Sustainable Development of Algae for Biofuel

2013 Peer Review

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Algae Platform

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http://www.ornl.gov/sci/ees/cbes/

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Goal Statement

Project Goal

- To support sustainable development of algal biofuels by conducting research that defines and addresses potential environmental, socioeconomic, and production hurdles
- To conduct **sustainability** studies (including indicator identification) and **resource analysis** for algal biofuels

Relates to Algae Technology Area goals

- To increase projected productivity of large-scale algae cultivation and preprocessing while maximizing efficiency of water, land, nutrient and power use
- To establish feedstock resource assessment models with geographic, economic, quality, and environmental criteria under which sustainable algal resource supply can be identified to support cultivation of 1 million metric tons ash-free dry weight algae biomass by 2017

Relates to Sustainability Area goals

- [To develop] the resources, technologies, and systems needed to grow a biofuels industry in a way that protects natural resources and maximizes economic, social, and environmental benefits

Quad Chart Overview

Timeline

- Project start date: FY13
- Project end date: TBD
- Percent complete: New start

Budget

- Total project funding
  - DOE share: TBD
- Funds Received
  - FY12: 0
  - FY13: $350K

    Total: $350K

Barriers

•St-B. Consistent, and Evidence-Based Message on Bioenergy Sustainability

•St-D. Implementing Indicators and Methodology for Evaluating and Improving Sustainability

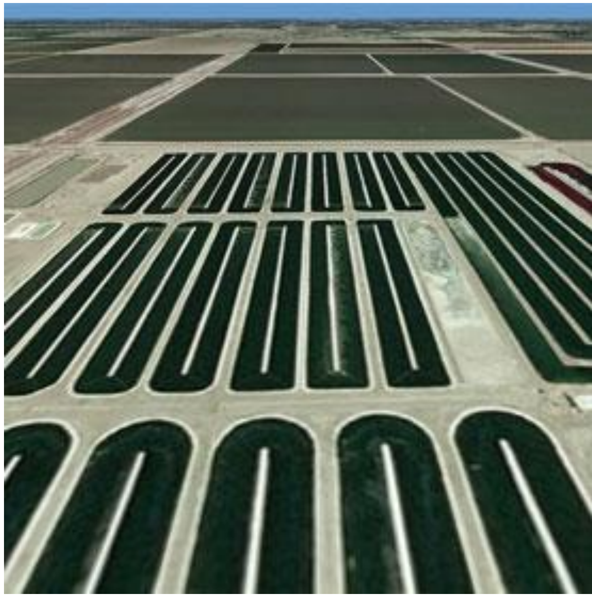
•Ft-A. Feedstock Availability and Cost

Partners

- University of Tennessee
- PNNL
- Using research results from Argonne, Los Alamos, Sandia, PNNL, Sapphire, others
- Woodrow Wilson International Center for Scholars (EPA, MIT)

Project Overview

- **History:**
  - New project for FY13
  - Grew from Efroymson participation in National Research Council Committee on Sustainable Development of Algal Biofuels
  - Grew from collaborations with PNNL on resource analysis
- **Context:**
  - Sustainability and resource analysis projects have emphasized vascular bioenergy crops and not algae.
  - This project aims to "catch algae up" to other bioenergy feedstocks with respect to sustainability and resource analysis
- **Objectives**
  - Identify sustainability indicators and targets that apply to algal biofuel systems to move toward best management practices
  - Add algae as a feedstock to resource assessment (i.e., add algae module to POLYSYS)



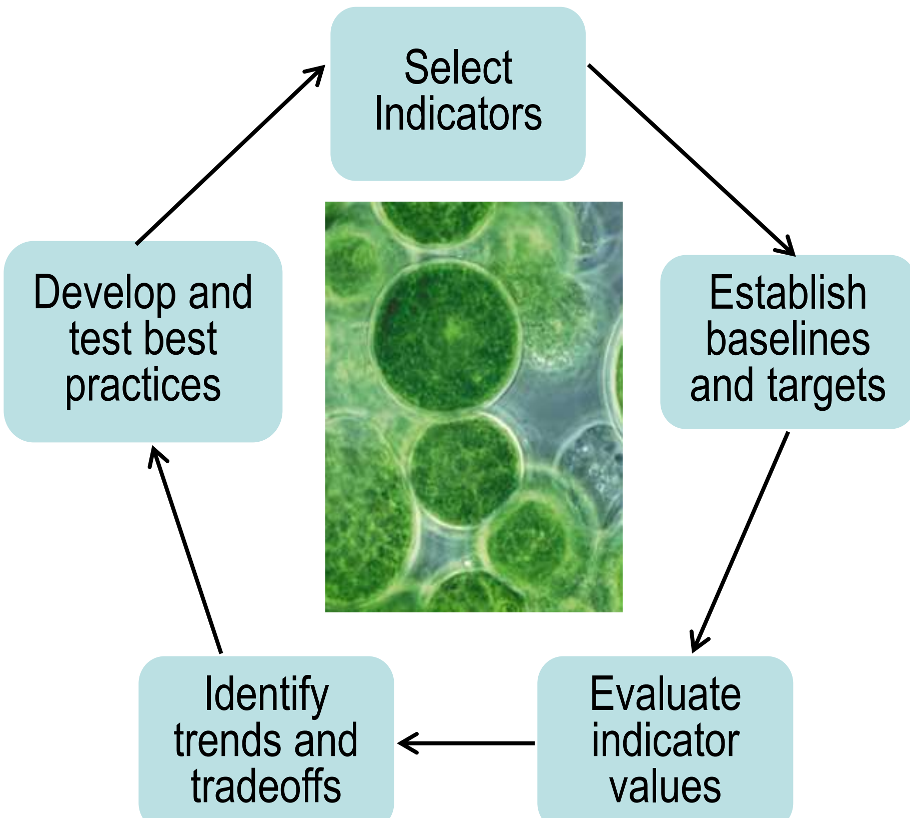
PNNL photo

NASA OMEGA

Project Overview

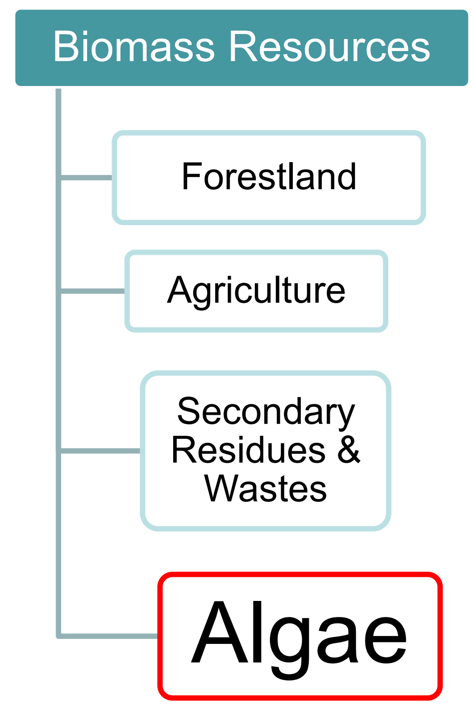
Objectives (continued)

Task 1. Sustainability



Task 2. Resource Analysis

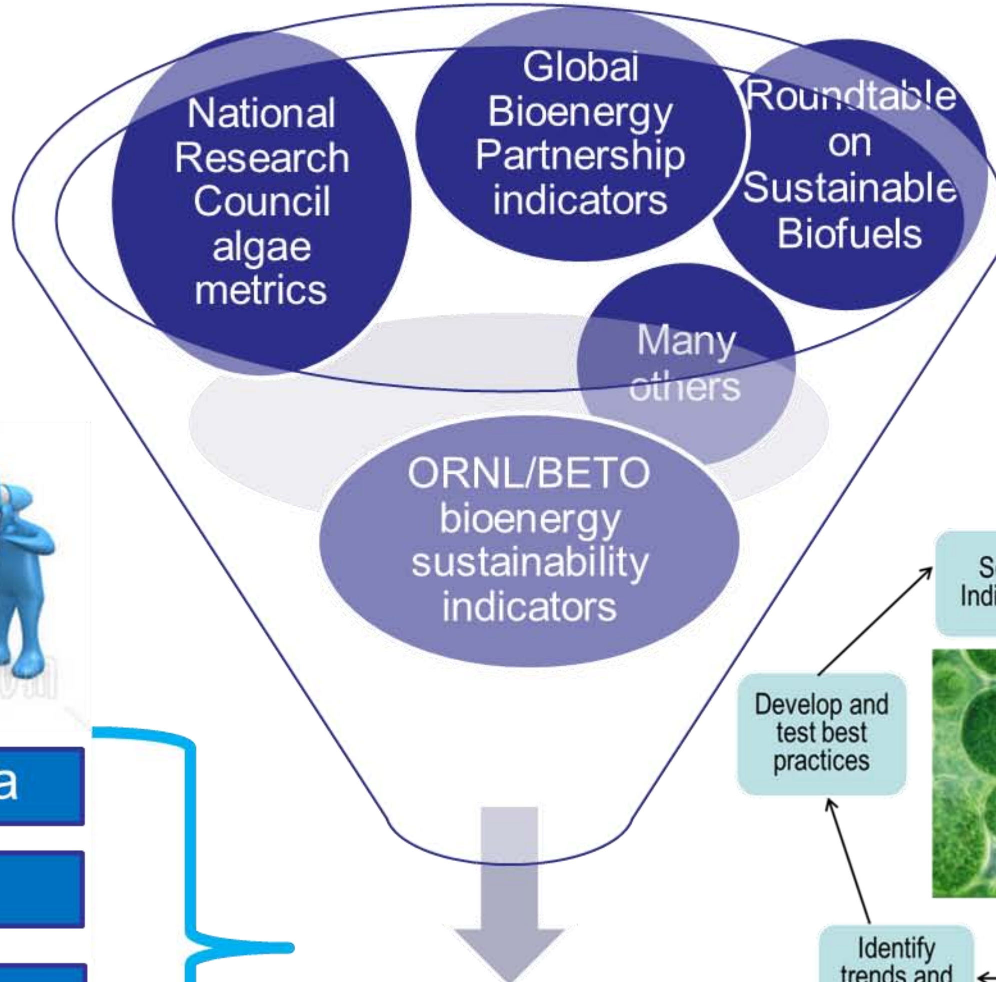
Resources in POLYSYS (feedstock market simulation model):



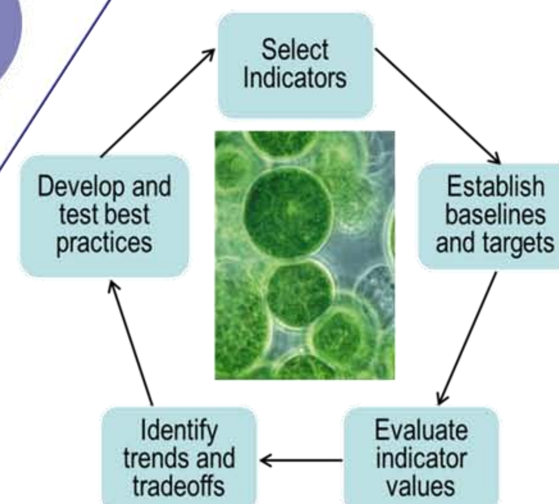
1 – Approach—Sustainability (1)

Research
- Industry
- National laboratories
- Universities

- Strain selection criteria
- Supply chain steps
- Open vs closed system
- Algae vs vascular crop



Practical, science-based generic set of sustainability indicators for algal biofuel



1 – Approach—Sustainability (2)

	Indicator
Soil quality	1. Total organic carbon (TOC)
	2. Total nitrogen (N)
	3. Extractable phosphorus (P)
	4. Bulk density
Water quality and quantity	5. Nitrate conc. in streams (and export)
	6. Total phosphorus (P) conc. in streams (and export)
	7. Suspended sediment conc. in streams (and export)
	8. Herbicide conc. in streams (and export)
	9. Storm flow
	10. Minimum base flow
	11. Consumptive water use (incorporates base flow)

	Indicator
Greenhouse gases	12. CO_2 equivalent emissions (CO_2 and N_2O)
Biodiversity	13. Presence of taxa of special concern
	14. Habitat area of taxa of special concern
Air quality	15. Tropospheric ozone
	16. Carbon monoxide
	17. Total particulate matter less than 2.5µm diam. ($PM_{2.5}$)
	18. Total particulate matter less than 10µm diam. (PM_{10})
Productivity	19. Aboveground net primary productivity (ANPP) / Yield

Product of Project 11.1.1.5

McBride et al. (2011) *Ecological Indicators* 11:1277-1289

1 – Approach—Resource Analysis (4)

FY12: Evaluate algae/terrestrial land competition

1. Pastureland is used for algae production in Wigmosta et al. (2011).
2. Pastureland is also used for terrestrial feedstock in POLYSYS, the economic model used in the Billion-Ton Update.

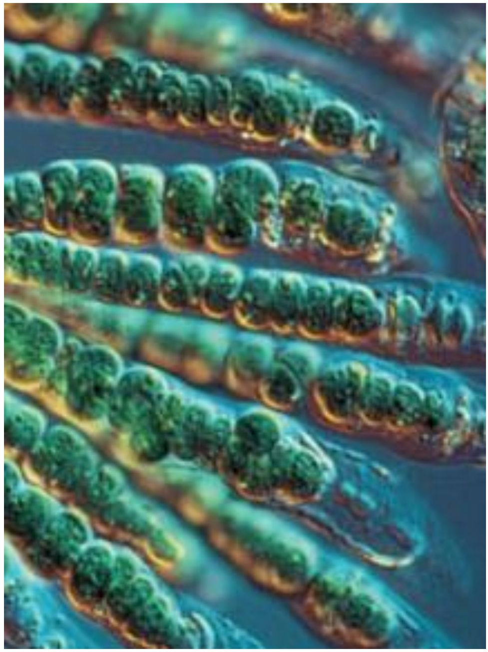
FY13: Incorporate algae into economic modeling.

1. Add algae module to POLYSYS.
2. Incorporate algae production budgets.
3. Make pasture rental rates endogenous.

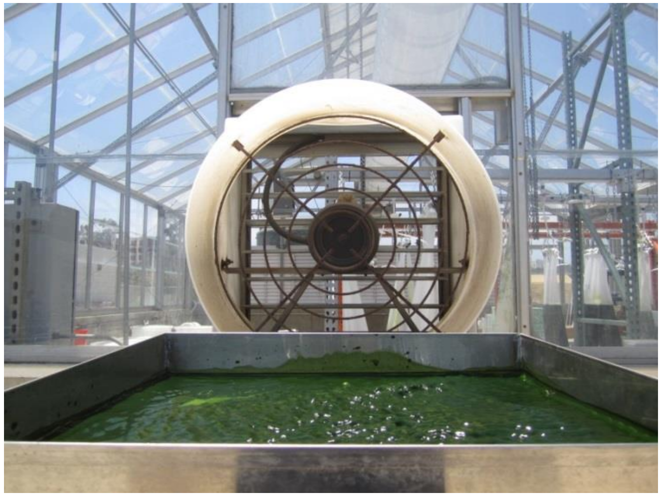
FY14-FY15: Assess economic availability of algal feedstocks

1. Include algae in economic modeling.
2. Niche applications (e.g., co-location).
3. Continue coordination with PNNL, others.

2 - Technical Accomplishments/ Progress/Results (1)



- **FY 13 Q1 Milestone met**
  - Presented webinar on progress on sustainability indicators and solicited feedback from PNNL, INL, NREL, and ANL and National Alliance for Advanced Biofuels and Bioproducts
- **FY13 Q2 Milestone met**
  - Beta version of Algae Production Module in POLYSYS completed and test scenarios defined.
- **Other progress**
  - Efroymson and Dale participated in invited workshop "Data needs and testing methods for assessing the safety of a field release of synthetically designed algae for biofuel production," sponsored by EPA, Woodrow Wilson Center, and MIT
  - Collaboration with PNNL on resource assessment was initiated.



San Diego Center for Algal Biotechnology

2 - Technical Accomplishments/ Progress/Results (2)

Algal Biofuel Difference	Sustainability Indicator Consequence
No local soil resource use	Most soil quality indicators not important
Some algae grown in salt water	Salinity important water quality measure
CO_2 needed	Added CO_2 factored into GHG indicator
Resources may limit locations	Resource availability indicators needed
Photobioreactors not interacting with ecosystem	Industrial sustainability indicators may be useful
Commercial-scale development in the future, not present	Indicators should be able to be simulated
Variety of potential supply chains	Practical indicators applicable to most supply chains
Potential occupational hazards	Indicator (e.g., toxin) measurable/predictable at local scale
Breaches from natural disasters possible	Same water quality indicators; frequency of measure important
Fuels may be different in structure and manufacturing process	Air quality indicators possibly custom fit to product

2 - Technical Accomplishments/ Progress/Results (3)

Coordinating algae resource assessment efforts with PNNL

Wigmosta et al. (2011): microalgae have the potential to generate 58 × 10^9 g yr^{-1} of oil on 126 million acres of land, including 3 million acres of privately-owned pasture land across the U.S.

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]

Received 31 August 2010; revised 20 January 2011; accepted 11 February 2011; published 13 April 2011.

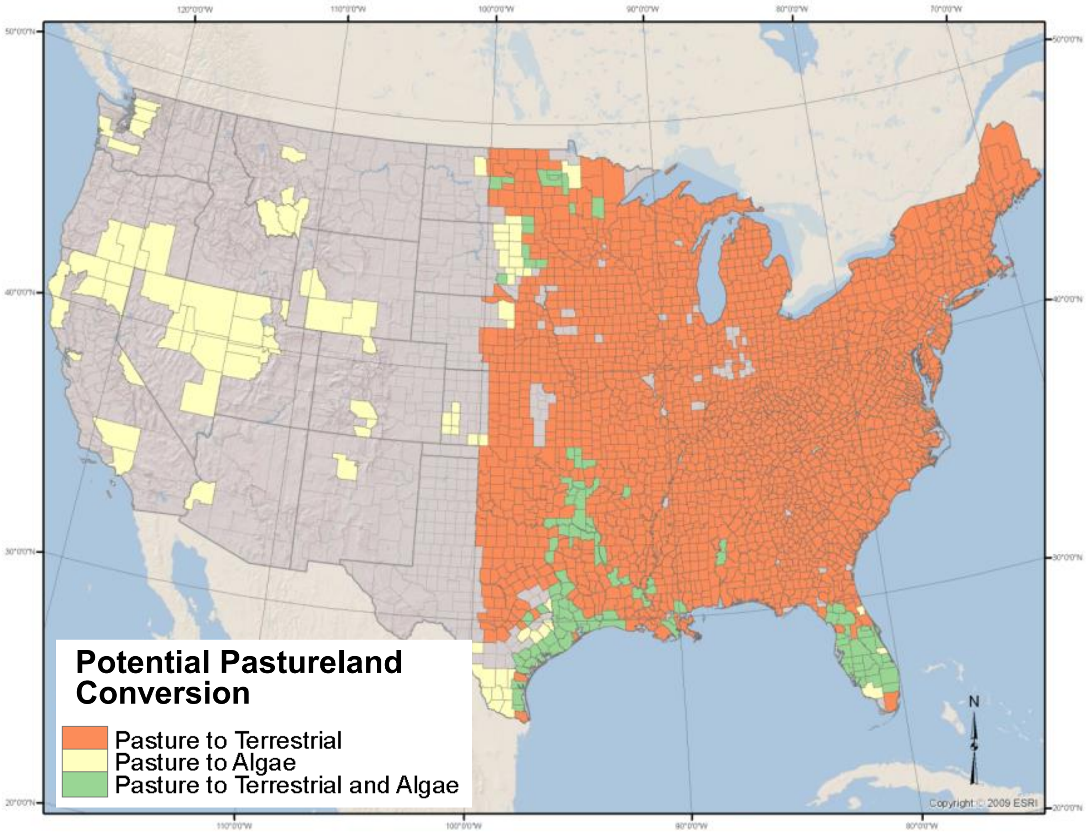
[1] Microalgae are receiving increased global attention as a potential sustainable "energy crop" for biofuel production. An important step to realizing the potential of algae is quantifying the demands commercial-scale algal biofuel production will place on water and land resources. We present a high-resolution spatiotemporal assessment that brings to bear fundamental questions of where production can occur, how many land and water resources are required, and how much energy is produced. Our study suggests that under current technology, microalgae have the potential to generate 220 × 10^9 L yr^{-1} of oil,

DOE (2011) models economic availability of terrestrial feedstocks. Allows for conversion of some pasture east of the 100th meridian.

2 - Technical Accomplishments/ Progress/Results (4)

In review: "Potential Land Competition Between Open-Pond Microalgae Production and Terrestrial Dedicated Feedstock Supply Systems in the U.S." (ORNL and PNNL)

110 counties with potential competition between terrestrial feedstocks and algal feedstocks for private pastureland.



2 - Technical Accomplishments/ Progress/Results (5)

In review: "Potential Land Competition Between Open-Pond Microalgae Production and Terrestrial Dedicated Feedstock Supply Systems in the U.S." (ORNL and PNNL)

Increasing land competition

Pasture land competition Index	Count of counties	Area to terrestrial (thousand ha)	Area to algal (thousand ha)	Combined pasture conversion (thousand ha)	Census private pasture (thousand ha)	% of Census pasture in 110 counties	% of private pasture in U.S.
0-0.19	7	42	6	49	462	1%	0.0%
0.2-0.39	65	1,126	141	1,267	3,942	19%	0.8%
0.4-0.59	25	434	358	792	1,564	12%	0.5%
0.6-0.79	5	39	147	186	272	3%	0.1%
0.8-1.0	3	27	106	133	155	2%	0.1%
>1	5	33	210	243	202	4%	0.1%
Total	**110**	**1,702**	**967**	**2,671**	**6,598**	**40%**	**1.6%**

Land competition expected to be minimal.

3 – Relevance (1)

Project contributes to meeting platform goals and objectives of BETO Multi-Year Program Plan

	Task 1 Sustainability	Task 2 Resource Analysis
Targets	-By 2022, evaluate, quantify, and document sustainable integrated pilot-scale production of biofuels from agricultural residues, . . . and algae	-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
Milestones	-By 2022, evaluate and compare the sustainability of biofuel production pathways -By 2022, demonstrate sustainable biofuel production from all feedstocks	-By 2016, produce a fully integrated assessment of the potentially available feedstock supplies under specified criteria and conditions

3 – Relevance (2)

- ***Project considers applications of expected outputs***
  - **Sustainability indicators** will be useful for
    - Comparing current measurements to baselines
    - Modeling future sustainability components, both for individual projects and for aggregation across regions or the nation
    - Generating targets
    - Comparing bioenergy scenarios to business-as-usual scenarios or other feedstocks
    - Developing new life-cycle-analysis units
    - Developing best management practices
    - Certification programs
  - **POLYSYS modifications** will be useful for
    - Resource analysis
    - Comparing economic feasibility of algae to other feedstocks

Compare with other feedstocks

Compare with petroleum diesel

4 - Critical Success Factors

- **Technical & commercial viability are defined in part by**
  - Sustainability
    - Efficiency of resource use
    - Productivity
    - Compliance with environmental regulatory frameworks (Clean Water Act, Energy Independence and Security Act)
    - Social acceptability (e.g., genetically engineered organisms)
    - Profitability
  - Resource analysis
    - Where to site algal biofuel facilities
    - How much fuel can be produced

- **Challenges for achieving results include**
  - Data from industry
  - Case study with minimal proprietary data
  - Diversity of potential supply chains
- **Project success will positively impact commercial viability of bioenergy**
  - Environmental, economic, and social factors can impede commercial viability of energy technologies
  - Measuring these factors and mitigating unfavorable ones early will speed social acceptance of commercialization

5. Future Work (1)

FY13 Milestones

Task	Milestone	Date
Sustainability	Draft environmental sustainability indicators for algal biofuels	June 2013
Resource analysis	POLYSYS Modified based on refined economic assumptions & sustainability constraints	September 2013

FY14 Plans

- Evaluate socioeconomic indicators for applicability to algal biofuels
- Begin to develop regional or case-specific targets for indicators
- Refine algae production costs in POLYSYS
- Account for competition for water, fertilizer, CO_2, and other resources

Decision Points

- If environmental and socioeconomic indicators are very intertwined, then the latter will be integrated in analysis.
- If there are no adequate sites for case studies, then large-scale of implementation of indicators and targets will be delayed.
- If algal feedstock is planned for non-pasture lands, then new areas must be considered in resource analysis.

5. Future Work (2)

Focus on socioeconomic sustainability indicators

External trade

Category	Indicator
Social well-being	Employment
	Household income
	Work days lost due to injury
	Food security
Energy security	Energy security premium
	Fuel price volatility
External trade	Terms of trade
	Trade volume
Profitability	Return on investment (ROI)
	Net present value (NPV)[2]

Category	Indicator
Resource conservation	Depletion of non-renewable energy resources
	Fossil Energy Return on Investment (fossil EROI)
Social acceptability	Public opinion
	Transparency
	Effective stakeholder participation
	Risk of catastrophe

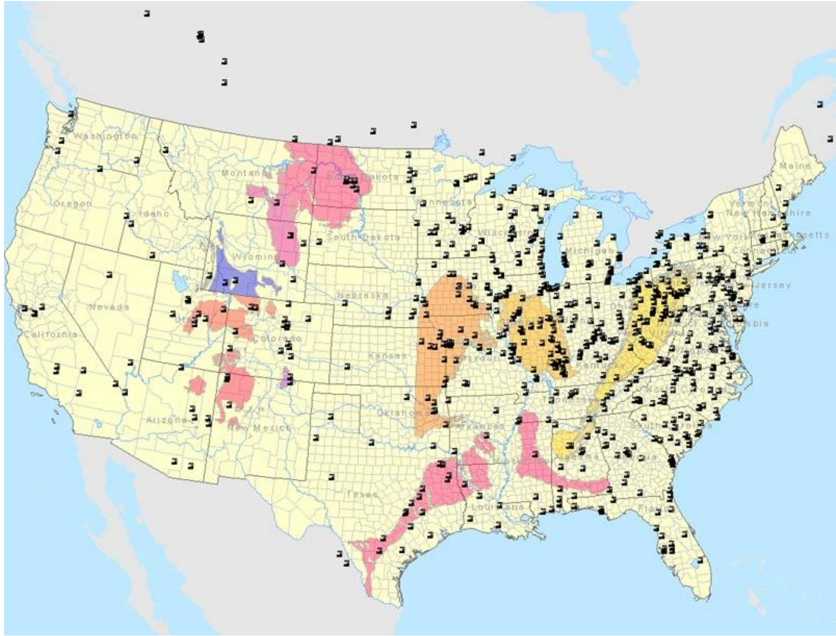
[shaded cells:] *Ten minimum practical measures* (Employment; Household income; Work days lost due to injury; Fuel price volatility; Trade volume; Net present value (NPV); Depletion of non-renewable energy resources; Fossil Energy Return on Investment (fossil EROI); Public opinion; Transparency)

Dale et al. (2013) *Ecological Indicators* 26: 87-102. Product of Project 11.1.1.5

5. Future Work (3)

- **Resource Analysis**
  - Identify scenarios (cost of production and biofuel price) at which algae production becomes economically competitive with alternative uses.
  - Complement other algae resource assessments with emphasis on economics and landowner profit maximization.
  - Niche applications (e.g., co-location with coal plants) to be executed outside of POLYSYS.

Algae residue powder for cattle feed (photo from Texas A&M)



Coal-fired power plants can supply CO_2 (map from NETL)

Summary

- **Relevance**
  - Conduct sustainability and resource analysis R&D for algae so that it catches up to R&D on other feedstocks in bioenergy portfolio
- **Approach**
  - Task 1. Evaluate biofuel sustainability indicators for relevance to algae; ultimately develop targets and best management practices
  - Task 2. Refine economic assumptions and sustainability constraints related to algal biofuels and modify tools for resource assessment
- **Technical accomplishments**
  - Webinar on sustainability indicators; engaged research community
  - Beta version of Algae Production Module in POLYSYS
- **Future work**
  - FY13—Environmental sustainability indicators; modified POLYSYS model
  - FY14—Socioeconomic sustainability indicators; production costs based on resource competition
- **Success factors and challenges**
  - Success = use of sustainability indicators and accuracy of resource analysis
  - Challenges = obtaining data from industry and uncertainties in future dominant supply chains

Additional Slides

Responses to Previous Reviewers' Comments

- No previous peer review comments

Publications and Presentations

- No publications yet. This is a new project.