DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

1.3.1.500 Sustainable Development of Algae for Biofuel

March 24, 2015

Algae Technology Area Review

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Presenters: Virginia Dale, Matthew Langholtz

ORNL Center for BioEnergy Sustainability

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Goal Statement

To conduct

1) **Sustainability** studies (evaluate indicators and develop best practices)
2) **Resource analysis** (quantify supply of 'low-hanging fruit' biomass)
3) Experimental work on algal **polycultures** to increase yield

Relevant to DOE Algae Technology Area goals

To develop production and logistics technologies that could support production of 5 billion gallons per year of sustainable, reliable, & affordable algal biofuels by 2030

- By 2017, model sustainable supply of 1 million metric tonnes ash free dry weight (AFDW) cultivated algal biomass (task 1 and 2)
- By 2018, demonstrate annual algal biomass productivity of 20-30 g/m^2/day AFDW (task 3)
- By 2022, model sustainable supply of 20 million metric tonnes AFDW cultivated algal biomass (task 1 and 2)

Relevant to DOE Sustainability Area goals

To understand and promote positive economic, social, and environmental effects and reduce potential negative impacts of bioenergy production

- By 2022, evaluate environmental and socioeconomic indicators across supply chain for algal bioenergy production systems to validate 50% GHG reduction, socioeconomic benefits, water consumption equal to that for petroleum, and wastewater and air emissions that meet federal regulations (task 1)

Quad Chart Overview

Timeline

- Project start date: FY13
- Project end date: FY18
- Percent complete: 14%
  (as of Feb 2015)

Barriers

- **Aft-A. Biomass Availability and Cost** (lack of credible data on potential price, location, environmental sustainability & quantity of algal biomass feedstock)
- **Aft-B. Sustainable Algae Production** (lack of data on environmental effects; need to address productivity issues and liner use)
- **St-D. Implementing Indicators** and methodology for evaluating and improving sustainability
- **St-E. Best Practices and Systems** for sustainable bioenergy production

Budget

	Costs (K)				
	FY 10-12	FY 13	FY 14	FY 15	FY 16-18
DOE Funds	0	263	183	800*	3078**
Cost Share	0	0	0	0	0

* Budget **Planned funding level

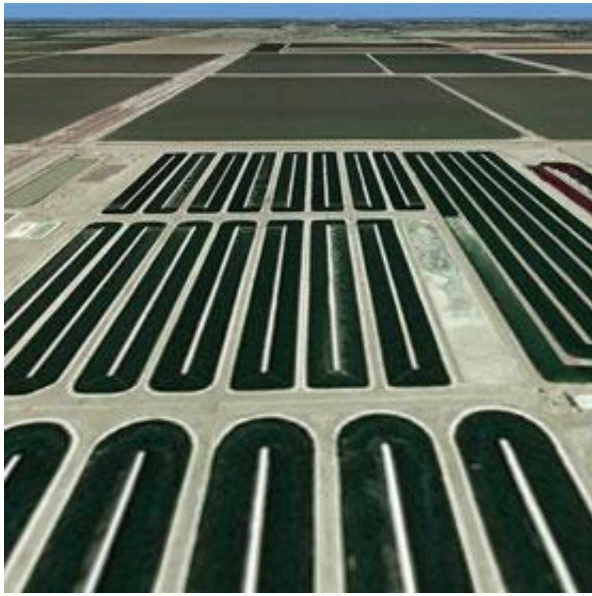
Partners

- Contractor: Longitude 122 West
- Academic: (U Tennessee, UC San Diego, U Kansas)
- National labs: (PNNL, INL, SNL)
- Industry (in kind): Sapphire Energy, Algenol Biofuels, Bioprocess Algae
- Algae Biomass Organization

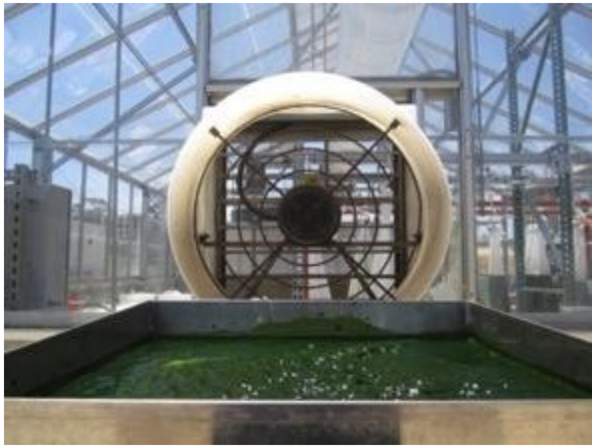
Project Overview

Objectives and History (2.5 of 3 tasks are new)

- **Task 1. Sustainability**
  - Began FY13, grew out of participation in NRC committee on sustainable algal biofuels
  - Identified indicators and targets and moving toward best management practices
  - New subtask on pond bioliners in FY15
- **Task 2. Resource analysis**
  - Grew out of
    - Collaboration with PNNL
    - Industry request to consider algae in Billion Ton studies
  - Identifying co-location opportunities and develop algae supply curves
  - New direction following Go/No-go, end of FY14
- **Task 3. Polycultures**
  - Grew out of research need to go beyond monocultures
  - Optimizing conditions for increased yield of algae
  - New task in FY15

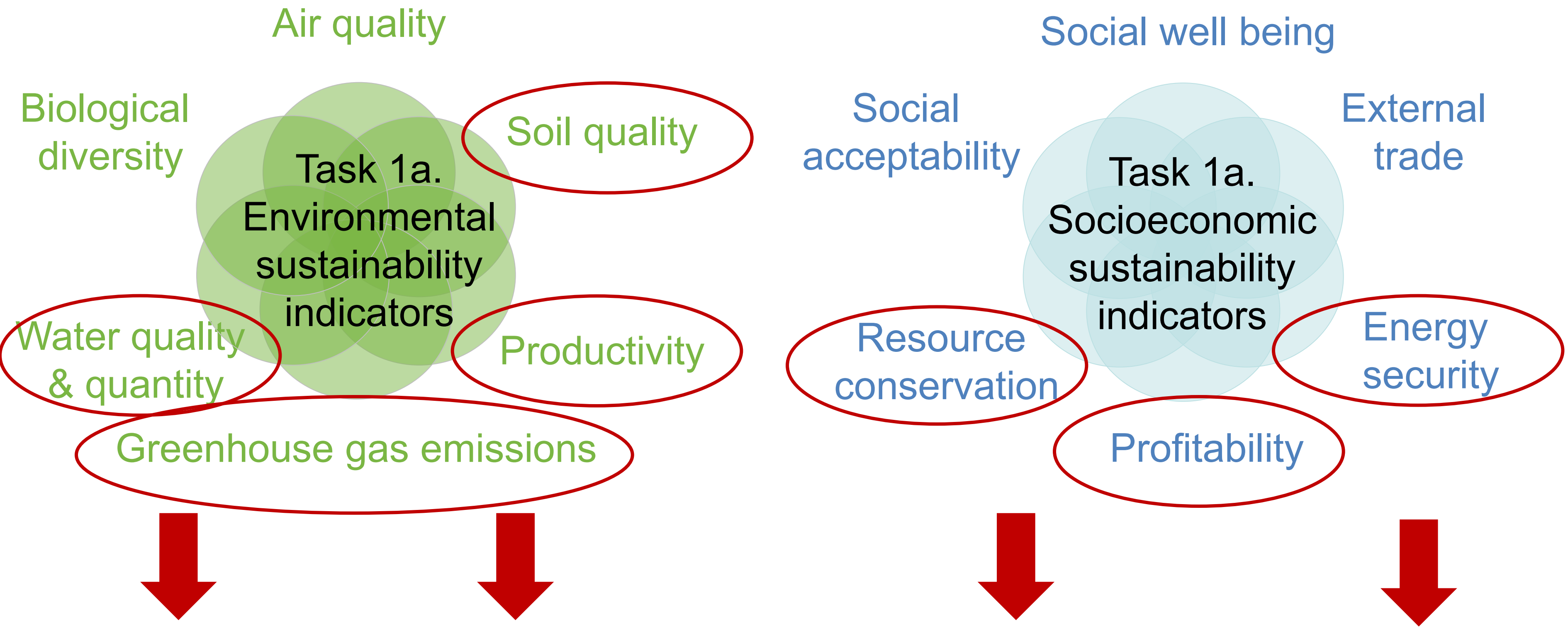


PNNL photo



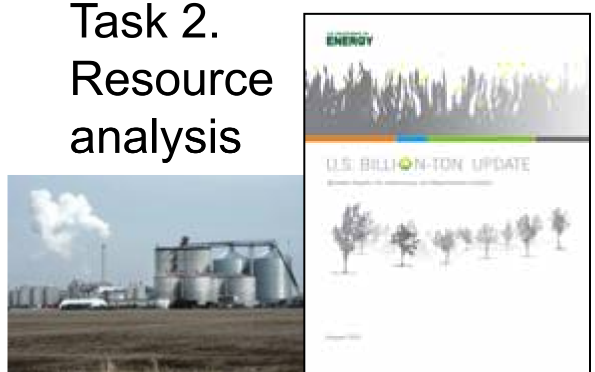
San Diego Center for Algal Biotechnology

Project Overview



Task 1b.
Pond bioliner

Task 2.
Resource analysis



Task 3. Increased yield from polycultures

Project Management Plan

Management processes

- Interactions with industry, consultants, postdocs, and graduate students
- Handoffs of information to and from other national labs (INL, PNNL, SNL)
- Integration with Project 1.3.1.102 Microalgae Analysis; 4.2.2.40 Bioenergy Sustainability: How to Define and Measure it; 1.2.3.1 Feedstock Supply Modeling; 1.3.2.401 Microalgal Polycultures; 1.3.1.103 Polyculture Analysis
- Integration with Billion Ton 2016 report team
- Webinars and conference calls with BETO; review of products by BETO
- Joint reports and papers

Task 1. Sustainability

- Rebecca Efroymson (PI) and Virginia Dale (ORNL)—sustainability indicators
- Melanie Mayes (ORNL)—experimental biogeochemistry of soils
- Val Smith (U Kansas)—algal systems

Task 2. Resource analysis

- Matt Langholtz (ORNL)—economic supply curves
- Susan Schoenung (Longitude 122 West)—engineering parameters

Task 3. Polyculture

- Teresa Mathews (ORNL)—algal ecology
- Jonathan Shurin (UC San Diego)—algal ecology and crop protection

Objectives—Task 1. Sustainability

Fig. 2.38 from BETO's Multi-Year Program Plan (MYPP)

Potential cost savings for avoiding HDPE liners

- 25% of cultivation/processing costs[1]
- 24% of capital costs for a facility[2]
- 75% of capital costs for a facility[3]

Uses of sustainability indicators

- Modeling future effects
- Energy comparisons
- Units for life-cycle analysis
- Certification

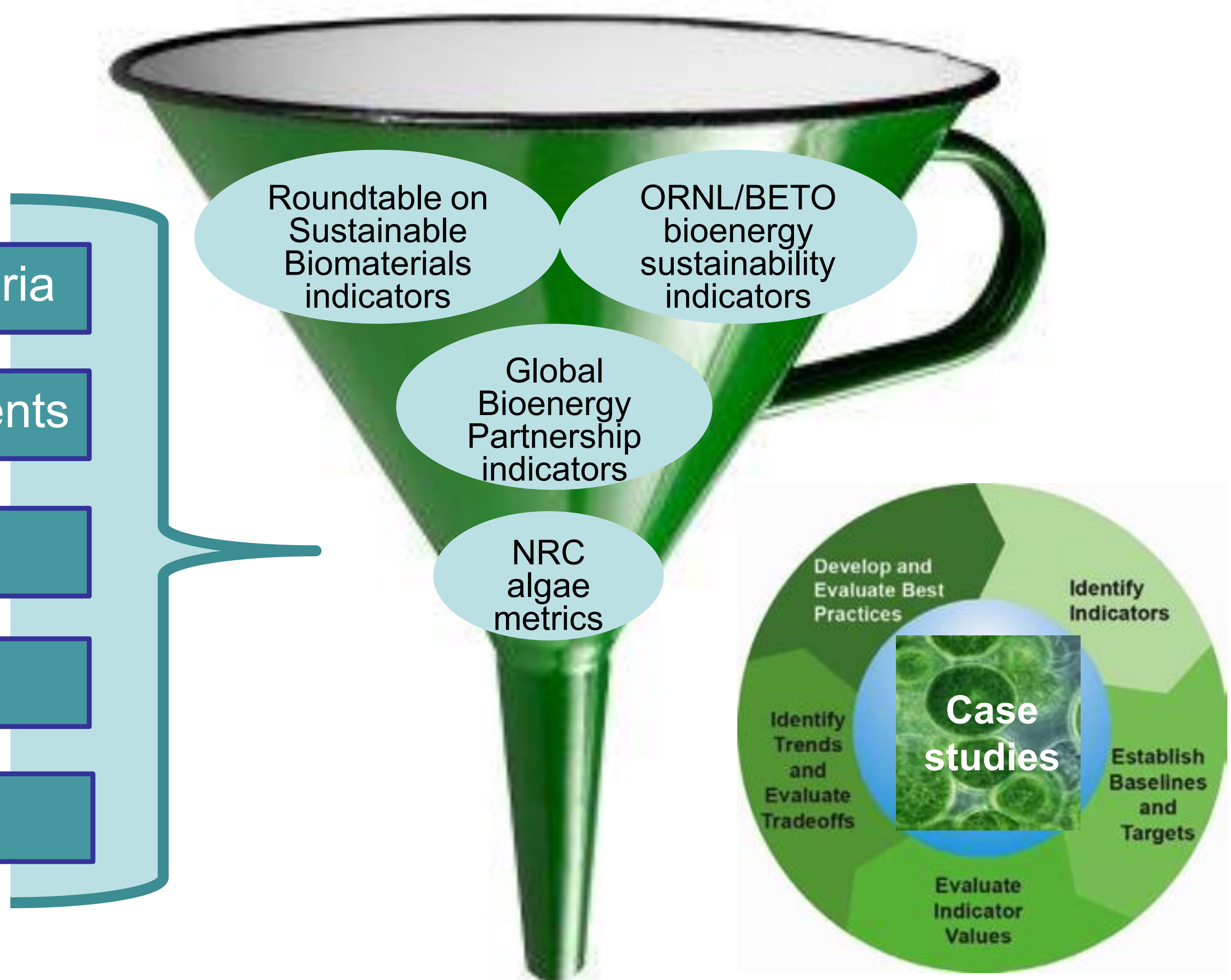
Development of pond bioliners as alternative for HDPE

- Improve profitability
- Maintain water quality and quantity

[1] Davis et al. 2014. *Environ Sci Technol* 48:6035-6042
[2] Rogers et al. 2014. *Algal Research* 4:76-88
[3] Coleman et al. 2014. *Algal Research* 5:79-94

Approach—Task 1a. Sustainability

- Strain selection criteria
- Resource requirements
- Infrastructure
- Cultivation media
- Supply chain steps



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

Technical accomplishments—Task 1a. Environmental sustainability indicators

Red ovals indicate differences from general bioenergy sustainability indicators

Category	Indicator
Soil quality	1. Bulk density
Water quality	2. Nitrate export
	3. Total P export
	4. Salinity
Water quantity	5. Peak storm flow
	6. Minimum base flow
	7. Consumptive water use
Greenhouse gases	8. CO_2 equivalent emissions (CO_2 and N_2O)

Category	Indicator
Biodiversity	9. Presence of taxa of special concern
	10. Habitat area of taxa of special concern
	11. Abundance of released algae
Air quality	12. Tropospheric ozone
	13. Carbon monoxide
	14. Total particulate matter less than 2.5μm diam
	15. Total particulate matter less than 10μm diam
Productivity	16. Primary productivity or yield

Efroymson RA, VH Dale. 2015. Environmental indicators for sustainable production of algal biofuels. *Ecological Indicators* 49:1-13 (published online in 2014)

Technical accomplishments—Task 1a. Socioeconomic sustainability indicators

Identical to indicators developed for bioenergy in general

Category	Indicator
Social well-being	1. Employment
	2. Household income
	3. Workdays lost to injury
	4. Food security
Energy security	5. Energy security premium
	6. Fuel price volatility
External trade	7. Terms of trade
	8. Trade volume
Profitability	9. Return on investment
	10. Net present value

Category	Indicator
Resource conservation	11. Depletion of non-renewable energy resources
	12. Fossil energy return on investment
Social acceptability	13. Public opinion
	14. Transparency
	15. Effective stakeholder participation
	16. Risk of catastrophe

Efroymson et al. submitted. Socioeconomic indicators for sustainable production of algal biofuels. *Ecological Indicators*

Technical accomplishments—Task 1a. Industry interactions

- **Queries of industry regarding**
  - Their ongoing measurements of environmental sustainability
  - Interest in categories of sustainability that they are not already measuring
  - Interest in potential cases studies
  - Industry data available to support case studies
  - Possibility of using case study to help site selection

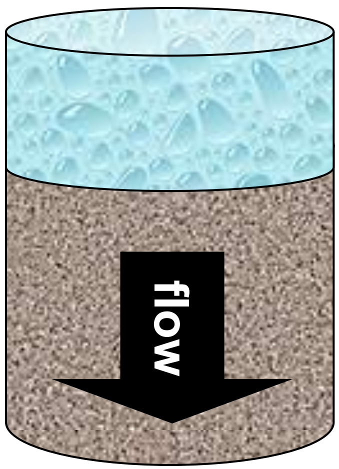
- **Preliminary conclusions**
  - Industry is measuring sustainability
  - Industry has prioritized on-site sustainability over regional environmental sustainability
  - Accident scenario case study involving off-site transport of algae and nutrients would be useful
  - Challenge: availability of data to support case study, given confidentiality concerns

Approach—Task 1b. Pond bioliner

Goal is to avoid costly HDPE liners in algal facilities by creating conditions for native soils to form pond bioliners

Approach:

Lab-scale soil column experiments designed to promote soil pore clogging through particle movement & biofilm growth



Biological and physical processes reduce soil hydraulic conductivity to protect underlying groundwater (~10^{-7} cm/s)

NATURAL BIOLINER

Critical success factor:

Need to identify critical soil properties required for pond bioliner formation

Potential challenges:

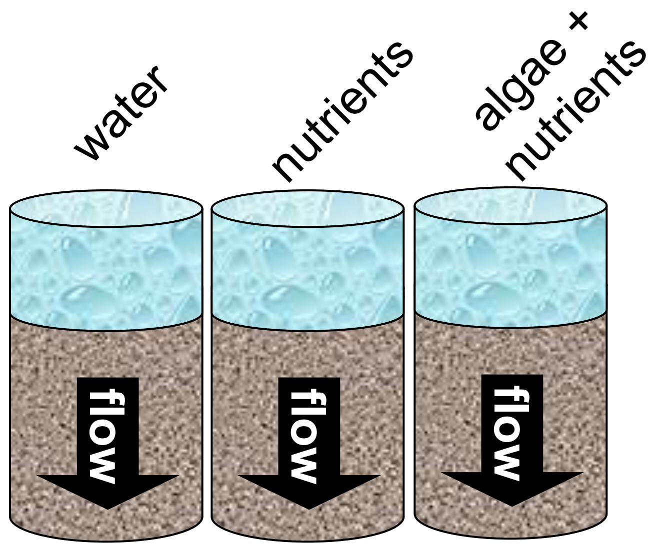
- While approach works in other types of waste holding facilities, will it work with algae?
- Need to test diverse soil particle size distributions to be applicable to many sites (not only clay soils)

Example soil: Deep clay from phosphate-mined lands

Future work—Task 1b. Pond bioliner

Lab experiments:

Water Chemistry Treatments



Alternate ponding & draining

Initial soil Particle Size Distributions

Measure effect of <u>Water Chemistry</u> and <u>Particle Size</u> on soil **hydraulic conductivity**

Outcomes:

Criteria to minimize leakage into ground water

Locations to deploy bioliners

Phase I
Mar-June 2015

Proof-of-principle design: column size, pond/drain frequency, etc.

Phase II
Jul-Dec 2015

Proof-of-principle test: 5 soils, 3 water chemistries

Phase III
Jan-Sep 2016

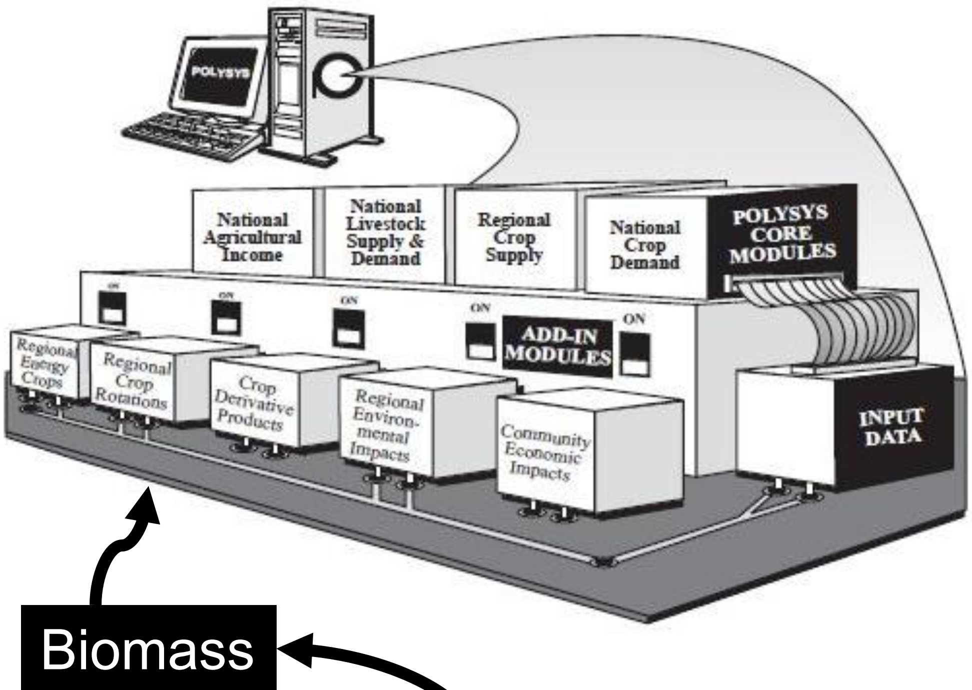
(depending on Phase II results)

- Continue proof-of-principle testing, <u>or</u>
- Test with real and proposed facility soils

Future work—Task 1. Sustainability

Sustainability task milestone	Date
• Complete preliminary lab-scale experiments on pond bioliners. • Design of experimental configuration (boundary conditions, choice of test soils, microbial growth substrates)	June 2015
• Complete report or paper on status of algal biofuel industry measurements of environmental sustainability	March 2016
• Complete pond bioliner experiments on 3 test soils with 2 microbial substrates	June 2016
• Complete report or paper on accident scenario case study	December 2016

Objectives—Task 2. Resource analysis



FY13 Objectives

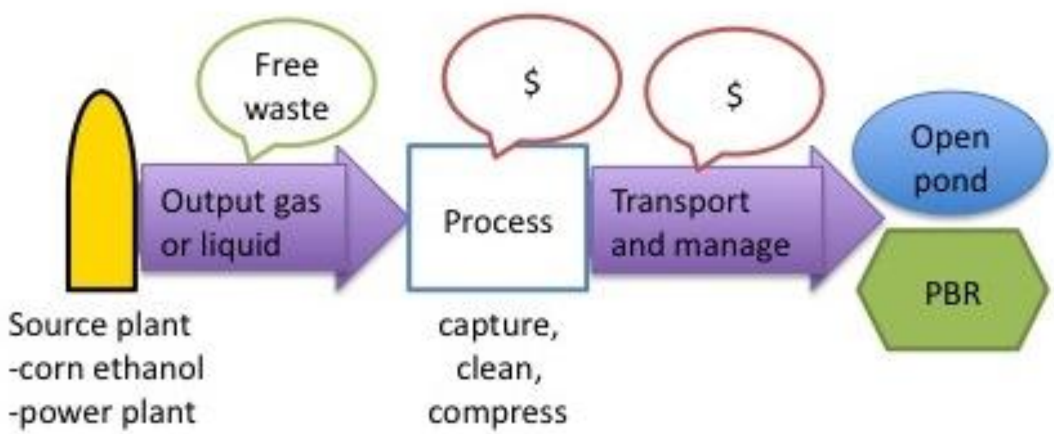
- Add algal biomass resources to POLYSYS (feedstock market simulation model)
- Algal biomass and oil prices very high compared to terrestrial feedstocks and oil

FY15 Objectives

- Quantify potential site-specific and national algal feedstock production and cost based on co-located resources (e.g., CO_2, waste heat, other nutrients)
- Investigate corn ethanol plants and power plants initially
- Identify cost-reducing co-location strategies
- Incorporate supply curves and prices in US Billion Ton 2016

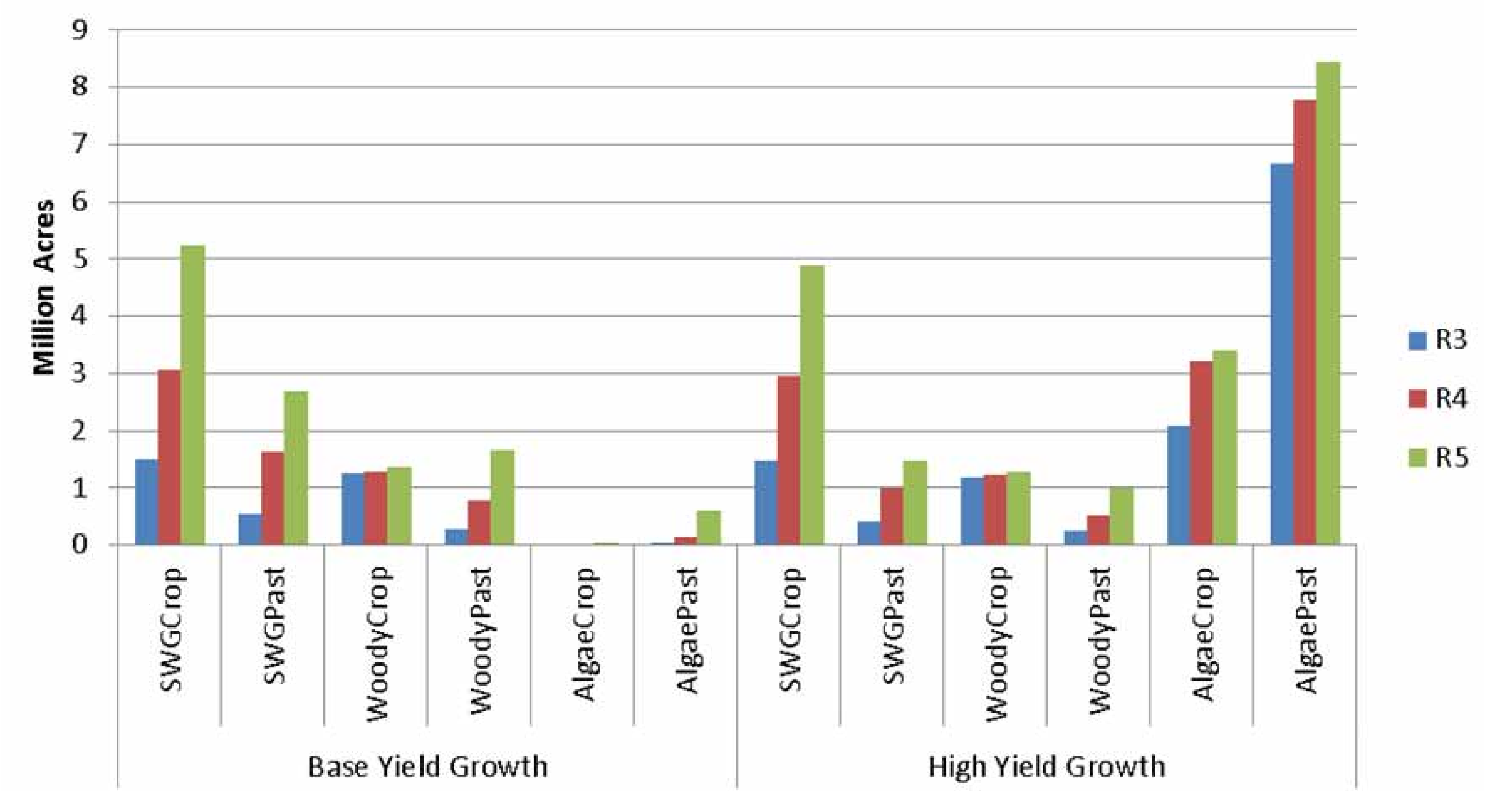
Approach—Task 2. Resource analysis

- Consult industry and scientific literature on engineering assumptions and cost
- Estimate cost differential between use of co-located resources (CO_2, heat, nutrients) and base case
- Consider photobioreactors and open ponds, 1000 acres of production
- Transfer assumptions to PNNL to generate biophysically-based production estimates and select priority land areas for resource co-location
- Generate supply curves for dry biomass
- Integrate with 1.2.3.1 Feedstock Supply Modeling to reveal post-harvest benefits of co-location
- Seek stakeholder feedback (e.g., Algae Biomass Organization)
- Challenge: Identify and quantify all costs



Technical accomplishments—Task 2. Resource analysis

- In review: “Potential land competition between open-pond microalgae production and terrestrial dedicated feedstock supply systems in the U.S.” (ORNL and PNNL)
- Minimal land competition between terrestrial and algal feedstock supply

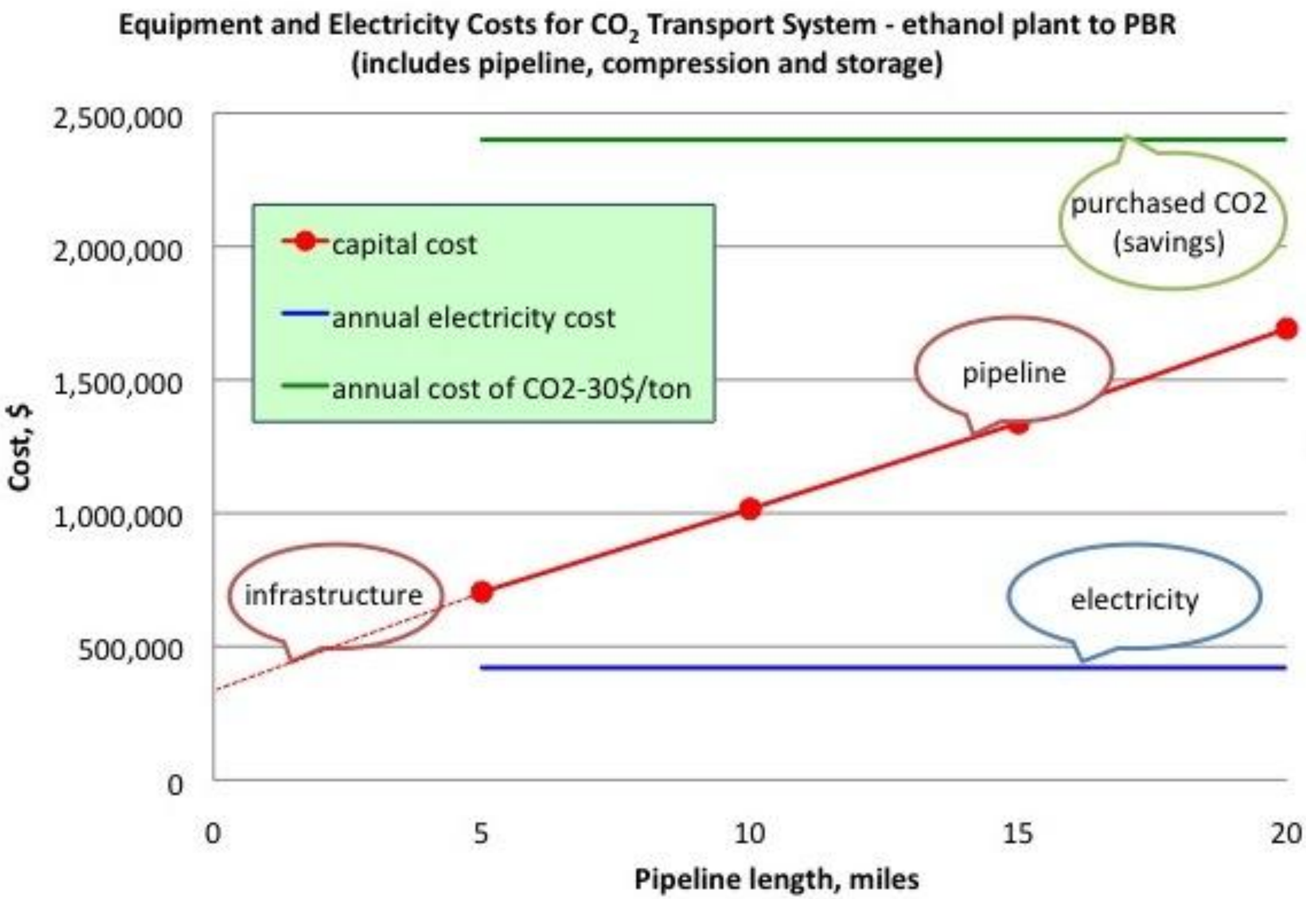


R3: \$600/dt Algae (\$7.06/gal Oil), \$60/dt Terrestrial
R4: \$660/dt Algae (\$7.76/gal Oil), \$66/dt Terrestrial
R5: \$720/dt Algae (\$8.47/gal Oil), \$72/dt Terrestrial

base yield growth: 5.2%/yr
high yield growth: 14.7%/yr
SWG=switchgrass

Technical accomplishments—Task 2. Resource analysis

- Decision framework identifying algae production technologies best suited to co-location strategies
- Unit costs for alternative resources, transport costs per unit distance, capital costs, and cost trades for CO_2 from ethanol plant

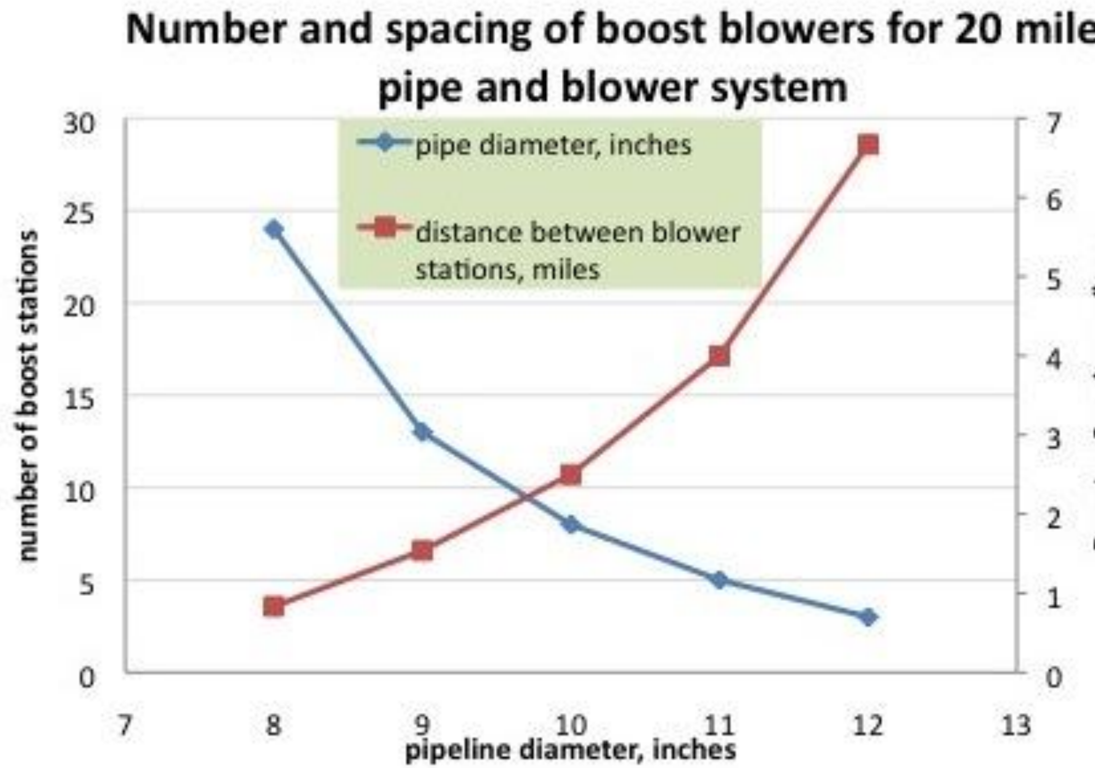


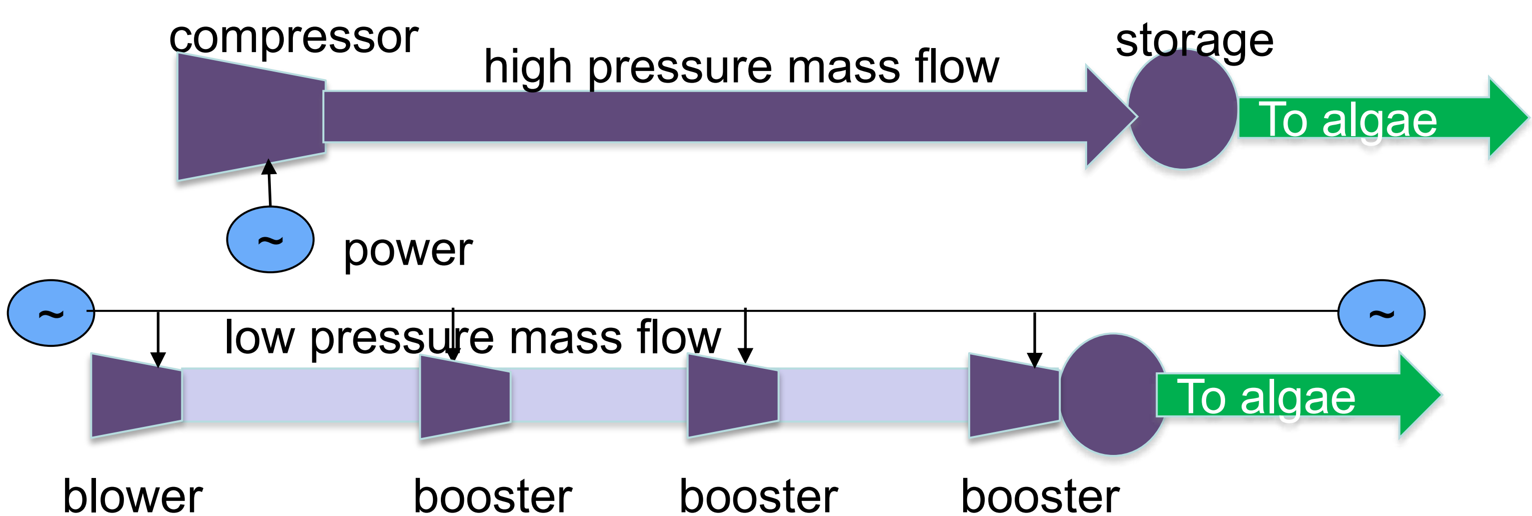
to PNNL

- Initial results for example systems show cost savings from CO_2 use from ethanol plants within **<u>about</u>** 20 miles or more and for power plants within **<u>about</u>** 5 miles

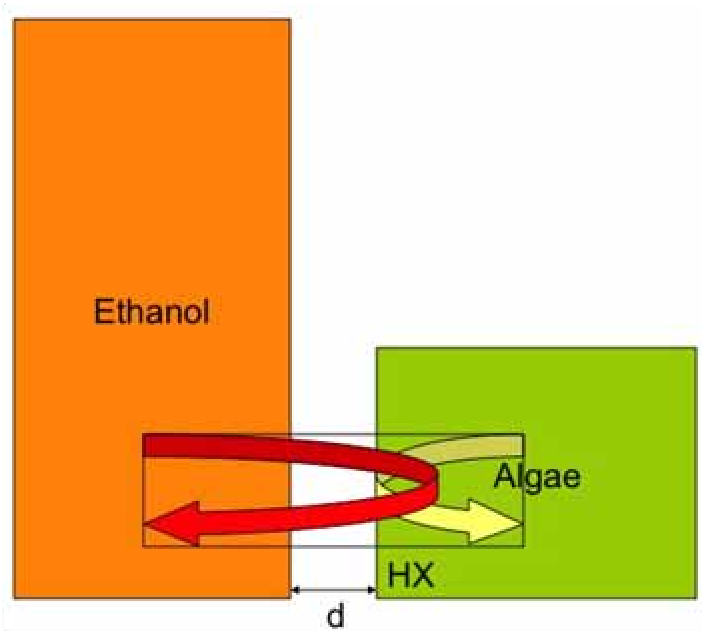
Technical accomplishments—Task 2. Resource analysis

Examined tradeoffs between alternative designs, e.g., CO_2 transport options

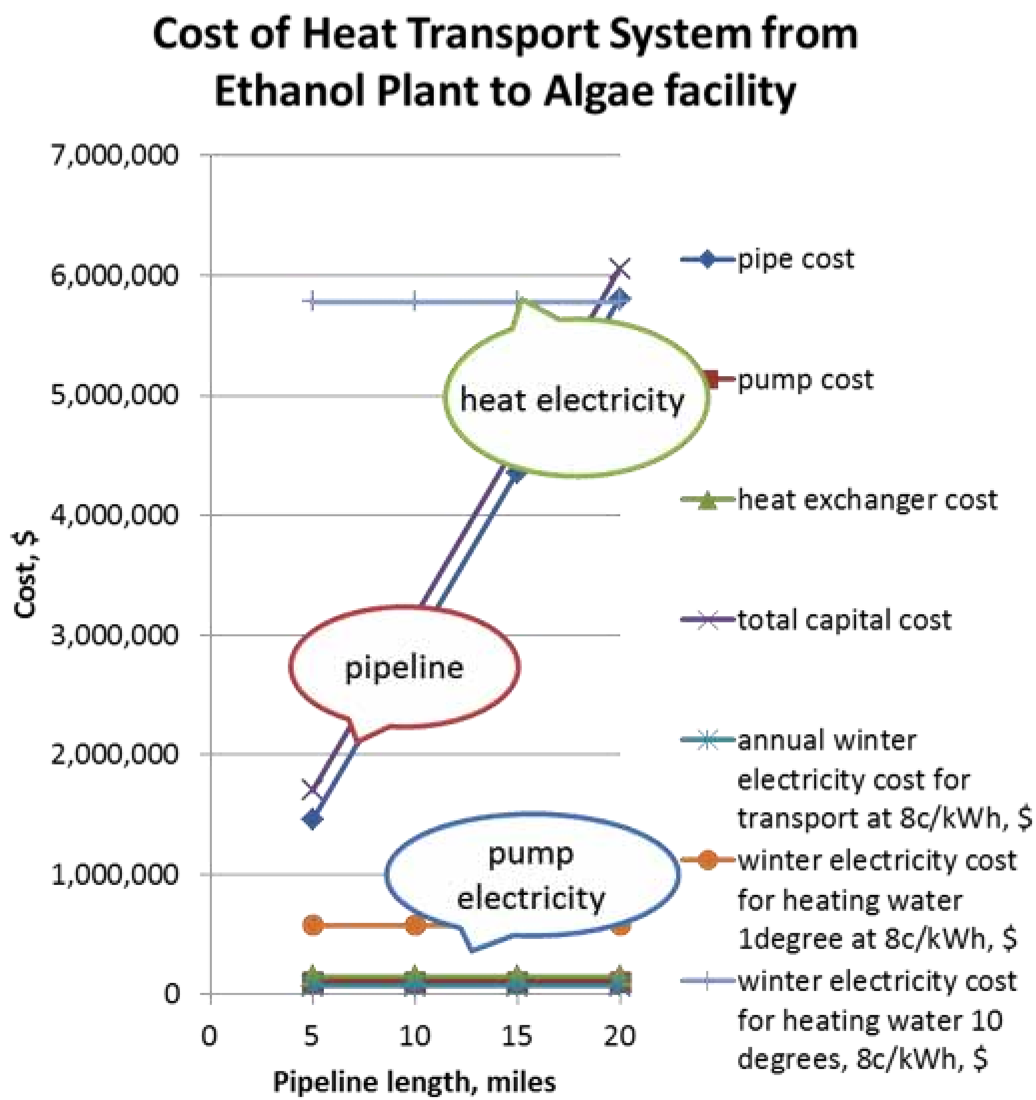




Technical accomplishments—Task 2. Resource analysis



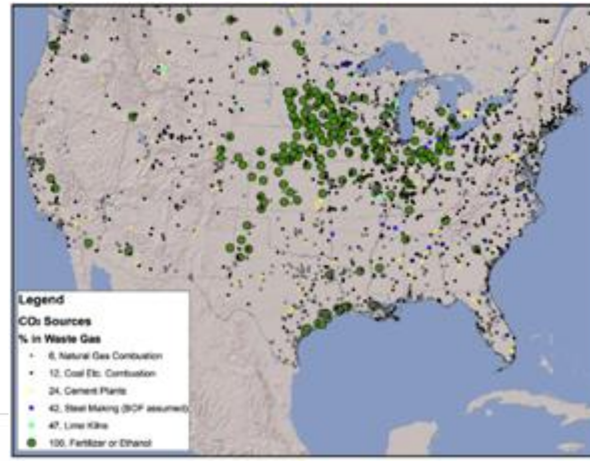
- Waste heat from ethanol plant is used to heat water for algae growth and washing/collection in PBR
- Costs are modeled similar to district heating
- Transport pipeline dominates cost
- Savings are still possible over water heating at the algae facility (depends on assumptions)

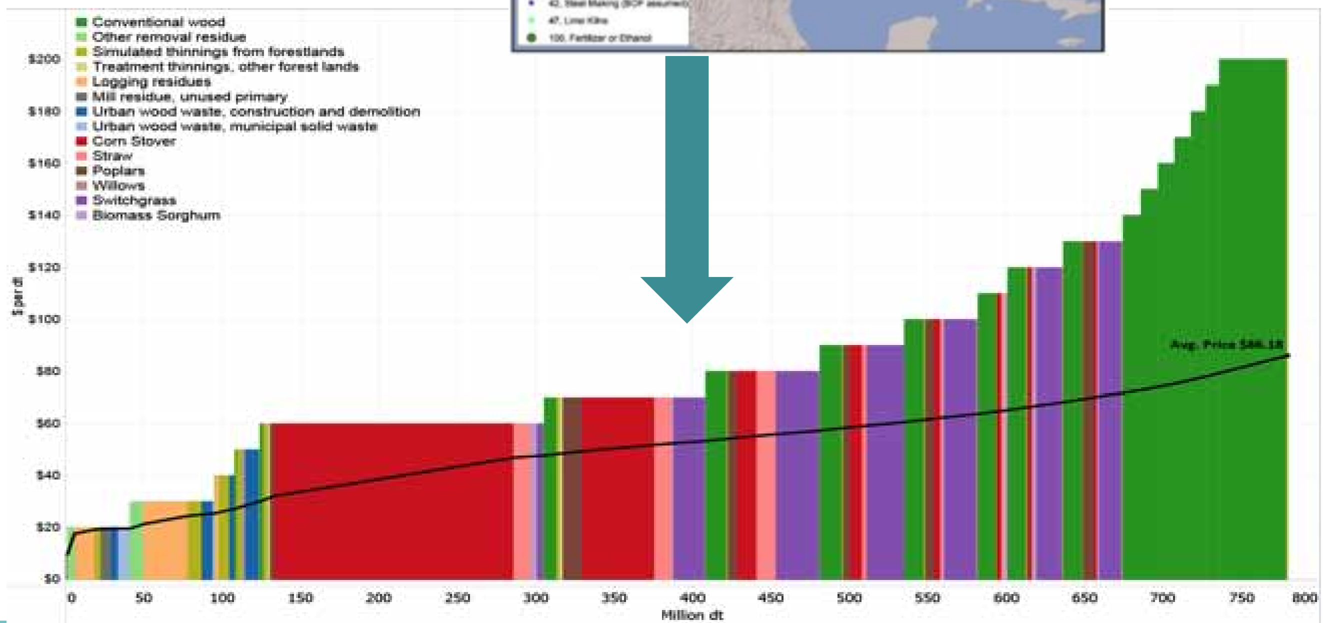


Future work—Task 2. Resource analysis

- Finalize analysis of co-location benefits of power plants
- Generate supply curves
- Consider co-location benefits of cement plants, ammonia plants, wastewater treatment

CO_2 sources (PNNL slide)



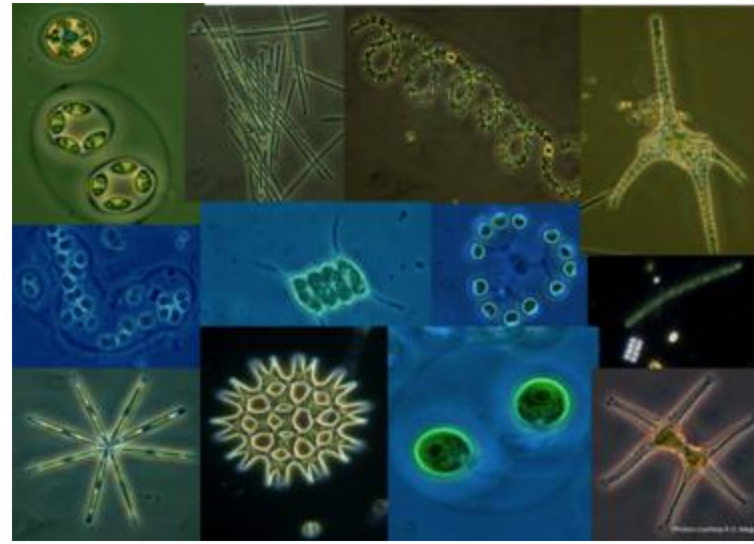


Milestone	Date
Generate supply curves illustrating economic availability of algae feedstocks under co-location scenarios with ethanol plants and power plants for use in Billion Ton 2016	September 2015
Generate supply curves illustrating economic availability of algal feedstocks under nutrient co-location scenarios, including wastewater	March 2016

Objectives—Task 3. Increased yield through algal polycultures

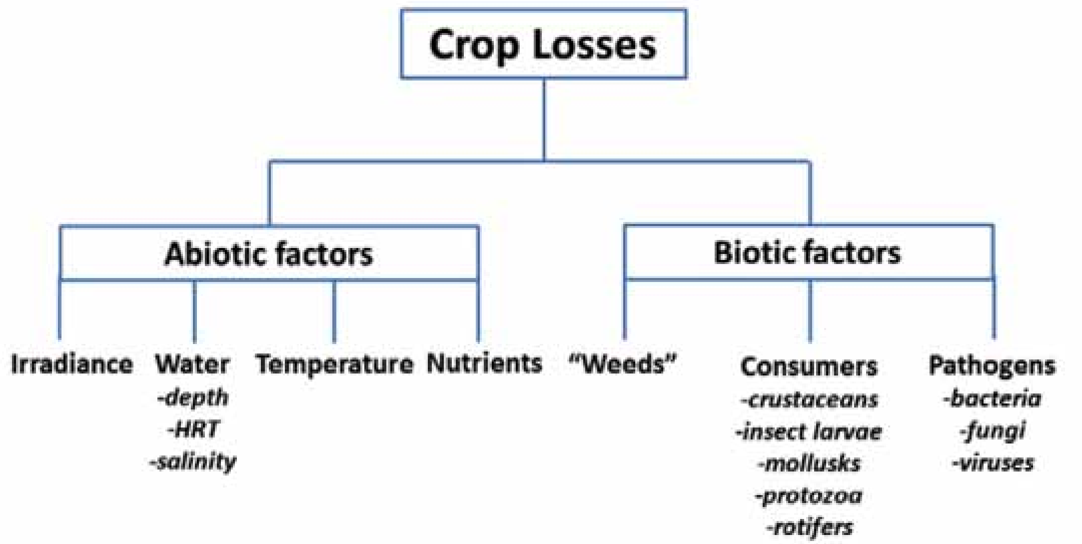
Background

- Increased biomass yields are critical for cost effective production of algal biofuels
- Crop losses are a challenge to large-scale production in outdoor ponds and to a stable supply
- Polycultures (multispecies consortia) should be more resilient to crop losses than monocultures



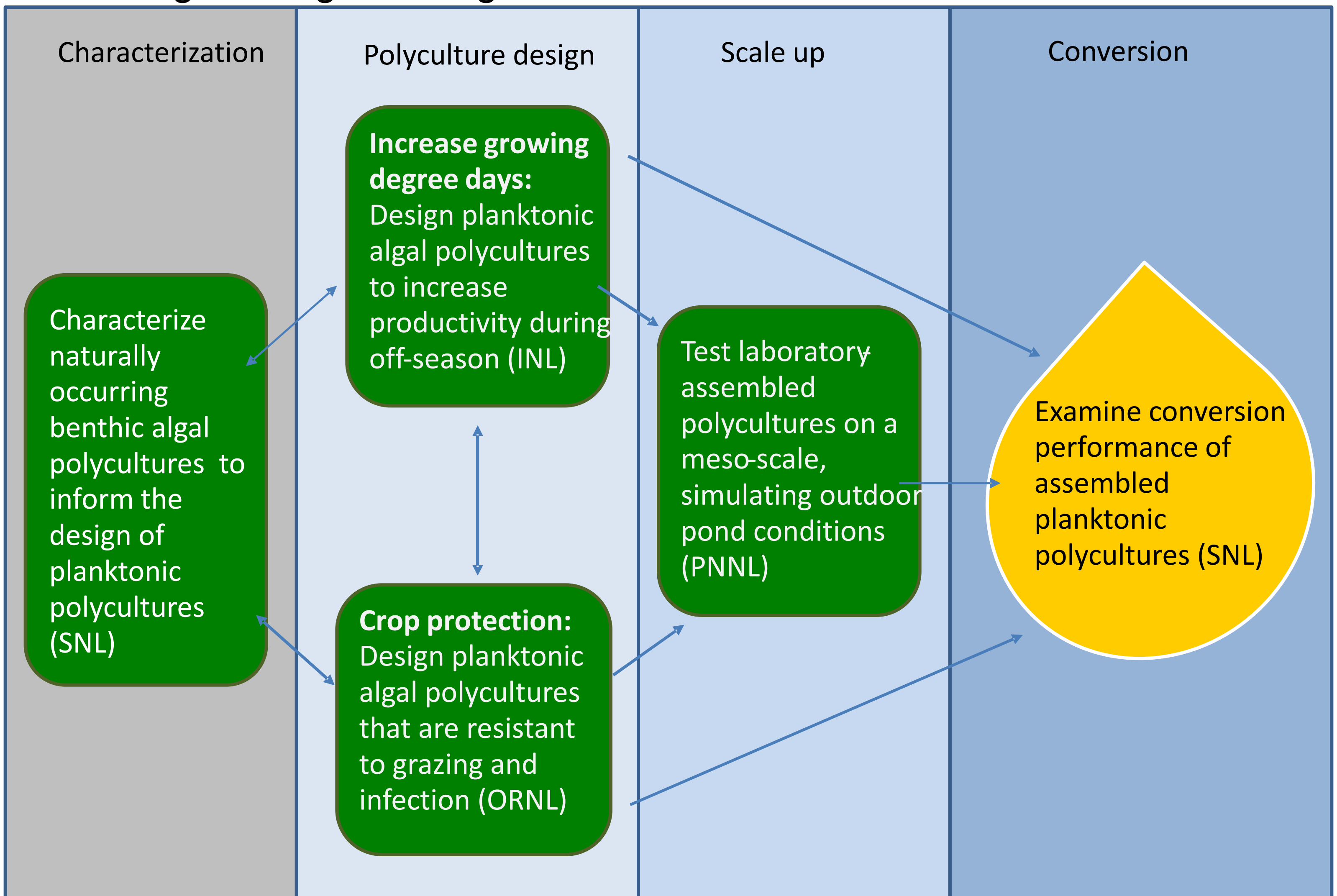
Objective

- Increase annual biomass production from current 13 g m^2 d^{-1} to target of 20-30 g m^2 d^{-1} using algal polycultures



Approach—Task 3. Algal polycultures

- Multi-organizational research hub assembled to address major ecological and engineering challenges



Future work—Task 3. Increased yield through algal polycultures

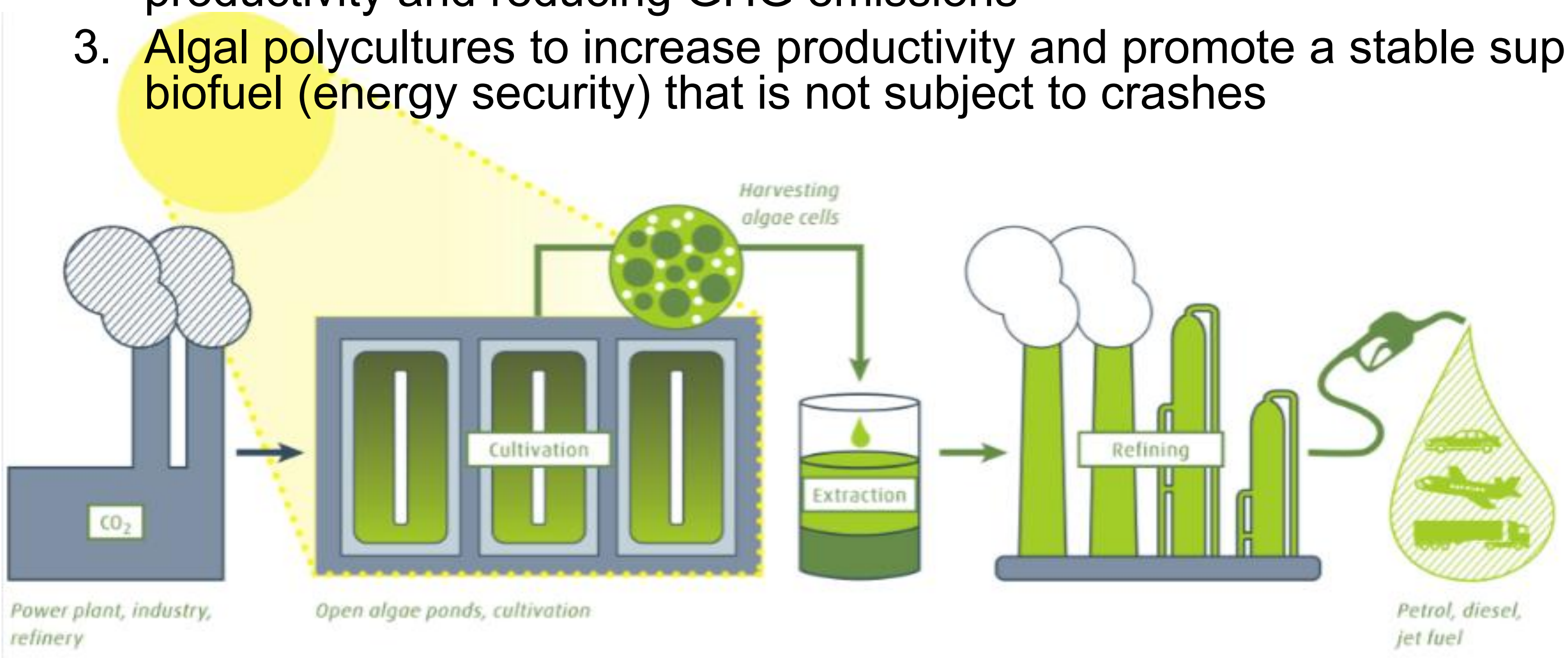
- Characterize naturally occurring algal polycultures to provide basis for rational assemblage (ORNL, INL, SNL)
- Expose algal polycultures to stressors (e.g. grazers, fungi) and quantify performance relative to monocultures in terms of:
  - Productivity (biomass)
  - Resilience (time to "reset" pond after stress)
- Start experiments at bench scale, informed by work at other labs in polyculture hub, but transition to meso-scale, with goal to use RAFT test beds by FY17
- Conduct handoffs between labs to accelerate progress toward scaling up and conversion

Milestone	Date
Submit joint review paper with national lab partners-baseline state of the art algal polycultures overyielding and resilience	March 2015
Demonstrate mesoscale polycultures performance through complementary approaches by partners	September 2015

Summary and Relevance

- Environmental, economic, and social factors can impede commercial viability of energy technologies
- Measuring indicators and mitigating unfavorable ones early will speed social acceptance of commercialization
- Based on needs of the algal biofuel community, this project has branched into 3 major research areas that should result in sustainability solutions

1. Pond bioliners to reduce costs and maintain water quality and quantity
2. Co-location with industry and utilities to increase profitability while maintaining productivity and reducing GHG emissions
3. Algal polycultures to increase productivity and promote a stable supply of algal biofuel (energy security) that is not subject to crashes



The Linde Group (used with permission)

Additional Slides

Responses to Previous Reviewers' Comments

Comment: *This project should look at the sustainability of algal biofuels for economically viable scenarios that are likely to be deployed with comparison to current state of technology scenarios. . . . There appear to be risks of premature dissemination of analysis results that are either based on non-viable scenarios that will never happen, or are based on highly speculative scenarios that are unlikely to be correct.*

Response: Task 2 (resource analysis) has been refocused on co-location scenarios (e.g., obtaining CO_2 from ethanol plants and power plants, obtaining nutrients from wastewater treatment plants), which should satisfy the reviewers. This also reflects a Go/No-go decision in June 2014 regarding the status and future of the resource analysis task. Task 1 is investigating the technical viability of in situ pond bioliners, which also gets us closer to economic viability.

Responses to Previous Reviewers' Comments

Comment: *Although it is good to get in front of sustainability issues, there is so much uncertainty about algal strains, cultivation, harvest, extraction, and co-products that the sustainability work will be highly speculative.*

Response: We are querying representatives of industry so that sustainability case studies can represent viable supply chains. Results may be system-specific, but examples of sustainability assessments should be broadly useful.

Comment: *While the importance of addressing sustainability and resource analysis is clear, the specific approach to be taken by the team appears to lack sufficient detail to know for sure if the plan will be successful.*

Response: The project was new in 2013, and approaches were under development. Tasks are more well-defined now.

Acronyms and definitions

Term	Definition
AFDW	Ash-free dry weight
biofilm	Thin film of microbiota (usually bacteria) that adheres to a surface, in this case to soil below pond
BETO	DOE Bioenergy Technologies Office
Co-location	Locating an algal biofuel production facility near a source of resources (e.g., CO_2)
consortium	Microbial community
EROI	Energy return on investment
GHG	Greenhouse gas
HDPE	High density polyethylene
INL	Idaho National Laboratory
In situ	In place
monoculture	Population of algae (single species)
NRC	National Research Council
PNNL	Pacific Northwest National Laboratory
ROI	Return on investment
polyculture	Community with multiple species of algae
resource analysis	Quantification of biomass resources for bioenergy
RAFT	Regional Algal Feedstock Testbed
SNL	Sandia National Laboratory
supply curve	Biomass or fuel product versus price

Publications, Presentations, Awards

Publications

Efroymson RA, VH Dale. 2015. Environmental indicators for sustainable production of algal biofuels. *Ecological Indicators* 49:1-13

Efroymson RA, VH Dale, M Langholtz. Submitted. Socioeconomic indicators for sustainable production of algal biofuels. *Ecological Indicators*

Langholtz M. Submitted, Potential land competition between open-pond microalgae production and dedicated feedstock supply systems in the U.S. *Renewable Energy*

Presentations

Efroymson RA. 2014. Sustainable development of algae for biofuel: Select accomplishments and directions. Algal Biofuels Strategy Workshop, Charleston, SC.

Efroymson RA and Dale VH. Environmental sustainability indicators for algal biofuels. Algae Biomass Summit. Orlando, FL, Sept-Oct 2013.

Award

Melanie Mayes was elected as a Fellow of the American Association for the Advancement of Science.