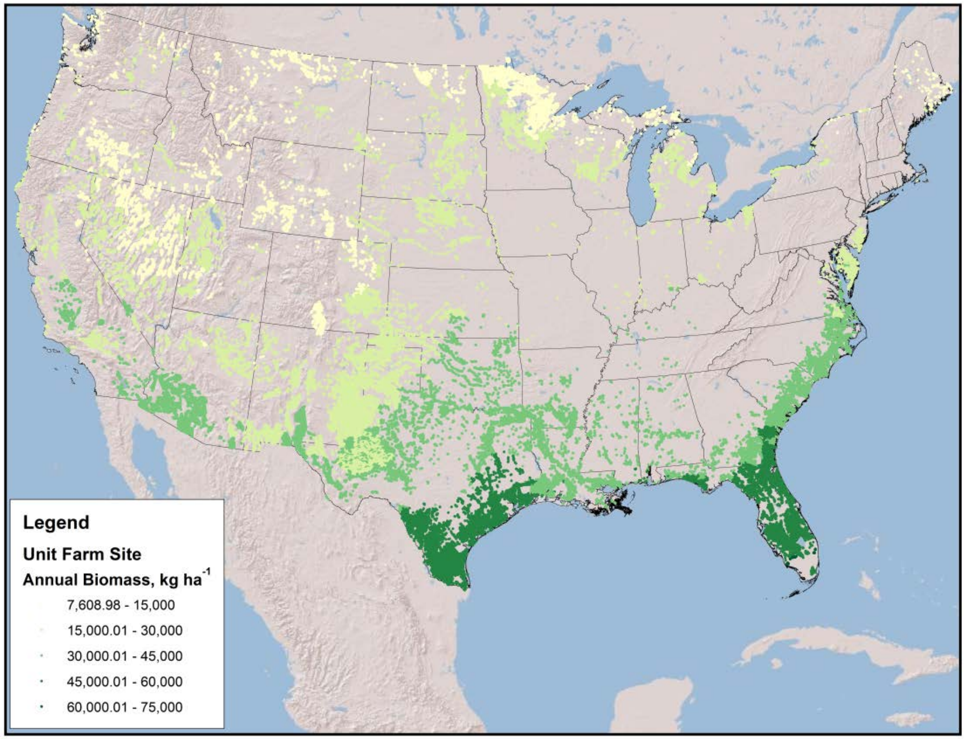
LE: Lipid = biomass* harvest efficiency*lipid fraction

(per Davis et al., 2012)

- Track N and P in the lipids and remaining biomass. Nutrient demand based on N,P in lipid fraction and in losses in AD and CHG

HTL: Track N and P in the oil, water and solid phases (per Frank et al., 2013)

- Nutrient demand based on N,P in the oil and losses in CHG aqueous phase



Nutrient demand based on BAT productivity for *Chlorella* using assumed nutrient profile per Williams and Laurens (2010): (C=0.55; N=0.078; P= 0.0081)

Highest productivity and associated nutrient demand likely to be in the Gulf of Mexico region.

2 - Technical Accomplishments/ Site Selection/Nutrient Demand

Water costs based on transport with 2 components:

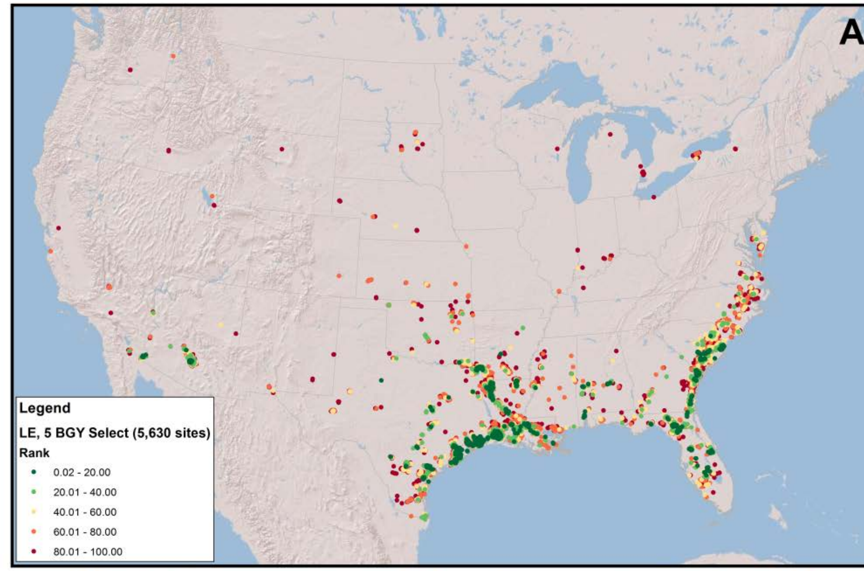
- 0–2000 mg/l TDS (0 – 300 m)
- 2000–60,000 mg/l TDS (0–1000 m)

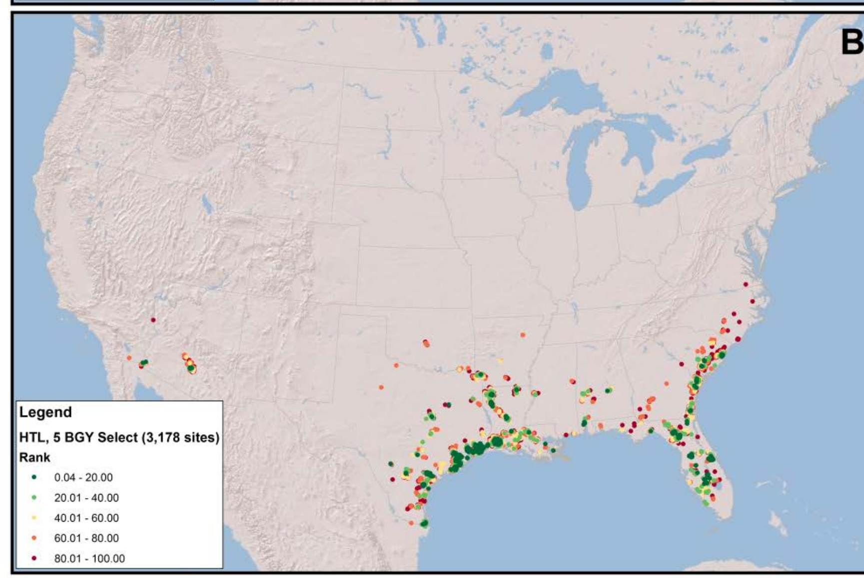
Non–water resource costs:

- CO_2 (flue gas), land value+ leveling, product refinery transport, etc.

Resource demand comparison for 5 BGY biofuel (HTL+CHG vs. LE+AD):

- Water: HTL = ~0.6 LE
- Land: HTL = ~0.6 LE
- CO_2: HTL = ~ 0.6 LE
- N: HTL =~0.75 LE
- P: HTL = ~0.30 LE





Preliminary results: HTL is much more efficient in overall resource use than LE.

2 - Technical Accomplishments/ Integrated Assessment Framework

Productivity & Resources

Process Design & Costs

Biomass Assessment Tool

Spatial Variation

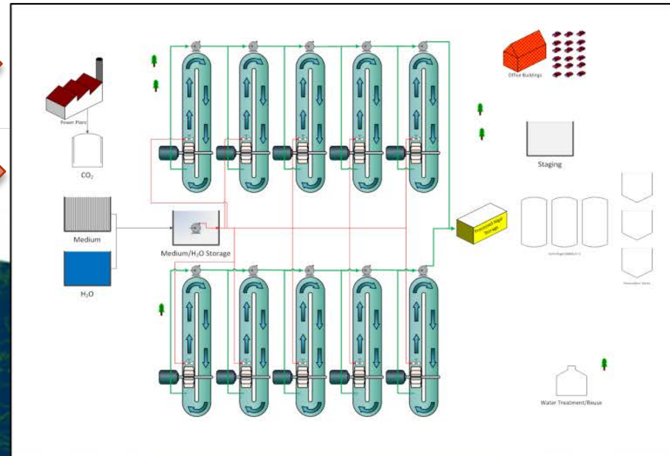
Temporal Variation

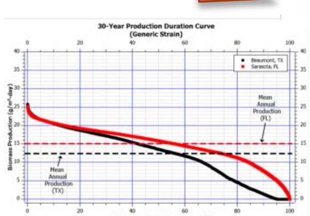
Pathway

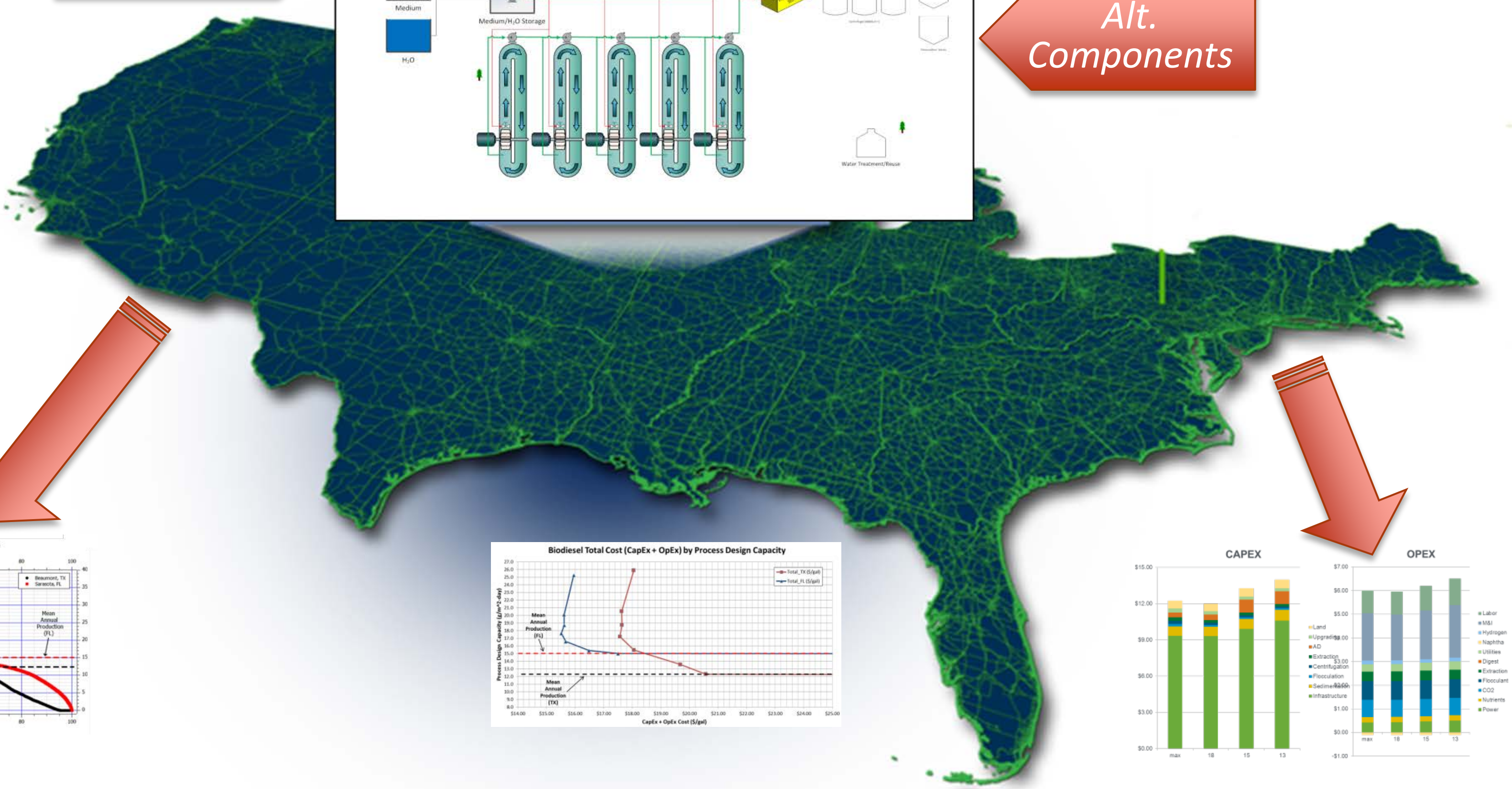
Capacity

Alt. Components

Algae Logistics Model

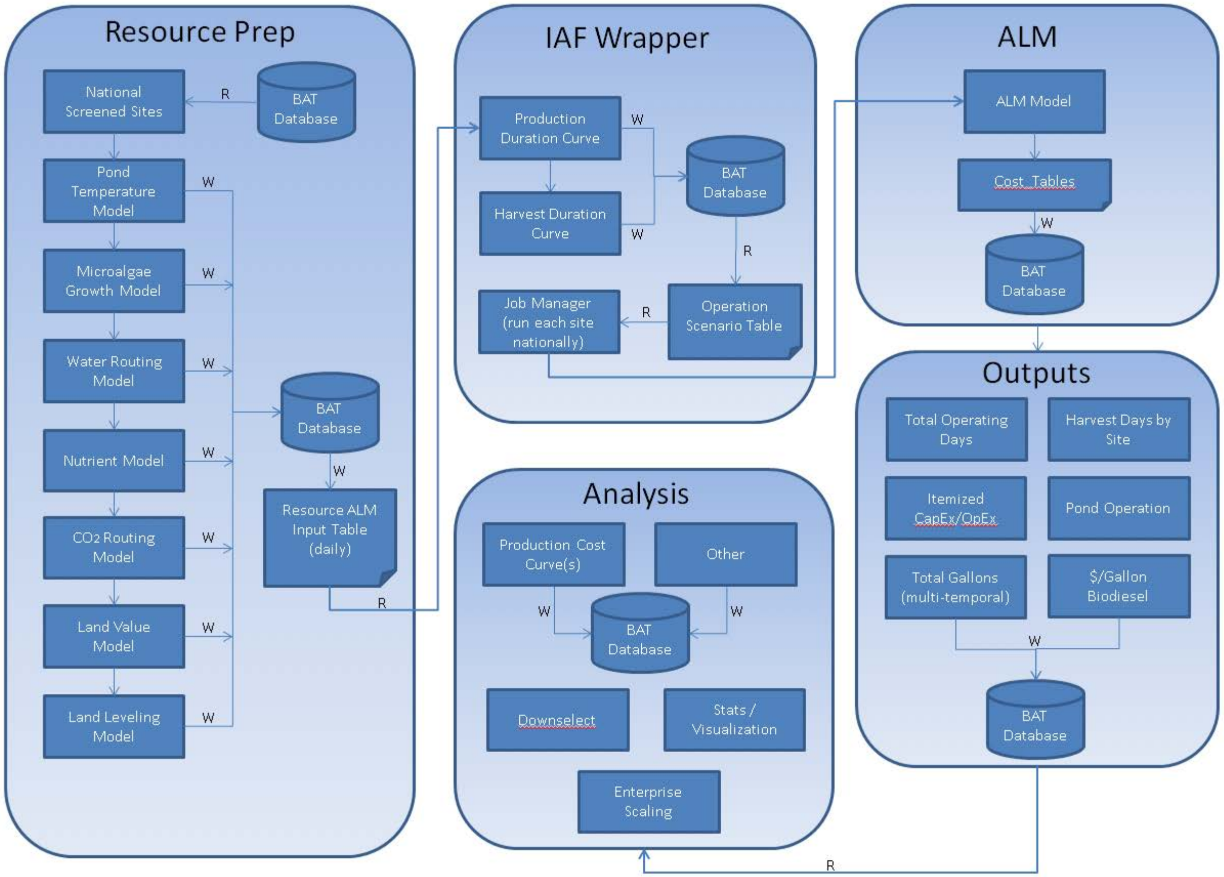






2 - Technical Accomplishments/ IAF Integration (BAT > ALM > BAT)

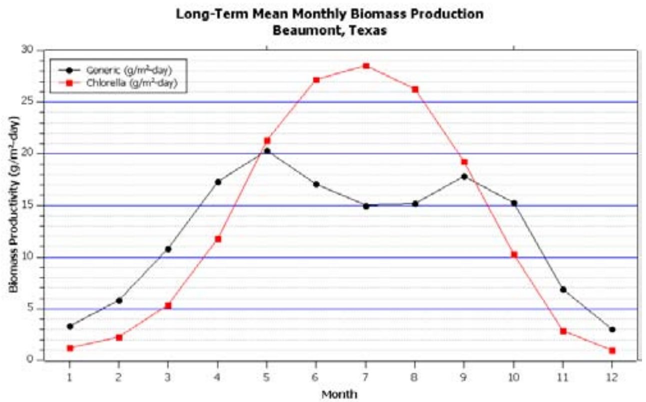
IAF Workflow

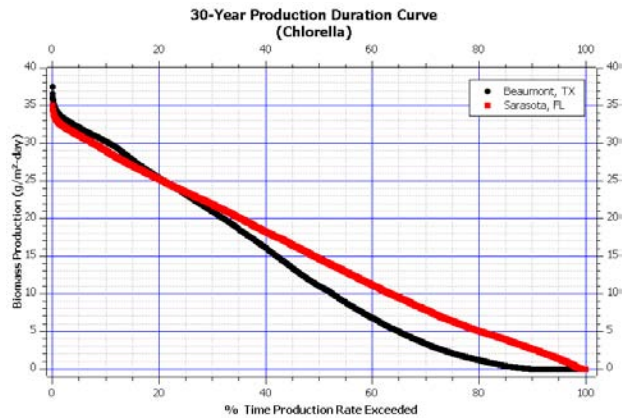


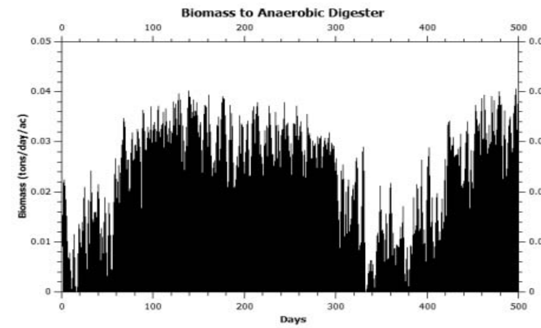
Architecture enables automated workflow processes to analyze across unit farm to "enterprise" scales integrating across the resources to production to refining lifecycle

2 - Technical Accomplishments/ IAF Application

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965







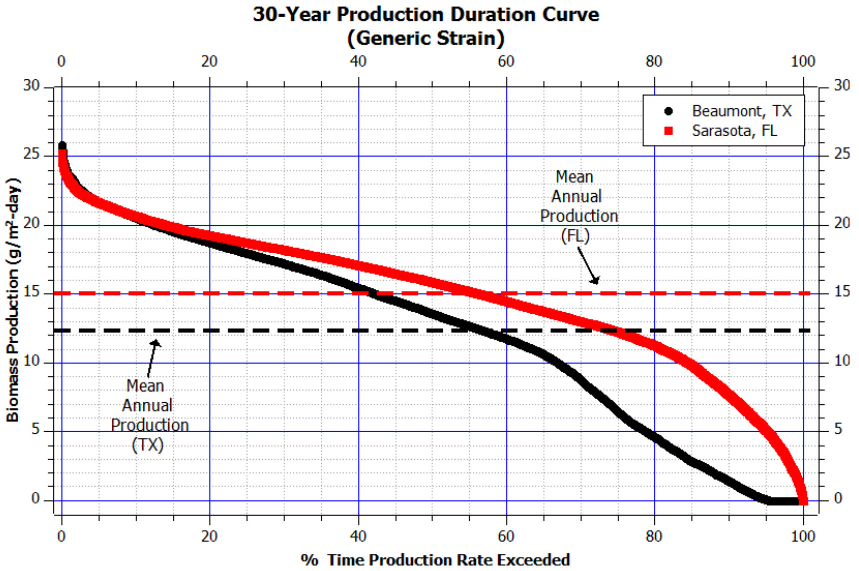
Key question: What is the impact of algal temporal/spatial variability on enterprise design scale and costs?

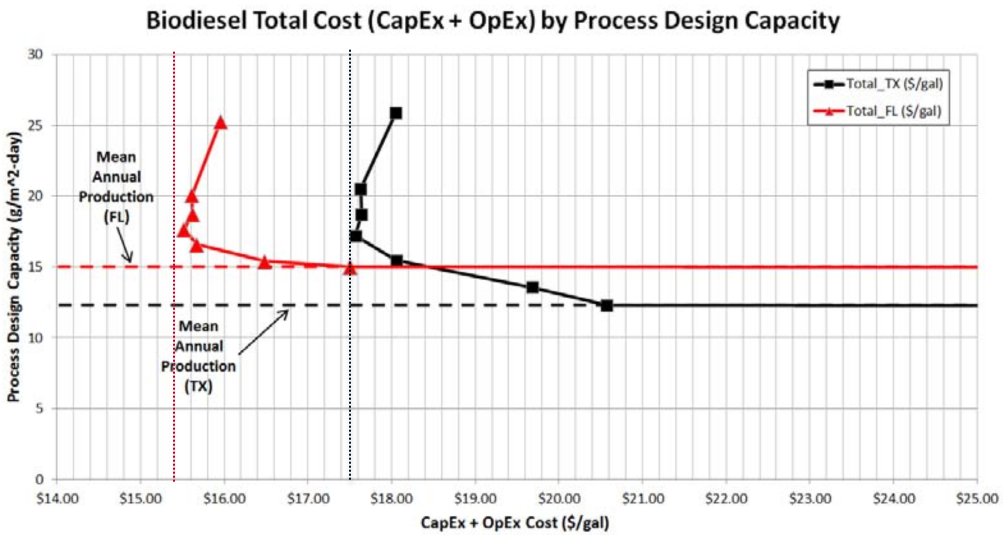
- Many dimensions of variability in the system
- Pond CAPEX dominates → maximize production/unit area of pond
- Tradeoffs between CAPEX/OPEX and production/harvest design levels
- Manage production > "optimize" overall design capacity

System "optimization": exploring the trade offs between site specific production potential, resource constraints, and "right sizing" processing capacity.

2 - Technical Accomplishments/ IAF Application (cont)

- Production duration and capacity-cost trade off curves (LE+AD)
- Assumes fixed number of ponds determined by resource constraints





Design based on average annual production suboptimal due to high pond CAPEX. Manage cultivation operations to “flatten” the production duration curve (e.g., seasonal species rotation)

2 – Technical Progress

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Milestone	Planned Completion Date	Completion
Complete land value model development	Mar. 2011	✓
Complete nutrient demand model	Sep. 2011	✓
Complete IAF prototype and preliminary implementation	Mar, 2012	✓
Complete initial comprehensive microalgae feedstock supply and tradeoff analyses.	Jun. 2012	✓
Submit nutrient demand manuscript	Mar. 2013	✓

3 - Relevance

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- Directly supports DOE goals and objectives in Biomass Program MYPP (November 2012) by providing a systematic national assessment to evaluate the U.S. potential for microalgae biofuel production
  - "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 2022, validate the potential for algae supply and logistics systems to product 5,200 gallons oils (or equivalent biofuel intermediate) per acre of cultivation per year, achieving a modeled nth plant minimum selling price of $3.27/GGE ($2011) of raw biofuel intermediate (corresponding to projected $3.73/GGE ($2011) of renewable diesel minimum fuel selling price)
- Leverages joint capabilities of PNNL and INL to provide DOE and industry a methodology for incorporation of climate, water, land, nutrients, infrastructure, and harvest logistics criteria into biomass supply assessments through development of a user-driven, adaptive GIS-based IAF

4 - Critical Success Factors

- Technical Success: Integrated, national scale feedstock resource assessment and harvesting logistics analysis at local-regional-national scales
  - Algal biofuel production system trade offs of location, productivity, scale and CAPEX/OPEX
    - Critical resource demands and availability
    - Sustainable production potential
    - Infrastructure requirements
- Technical Challenge: How to best incorporate new scientific data for validation and improved model predictions
- Business Success: Project is advancing the state of technology and is positively impacting commercial viability of microalgae biofuels by accelerating the identification of optimal locations and reducing the risks associated with resource availability and constraints
- Market Success:
  - Dissemination of study results through peer reviewed literature
  - Strategic partnerships with industry including Sapphire Energy and NAABB
  - Integration with Bioenergy Knowledge Discovery Framework

5 - Future Work

- This project will be completed in FY13 Q3. Remaining activities include:
  - Complete joint PNNL-INL manuscript on IAF
- Important questions to be addressed by IAF:
  - How are interdependencies between algae feedstock production and downstream processing impacted by technology pathway (e.g., LE vs. HTL)?
  - What are “excess” production handling/storage options, requirements, and costs?
  - What are the benefits of weather forecasting to algae feedstock production operations?

Summary

- ***Relevance:*** Provides DOE with analysis framework to holistically evaluate U.S. microalgae production potential, associated resource requirements and production system scale and costs
- ***Approach:*** Integration of systematic biophysical evaluation of resource demands and constraints on microalgae biofuel production with harvesting logistics and cost analysis.
- **Technical accomplishments**: Development of new BAT modules related to land valuation and nutrients demand. Development and initial deployment of the IAF.
- ***Success factors and challenges:*** Integration of on-site feedstock production and harvest/process assessments into complete production system trade off analysis.
- ***Technology transfer and future work:*** Collaboration with Sapphire, NAABB and INL. IAF applicable to future questions related to interdependencies between algae feedstock production and processing.

Acknowledgments

PNNL
Richard Skaggs
Andre Coleman
Erik Venteris
Mark Wigmosta

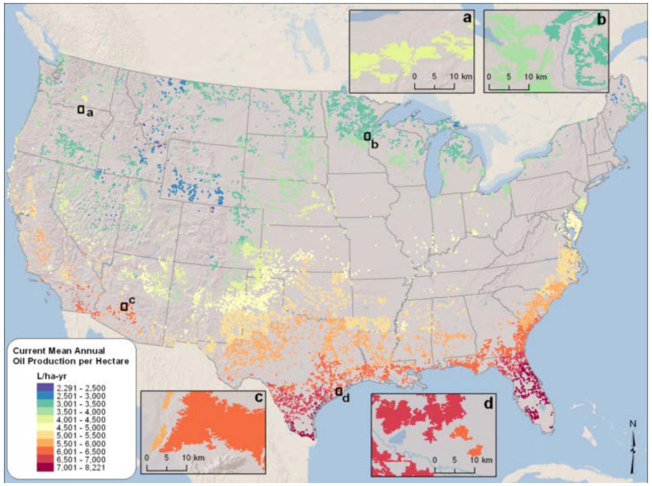
INL
Deborah Newby
Jared Abodeely

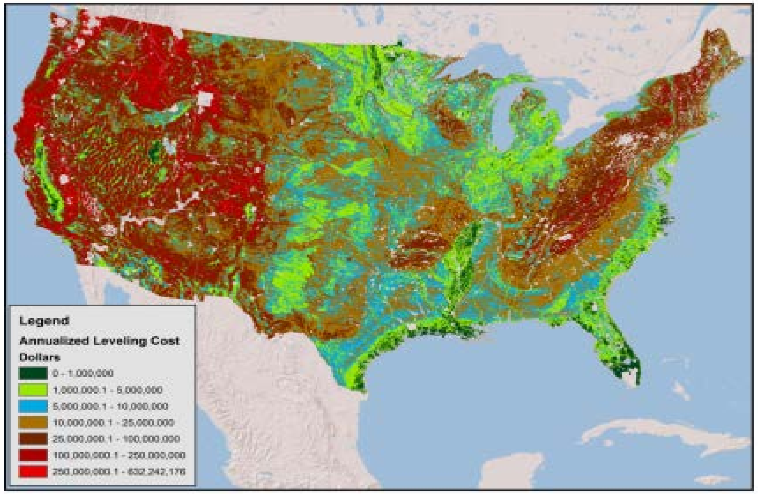
Additional Slides

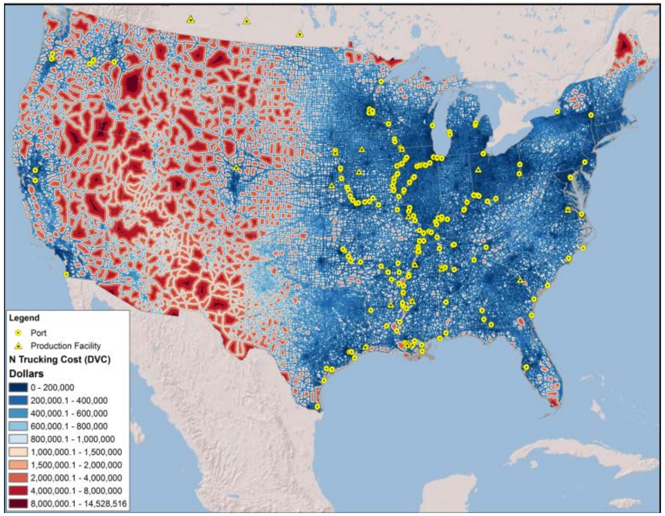
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

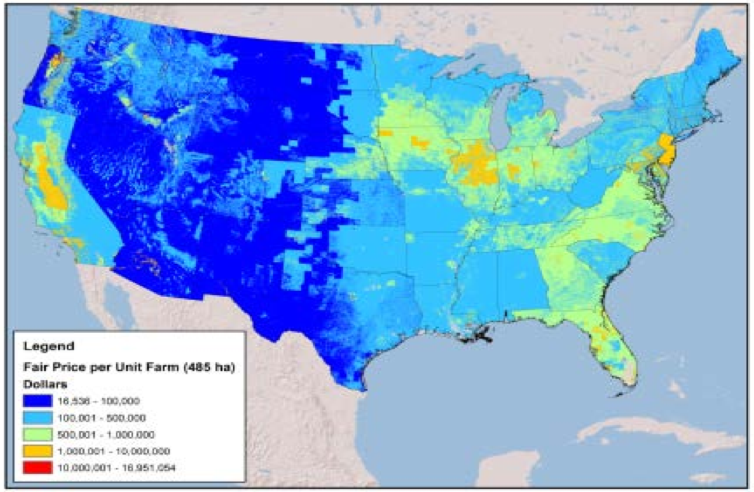
2 - Technical Accomplishments/ IAF Integration (BAT > ALM)

Example data BAT inputs to IAF









BAT enables local-regional-national scale IAF assessments

Responses to Previous Reviewers' Comments

- Comment: The models need to incorporate the newer data being produced (try to get input factors from several of the larger DOE projects) and spend more time with published literature, including on Redfield ratios
- Response: Given the limited availability of experimental data and field-scale results, and the immature nature of algal biofuels S&T, this project was heavily reliant on published information. For example concerning the above reviewer reference to the Redfield ratio, we used nutrient profile values published by Williams, P.L.J., and L.M.L. Laurens (2010). We later found agreement in the use of these values by Davis et al. (2012)

Williams, P.L.J., and L.M.L. Laurens (2010), Microalgae as biodiesel & biomass feedstocks: Review & analysis of the biochemistry, energetic & economics, Energy Environ. Sci, 3, 554-590, doi:10.1039/b924978b.

Davis R, Fishman D, Frank E, Wigmosta M, Aden A, Coleman A, et al. (2012). Renewable Diesel from Algal Lipids: An Integrated Baseline for Cost, Emissions, and Resource Potential from a Harmonized Model. National Renewable Energy Laboratory (NREL), Golden, CO.

Responses to Previous Reviewers' Comments

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- Comment: The assessment is valuable but challenging. Modeling must have flexibility to incorporate rapidly changing technology.
- Response: Case study comparison of nutrient demands for lipid extraction and hydrothermal liquefaction processing technology pathways is an example of our effort to provide an early evaluation of the potential benefits of an emerging pathway relative to a more "conventional" approach

Publications and Presentations

Venteris, ER, Skaggs, RL, Coleman, AM, Wigmosta, MS. An assessment of land availability and price in the coterminous United States for conversion of algal biofuel production. Biomass and Bioenergy, 2012, 47.

Venteris, ER, Skaggs, RL, Wigmosta, MS, Coleman, AM. A National-Scale Comparison of Resource and Nutrient Demands for Algae-Based Biofuel Production by Lipid Extraction and Hydrothermal Liquefaction. Submitted to Biomass and Bioenergy, April, 2013.

Venteris, ER. "A GIS-Based Spatial Model for Cost Effective Siting" presented at ABO, October, 2011.