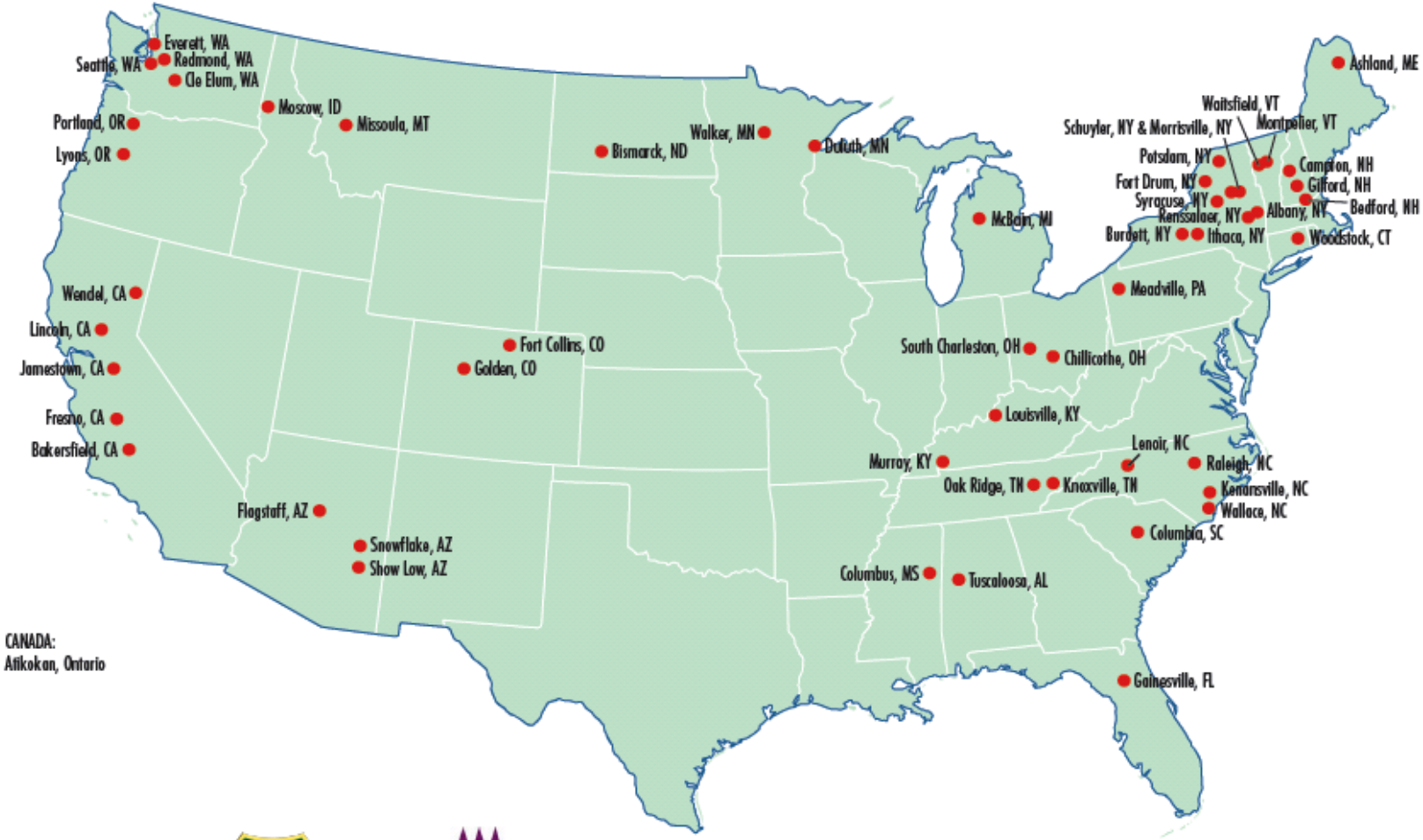
SECOND ANNUAL • October 22, 2014

# National Bioenergy Day

*Celebrating Nature's Energy Source*

**October 22, 2014** marks the **Second Annual National Bioenergy Day**. More than 40 events will be held in 22 states and Canada to celebrate the environmental and economic benefits of bioenergy on the local, state and national levels. For more information or to get involved, please visit www.bioenergyday.org or contact Carrie Annand at 703.506.3391 or carrie@usabiomass.org.




BIOMASS POWER ASSOCIATION

Plum Creek

Pellet Fuels Institute

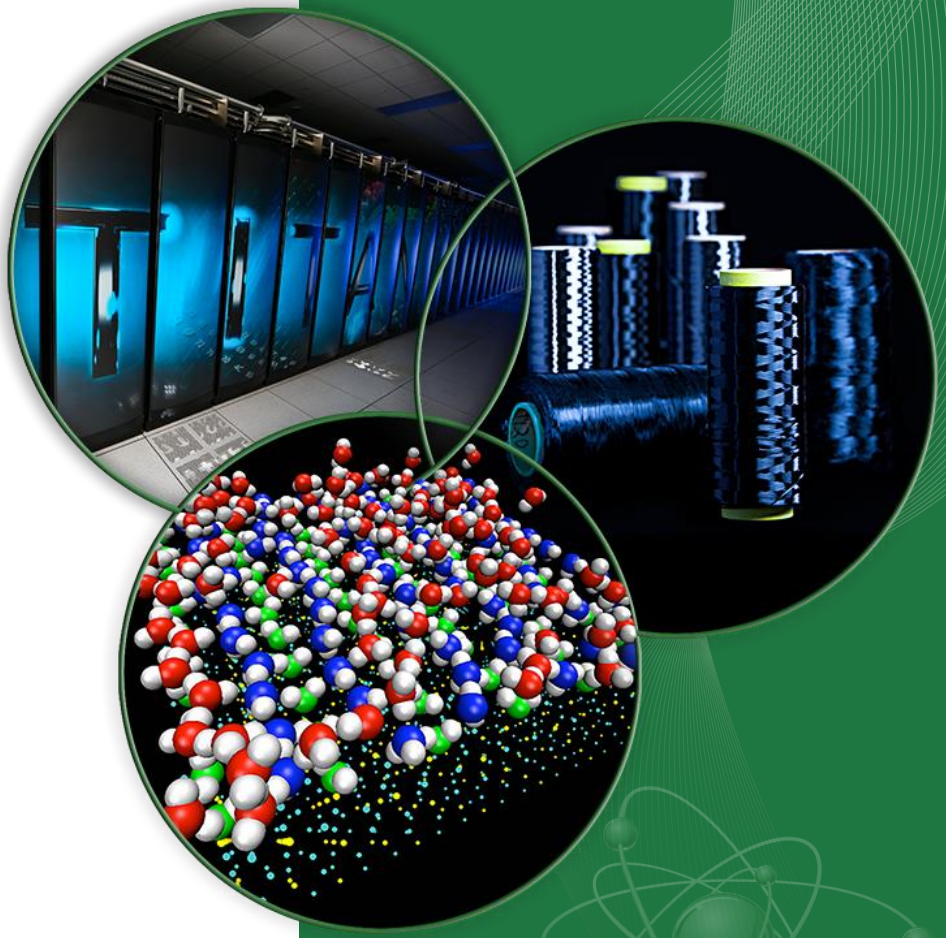
U.S. Industrial Pellet Association

BTEC Biomass Thermal Energy Council

BIOMASS MAGAZINE

# ASSESSING BIOENERGY SUSTAINABILITY:

# Application of a Suite of Environmental & Socioeconomic Indicators to a Cellulosic Biofuel Production System



Esther S. Parish

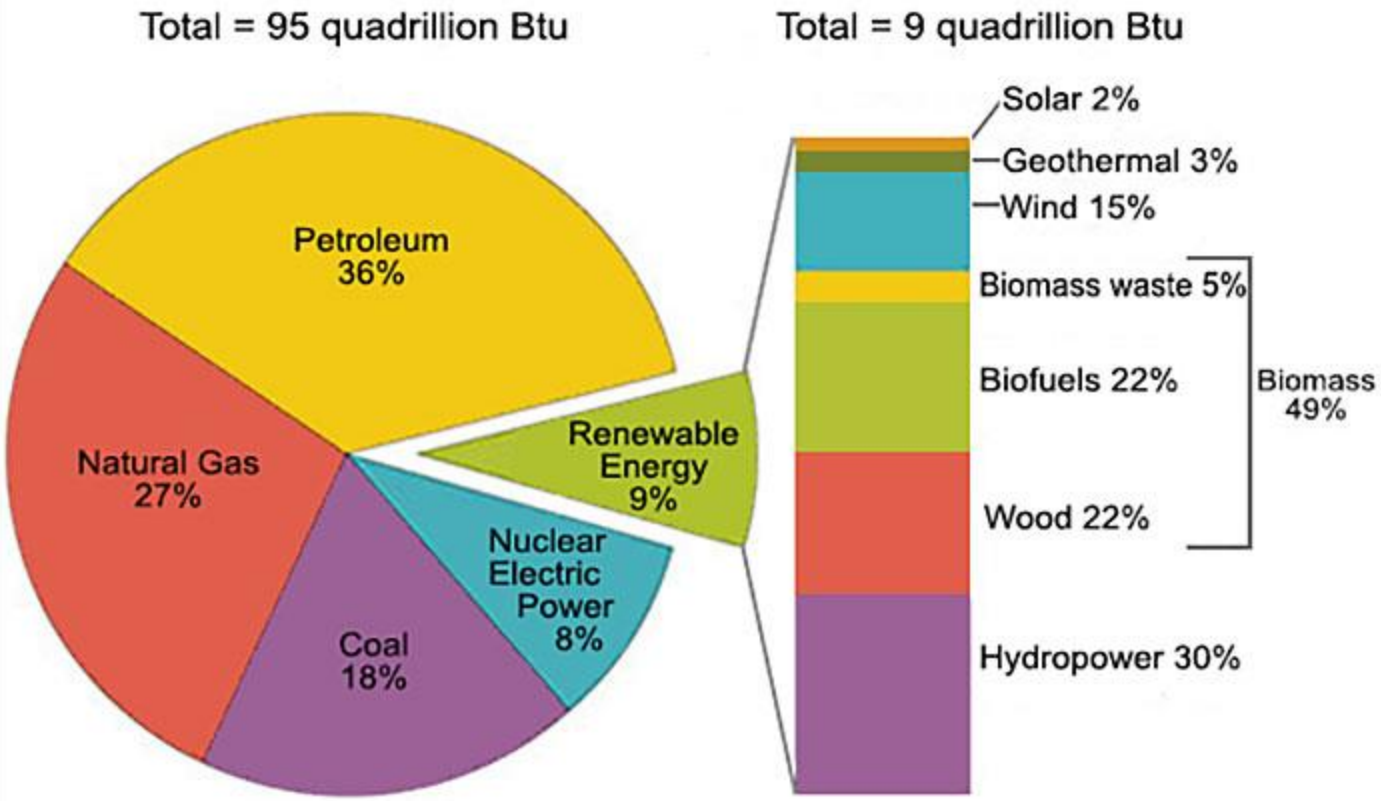
22 October 2014

ORNL CBES Seminar

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

OAK RIDGE National Laboratory

# U.S. energy consumption by energy source, 2012




Note: Sum of components may not equal 100% due to independent rounding.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1 (April 2013), preliminary 2012 data.

OAK RIDGE National Laboratory

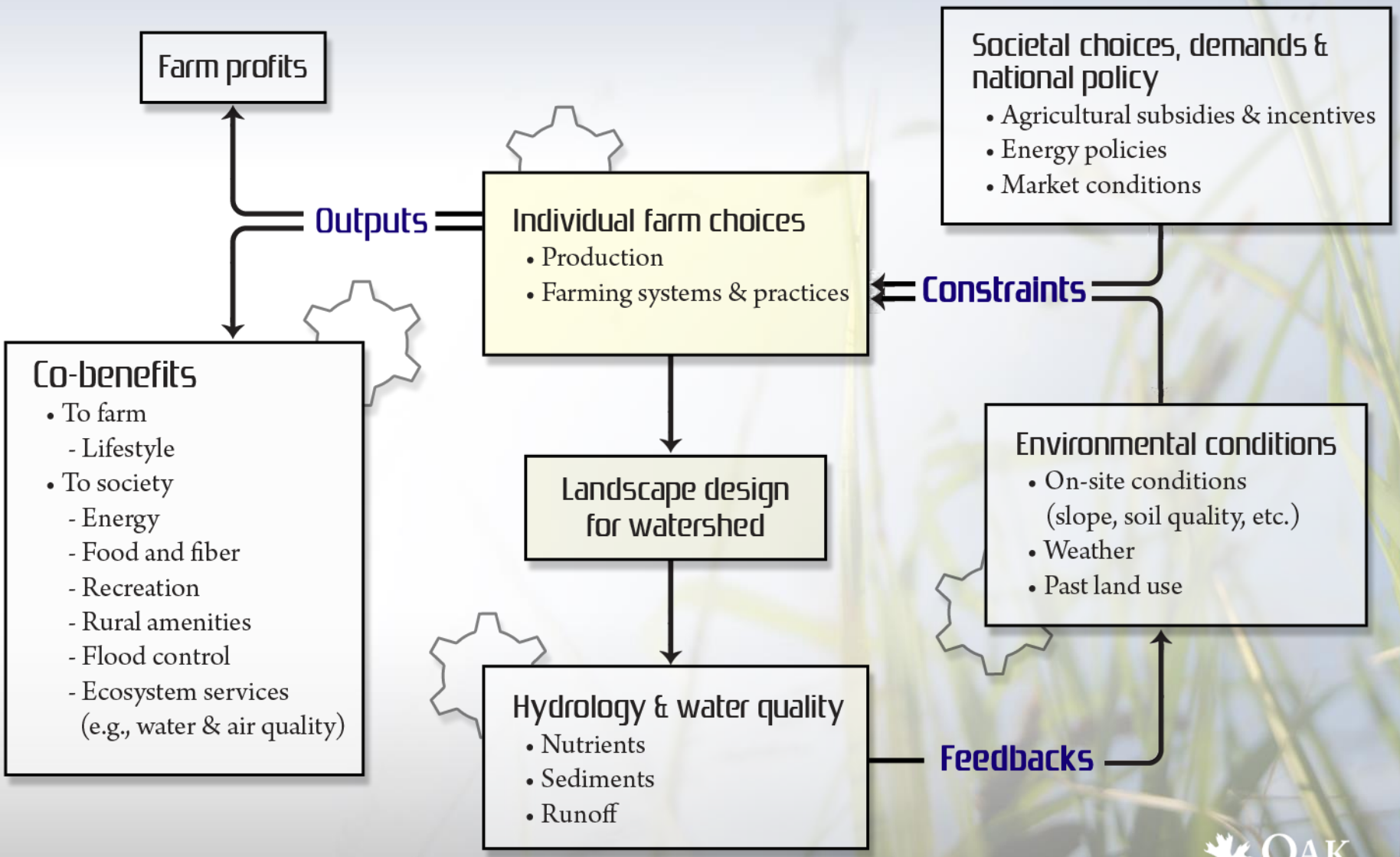
# Sustainability

**the capacity of an activity to continue while maintaining options for future generations.**

ORNL's research agenda includes:

- Defining environmental and socioeconomic costs and benefits of bioenergy systems
- Quantifying opportunities and risks associated with sustainable bioenergy in specific contexts
- Communicating the challenges and paths forward for sustainable bioenergy to a range of stakeholders

# The Effects of Bioenergy Choices *(Conceptual Diagram)*




Oak Ridge National Laboratory

# Sustainability Indicators

A measurement that provides information about the effects of human activities on the environment, society or economy.

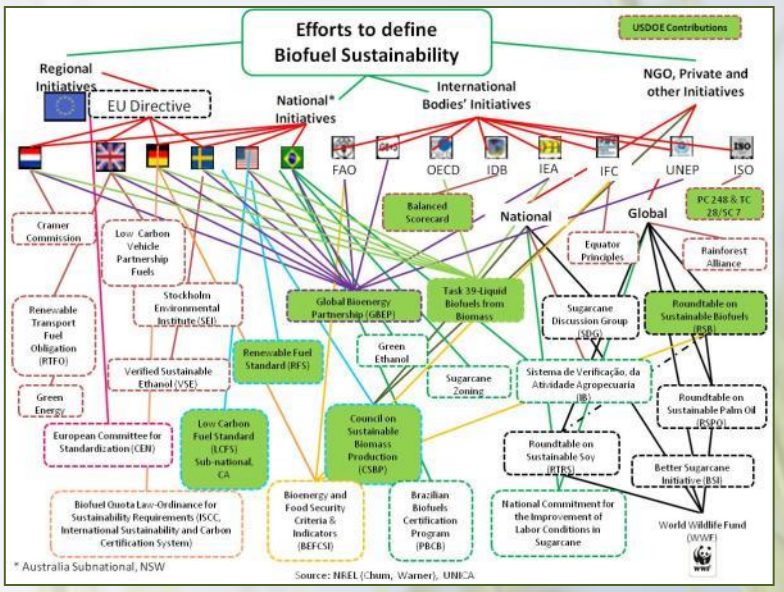
Indicators should be

- Useful
  - Policymakers
  - Producers
- Technically effective
  - Sensitive to stresses on system
  - Anticipatory: signify impending change
  - Have known variability in response
- Practical
  - Easily measured
  - Consider context of measure
  - Broadly applicable
  - Predict changes that can be averted by management actions

Dale and Beyeler. 2001. Challenges in the development and use of ecological indicators. *Ecological Indicators* 1: 3-10.

# Many initiatives are exploring indicators for sustainability – e.g. for bioenergy…

- ISO (International Organization for Standardization)
- GBEP (Global Bioenergy Partnership)
- CSBP (Council on Sustainable Biomass Production)
- RSB (Roundtable on Sustainable Biofuels)
- Many more

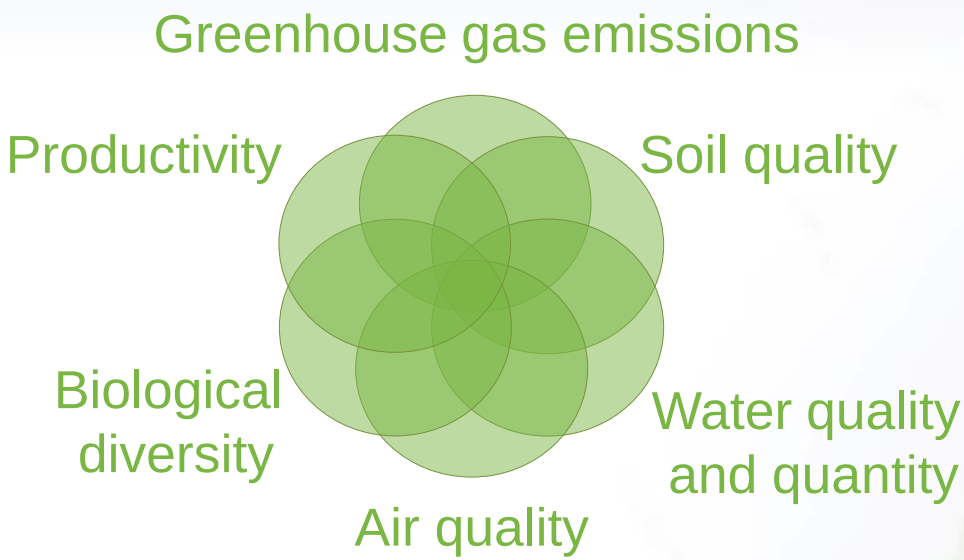



BUT

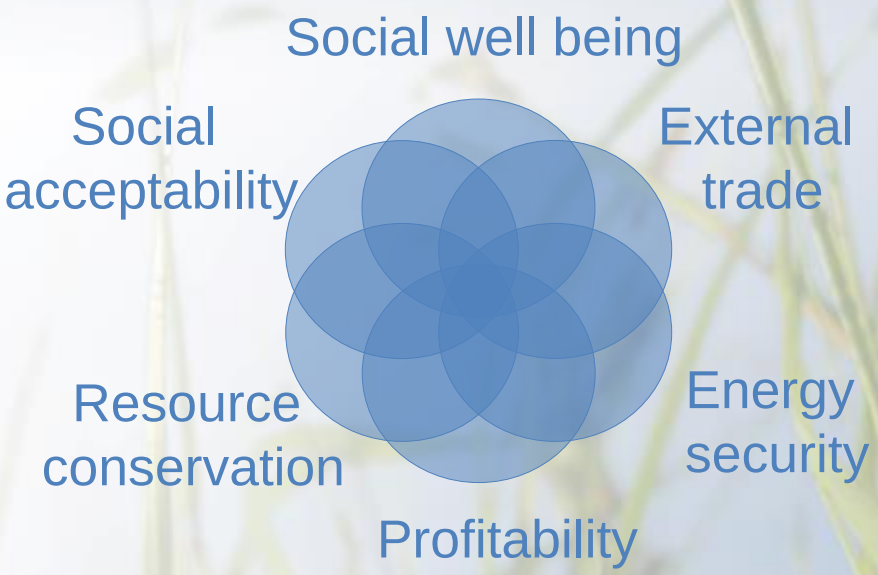
- Some indicators focus on management practices although knowledge is limited about which practices are "sustainable"
- Implementation is limited by indicators being too
  - ✓ Numerous
  - ✓ Broad
  - ✓ Costly
  - ✓ Difficult to measure

OAK RIDGE National Laboratory

# Categories for indicators of environmental and socioeconomic sustainability




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




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

**Recognize that measures and interpretations are <u>context</u> specific**

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

OAK RIDGE National Laboratory

# 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**

# Categories of socioeconomic sustainability indicators

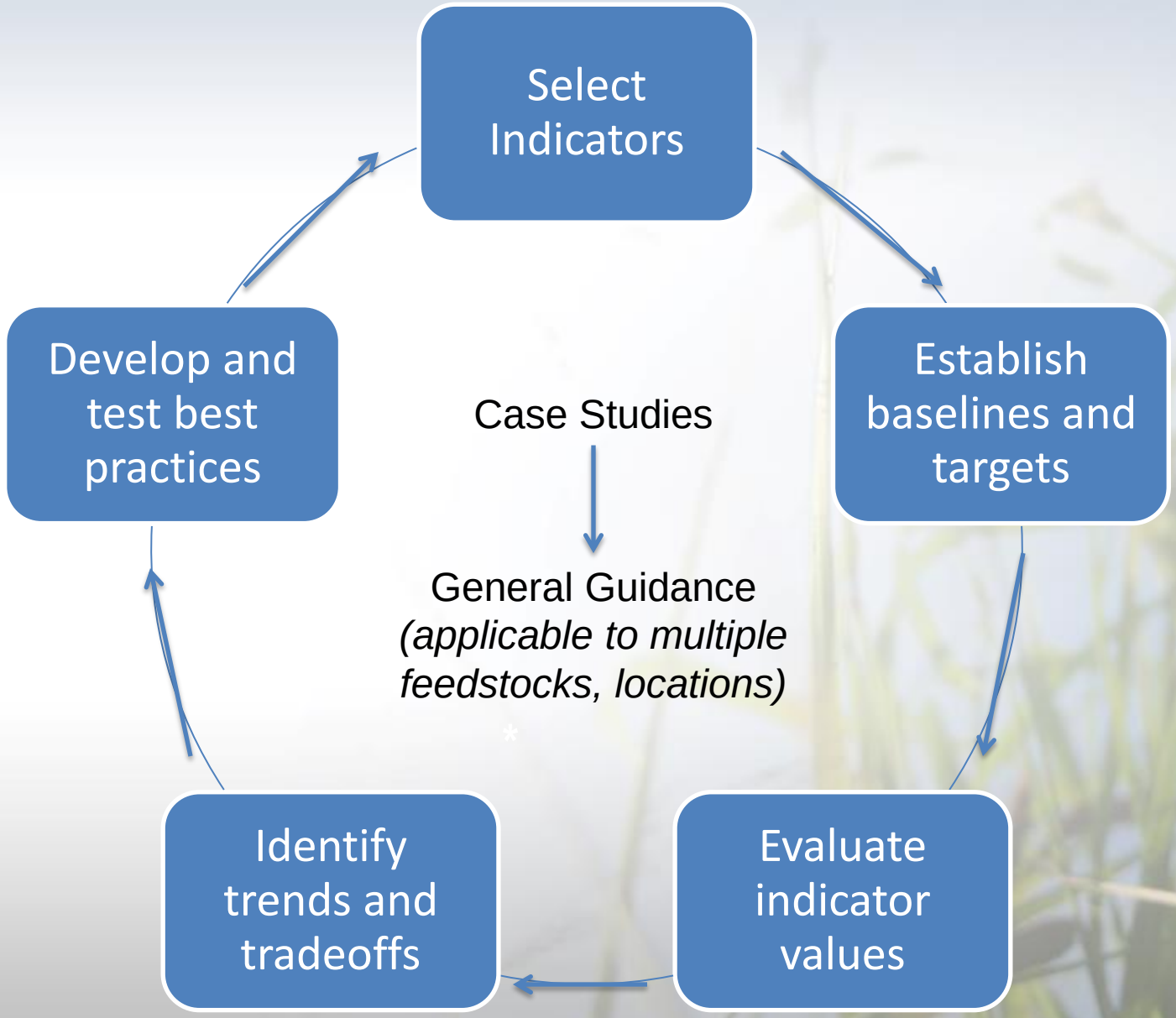
*Ten minimum practical measures*

| 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 outputt |
| **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.**

# DOE approach to assessing Bioenergy Sustainability

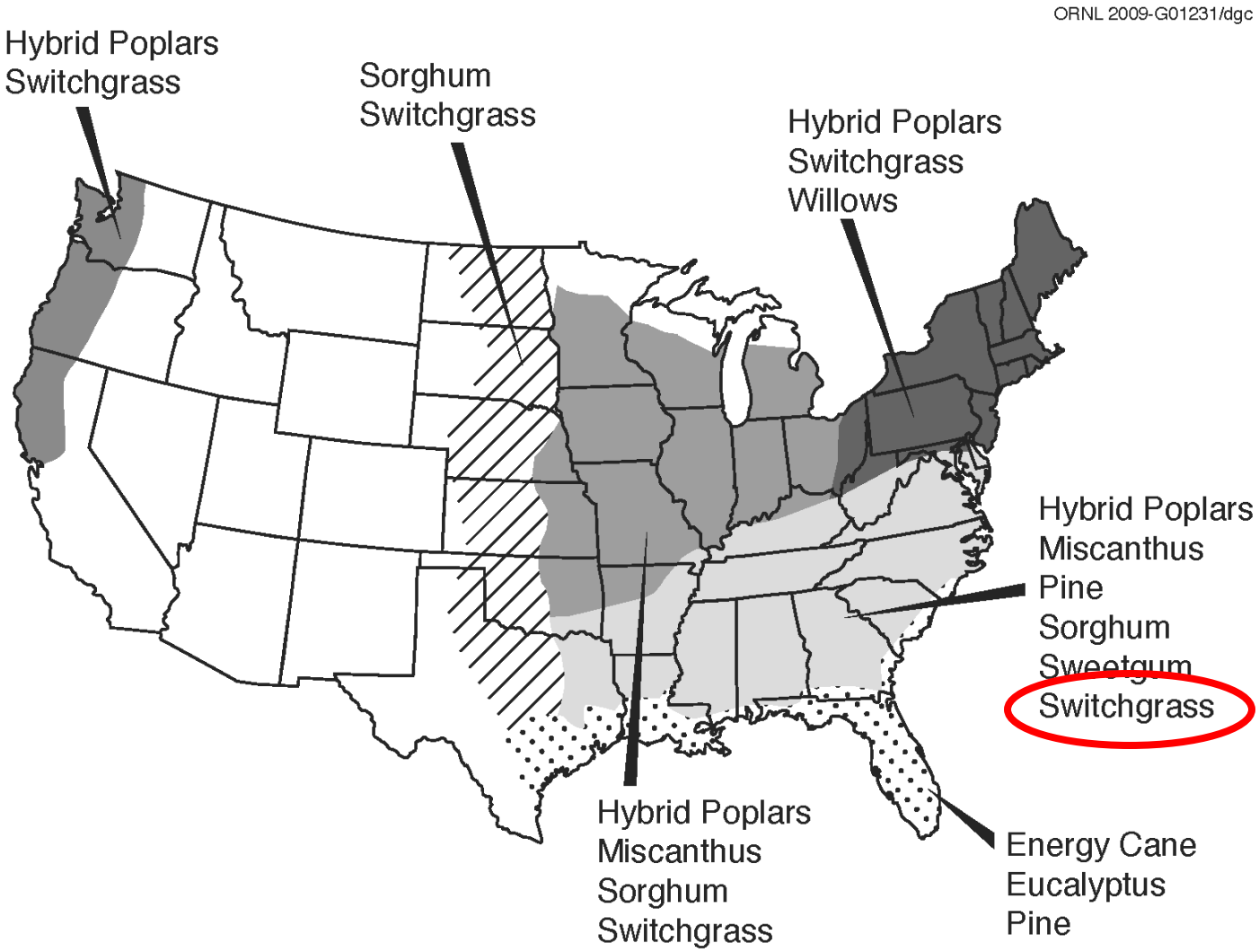



OAK RIDGE National Laboratory

# Adapting Suite to Particular Contexts

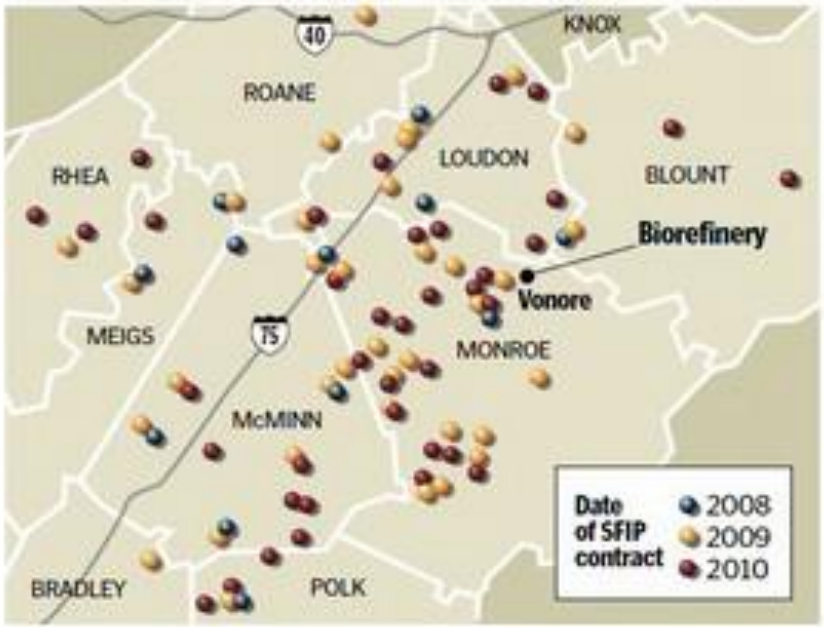
- **Indicator set is a starting point for sake of efficiency and standardization**
  - Particular systems may require addition of other indicators
  - Budget may require subtraction of some indicators
  - Some indicators more important for different supply chain steps
- **Protocols must be context-specific**

# Recommended Biofuel Feedstock Plantings in Regions of the U.S.




Dale et al. (2011) *Ecological Applications* 21(4):1039-1054.

# Selected East TN switchgrass experiment for case study




| 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*

Manuscript in preparation for “Ecological Monographs”

# Assessing Multimetric Aspects of Sustainability: Application to a Bioenergy Crop Production System in East Tennessee

**Esther S. Parish[1], Virginia H. Dale[1], Burton C. English[2], Samuel W. Jackson[3], Donald D. Tyler[4]**

[1]Center for BioEnergy Sustainability (CBES), Oak Ridge National Laboratory (ORNL), 1 Bethel Valley Road, Oak Ridge, TN 37831;
[2]Agricultural and Resource Economics Department, The University of Tennessee Institute of Agriculture (UTIA), 2621 Morgan Circle, Knoxville, TN 37996;
[3]Genera Energy, 167 Tellico Port Road, Vonore, TN 37885; [4]West Tennessee Research and Agricultural Station, 605 Airways Boulevard, Jackson, TN 38301

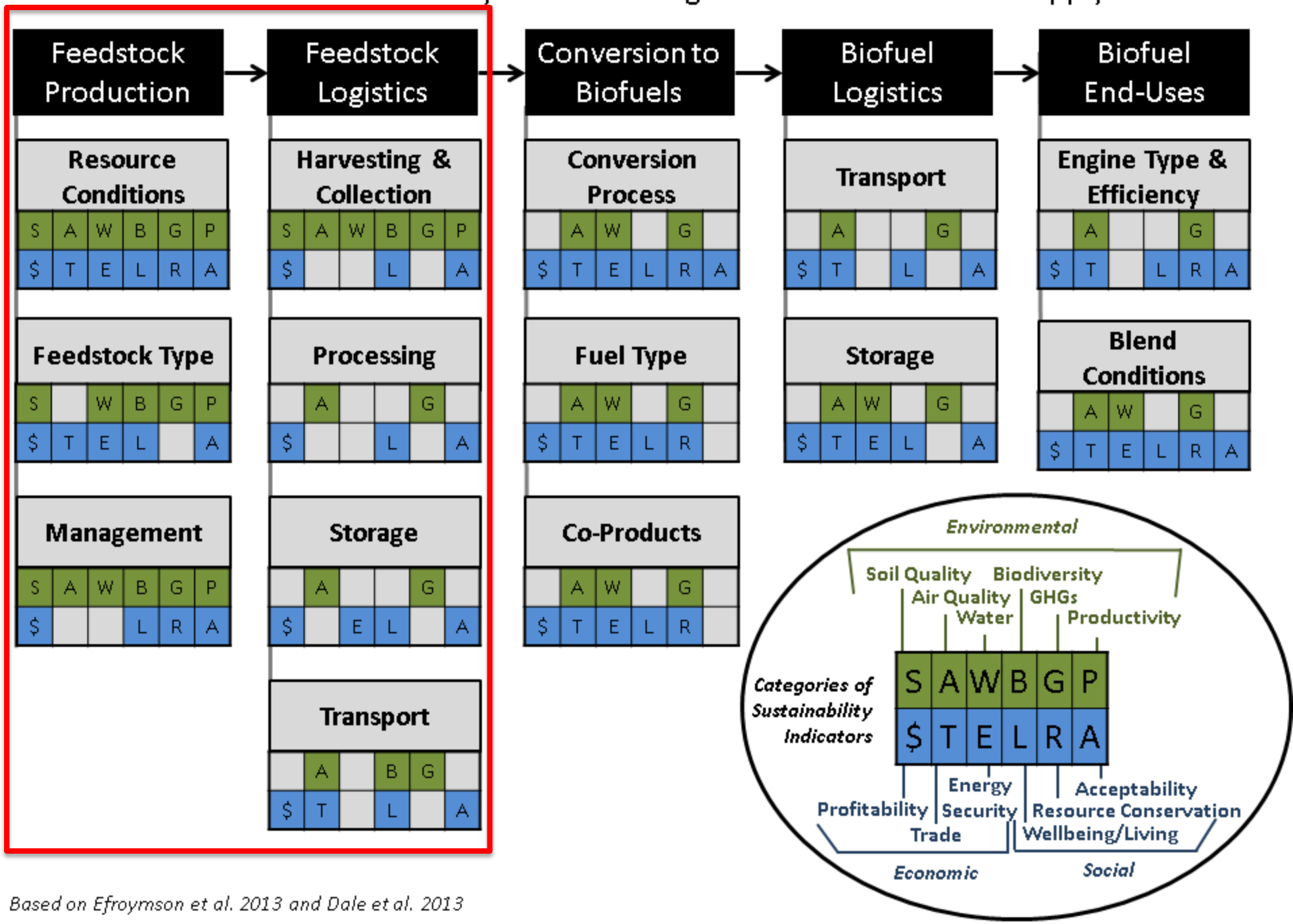
# Case Study objectives

- Help connect the science of sustainability with sustainability deployment
- Explore the following questions:
  - Is it possible to assess a bioenergy system's overall sustainability by integrating multimetric information gathered from across a variety of spatial and temporal scales?
  - Do some sustainability indicators contribute more to the overall sustainability determination than others? If so, how context-specific is this effect?



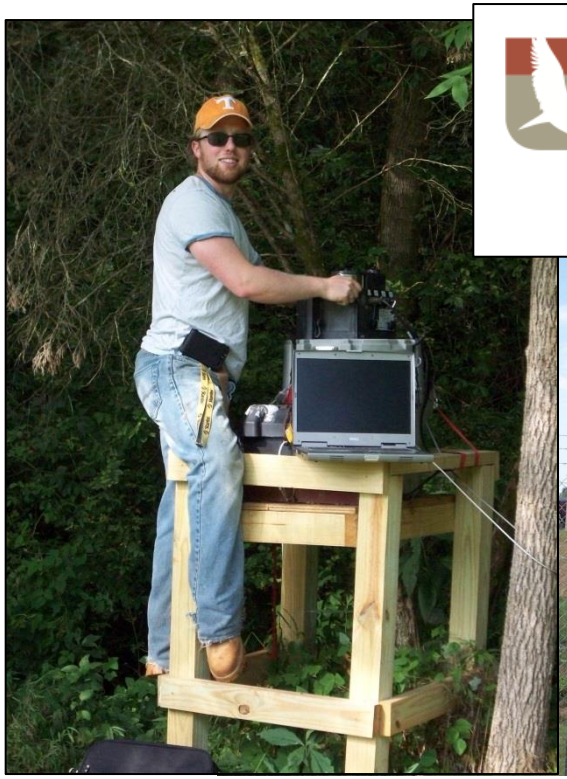
OAK RIDGE National Laboratory

# Relevance of 12 Sustainability Indicator Categories Across the Biofuel Supply Chain




*Based on Efroymson et al. 2013 and Dale et al. 2013*

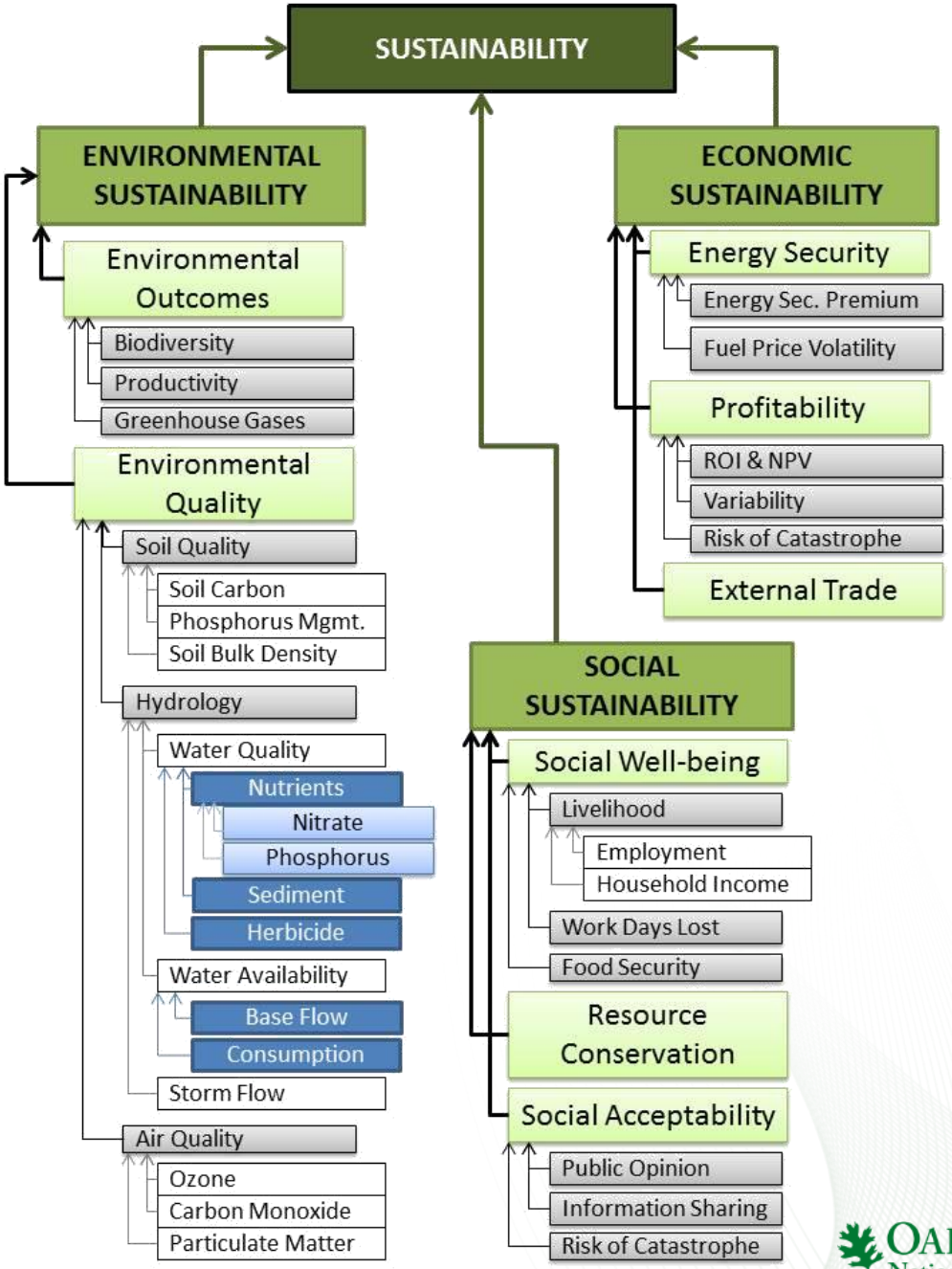
# Empirical data for Vonore switchgrass experiment were supplemented with modeling results, literature values & expert opinion.



IBSS
Southeastern Partnership for
Integrated Biomass Supply Systems

**Synthesized results were used to assign qualitative ratings for most of the 35 indicators & all 12 categories.**

# Aggregated indicators within a Multi-Attribute Decision Support System (MADSS)




**The MADSS was built using DEXi 4.0 software freely available from [www-ai.ijs.si/MarkoBohanec/dexi.html](www-ai.ijs.si/MarkoBohanec/dexi.html)**



OAK RIDGE National Laboratory

# Compared 3 scenarios

| 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 |

# Economic Sustainability Ratings

| | No-Till Switchgrass Scenario | Unmanaged Pasture Scenario | Tilled Corn Scenario |
|---|---|---|---|
| **ECONOMIC SUSTAINABILITY** | INTERMEDIATE ECONOMIC SUSTAINABILITY | **LOW ECONOMIC SUSTAINABILITY** | ***HIGH ECONOMIC SUSTAINABILITY*** |
| ├─**Energy Security** | ***improved energy security*** | no change in energy security | ***improved energy security*** |
| │ ├─Energy Security Premium | ***low energy security premium*** | neutral energy security premium | ***low energy security premium*** |
| │ └─Fuel Price Volatility | ***decreased fuel price volatility*** | no change in fuel price volatility | ***decreased fuel price volatility*** |
| ├─**Profitability** | average profitability | mixed profitability measures | mixed profitability measures |
| │ ├─ROI & NPV | average returns | **low returns** | average returns |
| │ └─Variability | ***low variability*** | ***low variability*** | **highly variable** |
| └─**External Trade** | no external trade | no external trade | ***high external trade*** |



OAK RIDGE National Laboratory

# Social Sustainability Ratings

| | No-Till Switchgrass Scenario | Unmanaged Pasture Scenario | Tilled Corn Scenario |
|---|---|---|---|
| **SOCIAL SUSTAINABILITY** | ***HIGH SOCIAL SUSTAINABILITY*** | INTERMEDIATE SOCIAL SUSTAINABILITY | INTERMEDIATE SOCIAL SUSTAINABILITY |
| **├─Social Well-being** | ***improved social well-being*** | **decreased social well-being** | ***improved social well-being*** |
| **│ ├─Livelihood** | ***improved livelihoods*** | **decreased livelihoods** | no change in livelihood |
| │ │ ├─Employment | ***more jobs*** | **fewer jobs** | no change in # of jobs |
| │ │ └─Household Income | ***more household income*** | some household income | some household income |
| │ ├─Work Days Lost | average work days lost | average work days lost | average work days lost |
| │ └─Food Security | no noticeable change in food volatility | no noticeable change in food volatility | ***decreasing food volatility*** |
| ├─Resource Conservation | ***net decrease in fossil fuel consumption*** | ***net decrease in fossil fuel consumption*** | **net increase in fossil fuel consumption** |
| **└─Social Acceptability** | ***high social acceptability*** | neutral social acceptability | neutral social acceptability |
| ├─Public Opinion | ***positive public opinion*** | neutral public opinion | neutral public opinion |
| ├─Information Sharing | ***high stakeholder engagement*** | average stakeholder involvement | average stakeholder involvement |
| └─Risk of Catastrophe | ***reduced risk*** | average risk | average risk |



OAK RIDGE National Laboratory

# Environmental Sustainability Ratings

| | No-Till Switchgrass Scenario | Unmanaged Pasture Scenario | Tilled Corn Scenario |
|---|---|---|---|
| **ENVIRONMENTAL SUSTAINABILITY** | ***HIGH ENVIRONMENTAL SUSTAINABILITY*** | ***HIGH ENVIRONMENTAL SUSTAINABILITY*** | **LOW ENVIRONMENTAL SUSTAINABILITY** |
| ├─**Environmental Outcomes** | ***improved environmental outcome(s)*** | mixed environmental outcomes | **negative environmental outcome(s)** |
| │ ├─Biodiversity | ***more biodiversity*** | some biodiversity | **less biodiversity** |
| │ ├─Productivity | ***high productivity*** | **low productivity** | average productivity |
| │ └─Greenhouse Gases | some GHG emissions | ***fewer GHG emissions*** | **more GHG emissions** |
| └─**Environmental Quality** | ***improving aspect(s) of environmental quality*** | ***improving aspect(s) of environmental quality*** | **declining aspect(s) of environmental quality** |
| ├─**Soil Quality** | ***improving soil quality*** | ***improving soil quality*** | **declining soil quality** |
| │ ├─Soil Carbon | ***increasing soil TOC*** | no change in soil TOC | **decreasing soil TOC** |
| │ ├─Phosphorus Mgmt. | maintenance of soil P | ***no P applied to soil*** | maintenance of soil P |
| │ └─Soil Bulk Density | nonrestrictive bulk density | nonrestrictive bulk density | nonrestrictive bulk density |
| ├─**Hydrology** | ***improving hydrologic conditions*** | ***improving hydrologic conditions*** | **declining hydrologic conditions** |
| │ ├─**Water Quality** | ***increasing water quality*** | ***increasing water quality*** | **decreasing water quality** |
| │ │ ├─**Nutrients** | ***decreasing nutrient concentrations*** | no change in nutrient concentrations | **increasing nutrient concentrations** |
| │ │ │ ├─Nitrate | ***decreasing nitrate concentrations/export*** | no change in nitrate concentration | **increasing nitrate concentrations/export** |
| │ │ │ └─Phosphorus | ***decreasing P concentrations/export*** | no change in P concentrations/export | **increasing P concentrations/export** |
| │ │ ├─Sediment | ***decreasing sediment concentrations*** | no change in sediment concentrations | **increasing sediment concentrations** |
| │ │ └─Herbicide | herbicide applied during establishment only | ***no herbicide applications*** | **frequent herbicide applications** |
| │ ├─**Water Availability** | ***increasing water availability*** | no change in water availability | no change in water availability |
| │ │ ├─Base Flow | no change in baseflow | no change in baseflow | no change in baseflow |
| │ │ └─Consumptive Use | ***highly efficient water use*** | normal water use | normal water use |
| │ └─Storm Flow | ***improved capacity to absorb excess water*** | expected storm runoff behavior | expected storm runoff behavior |


OAK RIDGE National Laboratory

# Overall Sustainability Ratings

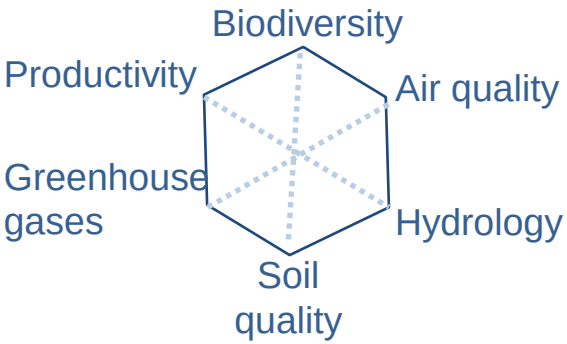
| | No-Till Switchgrass Scenario | Unmanaged Pasture Scenario | Tilled Corn Scenario |
|---|---|---|---|
| **SUSTAINABILITY** | ***HIGH SUSTAINABILITY*** | INTERMEDIATE SUSTAINABILITY | INTERMEDIATE SUSTAINABILITY |
| **├─ENVIRONMENTAL SUSTAINABILITY** | ***HIGH ENVIRONMENTAL SUSTAINABILITY*** | ***HIGH ENVIRONMENTAL SUSTAINABILITY*** | **LOW ENVIRONMENTAL SUSTAINABILITY** |
| **├─ECONOMIC SUSTAINABILITY** | INTERMEDIATE ECONOMIC SUSTAINABILITY | **LOW ECONOMIC SUSTAINABILITY** | ***HIGH ECONOMIC SUSTAINABILITY*** |
| **└─SOCIAL SUSTAINABILITY** | ***HIGH SOCIAL SUSTAINABILITY*** | INTERMEDIATE SOCIAL SUSTAINABILITY | INTERMEDIATE SOCIAL SUSTAINABILITY |

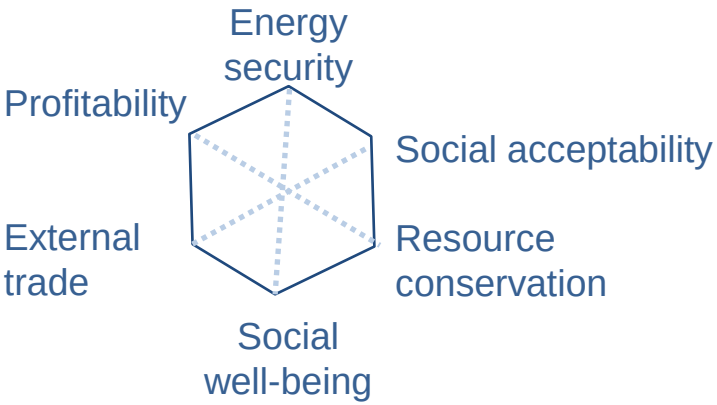


OAK RIDGE National Laboratory

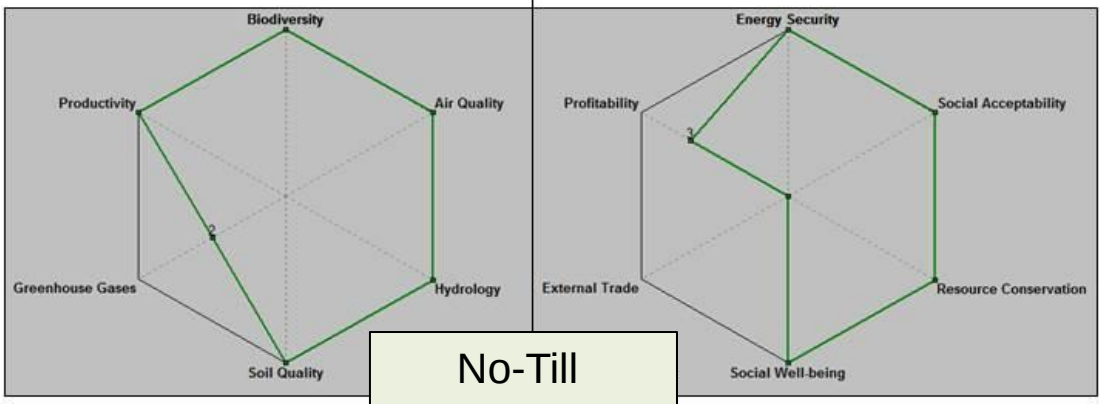
# Ratings of six environmental and six socioeconomic sustainability categories

Key to chart

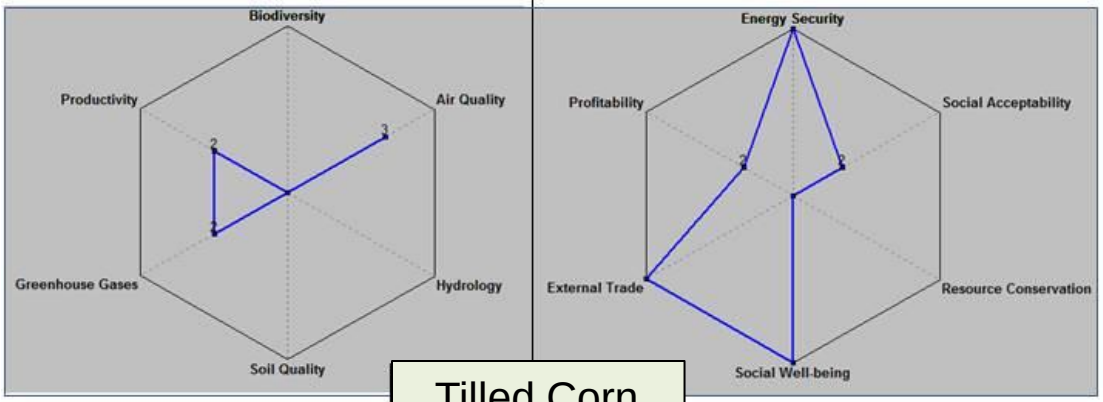


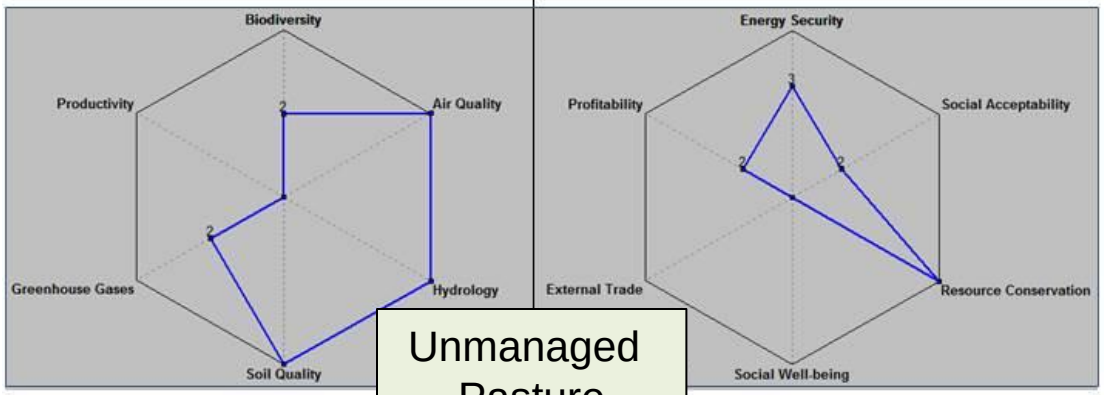

Environmental categories | Socioeconomic categories




No-Till Switchgrass




Tilled Corn

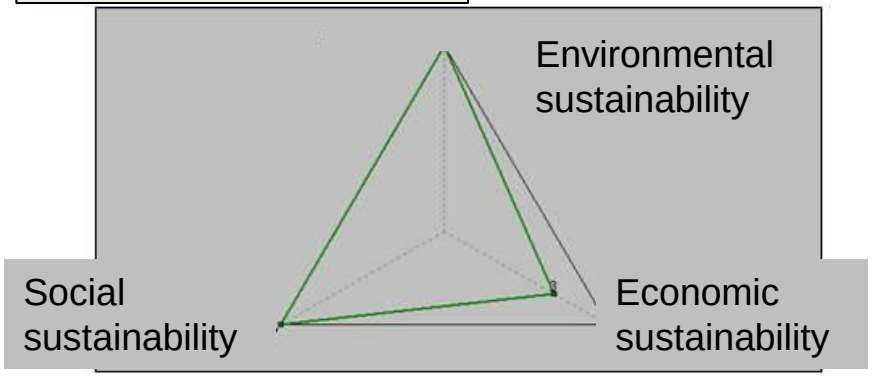



Unmanaged Pasture

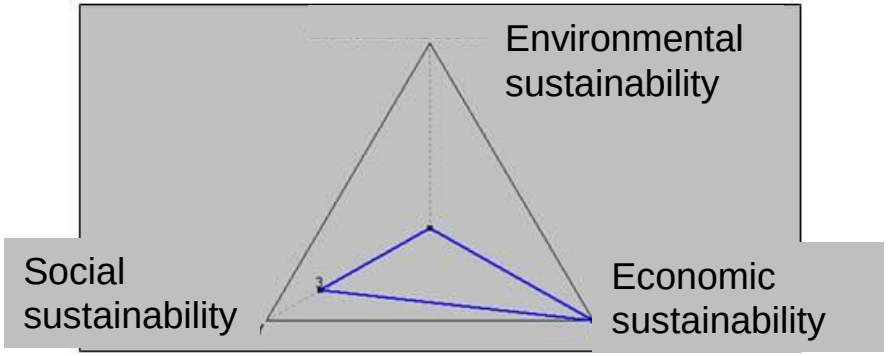
# Relative contributions of the three sustainability "pillars" to the overall sustainability

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

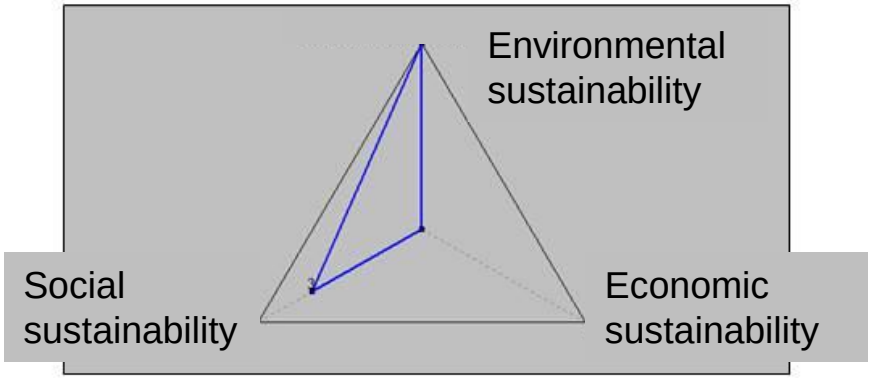
No-Till Switchgrass



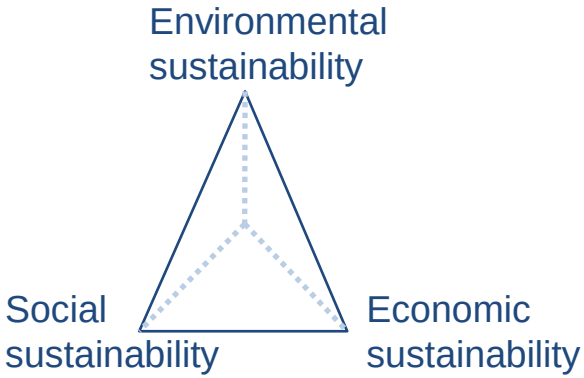

Tilled corn




Unmanaged pasture




Key to chart



# Results of Vonore Case Study

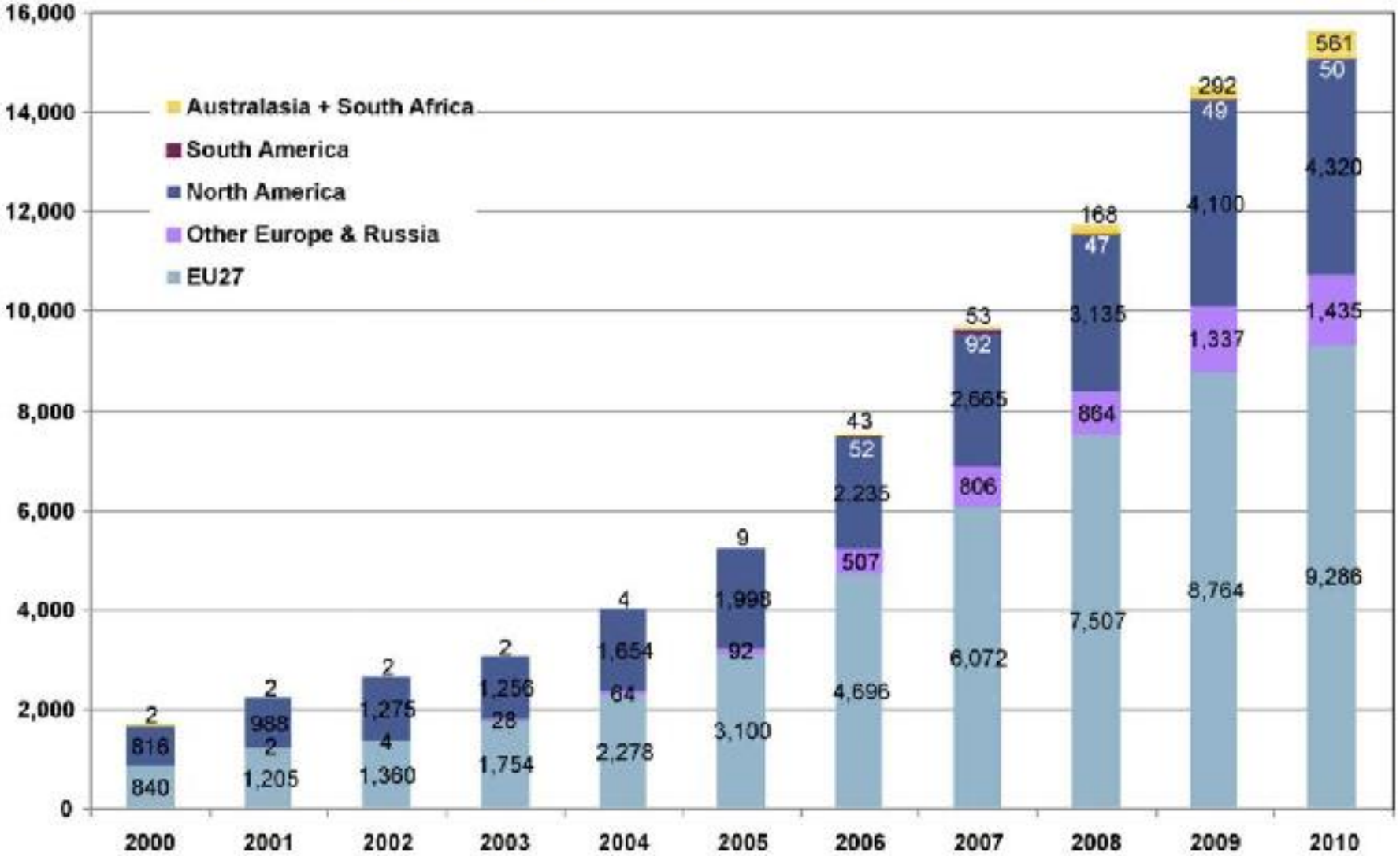
- Within this East Tennessee context, switchgrass production shows potential for improved environmental and social sustainability trajectories without adverse economic impacts.
- This case study demonstrates that integration of qualitative sustainability indicator ratings may increase holistic understanding of a bioenergy system in the absence of complete information.

Photo Credit:
Ken Goddard,
UT Extension



OAK RIDGE National Laboratory

# Global wood pellet production 2000 - 2010




(Source: Lamers et al. RSER, 16(2012) 3176-3199

# Next step: Evaluate sustainability indicators for bioenergy developed from woody biomass in the SE US.

**ORNL CBES is assembling information on woody biomass in the SE US**
**A draft work plan has been developed for a FY15 test assessment**

- Key participants
  - Floor van der Hilst and Judith Verstegen, Utrecht University
  - Jake Jacobson, INL
- Other potential collaborators:
  - Bob Emory, Weyerhaeuser
  - USDA Forest Service - David Wear and FIA analysts
  - SFI: Nadine Block
  - NCASI: Ben Wigley and Eric Vance
  - Plum Creek: Mike Jostrom
  - Small land owners – need to identify group
  - NCSU: Steve Kelly, Jesse Daystar, Jenn Costanza, Bob Abt
  - RWE: Waycross plant
  - IEA: Tat Smith, Marilyn Buford, Göran Berndes, etc.
  - Enviva – Liz Woodworth
- Case studies – Pellets mills feeding into ports of
  - Savannah, Georgia
  - Chesapeake, Virginia

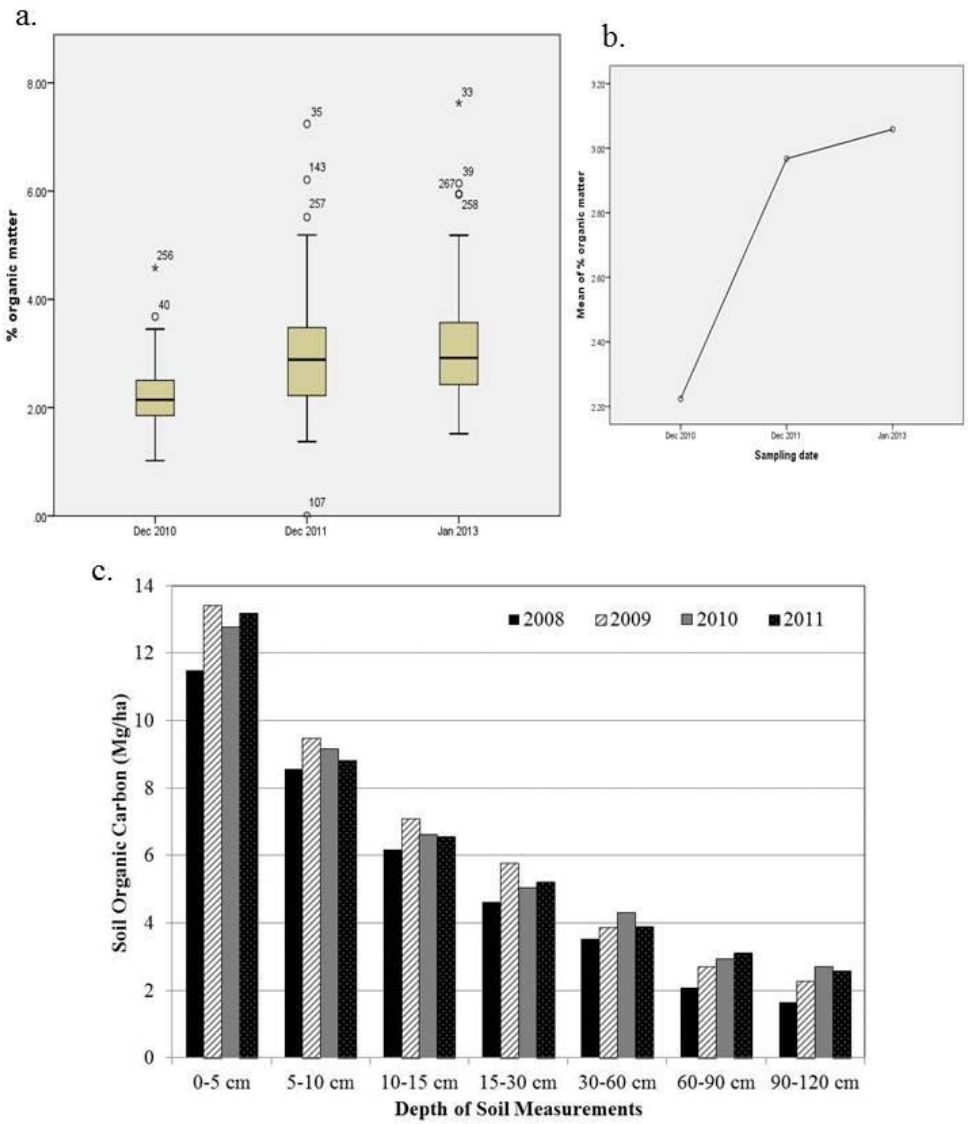
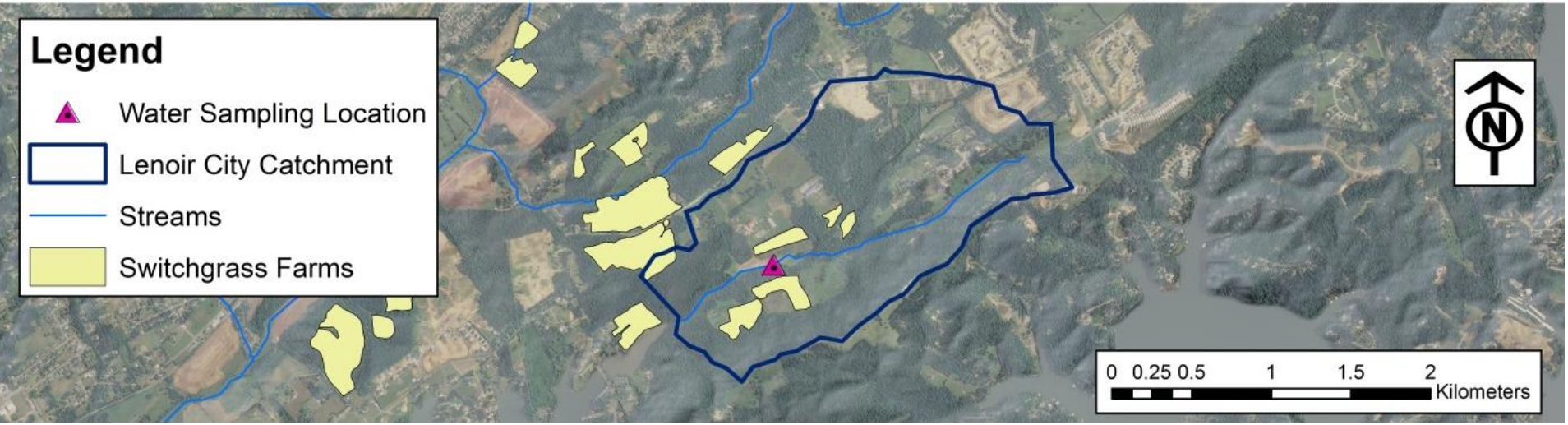
# Thank you!

CBES
Center for BioEnergy Sustainability

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

ACKNOWLEDGMENTS
Funding for this research was provided by the US Department of Energy (DOE) under the Bioenergy Technologies Office (BETO). Oak Ridge National Laboratory (ORNL) is managed by UT-Battelle, LLC, for DOE under contract DE-AC05-00OR22725. Support for this research was also provided by the Southeastern Partnership for Integrated Biomass Supply Systems (IBSS), which is funded through Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30410 from the USDA National Institute of Food and Agriculture. Thank you to our DOE BETO sponsor, Kristen Johnson, for her support of this project. Thanks to Latha Baskaran of ORNL for her analysis of hydrologic data provided by Zachariah Seiden and John Schwartz of the University of Tennessee (UT). Thanks to Jamey Menard of UT for conducting economic analysis of our case study and alternative scenarios. Thanks to Jessica McCord, Chris Clark and Edward Yu of UT, Jesse Daystar of North Carolina State University, and other IBSS collaborators for the providing their publications and clarification.

# Soil carbon-related data from East Tennessee switchgrass farms



# Lenoir city catchment (247.5 ha) used to model water quality difference for the 3 alternative scenarios