OAK RIDGE National Laboratory

DOE Bioenergy Technologies Office (BETO) 2019 Project Peer Review

4.2.2.40 Quantifying and Visualizing Progress Toward Sustainability

March 5, 2019

Analysis and Sustainability Technology Area

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ORNL is managed by UT-Battelle, LLC
for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

Goal Statement

- **Quantify the environmental & socioeconomic benefits**, impacts and costs of cellulosic bioenergy options measured relative to stakeholder sustainability goals.
- Enable informed decisions and consistent, science-based communication via a web-based tool: the ***Bioenergy Sustainability Tradeoffs Assessment Resource (BioSTAR).***
- Help DOE, industry and other researchers quantify, visualize and communicate potential effects of bioenergy deployment options.

4.2.2.40, Quantifying & Visualizing Progress Toward Sustainability

Timeline

- Start date: October 1, 2018
- End date: September 30, 2021
- Project is 15% complete

This is a new 3-year cycle of "Bioenergy Sustainability: How to Define & Measure It".

	Total Costs Pre-FY17	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY19-Project End Date)
DOE Funded	$700,000 to $750,000/year	$800,000	$700,000	$700,000 per year

Collaborators include researchers at the USDA Forest Service, Antares, International Energy Agency (IEA), UT, Penn State, ANL, INL & more

Barriers addressed

- Quantification of Economic, Environmental, and Other Benefits & Costs (At-E)
- Science-Based Methods for Improving Sustainability (At-F)

Objective

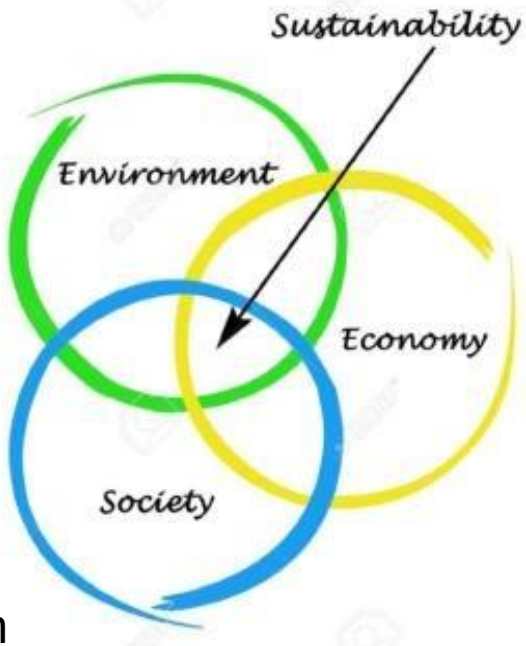
Propel the US bioenergy industry toward implementation of systems that maximize benefits while minimizing negative impacts.

End of Project Goal

Provide science-based data and web-based analytical tools (e.g., ***BioSTAR****) to holistically analyze tradeoffs of US biomass production options by integrating environmental and socioeconomic indicators of sustainability tailored to local conditions and stakeholder priorities.

BioSTAR = Bioenergy Sustainability Tradeoffs Assessment Resource

1 - Project Overview



Understanding potential trade-offs among environmental and socioeconomic indicators can **help government & industry maximize potential benefits** for local communities.

ORNL's research agenda includes

- Defining environmental & socioeconomic benefits and costs of bioenergy systems
- Quantifying opportunities & tradeoffs associated with bioenergy systems in specific geographic contexts
- Engaging with a range of stakeholders to better understand the challenges & paths forward for sustainable bioenergy production
- Communicating case study results & generalizing lessons learned for improved practices

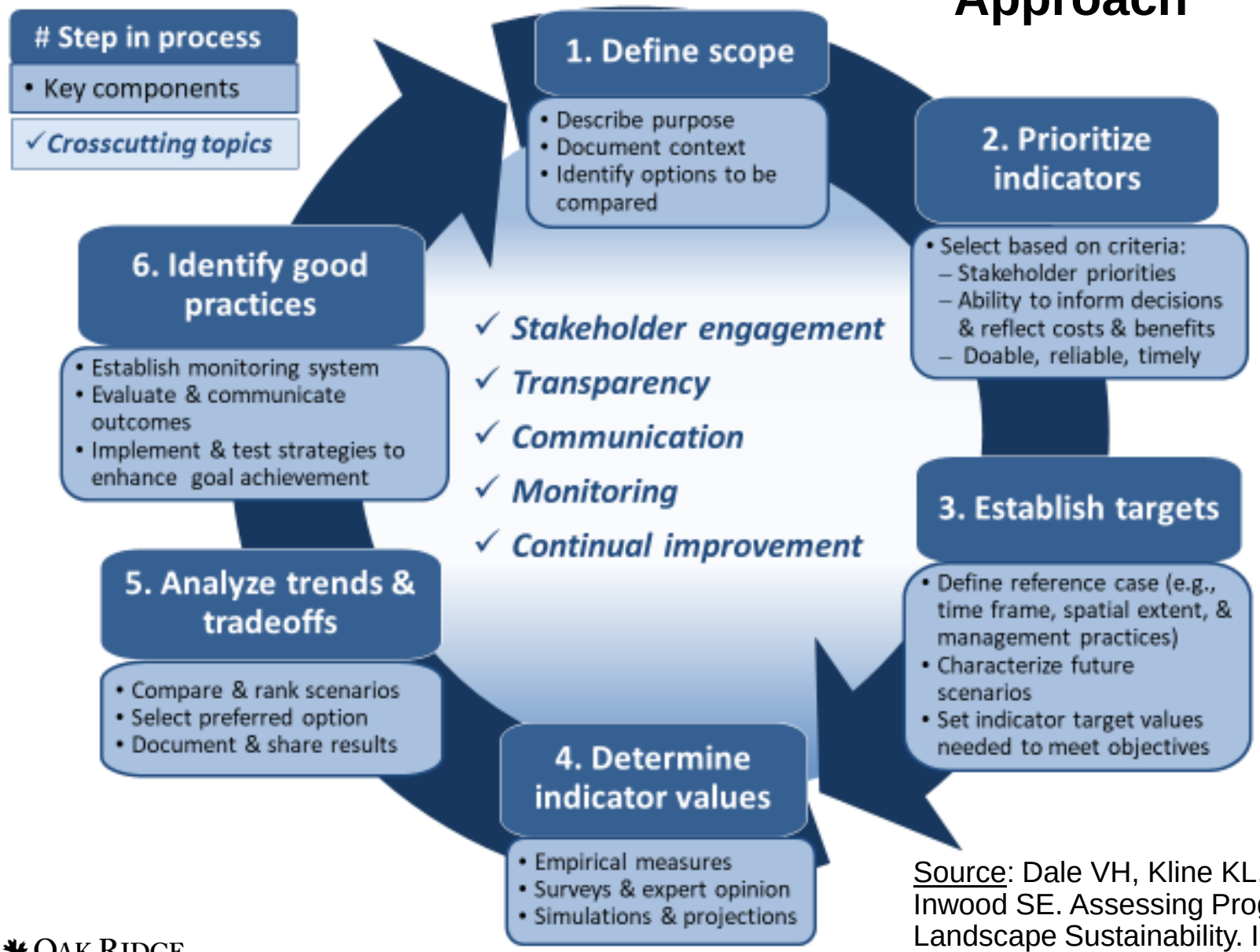
Sustainability Indicators:
- Environmental indicators in McBride et al. 2011
- Socioeconomic indicators in Dale et al. 2013

35 total in 12 categories

Key challenges

- New methods are needed to accurately represent complex tradeoffs
- Indicator data are collected at different spatial & temporal scales

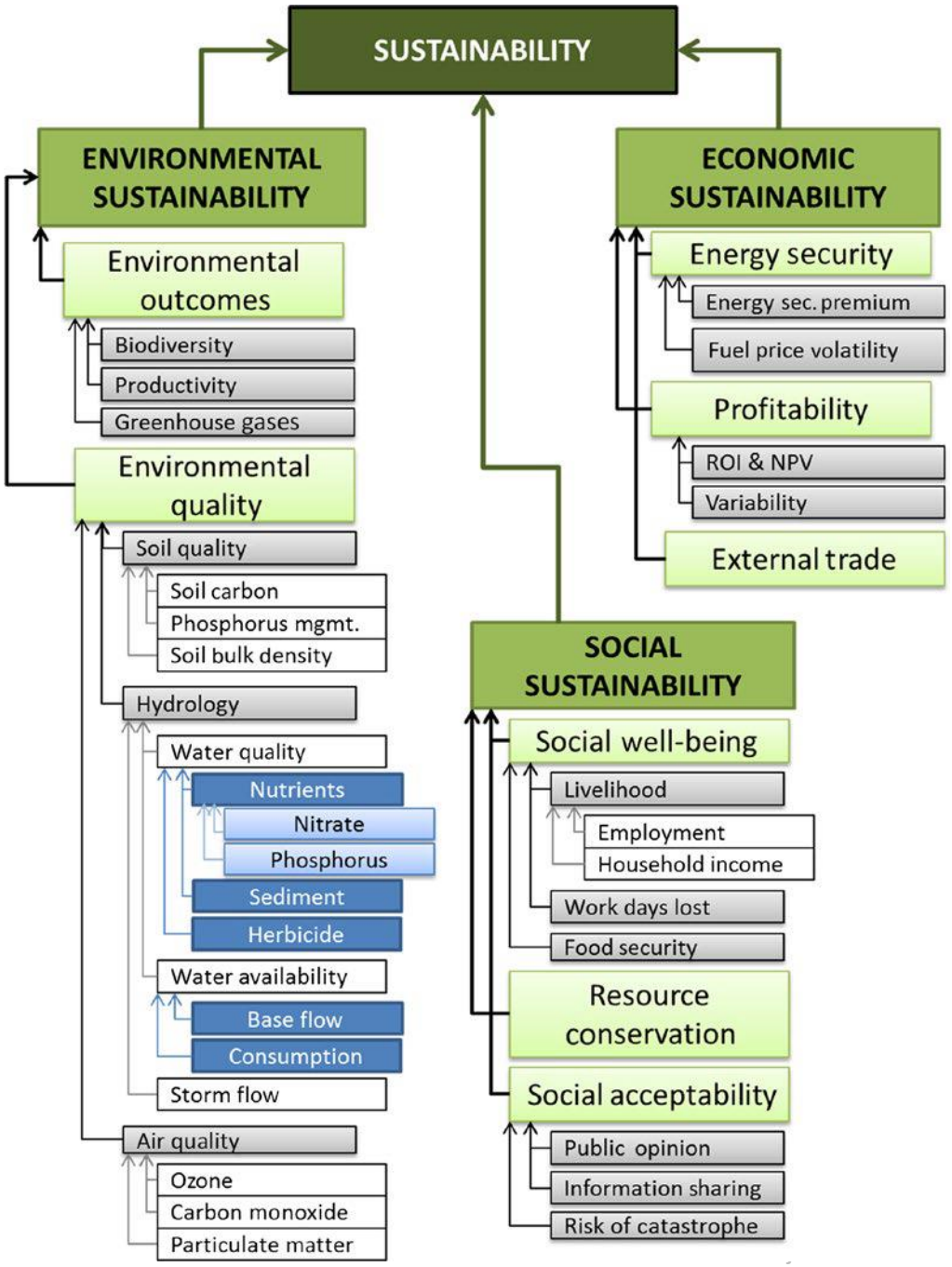
Sustainability Assessment Approach



Source: Dale VH, Kline KL, Parish ES, Inwood SE. Assessing Progress toward Landscape Sustainability. In Review.

Integrated assessment of sustainability using up to 35 indicators

- Aggregate indicators within a multi-attribute decision support system (MADSS) framework
- Assign ratings to each environmental & socioeconomic sustainability indicator
- Compare sustainability outcomes of alternative scenarios



Parish et al. (2016)
Ecosphere 7(2):e01206.

2 – Approach: Project Management

Our FY19-21 project is organized into two inter-related tasks:

Task 1: Theory
Develop methods & frameworks to quantify and integrate environmental and socioeconomic sustainability indicators for tradeoffs analyses

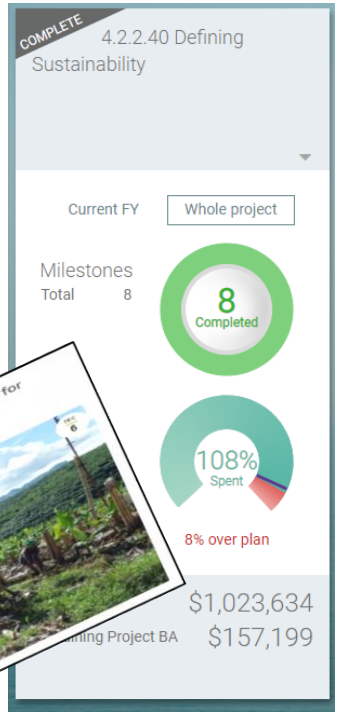
Task 2: Case-Study Application
Develop & test a multimetric visualization platform for informed decision-making

SUCCESSFUL PROGRESS RESULTS FROM:

- Bi-weekly ORNL team meetings
- Monthly spending reviews
- Monthly BETO A&S Lab calls
- Monthly Antares Group webinars and in-person meetings
- Quarterly milestones for BETO
- Stage Gate & Merit reviews (2018)
- Preparations for a 'Go/No Go' milestone (June 2020)

--plus--

- **Journal publications**
- **Conference presentations & invited talks**
- **Preparations for May 2019 IEA workshop**



2 – Approach: Project Team

Esther Parish (PI)
Geographer & landscape ecologist with > 10 years bioenergy sustainability research experience; Recent PhD in Energy Science & Engineering

Mike Hilliard
Expert in logistics and supply chain management, modeling & simulation; Created Billion Ton 2016 report data visualizations

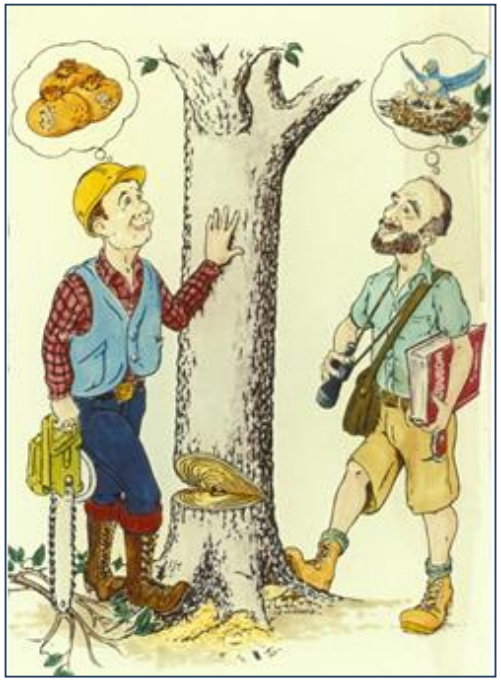
Rebecca Efroymson
Risk assessment expert with 30 years experience studying environmental effects of energy technologies

Keith Kline
> 30 years of international experience with sustainable development projects involving renewable energy systems and community engagement

- **Subcontractors include 2 usability experts + 1 programmer**
- **Collaborators include researchers at the US Forest Service, International Energy Agency (IEA), Antares Group, Penn State, University of Tennessee, ANL, INL, and more**

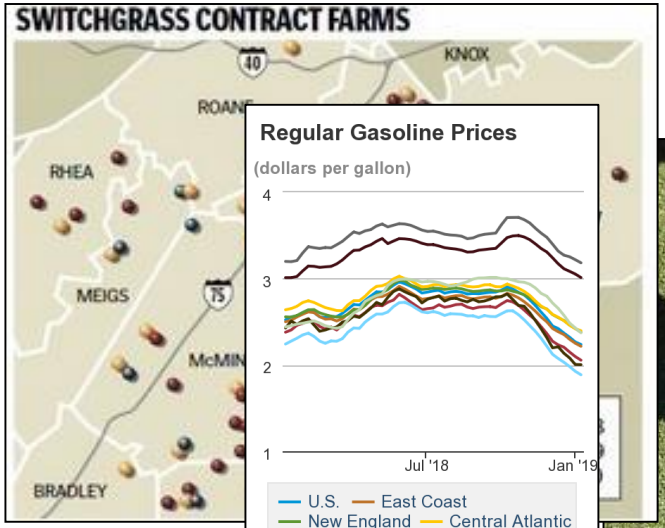
2 – Approach: Advance Sustainability Science

How should we set targets for indicators?

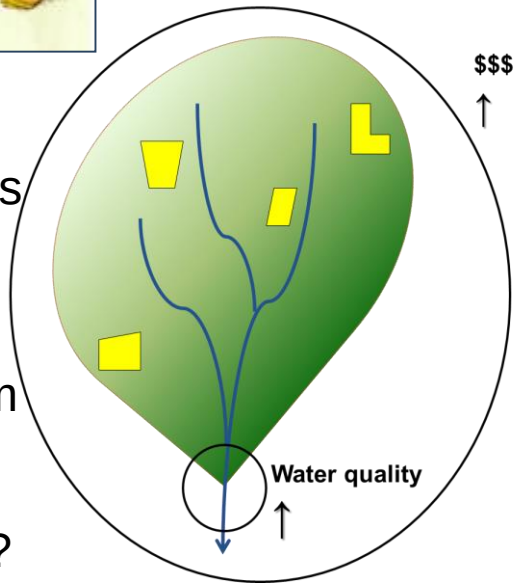


How will prioritization of indicators by different stakeholders affect sustainability outcomes?

How can we integrate and visualize indicator data that have been collected across many spatial & temporal scales?



How can combinations of indicators be used to maximize benefits from landscape design alternatives?



2 – Approach: Share Research through BioSTAR

BIOENERGY
KNOWLEDGE DISCOVERY FRAMEWORK
U.S. DEPARTMENT OF ENERGY

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BioSTAR
Bioenergy Sustainability Tradeoffs Assessment Resource

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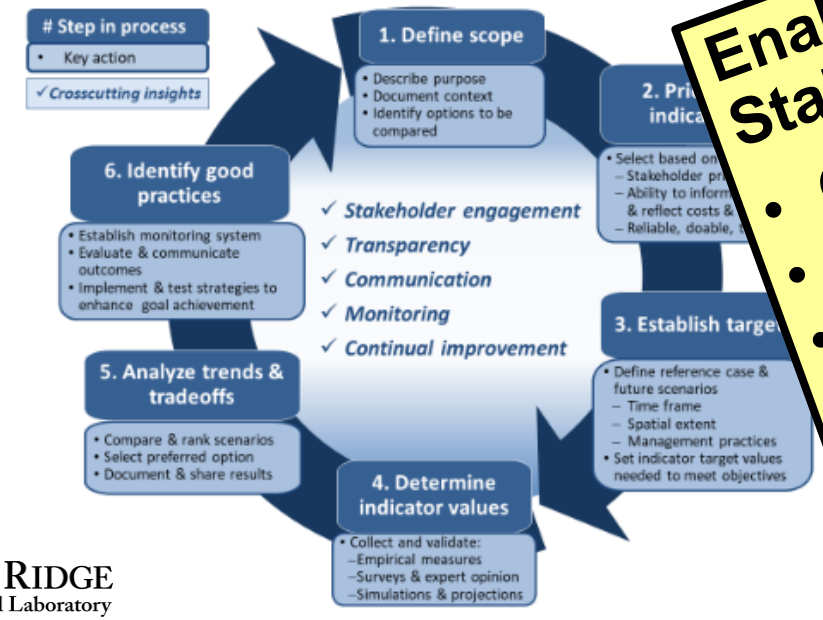
BioSTAR - Bioenergy Sustainability Tradeoffs Assessment Resource

The Bioenergy Sustainability Tradeoffs Assessment Resource (BioSTAR) tool (Figure 1) is being developed by Oak Ridge N
Department of Energy's BioEnergy Technologies Office (DOE BETO). BioSTAR is designed to help stakeholders q
tradeoffs of cellulosic biomass production systems (Figure 2).



Enable web-based Stakeholder interaction with

- Case Study examples
- Indicator datasets
- User-contributed datasets

for improved decision-making

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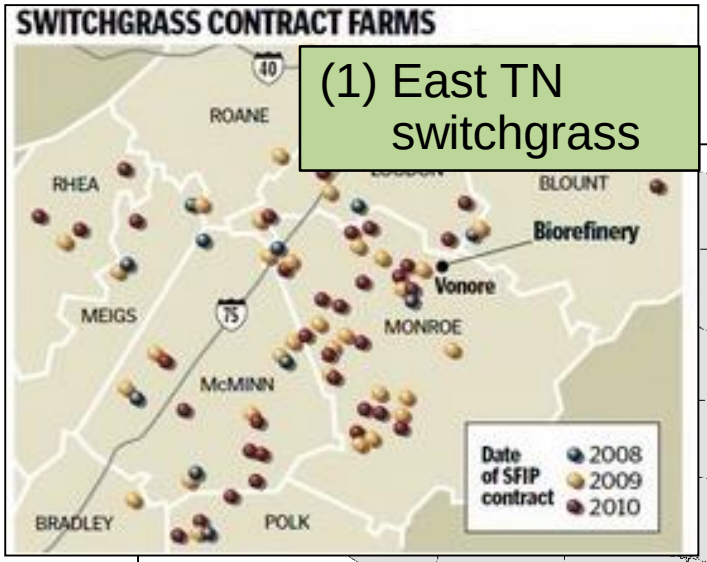
3 – Technical Accomplishments/ Progress/Results

Develop sustainability science theories

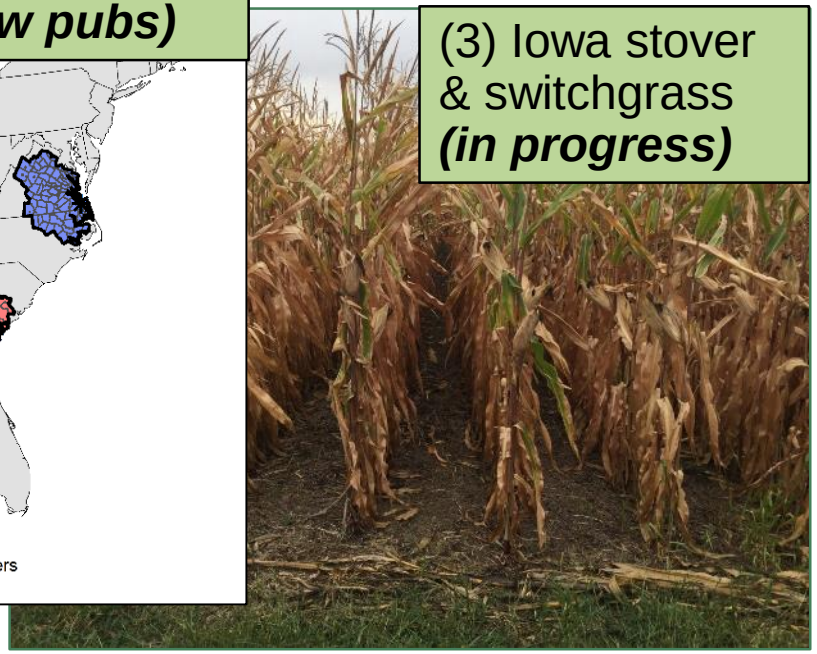
Test theories through **case study** application

Share lessons learned via BioSTAR for improved practices



(1) East TN switchgrass

(2) Southeastern U.S. wood pellets ***(10 new pubs)***



(3) Iowa stover & switchgrass ***(in progress)***

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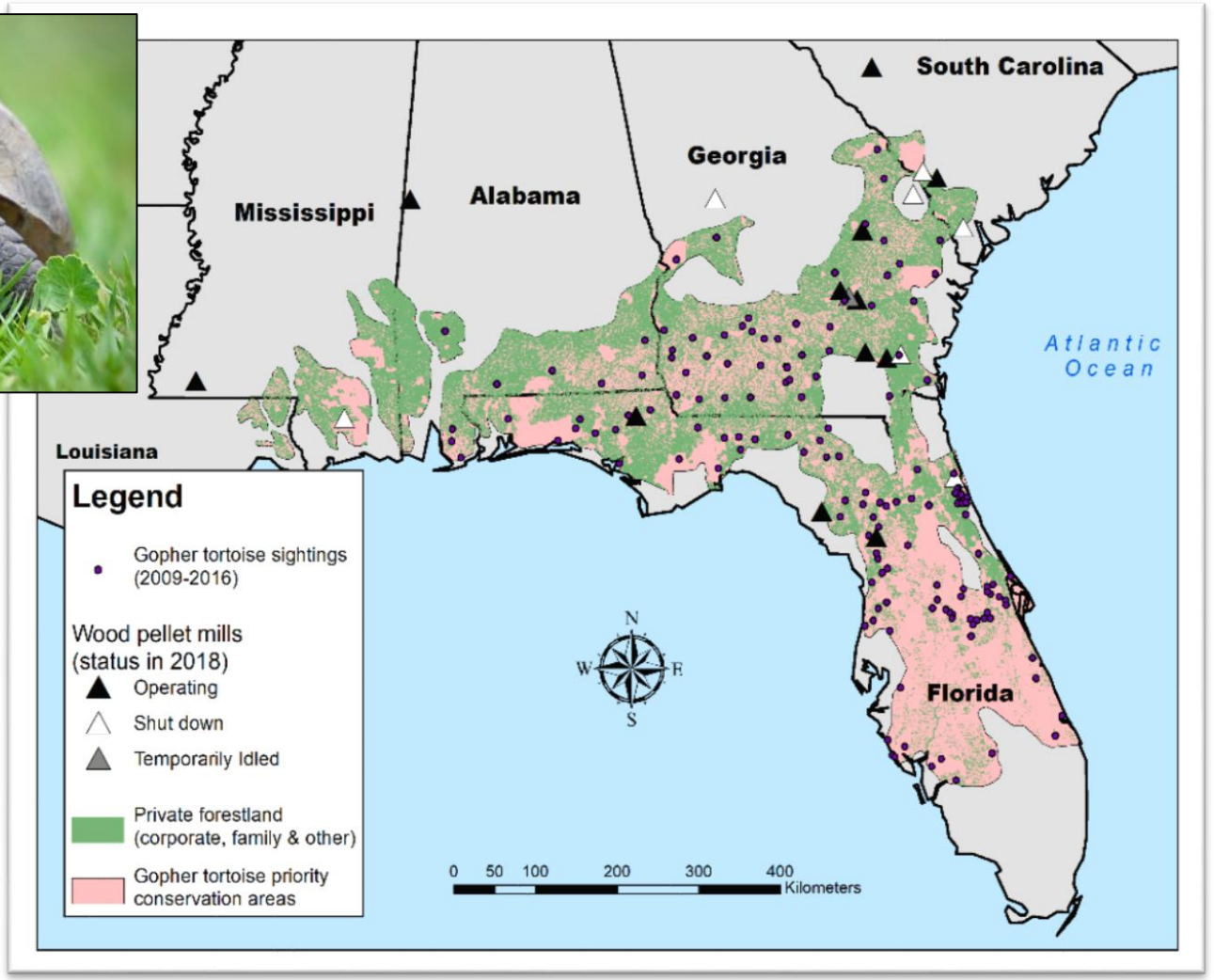
Are species affected by wood pellet production?

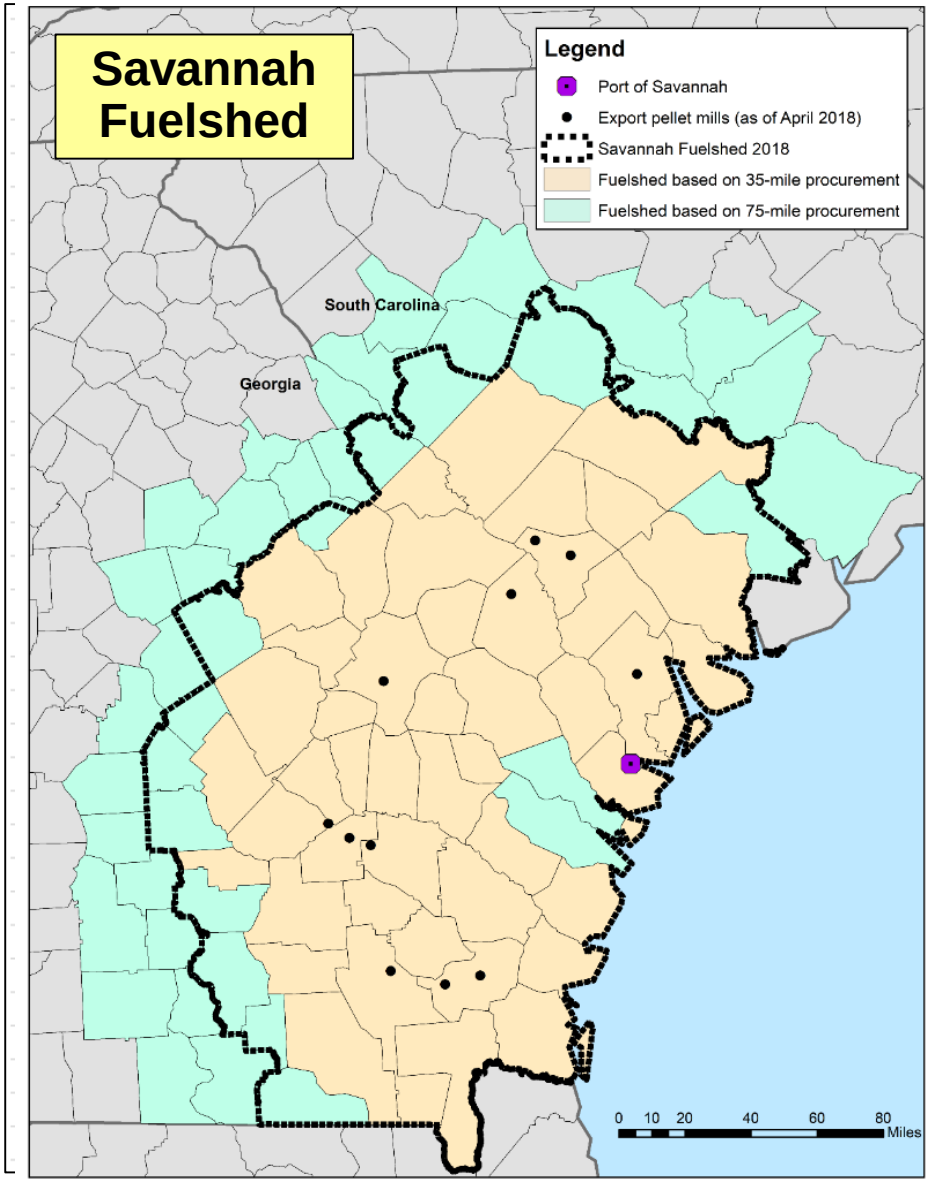
Gopher tortoise (GT) is a keystone species in SE US pine forests

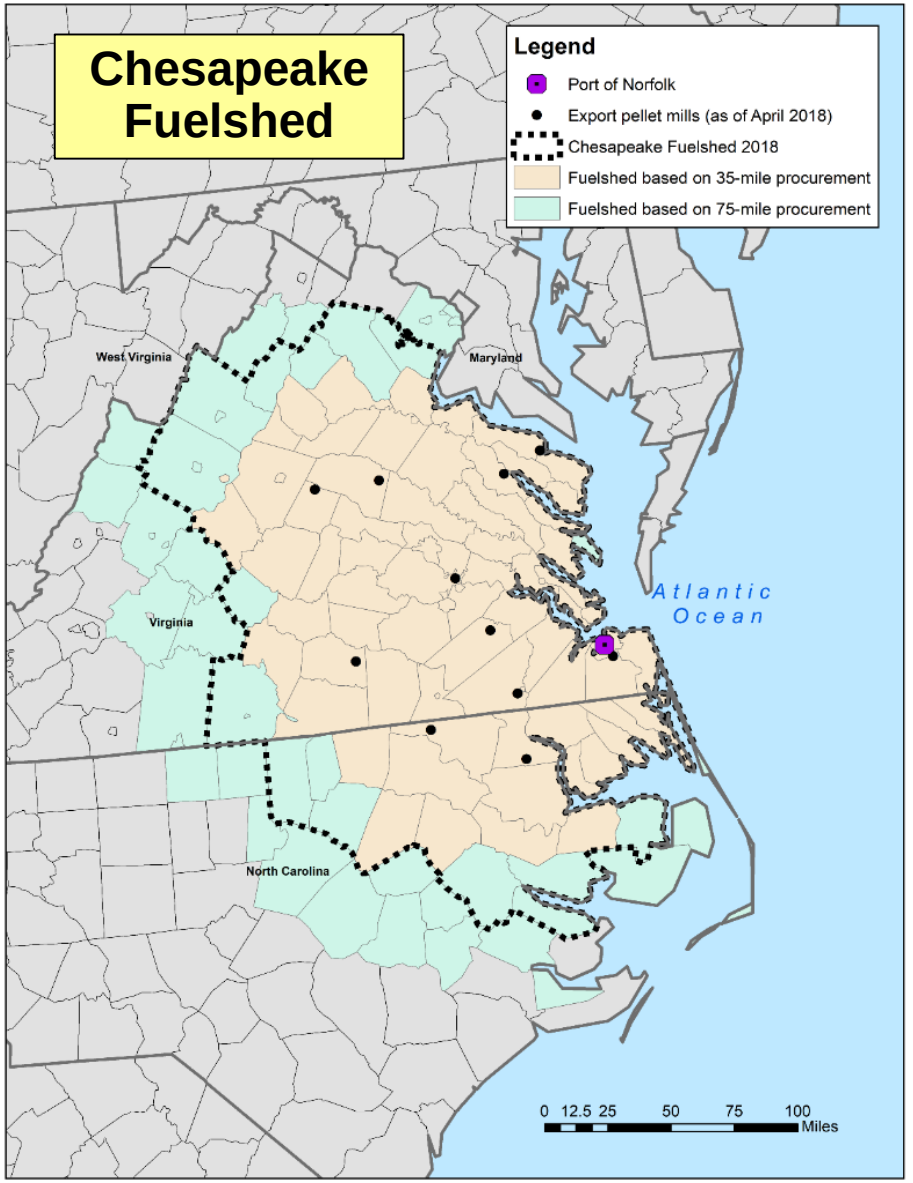
- Documented wood pellet supply chain steps & intersections with GT life history
- Identified practices that will protect GT
- Assessed Savannah fuelshed thinning effects on several species distributions using Bio-EST model



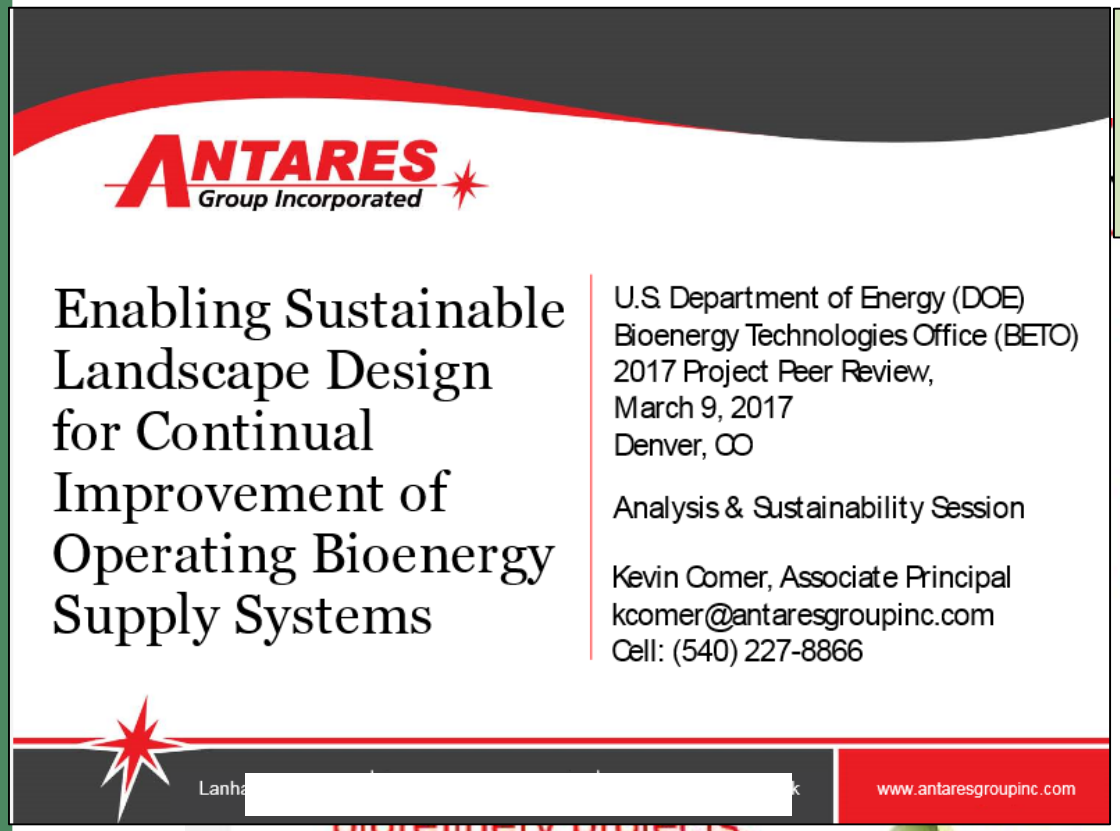
Overlapping bioenergy wood pellet industry & GT priority conservation areas

Case Study of 2 Wood Pellet Fuelsheds





Iowa Landscape Design Case Study



Cellulosic ethanol from:

- Corn stover
- Switchgrass

ANTARES Group Incorporated
POET Energy inspired.
DU PONT
PacificAg
PURDUE UNIVERSITY
USDA
USGS science for a changing world
INL Idaho National Laboratory
OAK RIDGE National Laboratory
Argonne NATIONAL LABORATORY
Biomass Toolbox
AGSOLVER
SCSglobal SERVICES
IOWA DEPARTMENT OF AGRICULTURE AND LAND STEWARDSHIP
Southfork WATERSHED ALLIANCE INC.
IOWA STATE UNIVERSITY
Iowa Agricultural Bio Fibers
BUENA VISTA COUNTY SOIL AND WATER CONSERVATION DISTRICT
PENNSTATE
FDC Enterprises Grasslands Services
MONSANTO
IOWA FARM BUREAU PEOPLE. PROGRESS. PRIDE.
IOWA CORN

Engaged with Iowa stakeholders to prioritize indicators

- Survey by Drake University
- Stakeholder & project workshops
- Interviews with key stakeholders
- Results documented in Dale et al. 2018


NGO workshop


Project members workshop

Linked Iowa sustainability indicators & goals

Sustainability Goals	Key Stakeholder(s)	Related Indicator Categories	Source(s) of Information
Produce cellulosic feedstock supply for commercial-scale biofuels production	Biorefinery Operator, Farmers	Productivity, Profit, Soil quality	AgSolver/EFC, Purdue, Penn State PIHM-Cycles modeling, INL BLM, ORNL IBSAL
Reduce nitrate and phosphorus runoff from nonpoint sources to meet Iowa Nutrient Reduction Strategy goals	State of Iowa	Water quality (and quantity)	USDA ACPF, ANL SWAT modeling, Penn State PIHM-Cycles modeling
Improve pheasant populations for recreational hunting	USDA CRP, Pheasants Forever	Biodiversity	USDA NRCS, ORNL Bio-EST modeling and optimization

ORNL is working with Antares project consortium to define scenarios and indicator baselines & targets needed to quantify sustainability tradeoffs

3 – Technical Accomplishments/Progress (cont'd)

BioSTAR tool designed to compare feedstock sustainability

Explanation

↑ Expected to improve ≈ Mixed results expected ↓ Expected to worsen

	Switchgrass	Miscanthus	Corn Stover	Biomass sorghum
Environmental				
Air Quality				
Biodiversity				
Greenhouse Gases				
Productivity				
Soil Quality				
Water Quality	↑	↑	↓	↓
Water Quantity	↑	↑	≈	↓
Socio-economic				
Energy Security	↑	≈	↑	≈
External Trade	≈	≈	↑	↓

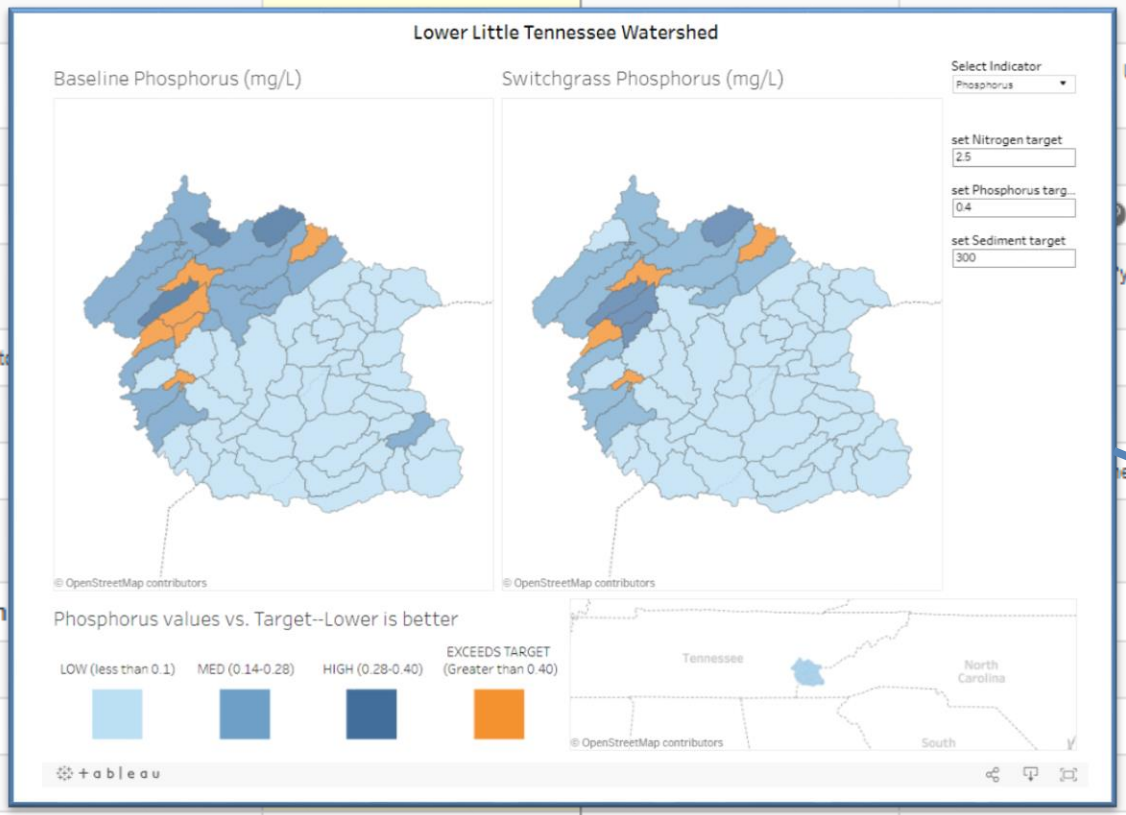
Water Quality			↑
Total Nitrogen			
Nitrate			↑
Total phosphorus			↑
Suspended sediment			↑
Herbicide			≈

BioSTAR tool designed to make indicator data transparent

Indicator: Water Quality - Total Phosphorus

Feedstock: Switchgrass

Description	Billion Ton Reference Scenario	Billion Ton 2 - AWR	Billion Ton 2 - IRB	East Tennessee Switchgrass
Citation				"
Study Location			USA	East Tennessee, USA
Data Type				Empirical, Modeled
Feedstock Types Analyzed				Agricultural
Units			yr^{-1}	Run-off:kg*ha^{-1}*yr^{-1} Concentration:mg/L
Spatial Resolution of Indicat				Field
Temporal Resolution				
Reference Case Used			e	Corn and Pasture
				Explore Details
Feedstock Supply Chain				
Planting				✓
Harvesting and Collection				✓
Storage				
Transportation to Biorefinery Gate				✓
Conversion to Biofuel				



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4 – Relevance

- Advance sustainability science needed to **analyze environmental & socioeconomic tradeoffs** of cellulosic bioenergy options
- Web-based BioSTAR tool will enable users to **integrate indicators of sustainability** tailored to local conditions + stakeholder goals/priorities
- Sustainability quantification & visualization will help government & industry implement bioenergy systems that **maximize potential benefits**

PROJECT BENEFITS

- ✓ Rural Jobs
- ✓ Farmer Profits
- ✓ Soil Quality
- ✓ Water Quality
- ✓ Biodiversity
- ✓ Reduced Carbon Emissions
- ✓ Energy Security

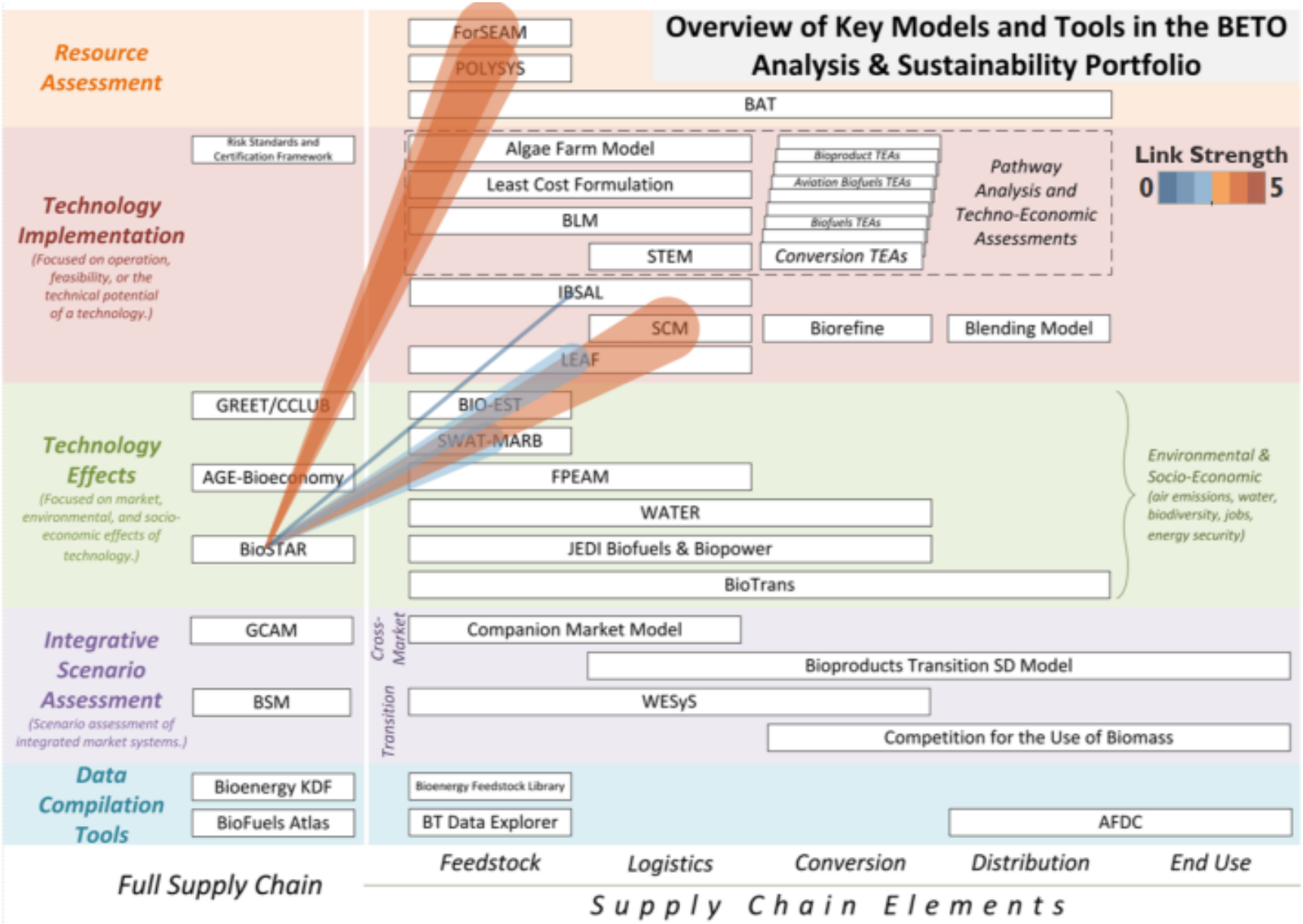
4 – Relevance (cont'd)

Feedback from March 2018 Stage Gate Review Iowa Landscape Design Project

"**The process for prioritizing and choosing relevant sustainability indicators is outstanding**. The journal article published by Dale et al* (provided to us during the review meeting) on this process and its outcomes is an important contribution to the literature on sustainability metrics. The team has gone to extraordinary and yet efficient means to engage a large number of organizations and stakeholders who would be impacted by the development of sustainable bioenergy and product supply chains in the targeted region of Iowa by taking advantage of multiple venues during 2015 and 2016. The analysis of the stakeholder feedback is intelligently and cogently presented, and is **a model for others who wish to adopt a valid stakeholder engagement process**."

*Dale VH, Kline KL, Richard TL, Karlen DL, Belden WW (2018) Bridging biofuel sustainability indicators and ecosystem services through stakeholder engagement. Biomass & Bioenergy 114:143-156.

BioSTAR Inputs (2017)



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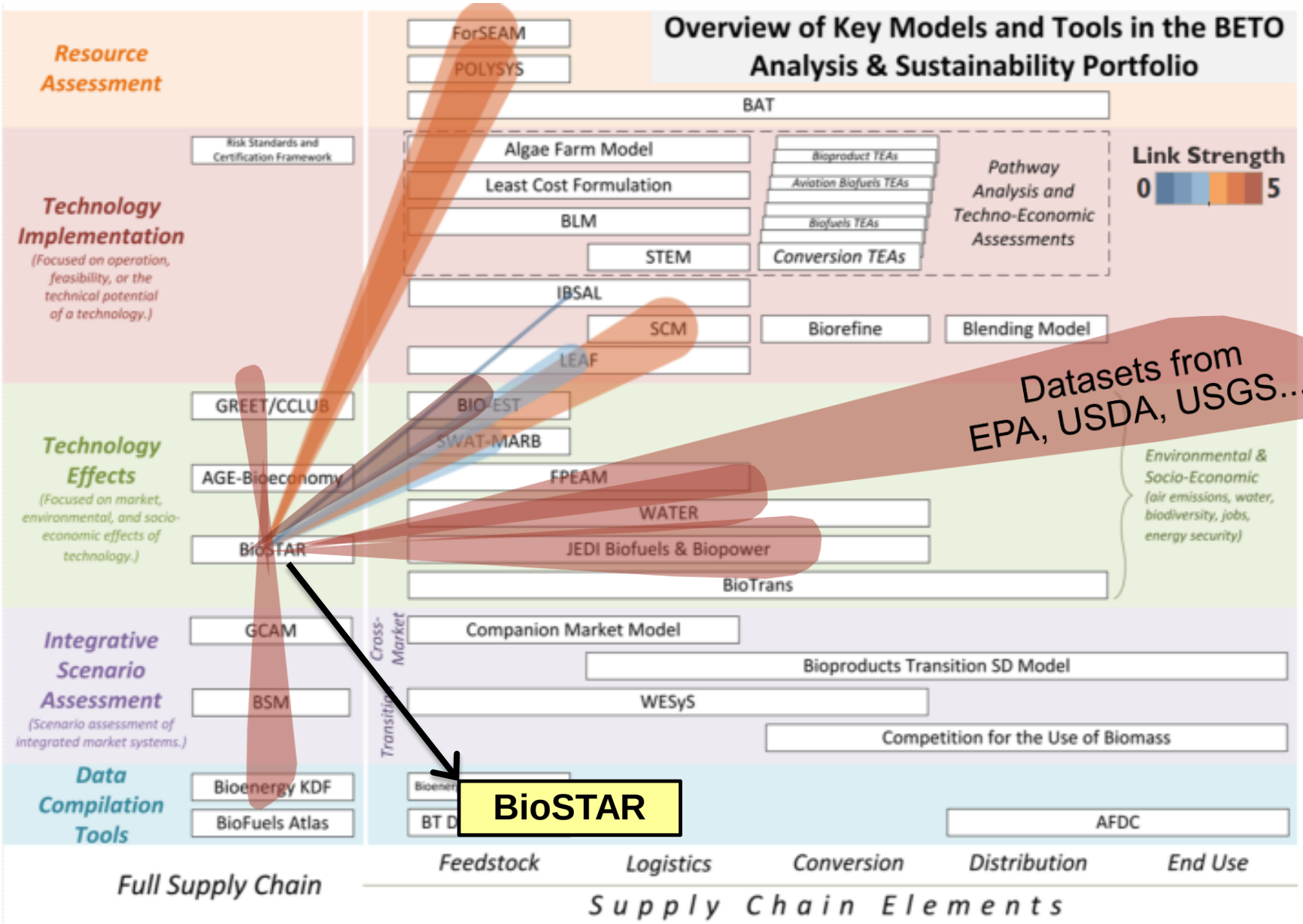
BioSTAR Inputs (Recent & Planned)



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5 – Future Work

Due Date	Milestone	Expected Outcomes
March 2019	Develop draft theoretical framework for setting targets	• Targets established for Iowa case study environmental & socioeconomic indicators • Publication(s) • Methodology incorporated into BioSTAR
June 2019	IEA collaboration session with BioSTAR prototype	• Wood pellet case study indicators vetted & prioritized by many stakeholders • Feedback used to refine & improve tool
Sept 2019	Pick set of national-scale datasets	• Incorporation of 'default' indicator datasets within BioSTAR to assist with new project evaluation
Dec 2019	Prioritization capability	• Visualize sustainability outcomes based on different stakeholder priorities
March 2020	Set Iowa socioeconomic targets	• Quantify changes in net jobs, household income & social acceptability for alternative landscape designs
June 2020	**'Go'/ 'No Go'**	• BioSTAR allows users to explore their own projects (+ the 3 case studies)

Project 'Go'/'No Go' Milestone (June 2020)

Is it feasible for users to enter their own projects into BioSTAR?

Demonstrate two separate examples:

1. User uploads indicator dataset
2. Data gets processes
3. Indicator results are visualized graphically

If successful → Refine & improve BioSTAR user interface. Ensure stakeholder access to tool

If it doesn't work → Meet with BETO to discuss options, including redirecting remaining $ to meet BETO sustainability visualization & communication goals through alternate approaches.

5 – Future Work (cont'd)

DRAFT Framework for Setting Sustainability Indicator Targets

Clear Objective

Target-Setting Drivers

Goal-Oriented Drivers:
- Policy
  - Regulations
  - Guidelines
  - Incentives
- Science
  - Indicator-Objective relationships
  - Thresholds/limits
  - Resilience
- Stakeholder values

Means-Oriented Drivers:
- Economic feasibility
- Engineering feasibility
  - Best available control technology
- Land management
  - Best management practice

Target-Setting Filters

Context Filters:
- Local/regional issues
- Scale
  - Spatial
  - Temporal

Data Availability & Reliability Filters:
- Baseline data and reference conditions
- Monitoring in place

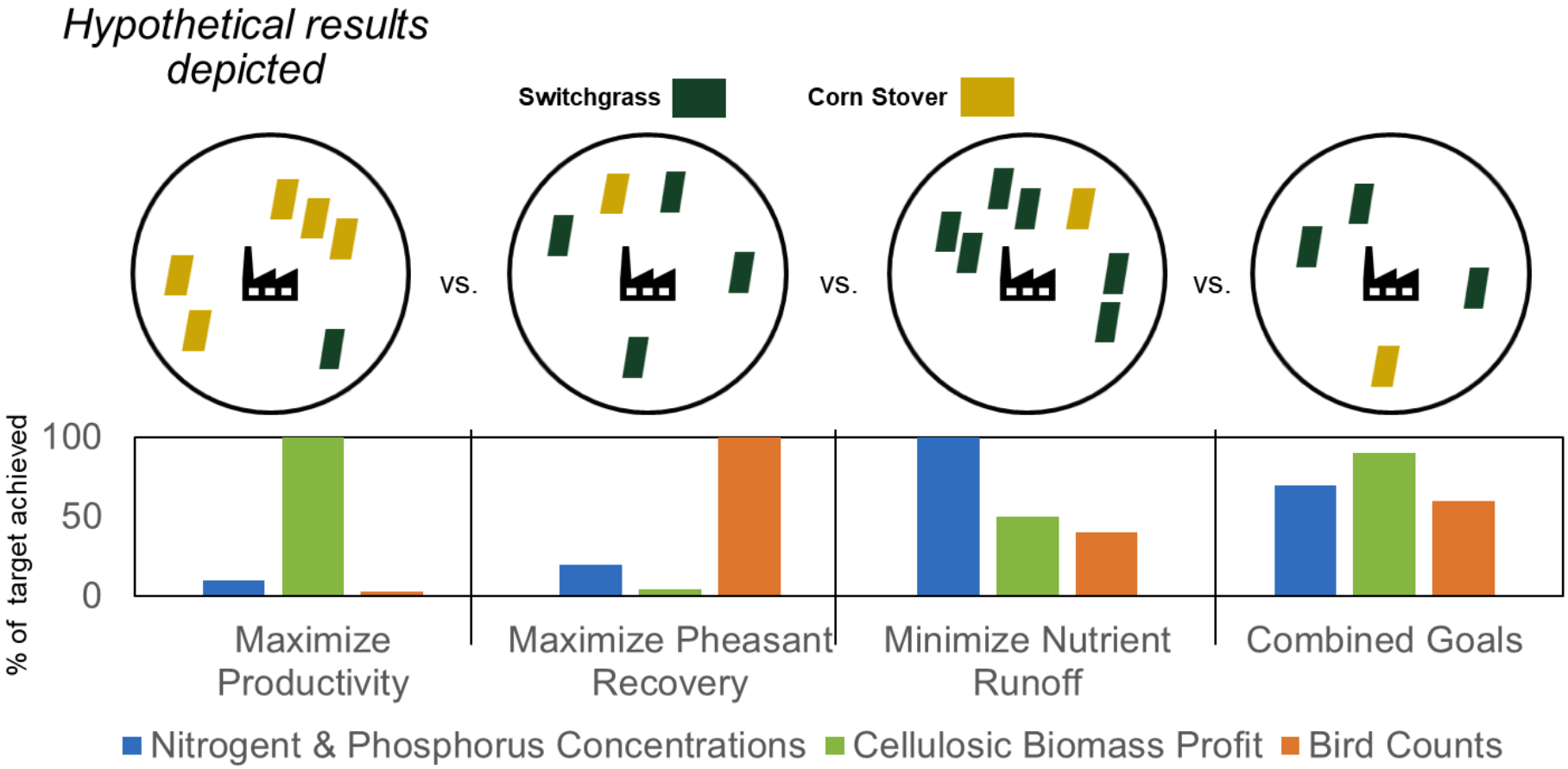
Proposed targets

Testing & Adaptation
- Relevance to stakeholder priorities
- Measured feasibility
- Consistency
- Tradeoffs & synergies
- Utility

'Targets' manuscript will be submitted to a peer-reviewed journal

5 – Future Work (cont'd)

Use Iowa Case Study to develop methods for quantifying & visualizing sustainability tradeoffs & synergies across a fuelshed



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5 – Future Work (cont'd)

QUANTIFY & VISUALIZE A SET OF SUSTAINABILITY INDICATORS based on transparent national-scale spatiotemporal datasets loaded into BioSTAR

USDA

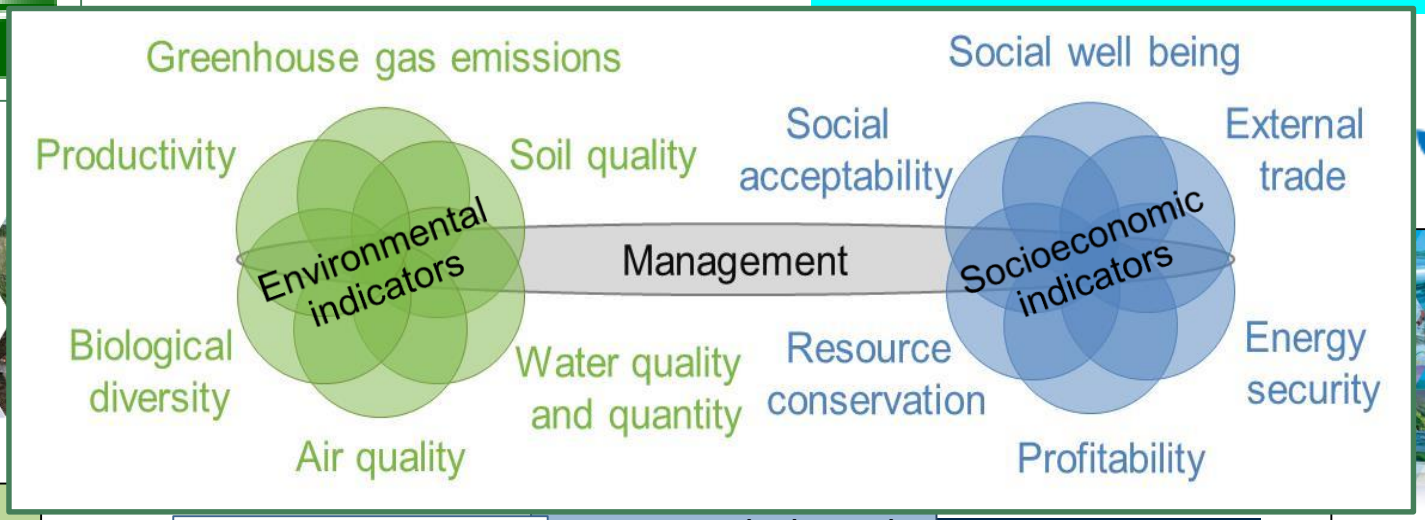
GREET LIFE-CYCLE MODEL

NREL Transforming ENERGY

JEDI - Cellulosic Ethanol

Jobs and Economic Development Impact Model

EPA

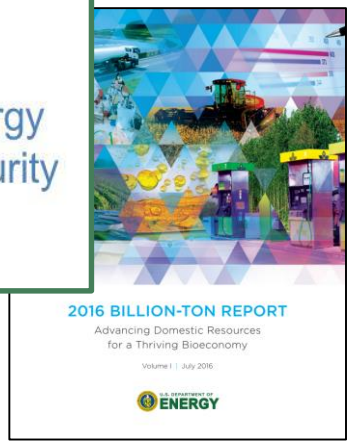


ORNL Bio-EST

Argonne NATIONAL LABORATORY

Water Analysis Tool for Energy Resources

USGS science for a changing world

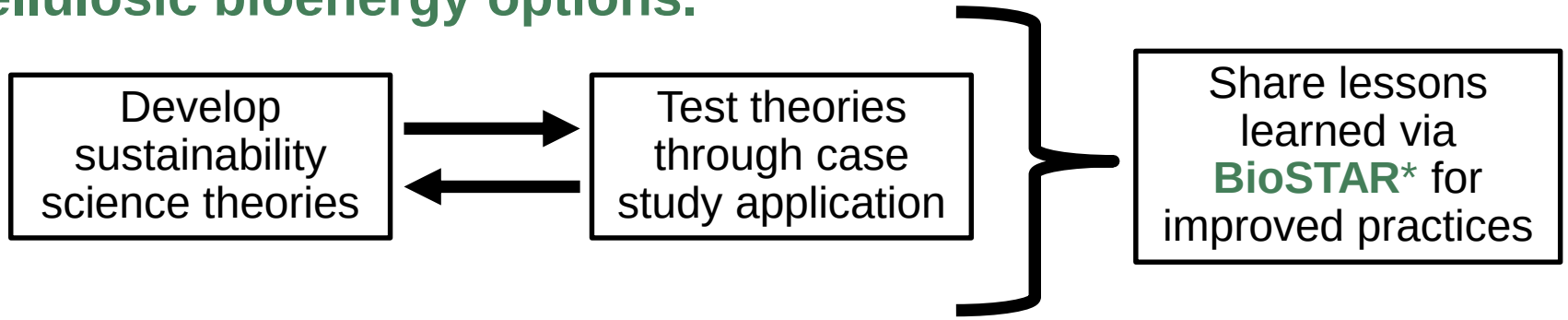


Potential Risk: Not getting enough indicator datasets of sufficient quantity/quality for consistent visualization of progress toward sustainability for all 12 categories.

Abatement Strategy: If this happens, we will narrow our focus to a few key indicators that have the best available data.

Summary of "Quantifying & Visualizing Progress Toward Sustainability" (Project 4.2.2.40)

GOAL: Provide DOE, industry and other researchers with tools to holistically quantify benefits & costs and visualize tradeoffs of cellulosic bioenergy options.



WHY? Maximize environmental & socioeconomic benefits for bioenergy stakeholders

ACCOMPLISHMENTS *(since March 2017)*:

- 19 new publications + 7 manuscripts + many invited presentations
- Effective collaboration with researchers at the USDA Forest Service, International Energy Agency (IEA), Antares Group, Penn State, University of Tennessee, INL, ANL, and more
- BioSTAR wireframes built to showcase 3 case studies + user-added projects

BioSTAR = Bioenergy Sustainability Tradeoffs Assessment Resource

Additional Information

Environmental sustainability indicators *(19 in 6 categories)*

Category	Indicator	Units
Soil quality	Total organic carbon (TOC)	Mg/ha
	Total nitrogen (N)	Mg/ha
	Extractable phosphorus (P)	Mg/ha
	Bulk density	g/cm^3
Water quality & quantity	Nitrate concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	Total phosphorus (P) concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	Suspended sediment concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	Herbicide concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	Storm flow	L/s
	Minimum base flow	L/s
	Consumptive water use (incorporates base flow)	feedstock production: m^3/ha/day; biorefinery: m^3/day

Category	Indicator	Units
Greenhouse gases	CO_2 equivalent emissions (CO_2 and N_2O)	kgC_{eq}/GJ
Biodiversity	Presence of taxa of special concern	Presence
	Habitat area of taxa of special concern	ha
Air quality	Tropospheric ozone	ppb
	Carbon monoxide	ppm
	Total particulate matter less than 2.5µm diameter ($PM_{2.5}$)	$\mu g/m^3$
	Total particulate matter less than 10µm diameter (PM_{10})	$\mu g/m^3$
Productivity	Aboveground net primary productivity (ANPP) / Yield	gC/m^2/year

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

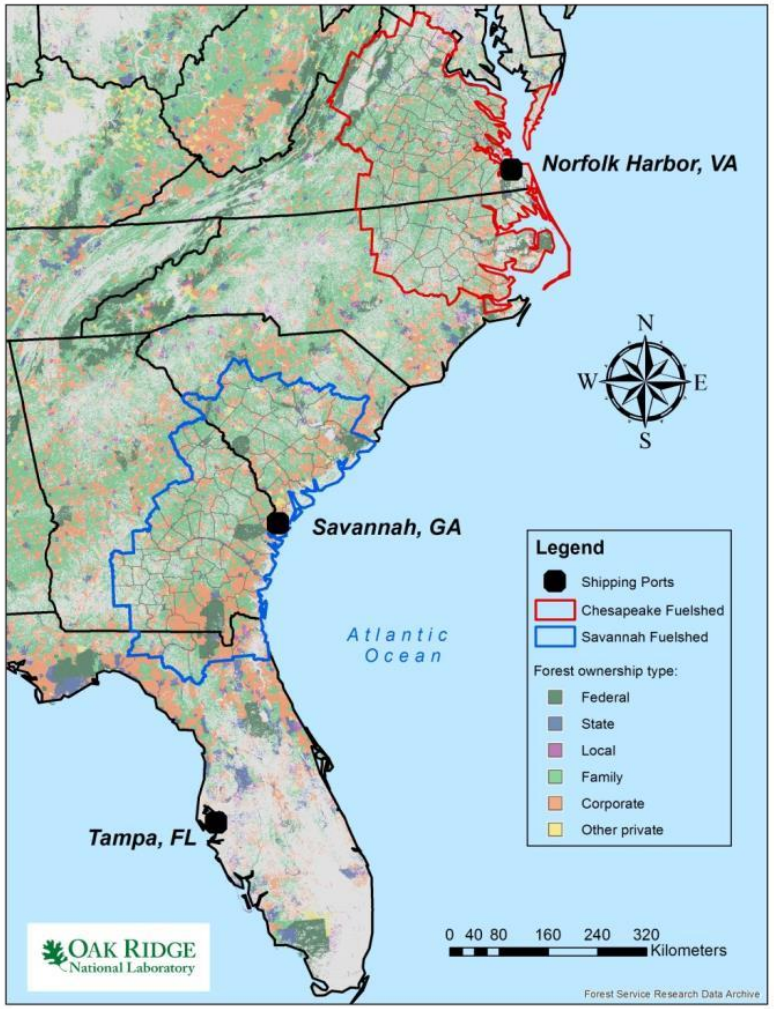
Socioeconomic sustainability indicators *(16 in 6 categories)*

Category	Indicator	Units
Social well-being	Employment	Number of full time equivalent (FTE) jobs
	Household income	$ per day
	Work days lost due to injury	Average number of work days lost per worker per year
	Food security	% change in food price volatility
Energy security	Energy security premium	Dollars /gallon biofuel
	Fuel price volatility	Standard deviation of monthly percentage price changes over one year
External trade	Terms of trade	Ratio (price of exports/price of imports)
	Trade volume	Dollars (net exports or balance of payments)
Profitability	Return on investment (ROI)	Percent (net investment/ initial investment)
	Net present value (NPV)[2]	Dollars (present value of benefits - present value of costs)

Category	Indicator	Units
Resource Conserv-ation	Depletion of non-renewable energy resources	MT (amount of petroleum extracted per year)
	Fossil Energy Return on Investment (fossil EROI)	MJ (ratio of amount of fossil energy inputs to amount of useful energy outputt
Social accept-ability	Public opinion	Percent favorable opinion
	Transparency	Percent of indicators for which timely and relevant performance data are reported
	Effective stakeholder participation	Number of documented responses to stakeholder concerns and suggestions reported on an annual basis
	Risk of catastrophe	Annual probability of catastrophic event

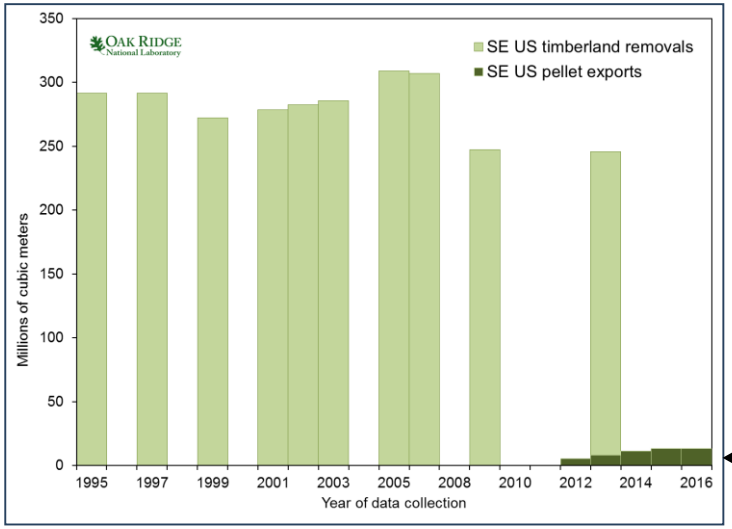
Dale et al. (2013) *Ecological Indicators* 26:87-102

Wood Pellet Case Study: Background Information



- Over half of US wood pellets ship to Europe from Savannah, GA & Norfolk, VA
- Examined USDA Forest Inventory & Analysis (FIA) data for changes from pellet production

Timberland Characteristic	Savannah Fuelshed	Chesapeake Fuelshed
Naturally regenerating stand volume	Increased	No change
Plantation volume	Increased	Increased
Large-diameter tree area	Increased	Increased
Medium diameter tree area	No change	No change
Small diameter tree area	No change	No change
Standing dead tree density of natural stands (#/ha)	Increased	No change
Standing dead tree density of plantations (#/ha)	Decreased	No change
Carbon content of soil and leaf litter	Increased	No change
Carbon content of live harvestable material	Increased	Increased
Carbon content of dead non-harvestable material	Increased	No change



Only a small portion of SE US timberland removals are used for bioenergy wood pellets

Dale et al. (2017) *GCB Bioenergy*, Dale et al. (2017) *Forest Ecology and Management*, Parish et al. (2017) *Data in Brief*, Parish et al. (2017) *World Biomass*, Parish et al. (2017) *WIRES*

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Current Manuscripts

Baskaran LM, Parish ES, Dale VH (In Revision) How will SE US wood pellet production affect the gopher tortoise (*Gopherus polyphemus*)?

Dale VH, Kline KL, Parish ES, Eichler SE (Submitted) Engaging Stakeholders to Assess Landscape Sustainability. *Landscape Ecology*

Hodges DG, Chapagain B, Watcharaanantapong P, Poudyal NC, Kline KL, Dale VH (In Review) Dataset of Forest Landowner Survey to Assess Interest in Supplying Woody Biomass in Two Southeastern United States Fuelsheds. *Data in Brief*

Hodges DG, Chapagain B, Watcharaanantapong P, Poudyal NC, Kline KL, Dale VH (In Review) Opportunities and attitudes of private forest landowners in supplying woody biomass for renewable energy. *Renewable and Sustainable Energy Reviews*

Nair S, Parish ES, Baskaran LM (In Preparation) Analysis of hydrologic impacts from forest thinning for bioenergy wood pellet production.

Parish ES, Brandeis C, Turner J, Kline KL (In Preparation) What is the sensitivity of environmental indicators derived from USDA Forest Inventory and Analysis Data to bioenergy fuelshed boundaries?

Parish ES, Baskaran LM, Brandeis C, Dale VH, Jager H, Kline KL, Langholtz LM, Nair S, Turner J (In Preparation) Sustainability analysis of two Southeastern US bioenergy wood pellet fuelsheds.

Related Team Publications *(since March 2017)*

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Feedback from March 2017 'Go/No Go' BioSTAR Workshop

BioSTAR is a "Very useful and one-of-a-kind tool for evaluating sustainability for different bioenergy land use options."

We agree that BioSTAR is unique. We do not know of any other decision tool that tries to address all three pillars of sustainability for bioenergy systems.

"It is challenging to communicate biomass sustainability to diverse stakeholder groups."

True! We think that BioSTAR users may include researchers from government & academia, industry, NGO's, and potential feedstock producers. It is challenging to build a tool that can assist all of these stakeholders with decision-making.

"Taking a lot of complex data on a large issue-sustainability-is a huge undertaking. Take a small slice of this challenge and focus on it to be successful."

We started with 3 case study applications before beginning to think about ways for users to analyze their own projects.

"Incorporate data from BT16 Vol 2 into the tool." We are currently working on this.

"Include options to explore all data by feedstock type, by sustainability indicator data available, etc."

BioSTAR's "Indicator Data Explorer" and "Feedstock Comparison" modules are under development to address these suggestions.

Responses to 2017 DOE Peer Review Comments

"The true value of this project is to get people thinking about a broad umbrella of indicators especially going beyond the traditional environmental indicators and including economic and social impacts as well. It will be important as the project moves forward to enable the use of best practices by providing examples of how these various metrics can be assessed, integrated, and effectively visualized."

> Our web-based BioSTAR tool is being built to demonstrate 3 case studies that use a combination of environmental & socioeconomic indicators to assess and visualize sustainability relative to stakeholder priorities. Sharing lessons learned will promote good practices.

"It would be useful to consider how the project could support making data available for the analysis of future biofuel systems and/or how could data be brought together from disparate sources to support a comprehensive sustainability assessment of biofuel systems."

> In addition to sharing ORNL's case study results, we are beginning to pull together national-scale datasets that can provide baseline values for our starting checklist of environmental & socioeconomic indicators of bioenergy sustainability (or perhaps a subset of key indicators).These datasets and our sustainability assessment methodology will be made available through the web-based BioSTAR tool so that they can be used to comprehensively evaluate the benefits & costs of new cellulosic biomass systems.

Comments from 2018 Project AOP Merit Review

"This proposal is to develop an online tool and support database to quantify and visualize the potential sustainability costs and benefits of using different cellulosic bioenergy feedstocks in different geographic contexts. ***It is very innovative, and if successful, could yield strong rewards to local and regional decision makers and planners****."*

"An important aspect of the work is making existing and forthcoming BETO research more understandable and accessible."

"Overall, this project's objective - to inform decisions and better implement bioenergy systems - is admirable and supports BETO's mission."