2015 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Bioenergy Sustainability: How to Define & Measure It

Date: March 23, 2015
Technology Area Review:
Analysis & Sustainability

Principal Investigator: Virginia Dale
Organization: Oak Ridge National Laboratory

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

Goal Statement

- Goal: Enable long- term supply of sustainable feedstock & bioenergy
  - Identify key indicators of how bioenergy production affects environmental, social & economic sustainability
  - Determine how those effects can be quantified
  - Demonstrate quantitative approach to assessment of progress toward sustainability in case studies
- Relates to BETO objectives
  - Establish performance metrics for bioenergy sustainability
  - Build consensus on specific definitions & ways to quantitatively measure bioenergy sustainability
  - Provide a consistent & evidence-based message on meaning of bioenergy sustainability
  - Build methodology to measure & assess sustainability
- Tangible outcomes for US
  - Agreement on definitions of bioenergy sustainability
  - Tools for quantification, aggregation of measures, & visualization
  - Examples of how to quantify sustainability in particular contexts

Quad Chart Overview

Timeline

- Project start date: FY09
- Project end date: FY17
- Percent- complete: 63%

Barriers

- St-B: Consistent, science-based message on bioenergy sustainability
- St-C: Sustainability data across the supply chain
- St-D: Implementing indicators and methodology for evaluating and improving sustainability
- St-G: Land use and innovative landscape design

Budget

- FY10-12: $2034k (DOE)
- FY13: $700k (DOE)
- FY14: $700k (DOE)
- FY15-17: $2200k (DOE)

Partners

- Stakeholders: Council on Sustainable Biomass Production (CSBP), Biomass Market Access Standards (BMAS), Global BioEnergy Partnership (GBEP), Roundtable for Sustainable Biomaterials (RSB), National Council on Air and Stream Improvement (NCASI)
- Other DOE Labs engaged (but no direct costs): NREL, ANL, INL, PNNL
- Other agencies: USDA, EPA, USFS, FAO (Food and Agriculture Organization), IEA (International Energy Agency)
- Universities: Univ. Tennessee, NC State Univ., Texas A&M, Great Lakes Bioenergy Research Center (GLBRC), Utrecht Univ., NSF Research Collaborative Network (RCN) led by Michigan Tech
- Industry: Arborgen, Ceres, Dupont, Genera, Institute for Forest Biotechnology, Weyerhaeuser, Plum Creek, Noble Foundation

Project Overview

- History of project 4.2.2.40
  - FY09: Initiated by DOE based on PI's experience with indicators
  - Challenges:
    - ➢ Some indicators focus on management practices but knowledge is limited about which practices are "sustainable"
    - ➢ Bioenergy sustainability not defined
    - ➢ Existing approaches use indicators that are too
      - – Numerous
      - – Costly
      - – Broad
      - – Difficult to measure

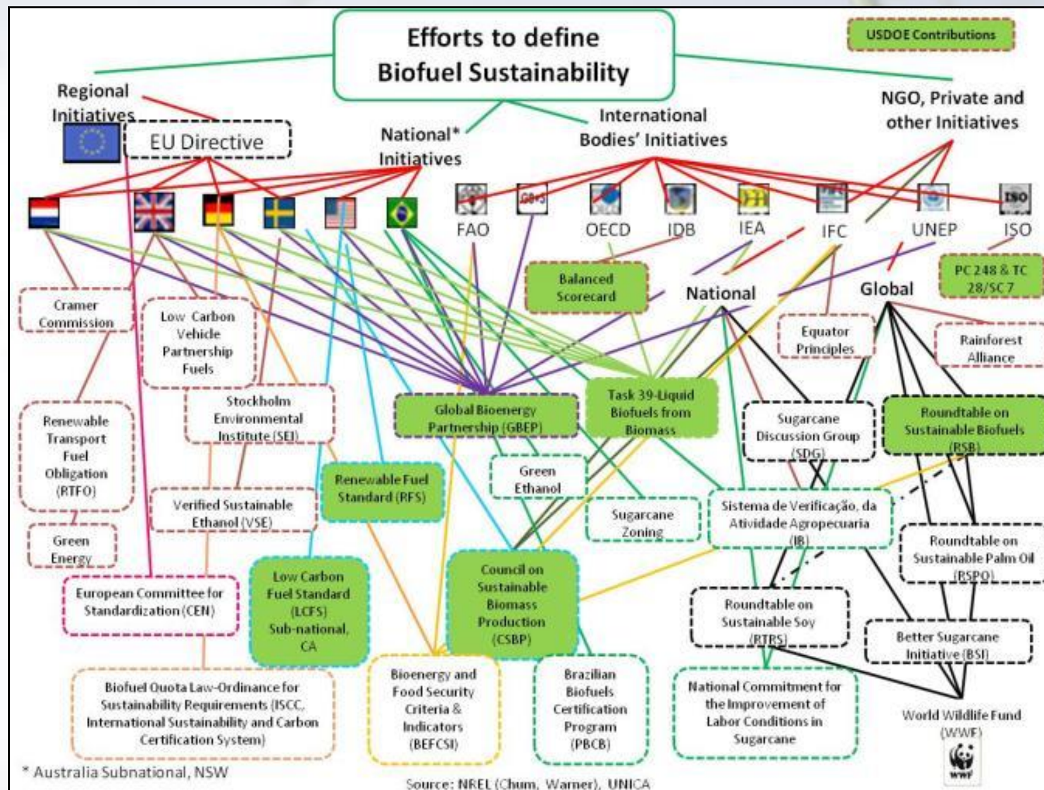

Chart of many initiatives exploring indicators for sustainability

- Objectives
  - Review existing sustainability indicators
  - Assist BETO in defining sustainability for bioenergy and determining indicators for use at the national scale
  - Determine ways to implement and evaluate sustainability indicators for bioenergy decisions

Previous Accomplishments (2009 to mid-2013)

- **Evaluated key challenges for bioenergy sustainability ***
  - **Interaction between land use & bioenergy**
    - Led BETO's Land-use change workshop and report
    - Biofuels, causes of land-use change, & the role of fire [Kline & Dale 2008. *Science* 321:199]
    - Land use – climate change – energy nexus [Dale et al. 2011. *Landscape Ecology* 26(6):755-773]
  - **Developing a balanced, science-based perspective about bioenergy**
    - Participated in Ecological Society of America (ESA) workshop and its products
      - Sustainable biofuels redux [Robertson et al. 2008. *Science* 322(5898): 49–50]
      - Biofuels: Implications for land use and biodiversity [Dale et al. 2010. ESA report]
      - Interactions among bioenergy feedstock choices, landscape dynamics & land use [Dal et al. 2011. *Ecol. App.* 21:1039-1054]
    - Biofuels, Done Right [Kline et al. 2009. *Issues in Science and Technology* 25(3): 75-84]
  - **Communications**
    - Communicating about bioenergy sustainability [Dale et al. 2013. *Environ. Manage.* 51:279-29]
  - **Regional approaches**
    - Bioenergy sustainability at the regional-scale [Dale et al. 2013. *Ecology and Society* 15(4): 23]
    - Multi-scale comparison of gasoline and ethanol [Parish et al. 2013. *Environ. Manage.* 51: 307-338]
    - Important of context [Efroymson et al. 2013. *Environ. Manage*. 51:291-306]
- **Proposed sustainability indicators for bioenergy ***
  - **Ecological indicators** [McBride et al. 2011. *Ecological Indicators* 11:1277-1289]
  - **Socioeconomic indicators** [Dale et al. 2013. *Ecological Indicator*s 26: 87-102]
- **Applied proposed approach ***
  - **Multimetric spatial optimization of switchgrass** [Parish et al. 2012. Biofuels, Bioprod. Bioref. 6(1):58-72]
  - **Indicators for bioenergy sustainability applied to Eucalyptus** [Dale et al. 2013. International Journal of Forestry Research]

*** Shared findings with industry, universities, NGOs, land holders & other stakeholders**

Approach (1)

Code for checks	
✔	Completed
✔	Tested in East TN
✔	Reviewed

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

Summary of approach: Indicators

Best practices

Approach (2)

A. ***Advance common definition of environmental & socioeconomic costs and benefits of bioenergy systems***
   - Assist BETO in defining sustainability for bioenergy
   - Identify indicators of bioenergy sustainability
   - Work with others to establish concepts of bioenergy sustainability

B. ***Quantify opportunities, risks & tradeoffs associated with sustainable bioenergy production in specific contexts***
   - Clarify appropriate use of tools to aggregate indicators of bioenergy sustainability
   - implement & evaluate sustainability indicator framework considering
     - Switchgrass in east Tennessee
     - Pellet production in SE US
     - Feedstocks in other regions (working with other DOE Labs, universities, & industry)

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Project Management Approach (1)

- ***Team:***
  - Virginia Dale, landscape ecologist (principal investigator)
  - Latha Baskaran, watershed modeling
  - Rebecca Efroymson, risk assessment
  - Keith Kline, energy specialist and international issues
  - Esther Parish, geographer
  - Nate Pollesch, mathematician
  - Mike Hilliard, optimization analyst
- ***Supplemental team***
  - Other ORNL staff
  - Scientists at other DOE Labs
  - University partners
  - Other agencies: USDA, EPA, FAO, IEA
  - Private partners: Industry and NGOs
- ***Review of progress***
  - Workshops that foster discussion
  - Publications in peer reviewed journals
  - Presentations at conferences
  - Engagement with stakeholders

Project Management Approach (2)

Key milestones for monitoring progress

- **Milestones defined & delivered**
  - Annual update of project plan
  - Quarterly reports & conference calls with BETO
- **Resources & partnerships leveraged**
  - Southeastern Partnership for Integrated Bioenergy Supply Systems (IBSS) – supported by USDA
  - International Energy Agency (IEA) Task 43
  - Coordination with other National Labs
    - Landscape design workshops planned & held in conjunction with Argonne National Lab
    - Testing of indicator-to-BMP approach
- **Risks defined & addressed**
  - Risk definition part of annual plan
  - Report to BETO on how risk addressed

Approach:
Indicators
↓
Best practices

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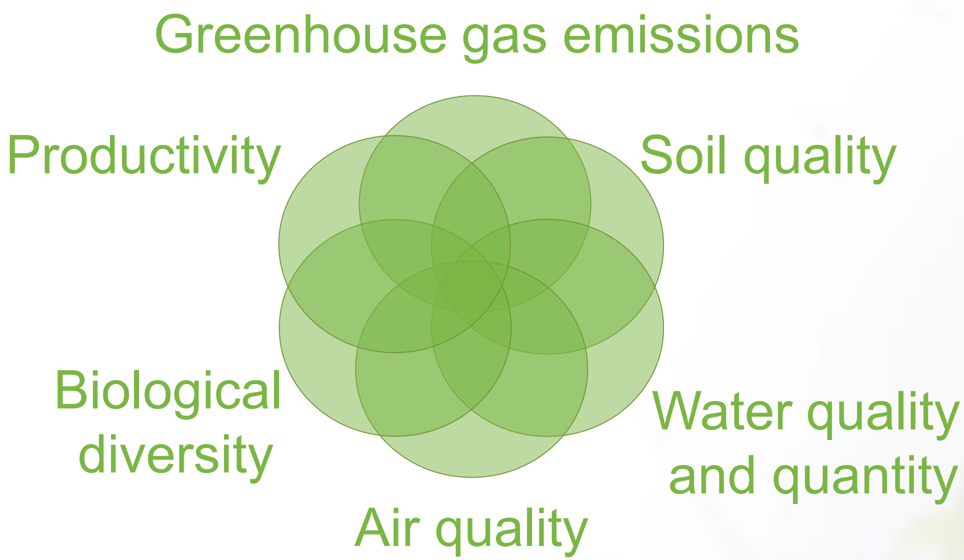
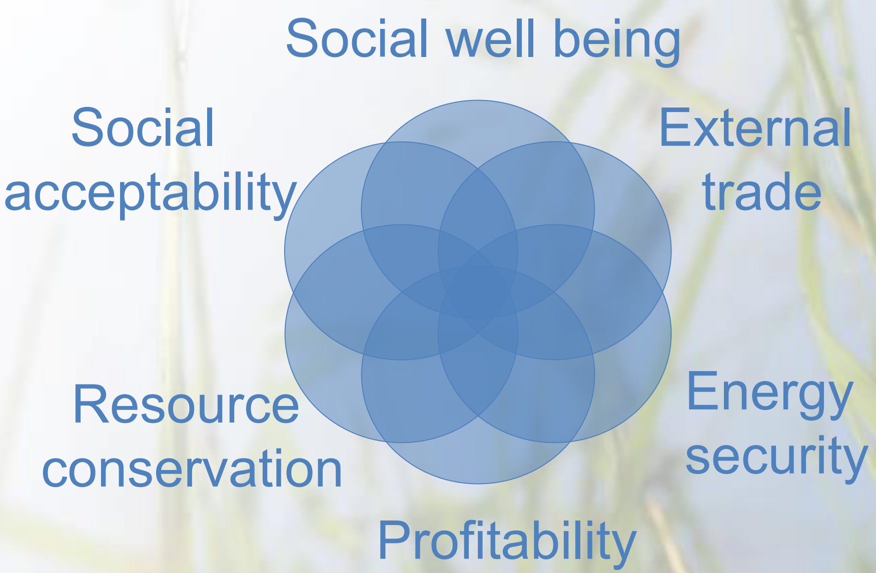
2 - Technical Accomplishments/Progress/Results

Goal A. Advance common definitions of environmental & socioeconomic costs and benefits of bioenergy systems



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



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

Recognize that measures & interpretations are <u>context</u> specific

Efroymson et al. (2013) *Environmental Management* 51:291-306.

Categories of socioeconomic sustainability indicators

Ten minimum practical measures

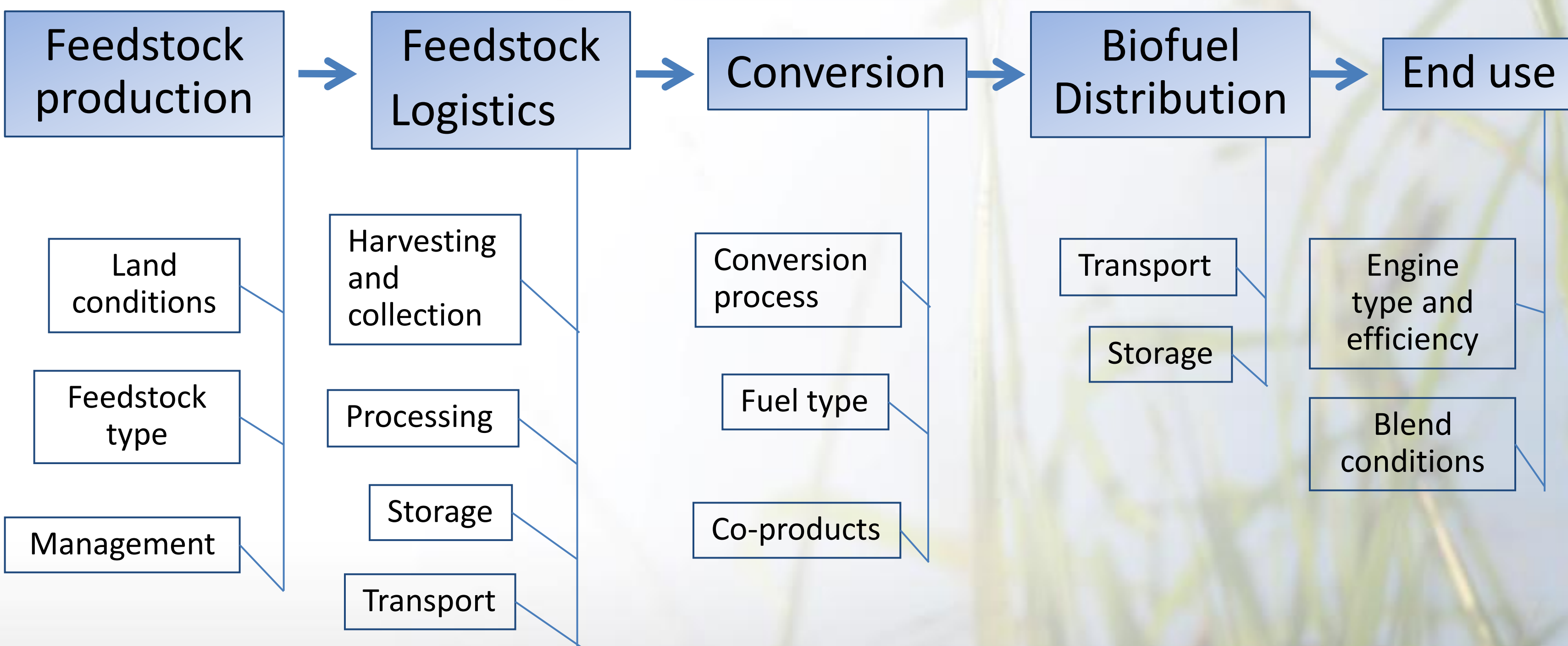
Category	Indicator	Units
Social well-being	Employment	Number of full time equivalent (FTE) jobs
	Household income	Dollars per day
	Work days lost due to injury	Average number of work days lost per worker per year
	Food security	Percent change in food price volatility
Energy security	Energy security premium	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 minus present value of costs)

Category	Indicator	Units
Resource conservation	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 output
Social acceptability	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.

Sustainability should apply to

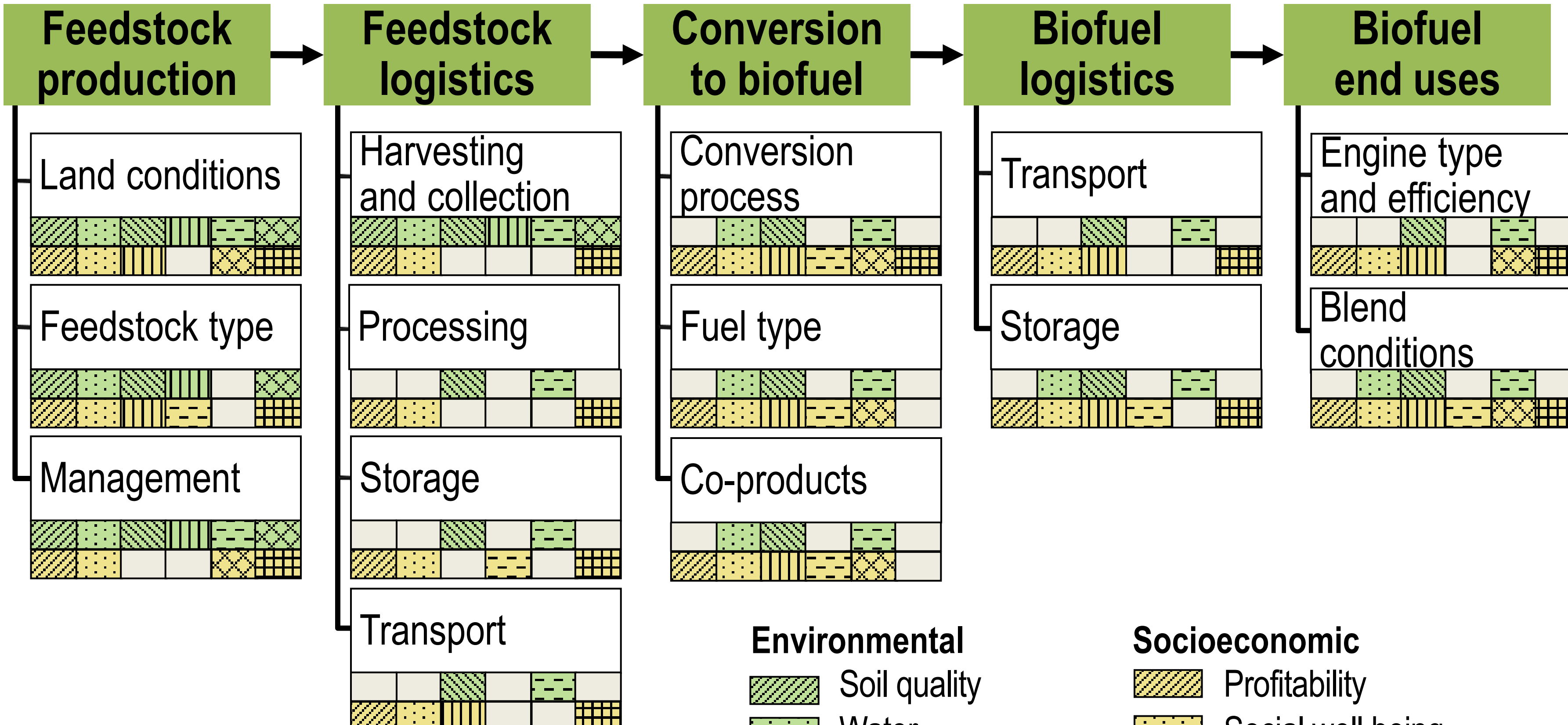
- Entire supply chain
- Diverse feedstocks
- All conversion pathways

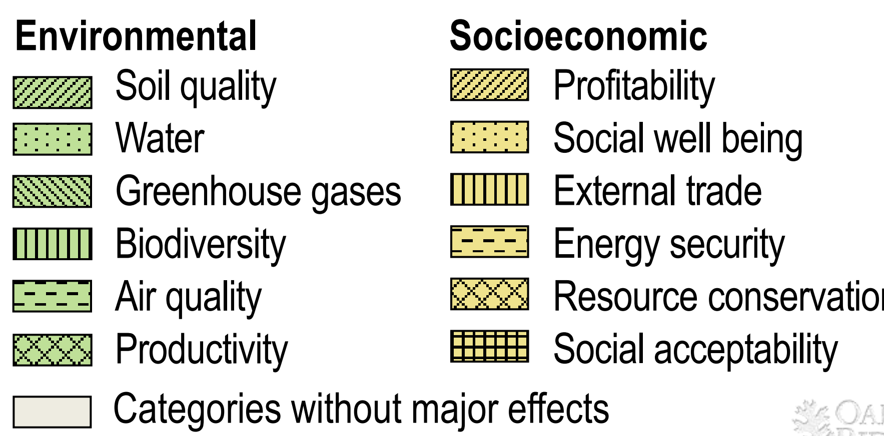


(Example shown is biofuel, but concepts are applicable to bioenergy as well)

Dale et al. (2013) *Environmental Management* 51(2): 279-290.

Consider biofuel supply chain in terms of sustainability indicators



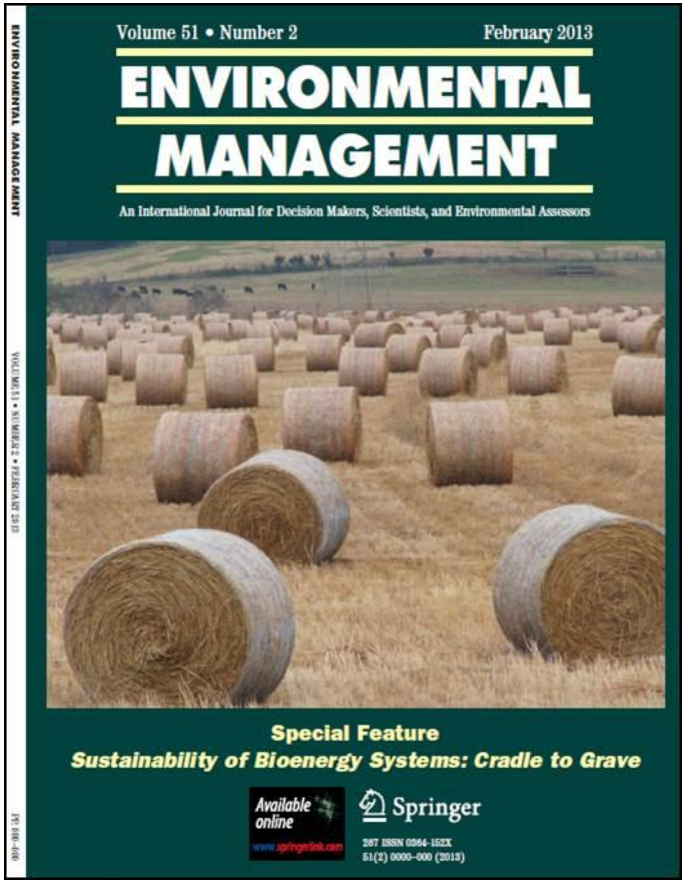


Efroymson et al. (2013) *Environmental Management* 51:291-306.

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

Advanced common definitions of environmental & socioeconomic costs & benefits of bioenergy

- **Worked with others to establish common definitions** (http://www.ornl.gov/sci/ees/cbes/Collaborations.shtml)
  - National Council for Air and Stream Improvement (NCASI)
  - National Science Foundation Research Collaboration Network on Bioenergy Sustainability
  - ORNL workshops: (http://www.ornl.gov/sci/ees/cbes/)
  - Bioenergy Sustainability: Cradle to Grave [Special feature in Feb 2013 issue of *Environmental Management*]
  - BETO workshops on landscape design
- **Assisted BETO by providing reviews and analysis when requested, for example**
  - GBEP (Global Bioenergy Partnership)
  - RSB (Roundtable on Sustainable Biomaterials)
  - FAO (Food and Agriculture Organization)
- **Worked to establish common basis for certification:**
  - BMAS (Biomass Market Access Standards)
  - IEA (International Energy Agency) Task 43
  - ISO (International Organization for Standardization)



[ORNL's engagement with international partners presented by Keith Kline]

Goal B. Quantify opportunities, risks & tradeoffs associated with sustainable bioenergy production in specific contexts

- **Develop/test tools for assessment of progress toward bioenergy sustainability**

  [outline for next part of presentation]

  - ➢ Developed or adapted needed tools for assessment of bioenergy sustainability
    - ✓ Mathematical aggregation
    - ✓ Multi-Attribute Decision Support Systems (MADSS)
    - ✓ Landscape design approach
  - ➢ Developed framework for using indicators
    - ✓ Reviewed BMPs
    - ✓ Showed how sustainably managed biofuels support sustainability goals
  - ➢ Focused on particularly challenging indicators
    - ✓ Biodiversity
    - ✓ Water Quality
- **Case studies of evaluating progress toward bioenergy sustainability**

  [cross cuts with tools above]

  - ➢ Switchgrass in east Tennessee - applied Multi-Attribute Decision Support Systems (MADSS)
  - ➢ Pellet production in SE US - testing landscape design
  - ➢ Feedstocks in other regions - testing indicator approach

  E.g., NCSU, NEWBio, and Pan American RCN with Michigan Tech

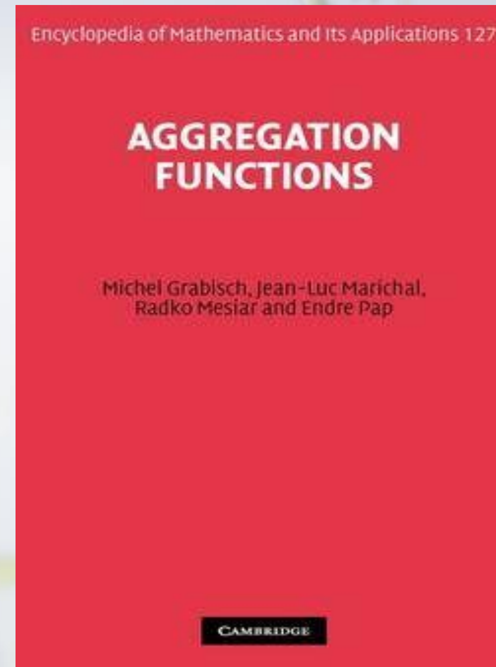
Conducting Mathematical Study of Aggregation Functions Applied to Bioenergy Sustainability

- **Challenges in bioenergy sustainability assessment**
  - ✓ Diverse production pathways
  - ✓ Varying environmental & sociopolitical sensitivities
  - ✓ Varying data quality & availability

- **Hence bioenergy sustainability assessments must be**
  - ✓ Flexible
  - ✓ Adaptable for assessment
  - ✓ Mathematically rigorous

- **Factors for determining appropriate aggregation strategies**
  - ✓ Desired assessment application
  - ✓ Characteristics of indicator data

- **Development of sustainability assessment protocol**
  - ✓ Bridges the gap between identification of bioenergy sustainability indicators and the creation of assessment and visualization tool
  - ✓ Addresses current challenges in sustainability assessment
  - ✓ Identifies potential challenges that may arise in deployment of a comprehensive bioenergy sustainability assessment strategy and visualization tool

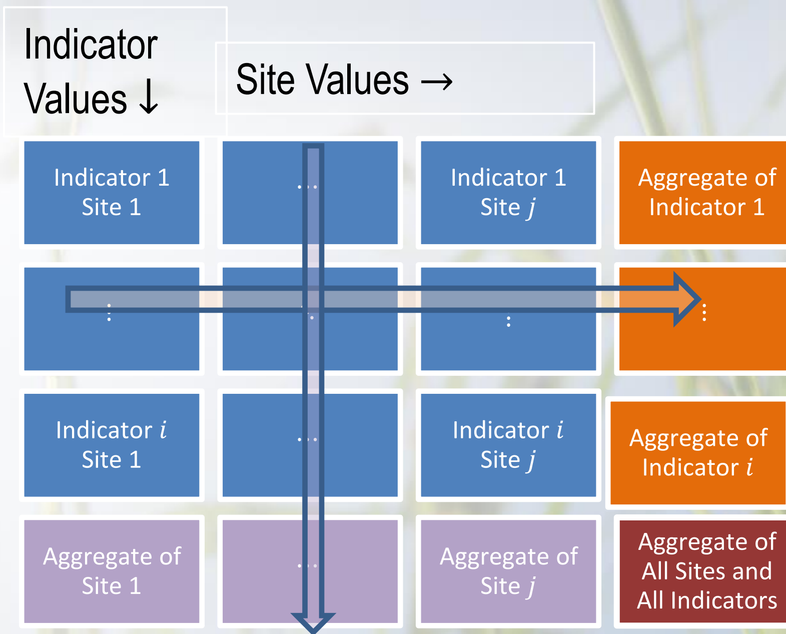


We are applying *Aggregation Functions* to formalize the application of aggregation theory to bioenergy sustainability.

[Pollesch and Dale (in prep) Toward a sustainability target assessment tool for bioenergy: Key components and requirement specifications.]

Applying Mathematical Approach to Assessment Protocol Development

- **Related mathematical properties of aggregation functions to assessment challenges:**
  - ✓ Repeated aggregation of indicators
  - ✓ Uncertainty in indicator measurements
    - at the level of individual indicator
    - in aggregate measures of groups of indicators
  - ✓ Compensatory behavior of assessment
    - E.g., in the aggregate, offsetting of low environmental scores by high economic scores
  - ✓ Transforming, normalizing, and weighting of data within assessment
  - ✓ Comparability of assessment results across multiple bioenergy contexts
- **Introduced relevant mathematical techniques for sustainability assessment**
- **Developing new mathematical techniques to address normalization, weighting, and aggregation that have application in**
  - ✓ Sustainability assessment
  - ✓ Other assessment and index development efforts



Next step: Develop & test <u>S</u>ustainability <u>T</u>arget <u>A</u>ssessment <u>T</u>ool for <u>B</u>ioenergy (STAT-B)

[Pollesch and Dale (In press) Applications of aggregation theory to sustainability assessment. *Ecological Economics*]

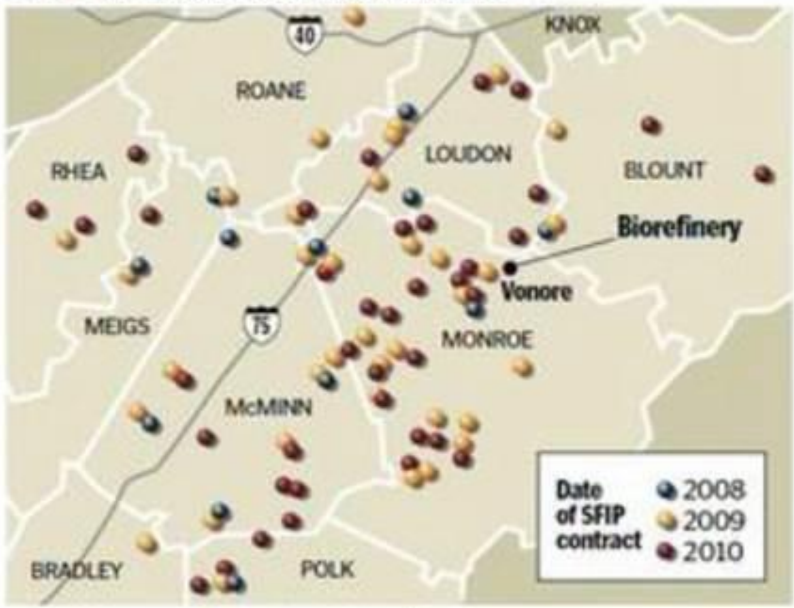
Used a Multi-Attribute Decision Support System (MADSS): to compare sustainability of 3 scenarios in east Tennessee

Parameter	NO-TILL SWITCHGRASS	TILLED CORN	UNMANAGED PASTURE
Time of planting	Establish once in spring; no replanting	Plant annually	Already established
Tillage type	No-till method with a drill is preferred	Planted conventionally	No need for replanting
Harvesting equipment	Conventional hay equipment	Combine	Harvest by cows (1.5 acres/cow)
Harvest frequency	Once per year (after Nov. 1 or first killing frost)	Once a year (October)	Continuous
Storage	Round bale tarped	Trucked off farm	None
Herbicide application	1-3 applications of glyphosate herbicide prior to planting	Annual application of glyphosate herbicide	No herbicide used
Fertilizer application	Apply 40 lbs/acre when soil test is "Low" for P and K	Apply 100-160 lbs/acre when soil test is "Medium"	No fertilizer used
Typical yield	6-8 tons/year after 3rd year	114.5 bushels/acre (average for 2007-2013)	2.1 tons/acre (estimated as mixed hay)
Price information	$450/acre actual contract price; estimated delivered price= $71.23/ton ($3.25/ton storage)	$5.04/bushel (2007-2013 average)	$90.79/ton (2007-2013 average)
Final destination	50 million gallon/year Biorefinery within a one-hour's drive (ton-to-gallon conversion rate of 76)	Multiple uses of corn grain throughout the region	On-site cattle roughage

Case study of MADSS applied to east TN:

Leverages data from SE Partnership for Integrated Biomass Supply Systems (IBSS)

SWITCHGRASS CONTRACT FARMS



County	Total acres	Farmers
Monroe	2,205.3	26
McMinn	818.1	10
Loudon	553.9	6
Blount	469.5	4
Bradley	354.7	2
Polk	291.9	3
Rhea	258.1	5
Roane	118.8	4
Hamilton	58.6	1
Meigs	33.3	2
Totals	**5,162.2**	**63**

Year	New farmers	Total production in tons
2008	16	1,000
2009	24	6,000
2010	21	*15,000

*Estimated

Farmer type	Farmers
Full time	31
Part time	30

Source: Genera Energy LLC — NEWS SENTINEL

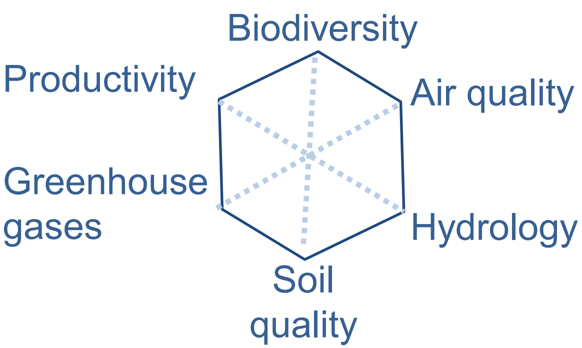
Vonore, Tennessee, USA demo-scale biorefinery (250Mgal/yr) & nearby switchgrass bales

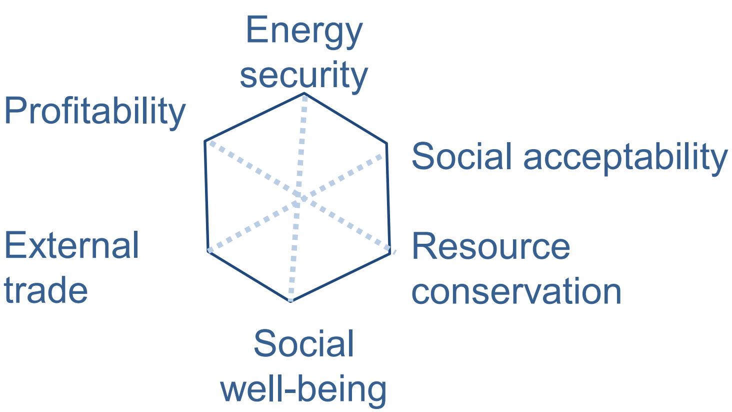
Photos from Genera Energy LLC

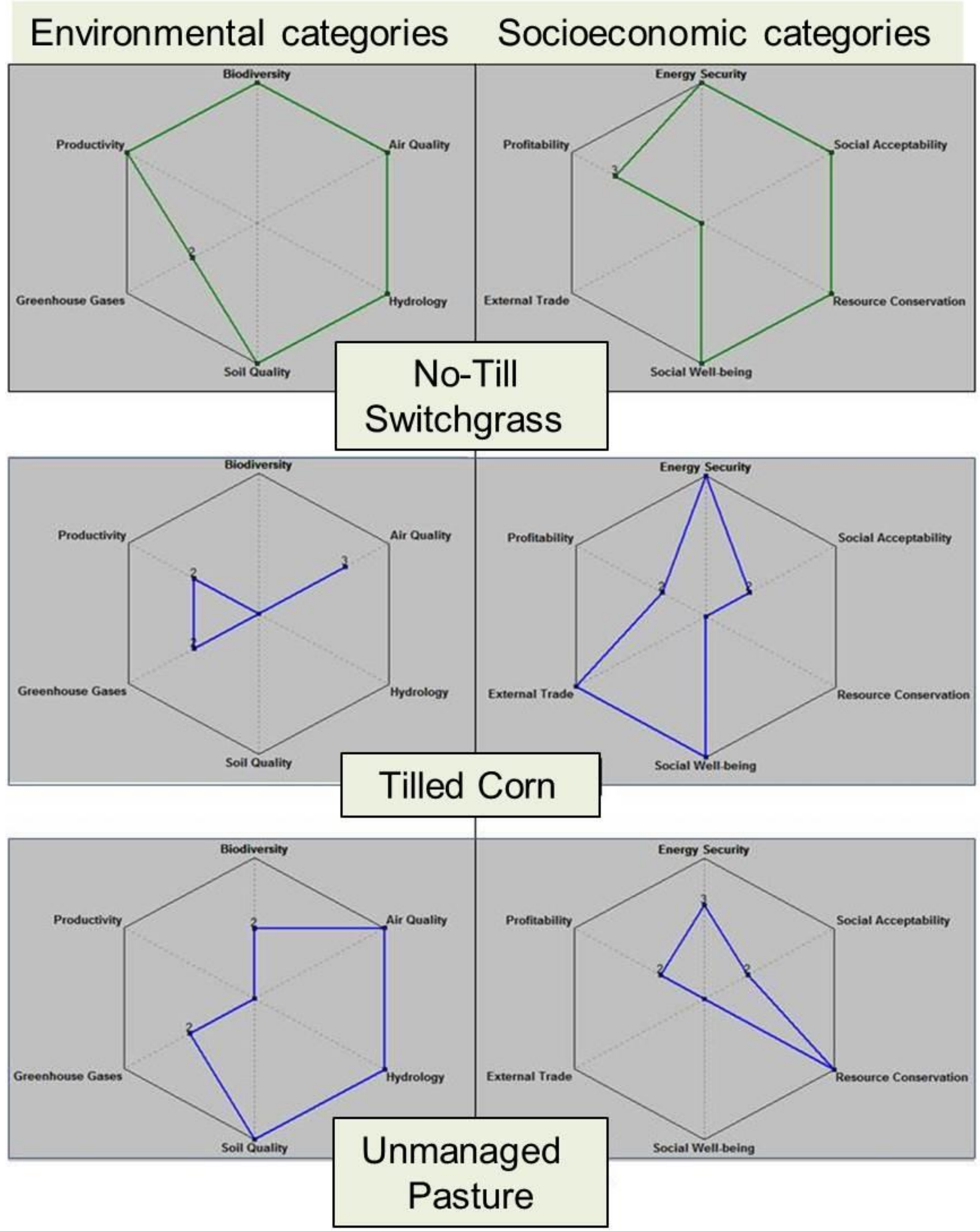
Case study of MADSS applied to east TN:

Rates environmental & socioeconomic sustainability

Key to chart







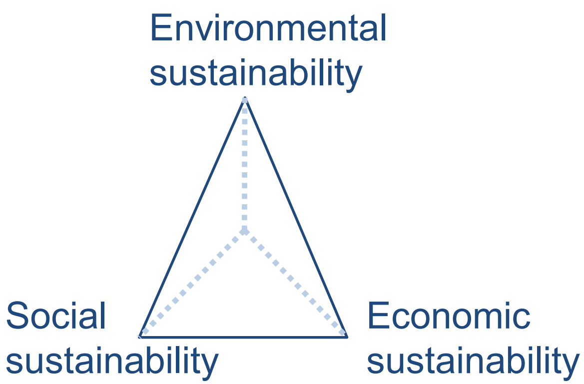
[Parish et al. (In review) Assessing multimetric aspects of sustainability. *Ecosphere*]

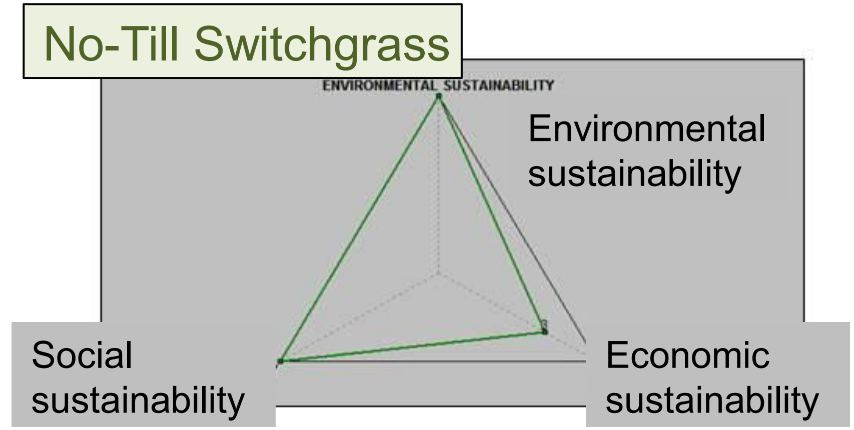
Case study of MADSS applied to east TN:

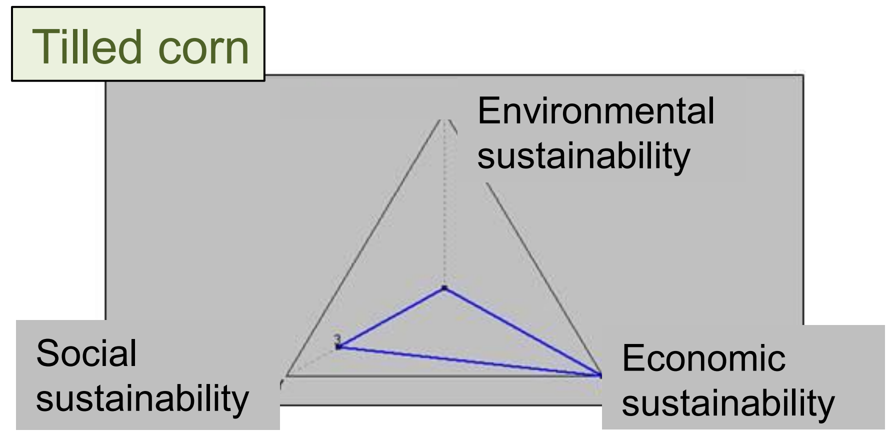
Determines relative contributions of three "pillars" to overall sustainability

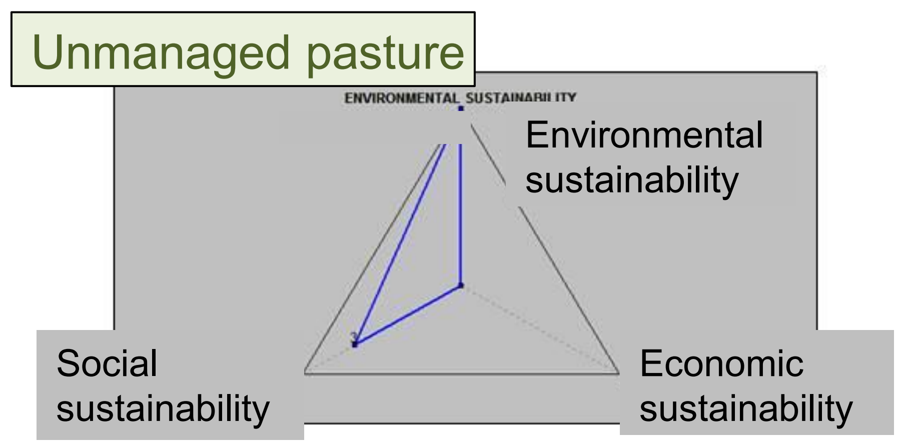
The center point of each triangle represents the lowest possible rating, & the outer edges represent the highest rating.

Key to chart









[Parish et al. (In review) Assessing multimetric aspects of sustainability. Ecosphere]

Developing Landscape Design Approach

BETO Workshop on Incorporating Bioenergy into Sustainable Landscape Designs

New Bern, North Carolina, March 4-6, 2014

Organizers: Oak Ridge National Lab, Argonne National Lab, BETO & NCASI

- **Landscape design approach**
  - Focused on bioenergy production systems
  - Integrates other components of the land, environment and socioeconomic system.
- **Tangible actions that can enable and expand sustainable development of the bioeconomy**
- **Southeast US opportunities using woody materials**
- **Workshop report, agenda, participant list, tour guide, & presentations at** http://web.ornl.gov/sci/ees/cbes/workshop.shtml.

Follow up workshop at Argonne National Lab (Christina Negri will discuss)

Developed Landscape Design Approach

[Dale et al. (In review) Incorporating Bioenergy into Sustainable Landscape Designs. *Renewable & Sustainable Energy Reviews*]

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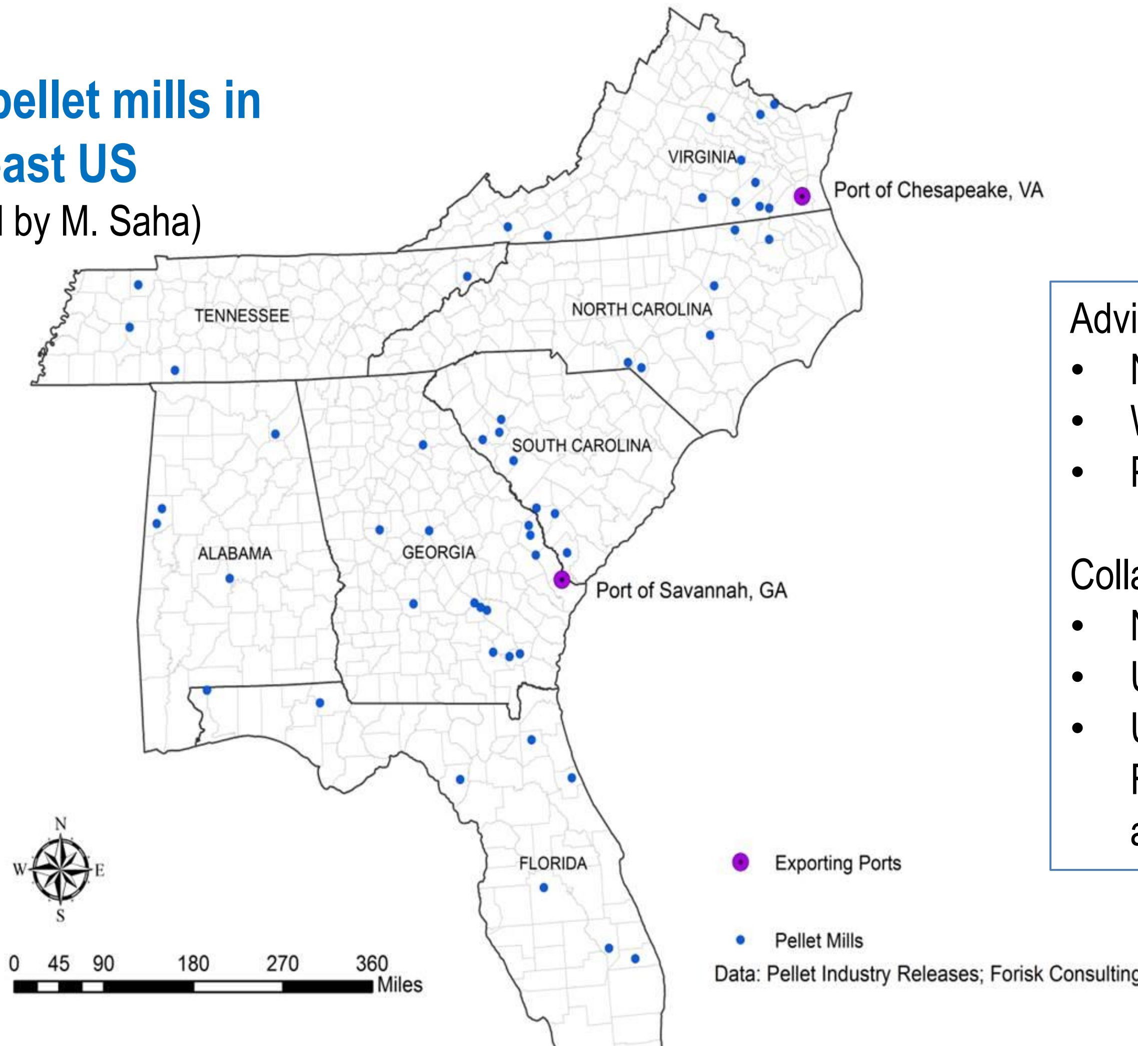
Next Step: Application of Landscape Design Approach to southeastern Pellet Mills

Focus on feeding the ports at Savannah (pines) and Chesapeake (bottomland hardwoods)

Location of pellet mills in Southeast US

(map created by M. Saha)



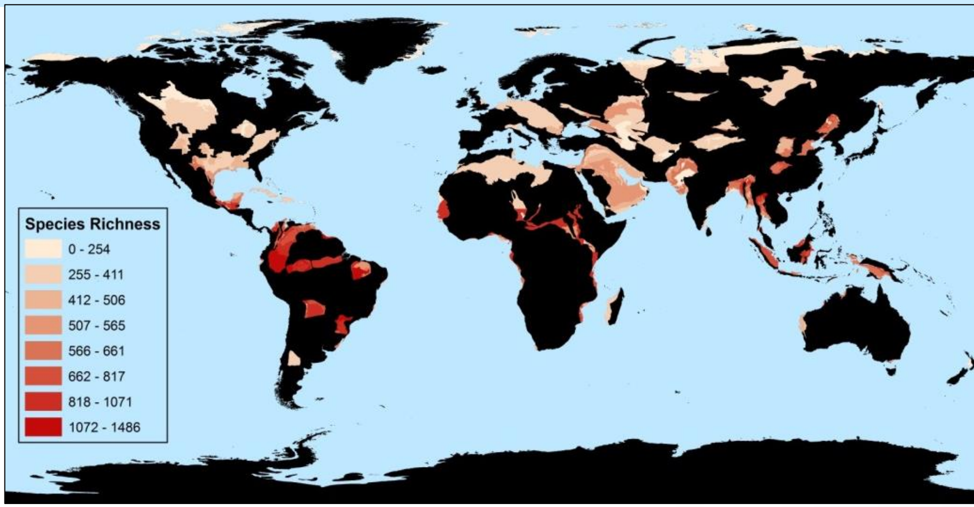
Advisory team:
- NCASI
- Weyerhaeuser
- Plum Creek

Collaborators:
- NCSU: Bob Abt
- USDA: Karen Abt
- Utrecht University: Floor Van der Hilst and Anna Duden

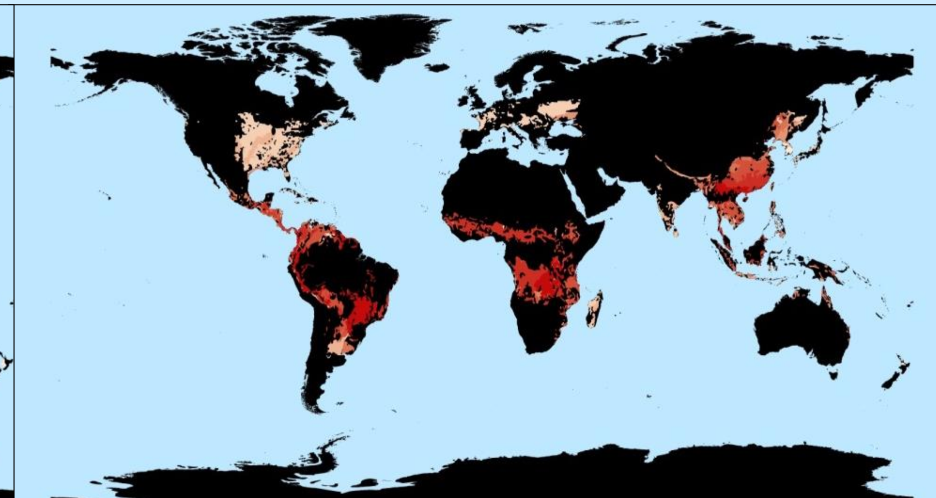
Compared Biodiversity Risks from Biofuels versus Gasoline

Overlay of Species Richness onto Locations with Sources of Fuel

Petroleum reserves



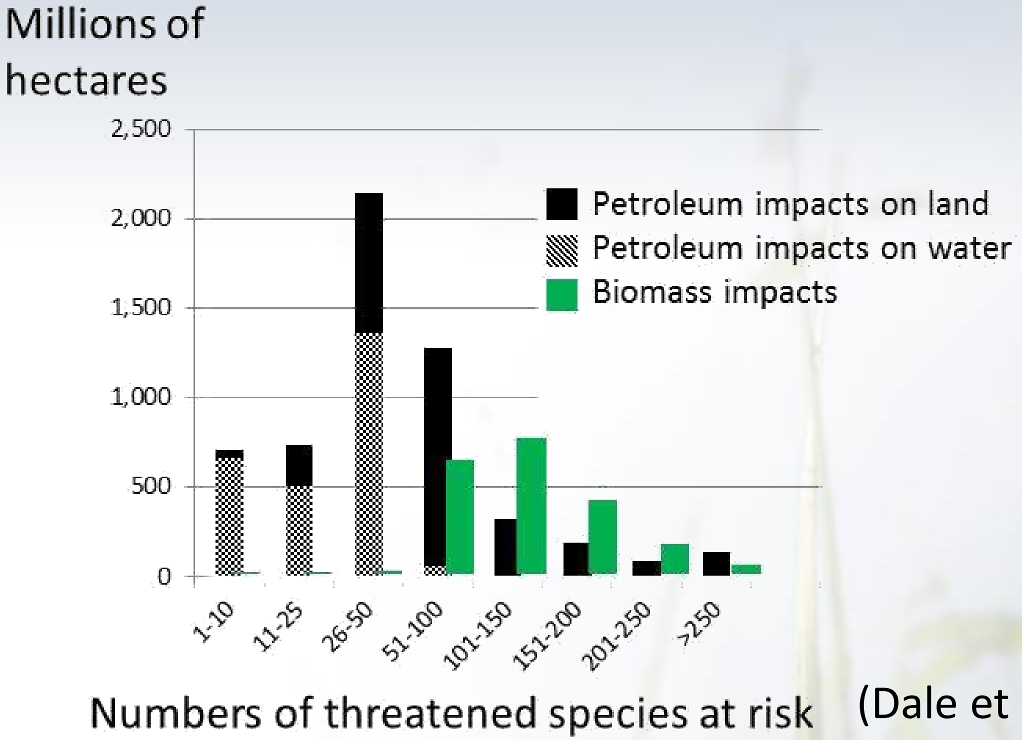
Bioenergy feedstock production areas



- Petroleum exploration activities projected to affect
  - > 5.8 billion ha of land and ocean worldwide (3.1 billion ha on land)
  - Much in remote, fragile terrestrial ecosystems or off-shore oil fields that would remain relatively undisturbed if not for interest in fossil fuel production.
- Biomass production for biofuels projected to affect
  - ~ 2.0 billion ha of land
  - Most located in areas already impacted by human activities.

Dale VH, ES Parish, KL Kline (2015). Risks to global biodiversity from fossil-fuel production exceed those from biofuel production. *Biofuels, Bioprod. Bioref*.

Biofuel Expansion could Impact Threatened Species



(Dale et al. 2015)

Negative effects of biofuel production on biodiversity & ecosystem services can be avoided or reduced & positive effects enhanced by:

- Identifying & conserving priority biodiversity areas
- Recognizing that effects of biofuel feedstock production on biodiversity & ecosystem services are context specific
- Location-specific management of biofuel feedstock production systems.

[Joly et al. 2015 – Chapter in SCOPE book – to be released in April 2015]

Identifying Cost Effective Surrogate for Measuring Water Quality Effects Associated with Bioenergy

Consider multiple effects:

Land-use change

⇩

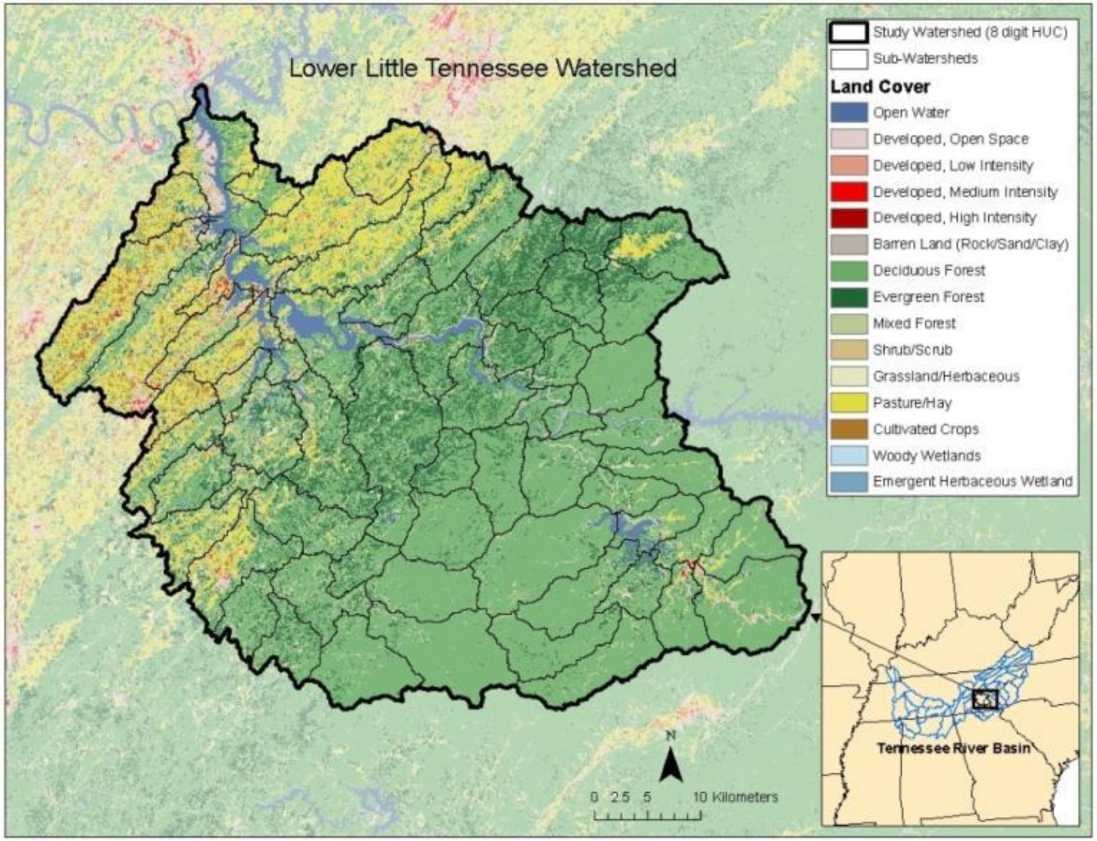
Changes in water quality

⇩

Changes in habitat

⇩

Changes in species



EPT richness = number of distinct taxa in the insect orders

- Ephemeroptera (mayflies)
- Plecoptera (stoneflies)
- Trichoptera (caddisflies)

[Baskaran et al. (in prep) Aquatic macroinvertebrate as water quality indicators for switchgrass-based land-use change across Tennessee.]

Reviewed Best Management Practices (BMPs) for Bioenergy

- **Many BMPs developed for forestry & other bioenergy feedstocks**
  - Some are applicable to bioenergy sustainability, but others are too general
  - Typically focused on a single sustainability category but may be useful for meeting other objectives (e.g., water quality BMPs often promote soil quality)
- **Most management practices have particular focus**
  - For energy crops are focused on productivity
  - For harvesting forest biomass are focused on soil & water quality
- **BMPs need to be expanded**
  - Are needed for
    - Water quantity
    - Biodiversity
    - Greenhouse gas emissions
    - Air quality
  - Need to be related to particular sustainability targets

- **Regional research is needed**
  - To identify BMPs appropriate for particular bioenergy systems
  - To consider tradeoffs in implementing BMPs for different aspects of sustainability

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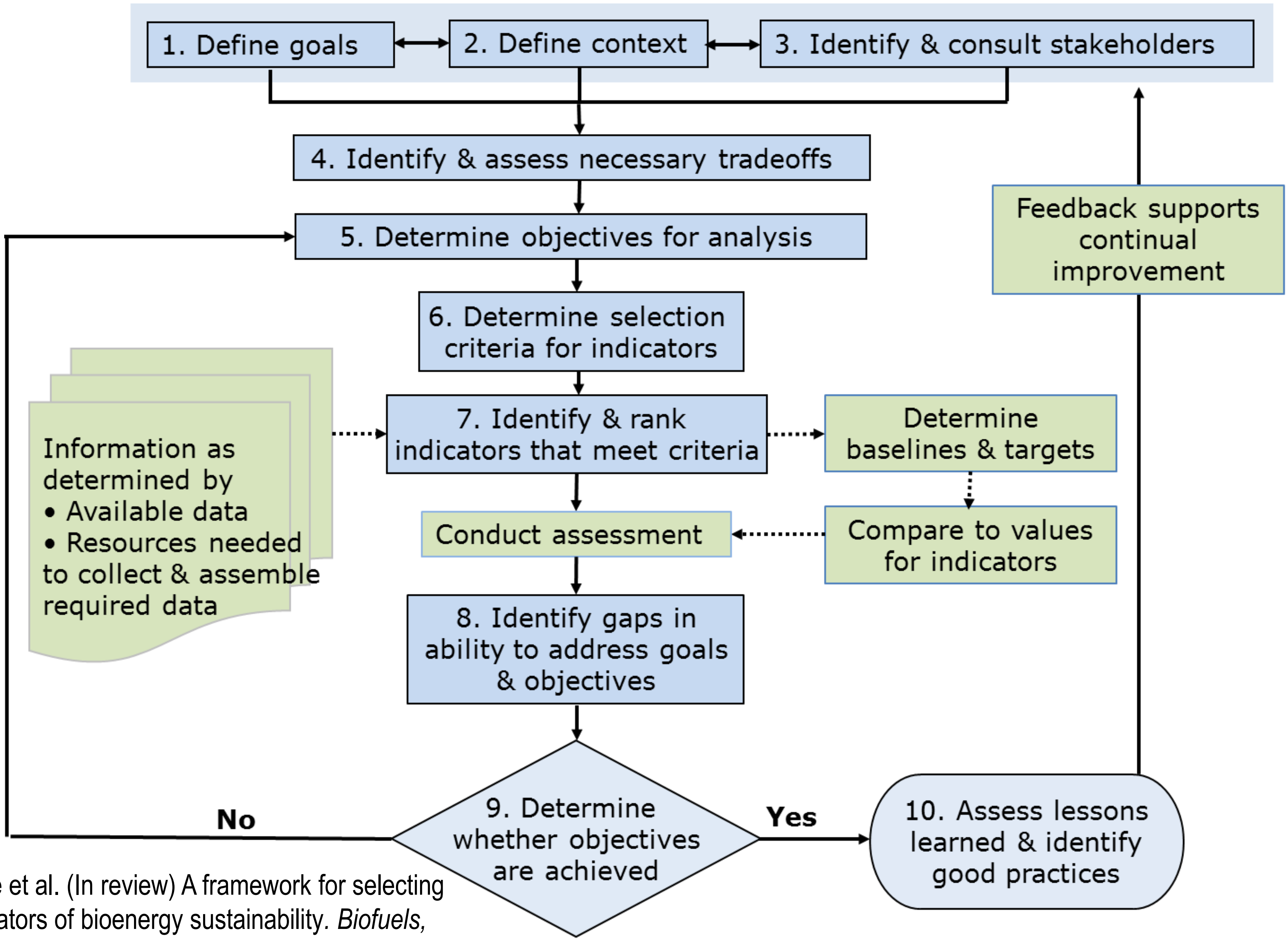
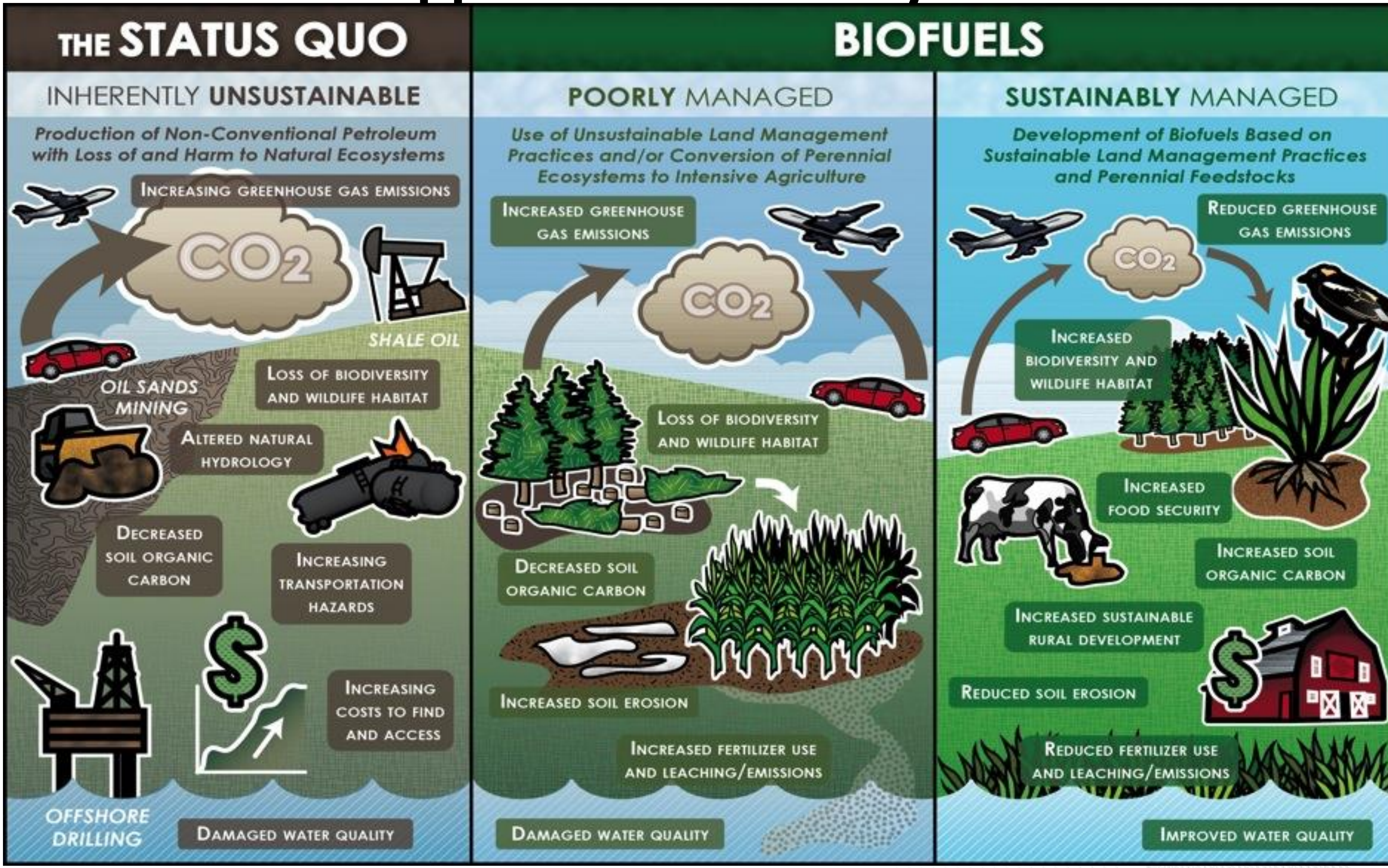
Developed Framework for Using Indicators to Assess Progress Toward Bioenergy Sustainability



[Dale et al. (In review) A framework for selecting indicators of bioenergy sustainability. *Biofuels, Bioproducts & Biorefining*.]

Sustainably Managed Biofuels Support Sustainability Goals



[Dale B et al. (2014) Take a Closer Look: Biofuels Can Support Environmental, Economic and Social Goals. *Environmental Science & Technology* 48: 7200-7203.]

4 - Relevance

- **Accomplishments contribute to goals and objectives of the industry & BETO sustainability goals**
  - Evaluating sustainability & identifying best practices for biofuels produced from cellulosic feedstocks
  - Considering environmental, social, and economic indicators across the supply chain.
  - Implementing & promoting best practices for all sustainability categories for an integrated biomass-to-bioenergy process from cellulosic feedstocks.
- **Project outputs are being applied**
  - Indicators were selected to
    - Build from indicators proposed by others engaged in bioenergy sustainability
    - Be useful, practical & technically effective

    √ Others are currently applying & testing ORNL approaches
  - Evolving framework is designed to focus on application, assessment, and development of best practices

Approach:
Sustainability Indicators

↓

Best Practices

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4 – Relevance (cont.)
Measures of Success for Project

- **Environmental & socioeconomic aspects of sustainability seen as critical to commercially viable and sustainable bioenergy industry**
  - Bioenergy sustainability is recognized as being context specific
  - Assessment of sustainability of bioenergy systems is deployed across the industry
  - Interactions & trade-offs for different bioenergy scenarios are considered
- **Best practices for sustainable bioenergy production based on**
  - Targets
  - Baselines
  - Trends
  - Environmental & socioeconomic sustainability of bioenergy systems
- **Landscape designs are used in deployment of sustainable bioenergy systems**
- **Aggregation & visualization tools support assessment of progress toward sustainable bioeconomy**

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5. Future Work

- **Develop <u>case study</u> of use of forest products for bioenergy in the SE US.**
  - Determine landscape design scenarios
  - Analyze landscape design opportunities for woody residues used for bioenergy
- **Identify environmental, social, & economic <u>incentives and barriers</u> to development of sustainable bioeconomies**
- **Complete and test <u>aggregation theory</u>**
- **Test & deploy <u>visualization tool</u> of measures of progress toward sustainable bioenergy**
- **<u>Evaluate approach</u> to assess progress toward bioenergy sustainability & its application in industry**

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Summary (1)

- **Approach**
  - ✓ From sustainability indicators to baseline & targets to evaluation to trends & tradeoffs to best practices
  - ✓ Working toward spatially explicit multi-metric analysis tools to visualize progress toward sustainability
- **Technical accomplishments**
  - ✓ Identified set of environmental & socioeconomic indicators of bioenergy sustainability
  - ✓ Adopted aggregation theory for assessment of bioenergy sustainability
  - ✓ Developed understanding of how to assess bioenergy sustainability in particular contexts
- **Relevance**
  - ✓ Focusing on bioenergy across supply chain
  - ✓ Considering environmental & socioeconomic aspects of sustainability
  - ✓ Quantitative means to assess progress toward bioenergy sustainability
- **Critical success factors and challenges**
  - ✓ Establishment of a baseline for environmental sustainability of feedstock supply (i.e., production, harvest/collection, & processing)
  - ✓ Obtaining sustainability data across the supply chain
  - ✓ Defining best practices for sustainable bioenergy production
  - ✓ Considering aggregation, interactions & trade-offs among different goals (environmental protection and profit) & (eventually) different bioenergy scenarios

Approach:
Indicators
↓
Best Practices

Summary (2)

- **Future Work**
  - Complete & test framework for sustainability assessment for full set of indicator categories
  - Determine BMPs for particular contexts of bioenergy sustainability (e.g., pellet production in SE US)
  - Develop & apply methods to aggregate & visualize progress toward bioenergy sustainability
- **Technology transfer**
  - Inclusion of information and data in BETO's Knowledge Discovery Framework (KDF) allows for archiving & sharing
  - Dissemination via 17 journal articles & book chapters and >50 presentations in past two years
  - Many presentations & exchanges with colleagues from industry, other National Labs, federal agencies, universities, & nongovernmental organizations
  - Provided ideas & material
    - To other presenters (e.g., Kristen Johnson, Keith Kline, SCOPE report, IEA TASK 43)
    - To industry, national & international meetings and certifications efforts (e.g., ISO, BMAS, NCASI)

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Additional Slides

Note that presentations, workshops, awards, and other activities are covered at the website for the ORNL Center for BioEnergy Sustainability: http://www.ornl.gov/sci/ees/cbes/

Progress Since 2013 Review of 4.2.2.40

- Strengths (select quotes from 2013 review)
  - “This project is a foundational effort and is already an important reference point for the biofuel sustainability community.“
  - “The effort to build consensus toward minimum datasets, standardized metrics, and metadata is increasingly being viewed as essential to the progress of science across the spectrum from medicine to agriculture. This project has made good progress to date.“
- Weaknesses/challenges (select quotes from 2013 review)
  - “Moving forward, continued success and full realization of the objectives …will require that increasing efforts be allocated to outreach and consensus building beyond DOE and its bioenergy technology areas.”
    - **Response: Much effort spent on outreach and consensus building in 2013-15**
  - “While there is some risk that the project may be heading toward a somewhat complex framework involving 35 different metrics, it is hard to think of what metrics might be removed at this point. The researchers may be overly ambitious in setting their sights on a set of metrics that are broadly applicable across many different applications and scenarios. It may be more realistic to think about allowing for more flexibility in the exact form of these metrics for a given context.”
    - **Response: Our framework paper and approach presents a way to select indicators depending on the context, goals and stakeholders involved. The visualization tool should make such flexibility possible in the process aggregating indicators.**
  - “The scope of the project is quite large and difficult to evaluate each individual element in detail given the time limitation of presentation formats. Data is always going to be a limiting factor in analysis, particularly with ecological indicators where geography is important. That begs the question whether such analyses will be feasible and implementable by other researchers even with technological transfer of the framework approach.”
    - **Response: We are working with other teams (e.g., NEWBio, NCSU and the RCN) to test and foster means of transferring the approach.**

Results of 2013 Review

Evaluation Criteria	Sustainability Platform Mean	This Project
Critical success factors	6.8	7.4
Future work	7.0	7.6
Project approach	7.2	8.6
Project relevance	8.0	9.4
Technical progress	7.0	8.2
Overall weighted average	7.0	8.3

Acronyms

- BETO = Bioenergy Technologies Office
- BMAS = Biomass Market Access Standards
- BMP = Best Management Practices
- CBES = Center for Bioenergy Sustainability (at Oak Ridge National Lab)
- CSBP = Council on Sustainable Biomass Production
- EPA = US Environmental Protection Agency
- EPT richness = number of taxa in the insect orders Ephemeroptera, Plecoptera, & Trichoptera
- FAO = Food and Agriculture Organization
- GBEP = Global BioEnergy Partnership
- GLBRC = Great Lakes Bioenergy Research Center
- IBSS = Southeastern Partnership for Integrated Bioenergy Supply Systems (supported by USDA)
- IEA = International Energy Agency
- INL = Idaho National Laboratory
- ISO = International organization for Standardization
- MADSS = Multi-Attribute Decision Support Systems
- NCASI = National Council on Air and Stream Improvement
- NCSU= North Carolina State University
- NEWBio = Northeast Woody/Warm Season Biomass Consortium (supported by USDA)
- NGO = Non-governmental organization
- NREL = National Renewable Energy Laboratory
- NSF = National Science Foundation
- RCN = Research Collaborative Network (a project at Michigan Tech supported by NSF)
- RSB = Roundtable for Sustainable Biomaterial
- SCOPE = Scientific Committee on Problems of the Environment
- USDA = US Department of Agriculture

Journal Articles & Book Chapters: 2013 to 2015

For more information see http://www.ornl.gov/sci/ees/cbes/

In review

- Dale VH, KL Kline, MA Buford, TA Volk, CT Smith, I Stupak (In review) Incorporating bioenergy into sustainable landscape designs. Renewable & Sustainable Energy Reviews.
- Dale VH, RA Efroymson, KL Kline, and M Davitt. (In review – minor revision requested) A framework for selecting indicators of bioenergy sustainability. Biofuels, Bioproducts & Biorefining.
- Parish ES, Dale VH, English BC, Jackson SW, Tyler DD. (In review) Assessing multimetric aspects of sustainability: Application to a bioenergy crop production system in East Tennessee. Ecosphere.

2015

- Dale VH, Parish ES, Kline KL. In press. Risks to global biodiversity from fossil-fuel production exceed those from biofuel production. Biofuels, Bioproducts & Biorefining
- Joly CA, Huntley BJ, LM Verdade LM, Dale VH, Mace G, Muok B, Ravindranath NH. 2015. Biofuel impacts on biodiversity and ecosystem services. Chapter 16 in (Souza GM and Joly CA, editors) Scientific Committee on Problems of the Environment (SCOPE) Rapid Assessment Process on Bioenergy and Sustainability, Paris, France.
- Kang S., D. Wang, J.A. Nichols, J. Schuchart, K.L. Kline, Yaxing Wei, D.M. Ricciuto, S.D. Wullschleger, W.M. Post, R.C. Izaurralde. 2015. development of mpi_EPIC model for global agroecosystem modeling. Computers and Electronics in Agriculture 111:48–54.
- Pollesch N, VH Dale. In press. Applications of aggregation theory to sustainability assessment. Ecological Economics.

2014

- Costanza R, K Chichakly, V Dale, S Farber, D Finnigan, K Grigg, S Heckbert, I Kubiszewski, H Lee, S Liu, P Magnuszewski, S Maynard, N McDonald, R Mills, S Ogilvy, PL Pert, J Renz, L Wainger, M Young, CR Ziegler. 2014. Simulation games that integrate research, entertainment, and learning around ecosystem services. Ecosystem Services 10:195-201.
- Dale B, Anderson J, Brown R, Csonka S, Dale V, Herwick G, Jackson R, Jordan N, Kaffka S, Kline K, Lynd L, Malmstrom C, Ong R, Richard T, Taylor C, Wang M. 2014. Take a Closer Look: Biofuels Can Support Environmental, Economic and Social Goals. Environmental Science & Technology 48(13): 7200-7203.
- Kang S, S Nair, KL Kline, JA Nichols, D Wang, WM Post, C Brandt, S Wullschleger, N Singh, and Y Wei. 2014. Global simulation of bioenergy crop productivity: analytical framework and case study for a perennial bioenergy crop – switchgrass. Global Change Biology-Bioenergy 6(1):14-24 http://onlinelibrary.wiley.com/doi/10.1111/gcbb.2013.6.issue-1/issuetoc

Journal Article & Book Chapters: 2013 to 2015

(Continued)

2013

- Dale, VH and KL Kline. 2013. Modeling for integrating science and management. Pages 209-240 In D.G. Brown, D. T. Robinson, N. H. F. French, and B.C. Reed (editors), Land Use and the Carbon Cycle: Advances in Integrated Science, Management, and Policy, Cambridge University Press.
- Dale VH and KL Kline. 2013. Issues in using landscape indicators to assess land changes. Ecological Indicators 28:91-99.
- Dale VH, RA Efroymson, KL Kline, MH Langholtz, PN Leiby, GA Oladosu, MR Davis, ME Downing, MR Hilliard. 2013. Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. Ecological Indicators 26: 87-102.
- Dale VH, Kline KL, Kaffka SR, and Langeveld JWA. 2013. A landscape perspective on sustainability of agricultural systems. Landscape Ecology. (DOI) 10.1007/s10980-012-9814-4 http://www.springerlink.com/openurl.asp?genre=article&id=doi:10.1007/s10980-012-9814-4
- Dale, VH, MH Langholtz, BM Wesh, and LM Eaton. 2013. Environmental and socioeconomic indicators for bioenergy sustainability as applied to Eucalyptus. International Journal of Forestry Research. vol. 2013, Article ID 215276, 10 pages, 2013. doi:10.1155/2013/215276
- Dale VH, KL Kline, D Perla, A Lucier. 2013. Communicating about bioenergy sustainability. Environmental Management 51(2): 279-290. DOI: 10.1007/s00267-012-0014-4 Efroymson, RA, VH Dale, KL Kline, AC McBride, JM Bielicki, RL Smith, ES Parish, PE Schweizer, DM Shaw. 2013. Environmental indicators of biofuel sustainability: What about context? Environmental Management 51(2): 291-306 DOI: 10.1007/s00267-012-9983-6
- Johnson TL, JM Bielicki, RS Dodder, MR Hilliard, PO Kaplan, CA Miller. 2013. Stakeholder decision making along the bioenergy supply chain: Sustainability considerations and research needs. Environmental Management 51(2): 339-353.
- Kline KL, Singh N, Dale VH. 2013. Cultivated hay and fallow/idle cropland confound analysis of grassland conversion in the Western Corn Belt. Proceedings of the National Academy of Sciences 110(31) www.pnas.org/cgi/doi/10.1073/pnas.1306646110
- Parish ES, KL Kline, VH Dale, RA Efroymson, AC McBride, TL Johnson, MR Hilliard, JM Bielicki, 2013. A multi-scale comparison of environmental effects from gasoline and ethanol production. Environmental Management 51(2): 307-338. DOI: 10.1007/s00267-012-9983-6
- Patton-Mallory M, KE Skog, VH Dale. 2013. Integrated forest biorefineries: Sustainability considerations for forest biomass feedstocks. In (L. Christopher, ed.) Integrated Forest Biorefineries. Royal Society of Chemistry, London, England, pp. 80-97
- Ridley, CE, HI Jager, RA Efroymson, C Kwit, DA. Landis, ZH Leggett, DA Miller, CM Clark. 2013. Debate: Can bioenergy be produced in a sustainable manner that protects biodiversity and avoids the risk of invaders? Ecological Society of America Bulletin 94(3): 277-290.

Categories of environmental sustainability indicators

Environment	Indicator	Units
Soil quality	1. Total organic carbon (TOC)	Mg/ha
	2. Total nitrogen (N)	Mg/ha
	3. Extractable phosphorus (P)	Mg/ha
	4. Bulk density	g/cm^3
Water quality and quantity	5. Nitrate concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	6. Total phosphorus (P) concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	7. Suspended sediment concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	8. Herbicide concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	9. storm flow	L/s
	10. Minimum base flow	L/s
	11. Consumptive water use (incorporates base flow)	feedstock production: m^3/ha/day; biorefinery: m^3/day

Environment	Indicator	Units
Greenhouse gases	12. CO_2 equivalent emissions (CO_2 and N_2O)	kgC_{eq}/GJ
Biodiversity	13. Presence of taxa of special concern	Presence
	14. Habitat area of taxa of special concern	ha
Air quality	15. Tropospheric ozone	ppb
	16. Carbon monoxide	ppm
	17. Total particulate matter less than 2.5µm diameter ($PM_{2.5}$)	$\mu g/m^3$
	18. Total particulate matter less than 10µm diameter (PM_{10})	$\mu g/m^3$
Productivity	19. Aboveground net primary productivity (ANPP) / Yield	gC/m^2/year

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