Bioenergy Sustainability: How to Define and Measure It

April 5, 2011

Analysis Platform Review

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Goal Statement

- Goal: To improve understanding of
  - How bioenergy production can affect sustainability
  - How those effects can be measured.

- Relates to these OBP objectives
  - Building consensus on definitions of bioenergy sustainability
  - Providing a consistent and defensible message on meaning of bioenergy sustainability
  - Establishing indicators to measure sustainability
  - Building methodology to measure and assess sustainability

Project Overview (1)

- History
  - FY09: Initiated as OBP project 1.7.1.2 with three parts:
    - **Sustainability – focus of this presentation**
    - Land use change – Reported by Debo Oladosu
    - Quantifying watershed sustainability indicators – reported by Natalie Griffiths and Virginia Dale in Feedstock Platform on April 6
  - FY11: Sustainability aspects separated out as DOE OBP Sustainability Project 11.1.1.5
- Objectives
  - Review and define sustainability indicators
  - Assist OBP in its role of defining sustainability for bioenergy and determining indicators for use at the national scale
  - Implement and evaluate sustainability indicators for bioenergy decisions

Project Overview (2)

- Context
  - Several national and international organizations are working to define sustainability for bioenergy systems
    - There is high agreement on the overall goal of sustainability
    - There is little agreement on
      - a small set of measures to quantify bioenergy sustainability
      - how to obtain and assess these indicators
  - Effort builds from ORNL's expertise in several areas
    - Risk assessment
    - Indicators for sustainability
    - Bioenergy systems
    - Relating science to decision making
    - Interdisciplinary approaches
    - Disciplinary strengths in environmental sciences and socioeconomics
    - Modeling at several scales

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1- Approach

A. Relate to and build from other work on sustainability for bioenergy systems

- Assist OBP in its role of defining sustainability for bioenergy and determining indicators for use at the national scale
- Work with other groups who are defining and establishing concepts of bioenergy sustainability

B. Establish definition for sustainability and develop methodology for measurement and assessment

- Review and define sustainability indicators
- Implement and evaluate sustainability indicators for bioenergy decisions

C. Provide a structure under which sustainability indicators can be used and interpreted

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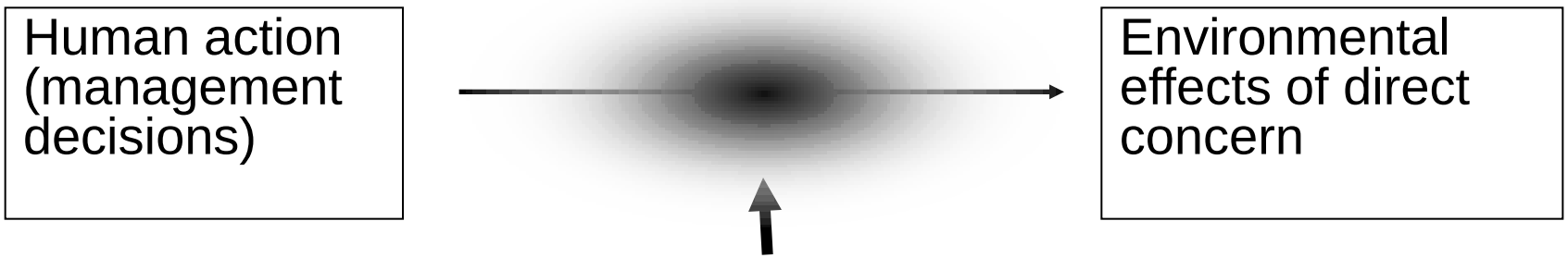
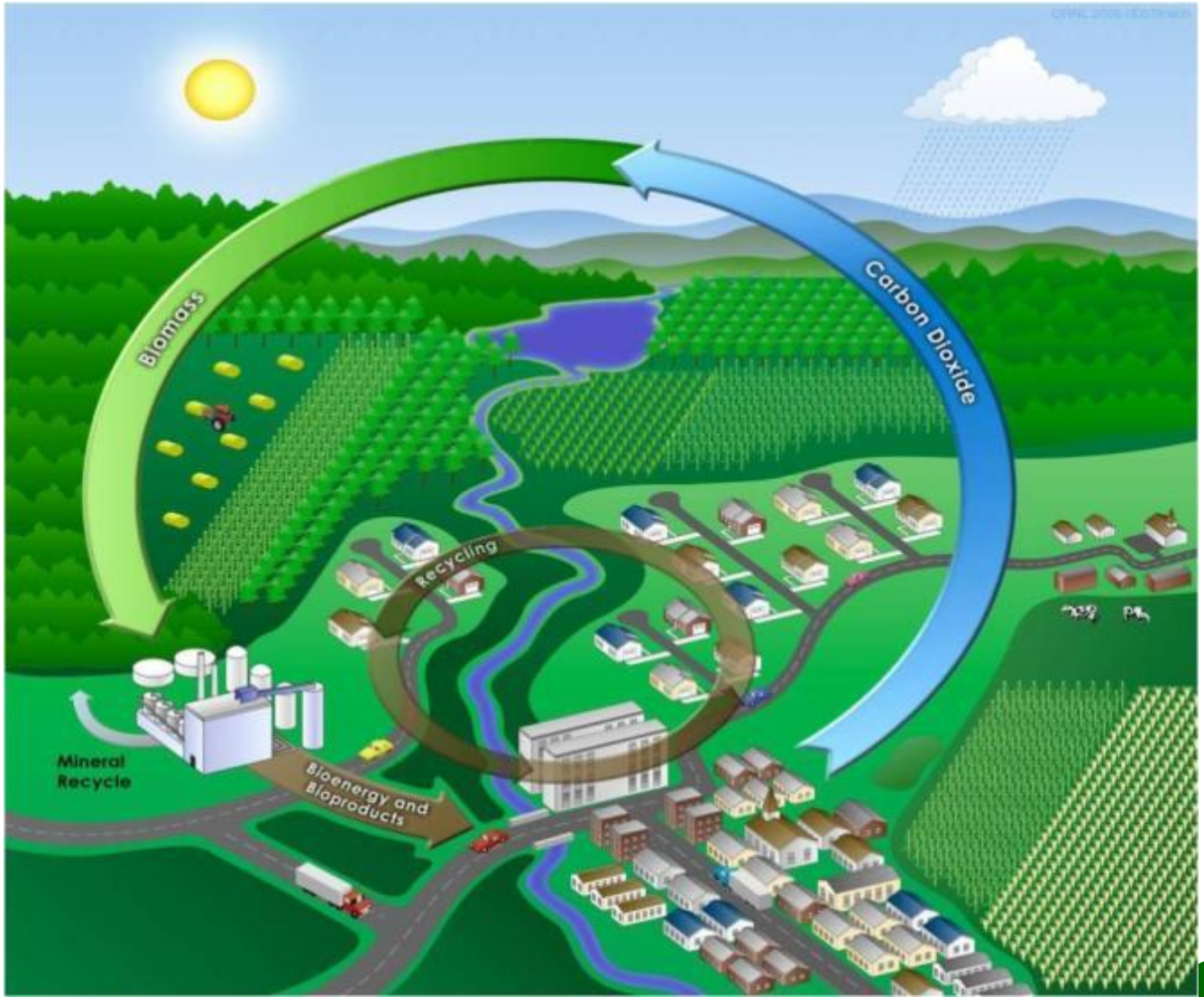
Task B: Approach for Selecting Indicators



- Causal chain: We selected indicators downstream from management, but not too far.
- We aimed for indicators that could be measured empirically, but modeling is sometimes inescapable.
- We selected indicators that are widely applicable
  - **Useful to policymakers, agronomists, producers**
  - **Improve empirical underpinning for management indicators**

Project leverages from indicator work conducted for the Department of Defense and reported by Dale VH and Beyeler SC. 2001. Challenges in the development and use of ecological indicators. *Ecological Indicators* 1: 3-10.

Task C Approach: Considering indicators within entire system as an opportunity to design landscapes that add value



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Management Approach

- ***Team:***
  - Virginia Dale, landscape ecologist (principal investigator)
  - Rebecca Efroymson, risk assessment
  - Keith Kline, energy specialist and international issues
  - Allen McBride, environmental sustainability
- ***Supplemental team: reach out to other ORNL staff when needed***
  - Latha Baskaran, watershed modeling
  - Mark Downing, agricultural economist
  - Laurence Eaton, socioeconomic issues
  - Chuck Garten, soils
  - Robin Graham, feedstock issues
  - Natalie Griffiths, aquatic ecologist
  - Yetta Jager, aquatic modeling
  - Matt Langholtz, economist
  - Paul Leiby, energy security
  - Pat Mulholland, biogeochemist
  - Debo Oladosu, economic modeling
  - Bob Perlack, feedstock projections
  - Peter Schweizer, biodiversity
  - John Storey, air quality
  - Erin Webb, feedstock logistics
- ***Milestones for monitoring progress***
  - ***2009***
    - *Written comments and support to OBP on draft sustainability criteria*
    - *"In Defense of Biofuels, Done Right" published in* Issues in Science and Technology
    - *"Interactions between Bioenergy Feedstock Choices, Landscape Dynamics, and Land Use." In press with* Ecological Applications.
    - *Report on state of science in developing a definition for "sustainability" and corresponding indicators for biofuels*
  - ***2010***
    - *Comments on draft sustainability criteria*
    - *Set of proposed hierarchical sustainability indicators for biofuels in the US*
  - ***2011***
    - *Comments on sustainability indicators and other reports being proposed by others*
    - *Final set of environmental sustainability indicators for biofuels*

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2 - Technical Accomplishments/ Progress/Results (Task A)

Activities under Task A - Relate to and build from other work on sustainability for bioenergy systems

- Assist OBP in its role of defining sustainability for bioenergy and determining indicators for use at the national scale by providing quick reviews and analysis when requested
  - GBEP (Global Bioenergy Partnership)
  - BRDi (Biomass Research & Development)
  - RSB (Roundtable on Sustainable Biofuels)

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

- Work with Council on Sustainable Biomass Production (CSBP) to establish basis for certification
  - Field Testing Task Force
  - Climate Task Force
  - Forestry Task Force

[CSBP is being reported by John Heisselbuttel on April 6]

- Work with other agencies (see http://www.ornl.gov/sci/ees/cbes/Collaborations.shtml) and evaluate agency-specific approaches
  - USDA – workshop Spring 2008 and small work group Sept 2010
  - EPA – workshop Sept 2009
  - Review of "Biofuels and the Environment: First Triennial Report to Congress"
- Participation on National Academy of Sciences (NAS) activities
  - Virginia Dale serves on Committee on Economic and Environmental Impacts of Increasing Biofuel Production
  - Rebecca Efroymson serves on Committee on Sustainable Development of Algal Biofuels

- **Milestone: All comments are transmitted to OBP as developed and a set of all comments to be delivered Sept 2011**

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2 - Technical Accomplishments/ Progress/Results (Task B)

Activities under Task B: Establish definition for sustainability and develop methodology for measurement and assessment

- Milestone: Overview of sustainability issues
  - Status: "In Defense of Biofuels, Done Right" published in *Issues in Science and Technology*
- Milestone: In-depth paper on environmental concerns
  - Status: "Interactions between Bioenergy Feedstock Choices, Landscape Dynamics, and Land Use." In press with *Ecological Applications*.
- Milestone: Report on state of science in developing a definition for "sustainability" and corresponding indicators for biofuels
  - Status: "Good policy follows good science: Using criteria and indicators for assessing sustainable biofuels production" published in *Ecotoxicology*
- Milestone: Set of proposed hierarchical sustainability indicators for biofuels in the US
  - Status: Report delivered
- Milestone: Set of environmental sustainability indicators for biofuels in the US
  - Status: Report delivered and manuscript in press: McBride et al. *Ecological Indicators.*

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Task B: Accomplishment: Identified Indicators of Environmental Sustainability

Category	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

Category	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 - in press. Indicators to support environmental sustainability of bioenergy systems. *Ecological Indicators.*

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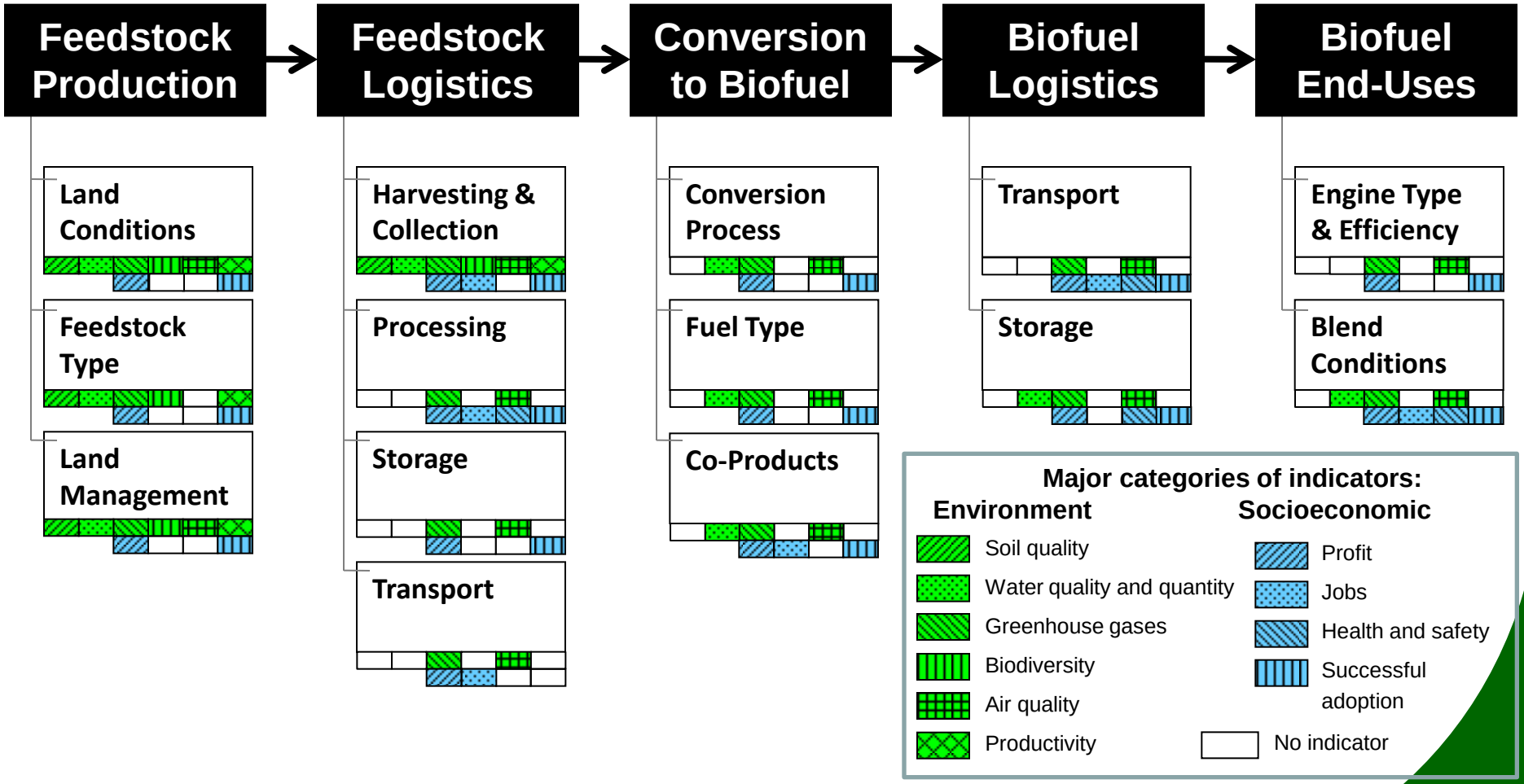
Task B: Accomplishment: Indicators of Sustainability in the Biofuel Supply chain.

Next: Effort building from environmental to socioeconomic indicators

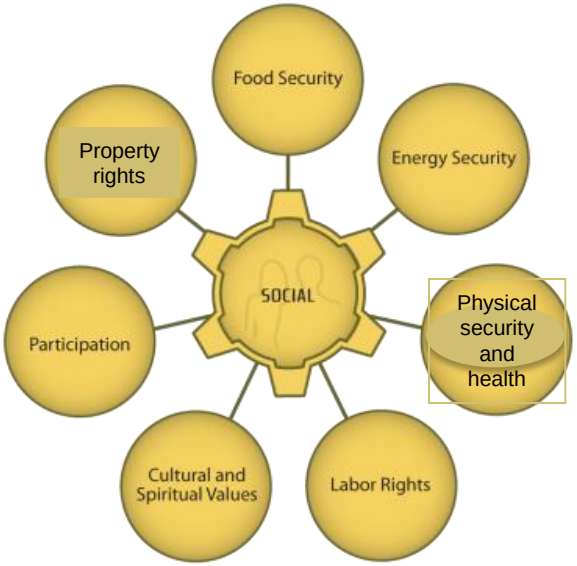


[based on Efroymson et al. In prep.]

Task B Accomplishments: Identified Potential Social and Economic Indicators

- Holistic approach: The indicators of environmental sustainability presented here is intended to help advance efforts by GBEP, RSB, CSBP, etc., to develop full suites of indicators for environmental, social, and economic sustainability.

- Next Step: Identify socioeconomic indicators of sustainability



2 - Technical Accomplishments (Task C)

Activities under Task C: Provide a structure under which sustainability indicators can be used and interpreted

- *Selection Criteria Framework for Bioenergy Sustainability*
  - *Milestone:* Selection criteria framework for bioenergy sustainability
  - *Status: Due March 2011 – Report and draft manuscript delivered*
- *Linkages between energy, land use, and climate change.*
  - *Milestone:* Analysis of the land use–climate change–energy nexus
  - *Status: Due Dec 2010 - Manuscript was submitted (and is accepted with revisions)*
- *Perennial Crop Options for Sustainable Bioenergy Feedstocks: Application to Vonore, TN*
  - *Milestone:* Description of implications of perennial crop options for sustainable bioenergy feedstocks
  - *Status: Due June 2011 – Draft report and manuscript in preparation*
- *Comparing Net Environmental Benefits of Different Energy Sources*
  - *Milestone:* A framework for comparing net environmental benefits of energy sources
  - *Status: Due June 2011 – Draft report and manuscript in preparation*
- *Sustainability issues in bioenergy from the cradle to the grave*

  Milestone: Analysis of key issues that arise in considering bioenergy sustainability systems: Communications, The context in which sustainability indicators are considered, Scale issues in environmental impacts of future fuels, Comparative analysis of bioenergy pathways, and Effects on ecosystem services.

  Status: Due Sept 2011 – Report and 3 manuscripts in preparation; 2 in review

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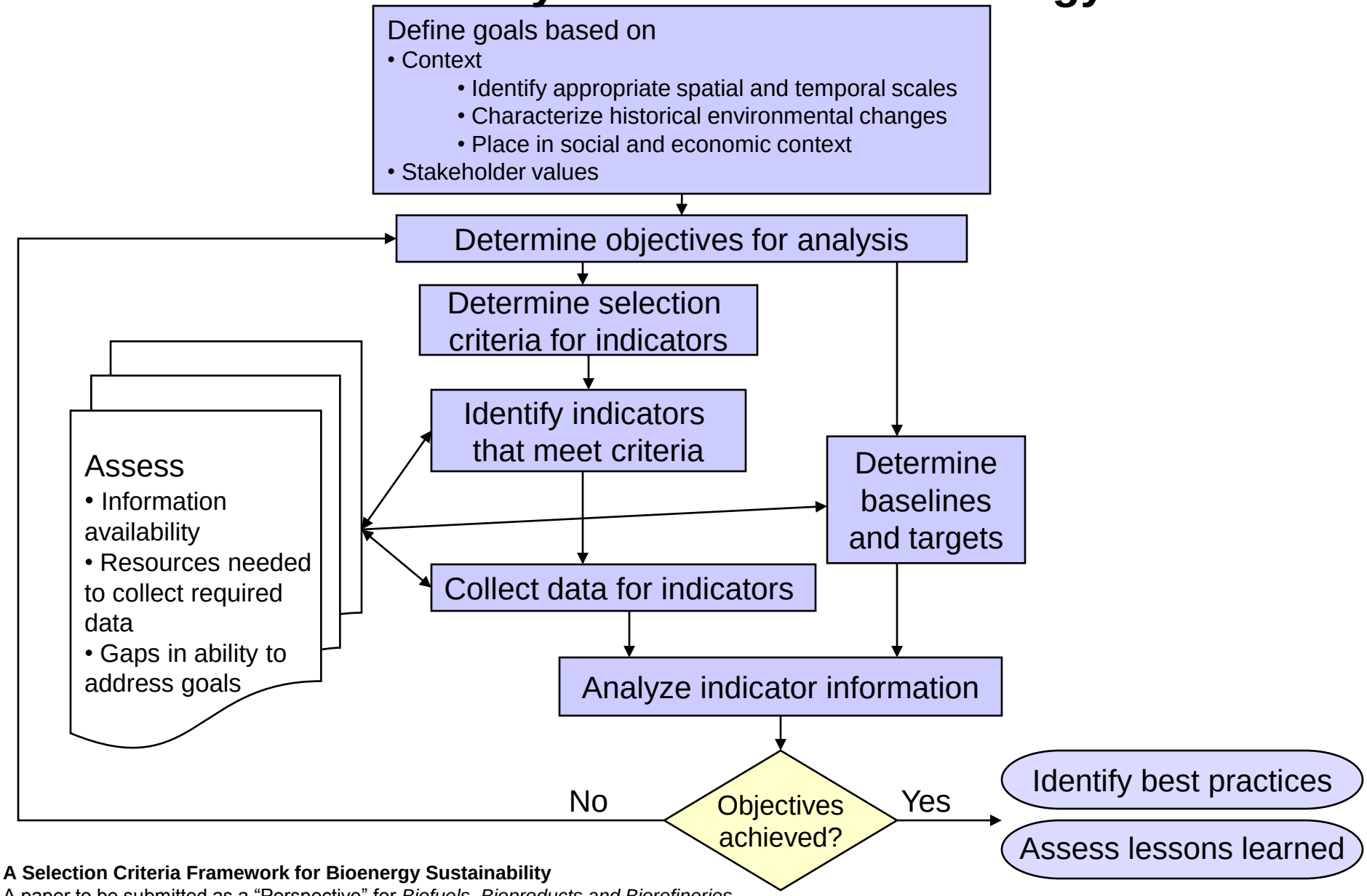
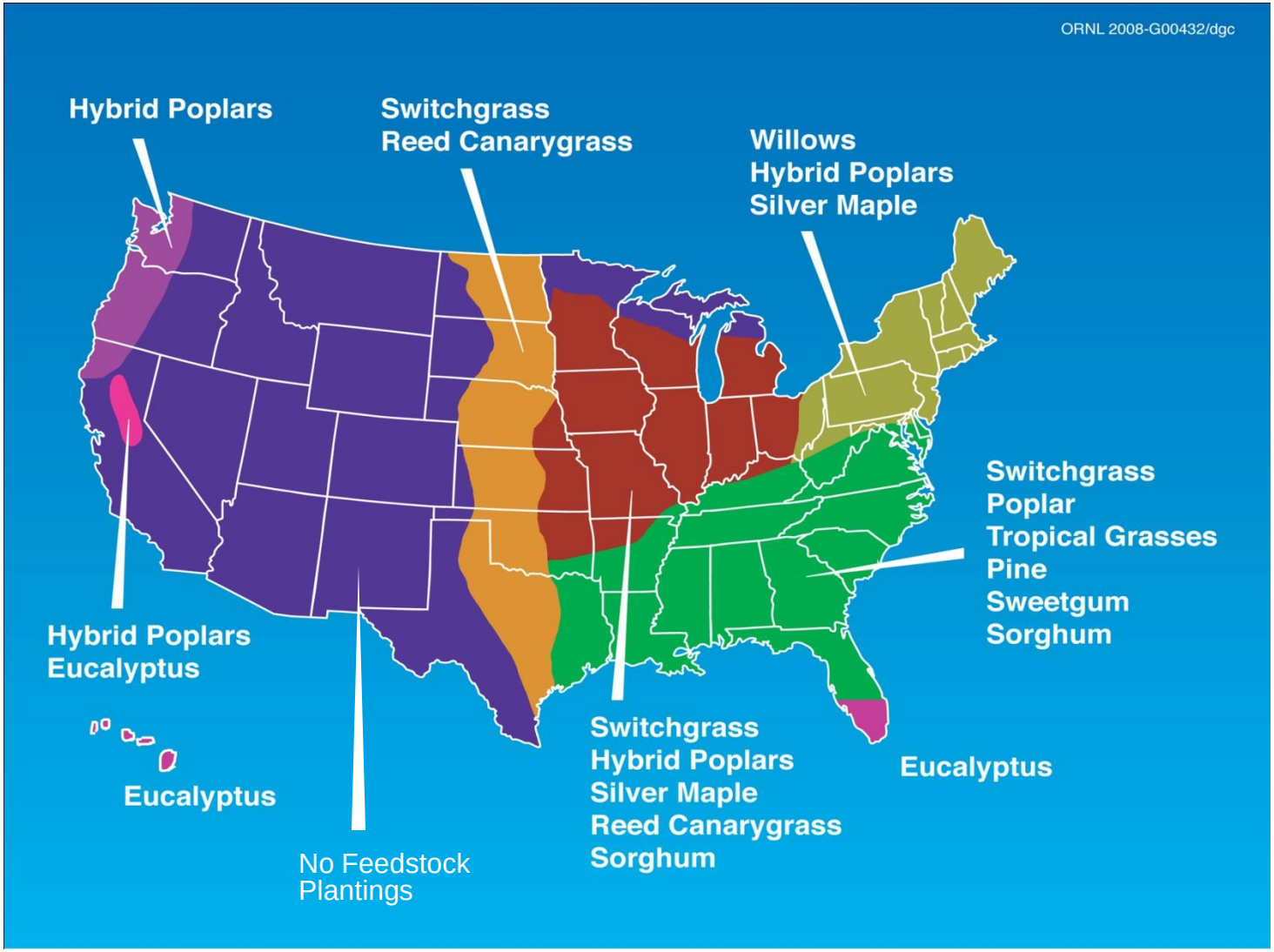
Task C In progress: Defined a Framework for Selecting Sustainability Indicators for Bioenergy



A Selection Criteria Framework for Bioenergy Sustainability
A paper to be submitted as a "Perspective" for *Biofuels, Bioproducts and Biorefineries.*
Authors (Order TBD): Virginia H. Dale, Marcia Davitt, Rebecca A. Efroymson, and Keith Kline [Oak Ridge National Lab]

Task C Accomplishment: Recognized that Some Feedstocks Perform Better in Certain Regions



Map of recommended biofuel feedstock plantings in the U.S. [updated from Wright (1994)] (from Dale et al. 2011 Ecological Applications).

Task C Accomplishment: Showed that Framework must Recognize and Build from Trends in Land Change

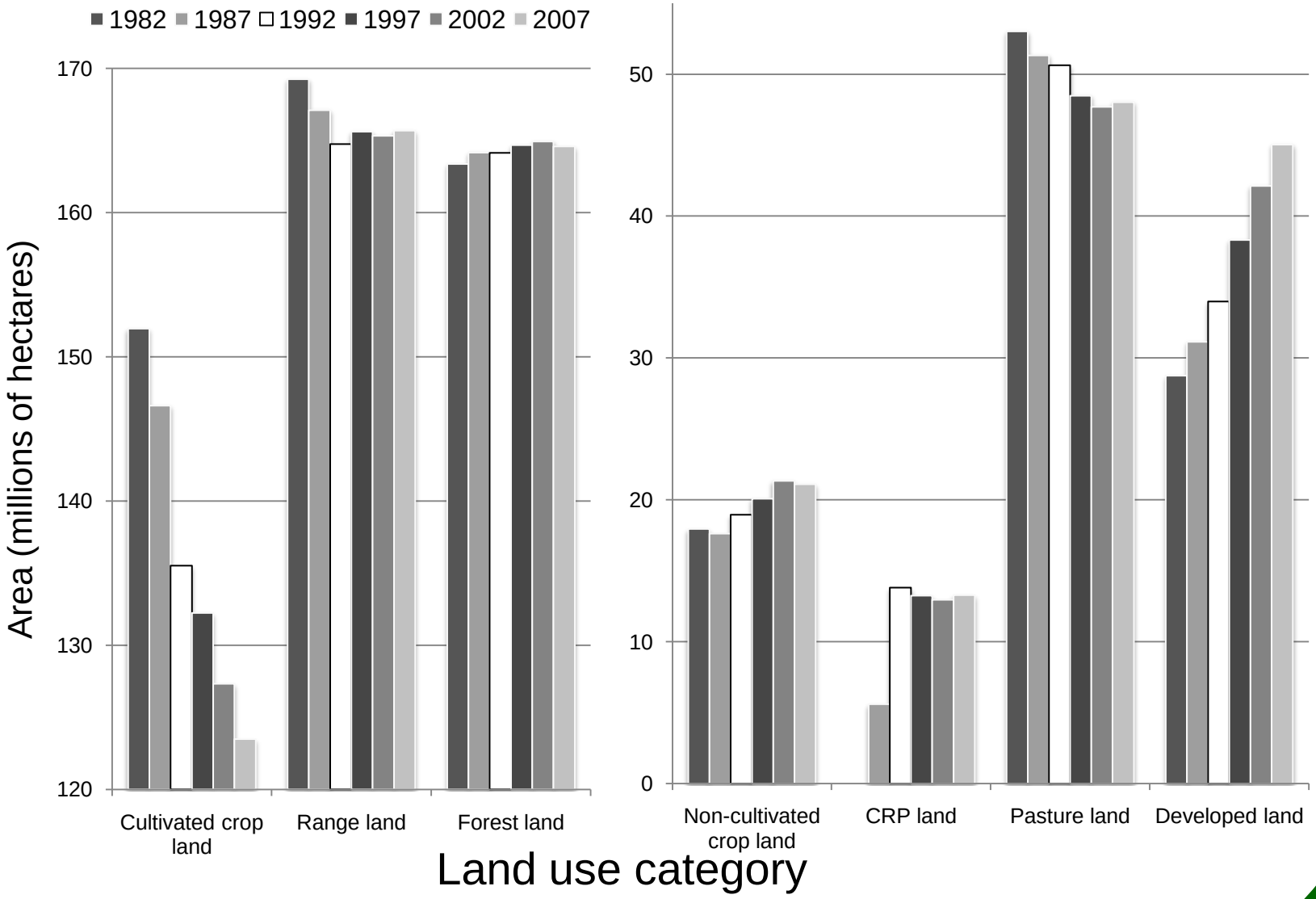
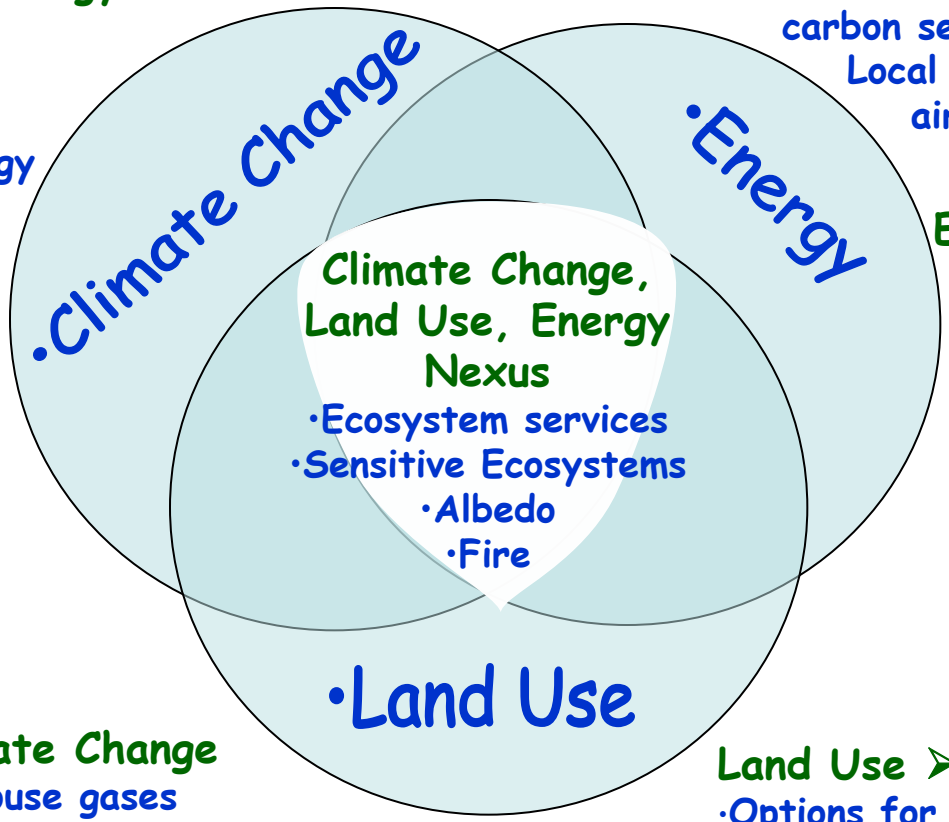


Illustration from Dale et al. (2011. *Ecological Applications) based on US data from NRI 2009.*

Task C Accomplishment: Considered Implications of Climate Change and Land Use on Bioenergy

Climate Change ➢ Energy
- Energy Options
- Intensity of use
- Distribution of supply and demand for energy

Energy ➢ Climate Change
- Greenhouse gas emissions and carbon sequestration
- Local weather and air quality



Energy ➢ Land Use
- Energy extraction, production and distribution footprint
- Infrastructure and settlement plans

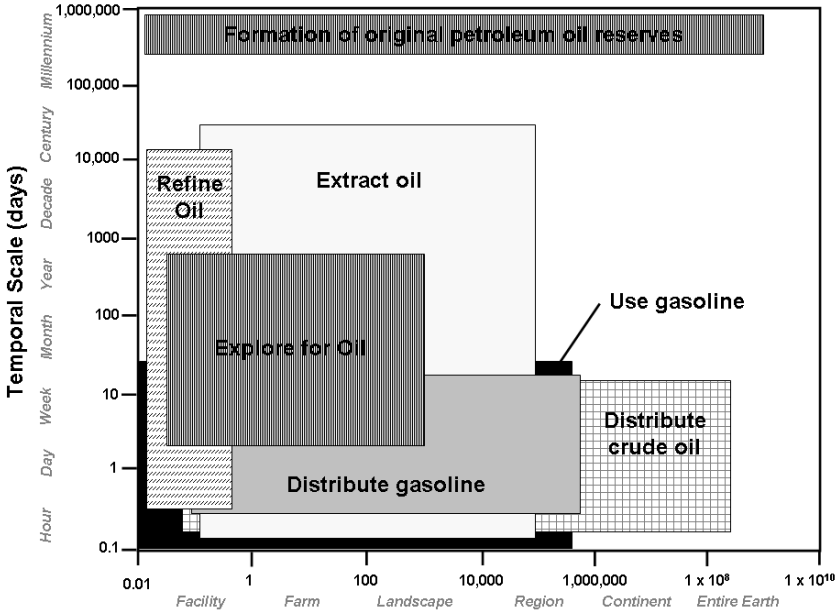
Climate Change ➢ Land Use
- Productivity
- Suitability for life forms and management practices
- Distribution of land uses
- Human settlement patterns

Land Use ➢ Climate Change
- Release of greenhouse gases
- Amount of carbon sequestration
- Weather changes
- Vulnerability to climate change

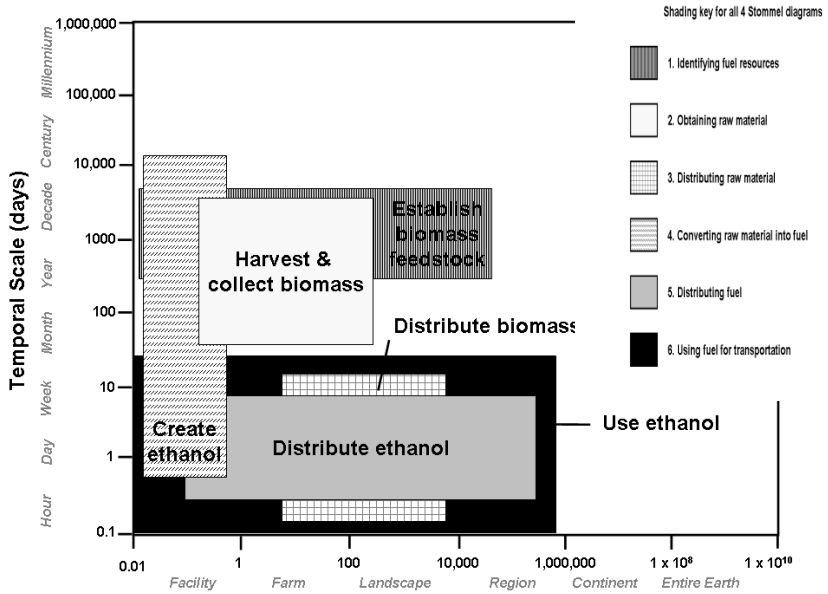
Land Use ➢ Energy
- Options for energy extraction, infrastructure, and production
- Efficiency of energy production
- Demand for energy

From: Dale VH, Efroymson R and Kline K. In press. The land use – climate change – energy nexus. *Landscape Ecology*.

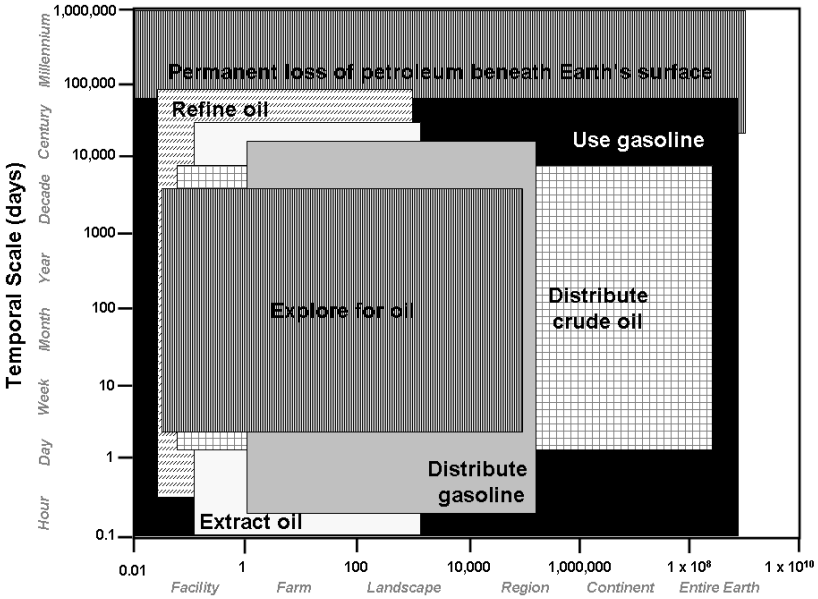
Task C In Progress: Develop understanding of effects of ethanol versus fossil fuels at different scales



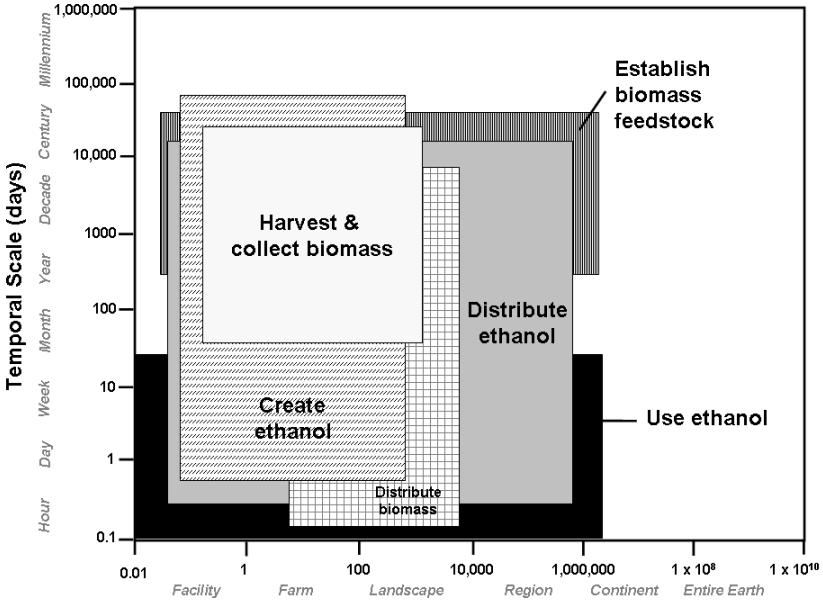
5A. GASOLINE PROCESSES



5C. ETHANOL PROCESSES



5B. GASOLINE PROCESS IMPACTS



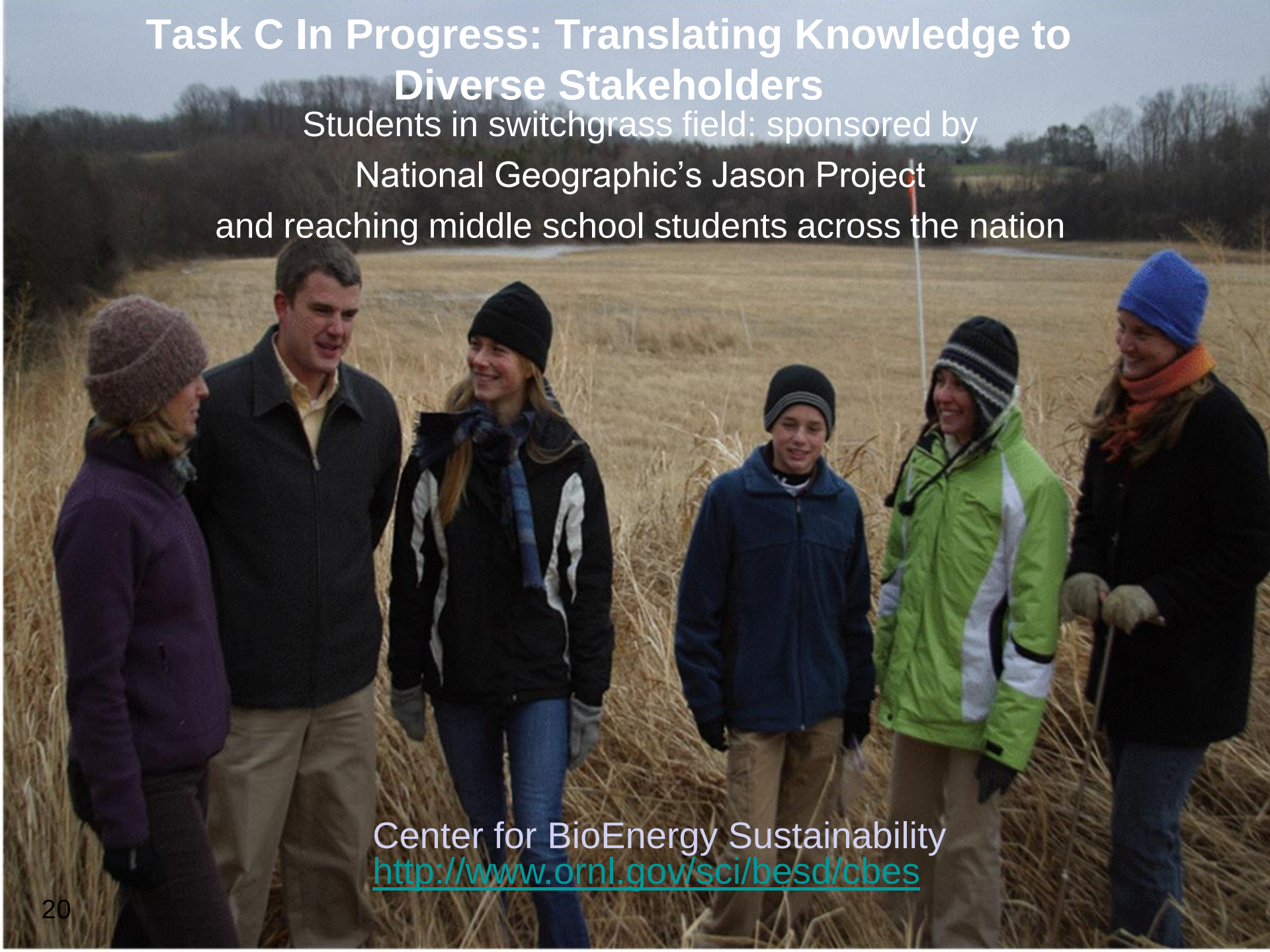
5D. ETHANOL PROCESS IMPACTS

Task C In Progress: Translating Knowledge to Diverse Stakeholders

Students in switchgrass field: sponsored by

National Geographic's Jason Project

and reaching middle school students across the nation



Center for BioEnergy Sustainability
http://www.ornl.gov/sci/besd/cbes

3- Relevance

- ***Contributes to the Platform Goals and Objectives of the OPB MYPP***
  - Project is identifying key indicators of sustainability: how to measure and include them in decision making
- ***Project considers applications of expected outputs***
  - Our team is working with several national and international organizations to
    - Select viable sustainability indicators
    - Determine ways to measure sustainability
    - Design certification programs
    - Build Life Cycle Assessment (LCA) approaches based on indicators that are not a part of most LCAs (e.g., water quality and quantity and biodiversity)

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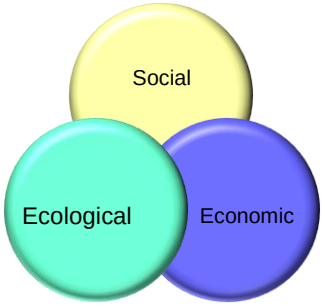
4 - Benefits and Expected Outcomes

This sustainability project will advance the state of technology and positively impact commercial viability and environmental performance by

- ***Defining indicators for evaluating sustainability***
- ***Evaluating and determining appropriate methodologies for evaluating sustainability***

Defining indicators for bioenergy sustainability



Considering other pressures on sustainability: climate, land use, etc.

Establishing a framework in which to assess and evaluate indicators

Devising ways to test indicators and framework (via collaborations and ORNL work)

Assessing multi-metric effects

Communicating sustainability analysis

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Summary

- **Relevance**
  - Focus on a full suite of sustainability indicators
  - Consider indicators that work across entire supply chain
- **Approach – Three tiered**
  - Outreach and relation to other activities
  - Indicator selection
  - Providing a structure in which sustainability indicators can be used and interpreted
- **Technical accomplishments**
  - Potential sustainability indicators identified
  - Environmental sustainability indicators described in detail
  - Framework for selecting sustainability indicators for bioenergy
  - Described nexus between climate change, land use and energy
- **Success factors and challenges**
  - Establishment of sustainability definitions (in collaboration with many others, of course)
  - Definition of a suite of the key environmental indicators of sustainability
  - Use of these indicators by stakeholder groups and those trying to establish certification procedures
- **Technology transfer**
  - Working with diverse stakeholder groups that are designing and implementing certification strategies
  - 11 journal publications, 3 proceedings
  - Many presentations to a variety of audiences

Jason students in soils lab at ORNL

Future new work

- Describing socioeconomic indicators in detail
- Testing indicators in a variety of systems
- Characterizing range of values so thresholds and trends can be determined
- Incorporating into LCA

Additional Slides

Progress Since 2009 Review

- Strengths – quotes from 2009 review
  - "Involves interdisciplinary effort by many collaborators"
  - "Address critical need affecting development of bioenergy systems"
  - "Generating information that is critical for formulating science-based, objective policies for the bioenergy industry"
  - "Has comprehensive scope and good outline of future work"
  - "KEEP GOING. THIS IS VERY, VERY IMPORTANT."

Results of 2009 Review

Evaluation Criteria	Sustainability Platform Mean	Project Mean
Relevance	3.98	4.71
Approach	3.66	4.14
Technical Progress	3.82	4.29
Success Factors	3.58	4.14
Future Research	3.66	4.14
Overall	3.74	4.28

- Weaknesses (quotes from 2009 review) and how they have been addressed
  - "Would have appreciated more conclusions; just starting so little real results"
    - 2011: Have defined a narrow list of indicators and approaches to measure and evaluate them
  - "Would have liked to have seen a list of proposed metrics"
    - 2011: List is presented, and environmental indicators are discussed in detail. Similar analysis is planned for socioeconomic indicators.
  - "The metrics area may be a show stopper. There is more disagreement here than agreement."
    - 2011: Have developed sustainability approach in concert with many others as a way to narrow debate; have communicated approach widely; are investigating how the context of a biofuels assessment influences indicator selection, measurement and interpretation"
  - "Policy debate is moving rapidly and this research must keep up or risk being irrelevant"
    - 2011: Working hard to communicate in all arenas and, specifically, to engage policy makers
  - "Examples are ag-focused (sustainability of switch grass); need to examine sustainability impacts of woody energy crop production—SRWC"
    - 2011: Indicators were selected to apply across diverse feedstocks and to entire supply chain. We are working with other groups to test these indicators in a variety of bioenergy systems.

Journal Publications from this Project

- Bruins,R. SK Hoekman, R.Efroymson, A.Aden, A.Hecht. November 2010. Transportation fuels for the 21st Century. EM Magazine pp. 26-32.
- Dale, VH, Fargione, J, Kline, K, Wiens, J. 2010. Biofuels: Implications for Land Use and Biodiversity. Biofuels and Sustainability report of the Ecological Society of America http://www.esa.org/biofuelsreports
- Dale VH, R Lowrance, P Mulholland, P Robertson. 2010. Bioenergy Sustainability at the Regional-Scale. *Ecology and Society* **15**(4): 23. [online] URL: http://www.ecologyandsociety.org/vol15/iss4/art23/
- Dale VH, Efroymson RA and Kline KA. In press. The land use – climate change – energy nexus. *Landscape Ecology*.
- Dale VH, KL Kline, LL Wright, RD Perlack, ME Downing, and RL Graham. 2011 (in press). Interactions between Bioenergy Feedstock Choices, Landscape Dynamics, and Land Use. *Ecological Applications.*
- Hecht, AD, D Shaw, R Bruins, V Dale, K Kline, A Chen. 2009. Good policy follows good science: Using criteria and indicators for assessing sustainable biofuels production. Ecotoxicology 18(1):1-4.
- Kline, KL and Dale, VH. 2008. Biofuels, causes of land-use change, and the role of fire in greenhouse gas emissions. *Science* 321:199.
- Kline KL, VH Dale, R Lee, and P. Leiby. 2009. In Defense of Biofuels, Done Right. Issues in Science and Technology 25(3): 75-84
- Kline KL, Dale VH, Grainger A. 2010. Challenges for Bioenergy Emission Accounting. *Science e-letter.* (2 March 2010) http://www.sciencemag.org/cgi/eletters/326/5952/527#13024
- McBride, A, VH Dale, L Baskaran, M Downing, L Eaton, RA Efroymson, C Garten, KL Kline, H Jager, P Mulholland, E Parish, P Schweizer, and J Storey. 2011 - in press. Indicators to support environmental sustainability of bioenergy systems. *Ecological Indicators.*
- Robertson GP, VH Dale, OC Doering, SP Hamburg, JM Melillo, MM Wander, WJ Parton, PR Adler, JN Barney, RM Cruse, CS Duke, PM Fearnside, RF Follett, HK Gibbs, J Goldemberg, DJ Mladenoff, D Ojima, MW Palmer, A Sharpley, L Wallace, KC Weathers, JA Wiens, and WW Wilhelm. 2008. Sustainable Biofuels Redux, *Science* 322(5898): 49–50.

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Proceedings Publications from this Project

- CBES (Center for BioEnergy Sustainability, Oak Ridge National Laboratory). 2009. Land-Use Change and Bioenergy: Report from the 2009 workshop, ORNL/CBES-001, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy and Oak Ridge National Laboratory, Center for Bioenergy Sustainability (http://www.ornl.gov/sci/besd/cbes.shtml).

- Dale, VH, R Efroymson, and K Kline. 2010. Using a Broad-scale Perspective to Address Changes in Lan*d, Climate, and Energy.* The Climate-Energy Nexus: Proceedings of the 2009 China-US Joint Research for Ecosystem and Environmental Change, pages 52-55, published by the Institute for a Secure and Sustainable Environment, University of Tennessee.

- Dale V, K Kline, P Mulholland, M Downing, R Graham, and L Wright. 2009. “Selecting Metrics for Sustainable Bioenergy Feedstocks” in the Proceedings of the Second Workshop. Beijing, October 15-17, 2008, China-US Joint Research for Ecosystem and Environmental Change, pages 49-53, published by the Institute for a Secure and Sustainable Environment, University of Tennessee.

Publications related to this Project

- Baskaran L, Jager HI, Schweizer P, Srinivasan R. 2009. Use of the SWAT model to evaluate the sustainability of switchgrass production at a national scale. 2009 International SWAT Conference Proceedings, Boulder, CO. http://twri.tamu.edu/reports/2009/tr356.pdf
- Baskaran, L., H.I. Jager, P.E. Schweizer, and R. Srinivasan. 2010. Progress toward evaluating the sustainability of switchgrass as a bioenergy crop using the SWAT model. *Transactions of the American Society of Agricultural and Biological Engineers* 53(5): 1547-1556.
- CBES.(Center for BioEnergy Sustainability, Oak Ridge National Laboratory). 2010. *A Watershed Perspective on Bioenergy Sustainability*. http://www.ornl.gov/sci/besd/cbes/workshop.shtml
- Dale, V.H., C. Kling, J.L. Meyer, J. Sanders, H. Stallworth, T. Armitage, D. Wangsness, T.S. Bianchi, A. Blumberg, W. Boynton, D.J. Conley, W. Crumpton, M.B. David, D. Gilbert, R.W. Howarth, R. Lowrance, K. Mankin, J. Opaluch, H. Paerl, K. Reckhow, A.N. Sharpley, T.W. Simpson, C. Snyder, and D. Wright. 2010. ***Hypoxia in the Northern Gulf of Mexico.*** New York: Springer.

Publications in Review or in Preparation

- Bruins R, Hoekman K, Efroymson R, Aden A, Hecht A. Transportation Fuels for the 21st Century. in review by EPA symposium editors. *EM Magazine*
- Efroymson RA, Dale VH, Covert C, Kline K. In Prep. A method for comparing net environmental benefits of different energy sources. *Energy Policy*

Collaborative papers resulting from 2009 EPA-ORNL Watershed Workshop

- Efroymson, E, V. Dale, K. Kline and others. In prep. Indicators of bioenergy sustainability: What about context?
- Dale, V., K. Kline, A. Lucier, D. Perla. In prep. Communicating about Biofuel Sustainability
- Bielicki, J.M., Sujit Das, Brian Davison, V.H. Dale, Fran Kremer, Paul Leiby, Andy Miller, Gdebo Oladusu, Sirisha Nukala, Donna Perla, Steven Peterson, Rekha Pillai, Rocio Uria-Marinez. In review. A Comparative Analysis of Bioenergy Pathways.
- Johnson, T., Jeff Bielicki, Rebecca Dodder, Mike Hilliard, Özge Kaplan, and Andy Miller. In review. Stakeholder decision making along the bioenergy supply chain: Sustainability considerations and research needs.
- Parish, E.S., T. Johnson, V. Dale, R. Efroymson, J.M. Bielicki, M.R. Hilliard R. Dodder, H.I. Jager, K. Kline, and A. McBride. In prep. Scale-dependent effects of bioenergy. Environmental Management.
- Smith, E., R. Efroymson, H.I. Jager, V. Dale and others. In prep. Review of ecosystem service impacts across the biofuels supply chain. Environmental Management.

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- Dale VH. 2009 “Designing Sustainable Options for Bioenergy Crops”. American Institute of Chemical Engineers (AIChE) Annual Meeting. Nashville, Tennessee.
- Dale VH. 2009. “Analysis of Bioenergy Sustainability Research” via live Internet. Southern Research Station for the USDA Forest Service. Auburn, Alabama.
- Dale VH. 2009. “Sustainability Considerations in Bioenergy Development” at ORNL to representatives from the French biofuel industry.
- Dale VH. 2009. ”Sustainability Concerns in Developing Countries.” Petronas Renewable Energy Laboratory. Battelle Columbus, Ohio.
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- Dale VH., Kline K., Efroymson R. 2009. “Ecological Sustainability Considerations in Bioenergy Development.” National Council for Air and Stream Improvement (NCASI). Chattanooga, Tennessee.
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- Dale VH. 2010. National Academies' Roundtable on Science and Technology for Sustainability Washington, D.C.
- Dale VH. 2010. “Bioenergy Sustainability Research at ORNL”. Joint US-UK Biofuels Sustainability Workshop at the National Renewable Energy Laboratory (NREL).
- Dale VH. 2010. “Bioenergy: The Issue of Sustainability in the Southeastern U.S.” meeting on “Advances in Bioenergy: A Southern States Briefing”. Knoxville, Tennessee.
- Dale VH. 2010. “Earth, Wind, & Fire in the 21st Century”. US Chapter of the International Association of Land Ecology symposia: Athens, Georgia.
- Dale VH. 2010. “Indicators for Assessing Environmental Impacts of Biofuels”. National Academy of Sciences Committee on Economic and Environmental Impacts of Increasing Biofuel Production.
- Dale VH. 2010. “Next Steps for Carbon Accounting”. The Time Value of Carbon and Carbon Storage: Implications for GHG Analysis and Policy Design Meeting. Washington, DC.

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- Graham R. 2010. “Bioenergy feedstocks and sustainability” at the ORNL Multi-Directorate Biomass Workshop. Oak Ridge, Tennessee.
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- Kline K. 2011. “Bioenergy, Land-Use Change and Food Security”. Advance 2011 Biodiesel Conference and Expo. Phoenix, Arizona.
- Parish E. 2010. “Environmental Engineering Seminar Series (ENV 508)” University of Tennessee, Knoxville.
- Parish E. 2010. “Water Challenges & Opportunities for Tennessee Landscapes.”Tennessee Watershed Conference. Nashville, Tennessee.
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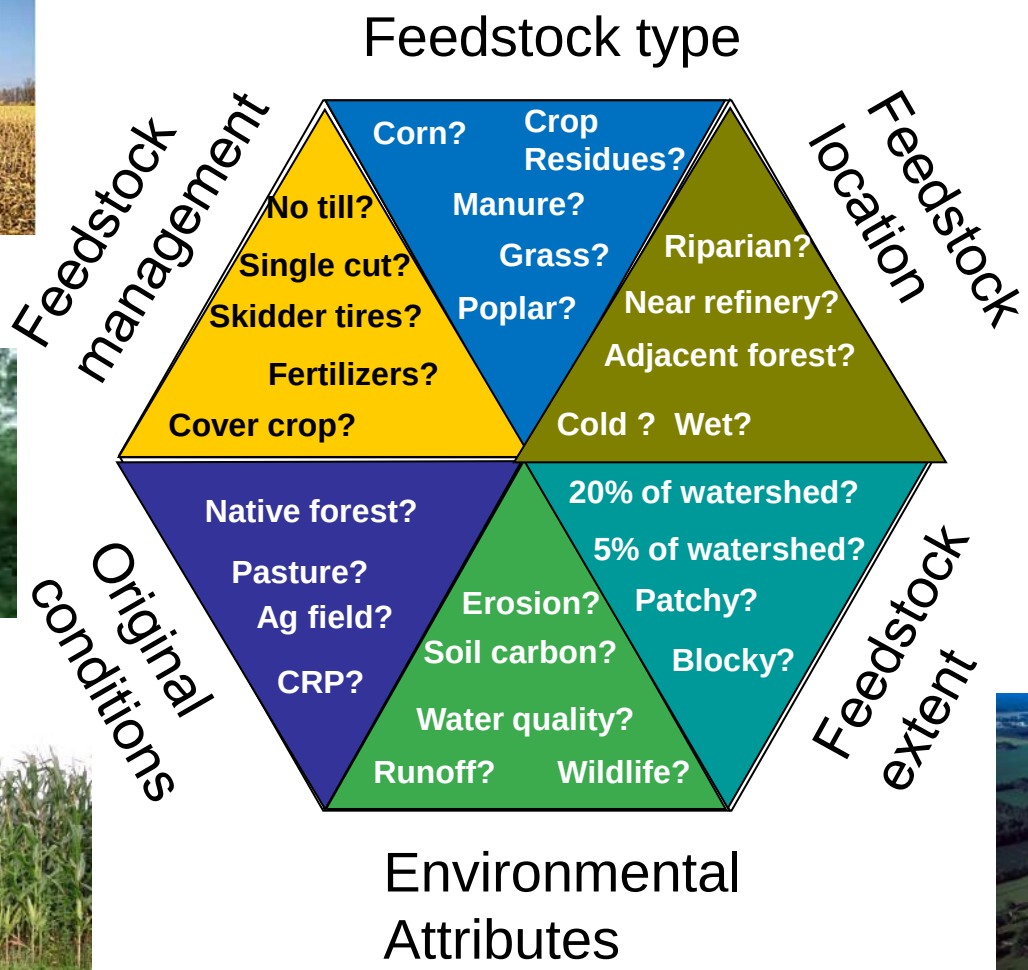
Task C Accomplishment: Identified Challenges of Sustainability



Address all six dimensions globally

From: Dale, Fargione, Kline, Wiens 2010. Biofuels: Implications for Land Use and Biodiversity. Biofuels and Sustainability report of the Ecological Society of America http://www.esa.org/biofuelsreports

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