Indicators to support environmental sustainability of agricultural production and bioenergy crops

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U.S. DEPARTMENT OF ENERGY

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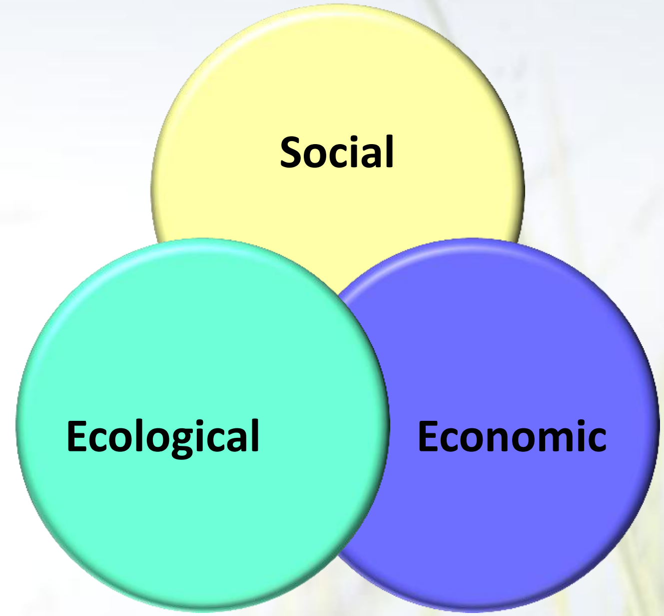
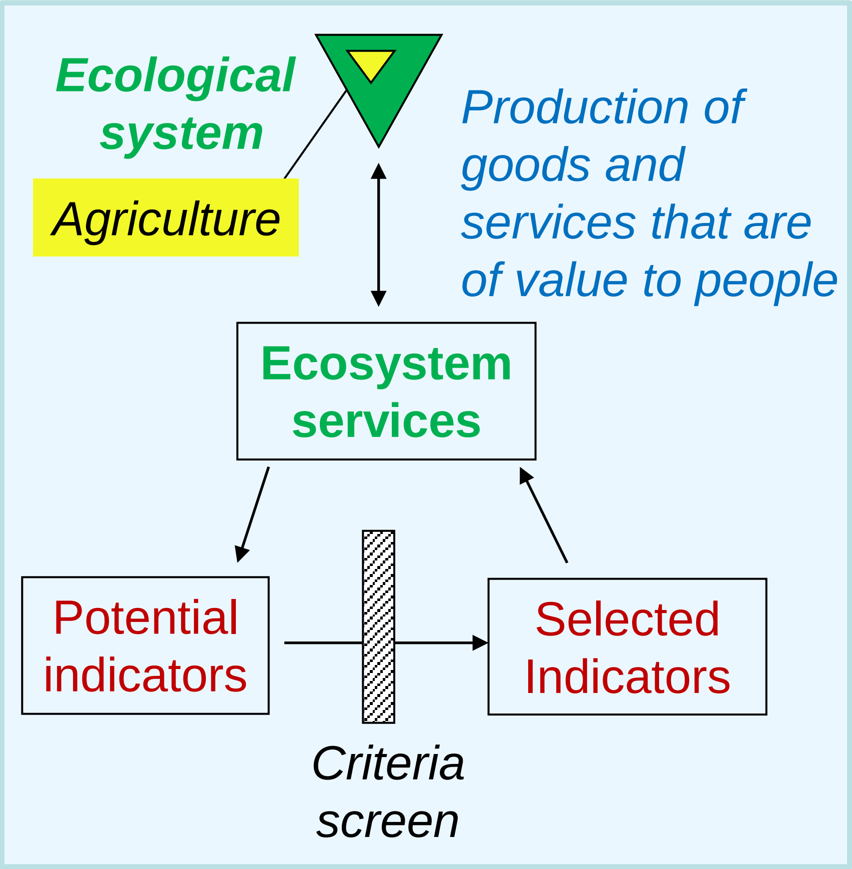
Key Points

- Sustainability is contextual, relative (more/less) and process based
- Sustainability implications of bioenergy choices can be large and complex
- Must consider a suite of measures
- You can only manage what you can measure



Sustainability – thinking about future generations

Relationship between Agricultural Practices, Ecosystem Services, and Indicators



Agent of Change → **Ecological Services**

Land cover

Erosion

Chemical use

Production services
- Food
- Materials
- Energy

Regulation services
- Water quality, quantity
- Soil quality
- Air quality
- Pollination services
- Seed dispersal
- Biodiversity
- Pest mitigation,
- Mitigate disturbances

Habitat services
- Biodiversity
- Habitat

Dale, V.H. and Polasky, S. 2007. Measures of the effects of agricultural practices on ecosystem services. *Ecological Economics* 64:286-296.

Sustainability Indicators

- Ideally – broadly useful to:
  - Policy makers
  - Producers
  - Society
- Improve empirical underpinning for management decisions

- Applied to particular contexts
  - Indicator set is starting point for sake of efficiency and standardization
  - Particular situations may require different indicators
  - Practical issues (data, costs) limit applicability of some indicators
  - Measurement and interpretation protocols must be relevant, useful and context-specific

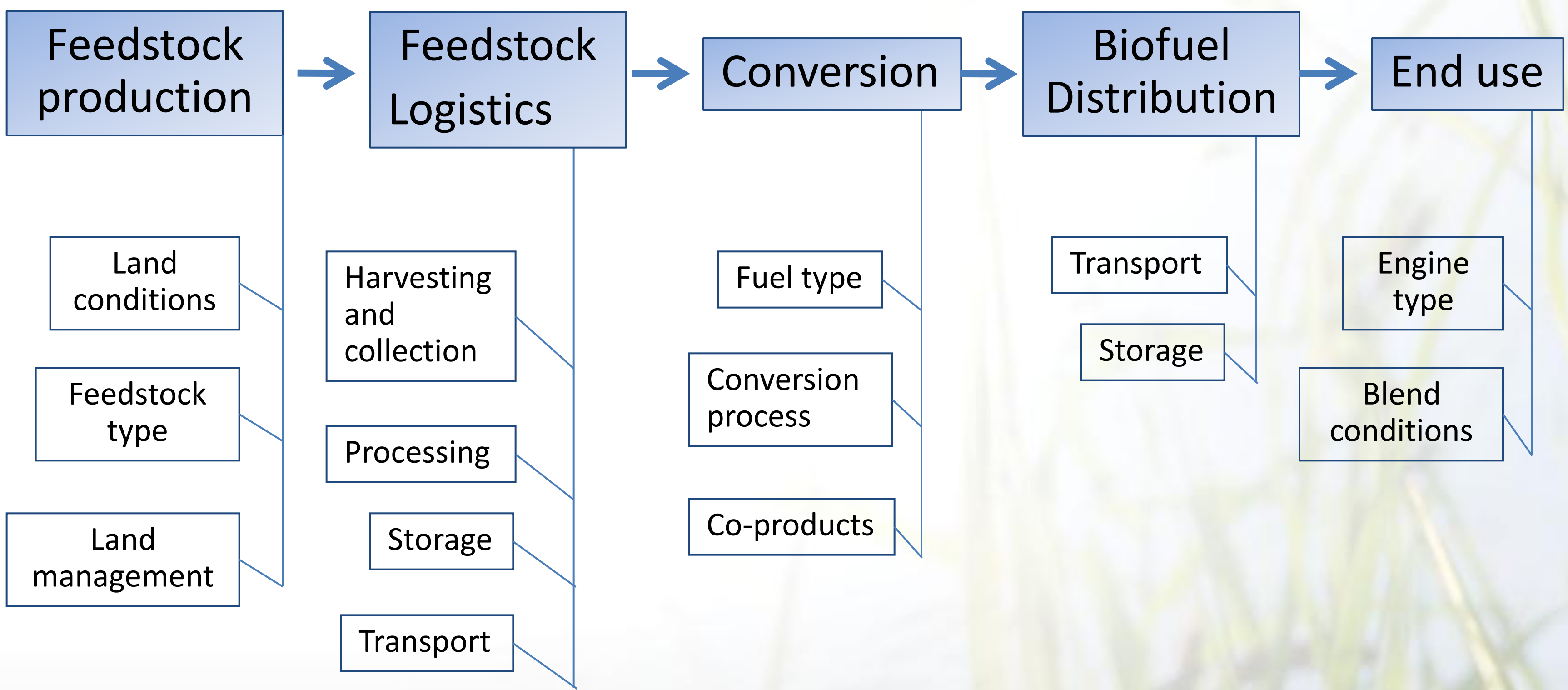
Indicators Should Be

- Technically effective
  - Are sensitive to stresses on system
  - Respond to stress in a predictable manner
  - Are anticipatory: signify an impending change in the ecological system
  - Have a known response to natural disturbances, anthropogenic stresses, and changes over time
  - Have known variability in response
  - Are integrative

- Practically useful
  - Are easily measured
  - Predict changes that can be averted by management actions
  - Consider spatial and temporal context of measure
  - Are broadly applicable across the system of interest and to other systems

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

Sustainability Indicators for Biofuels Should Apply to Entire Supply Chain



Many Groups Involved with Indicators for Bioenergy Sustainability

- GBEP (Global Bioenergy Partnership)
- RSB (Roundtable on Sustainable Biofuels)
- CSBP (U.S. Council on Sustainable Biomass Production)
- Specific industries (soy, sugar, palm oil)
- International Standards Organization (ISO)

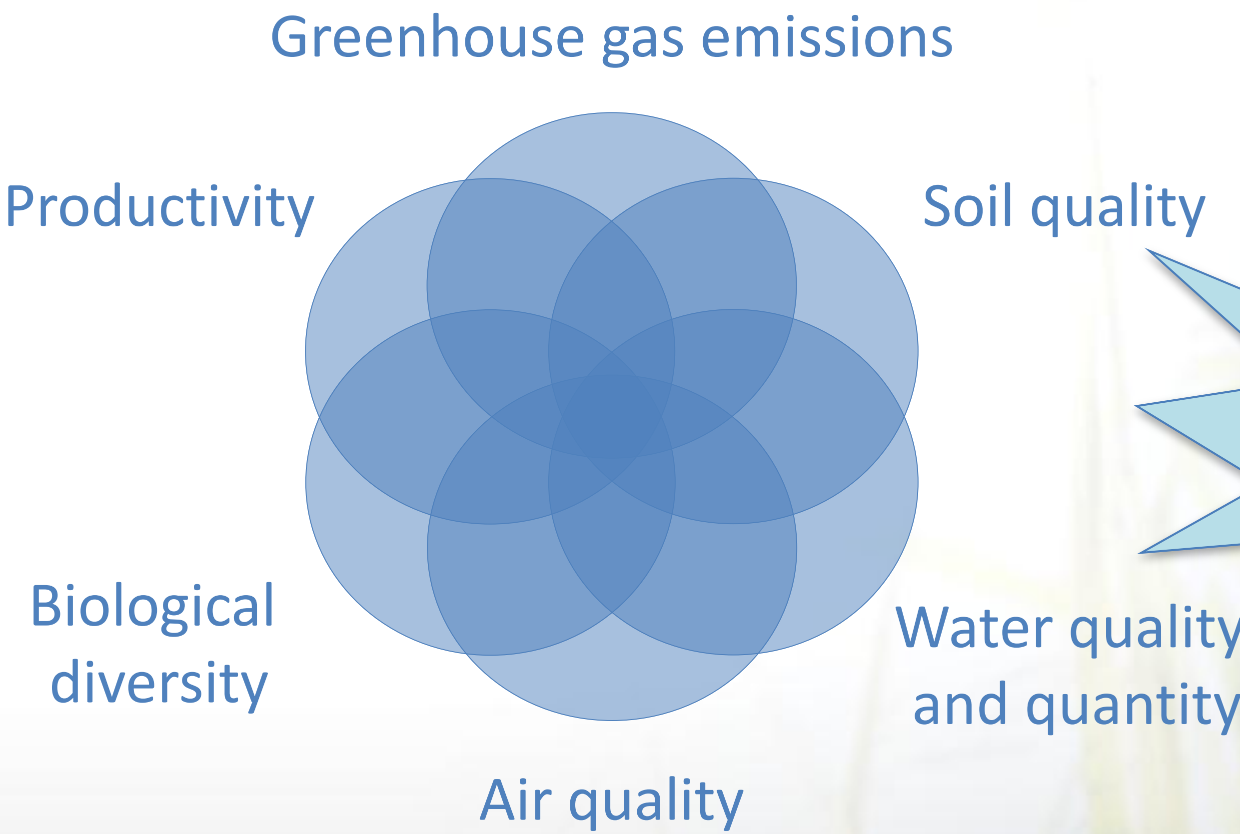
- Efforts often focus on management practices, but knowledge is evolving on effects and interactions of practices over time (scale is always important)
- Some indicator suites can be too complicated and/or too demanding for practical implementation.

Process for Indicator Selection

- Be clear about goals when selecting indicators
- Caveats
  - Measure what is measurable today
    - Effects of greatest interest
    - Interpret indicators in light of
      - How they change over time and space
      - How other factors change over time and space
      - Full suite of socioeconomic and environmental metrics
  - Analysis and verification
  - Refocus on measures most closely related to effects of interest

Einstein: "Not everything that can be counted counts, and not everything than can be counted should be counted."

Ecological Indicators of Bioenergy Feedstock Sustainability



Cross-cutting issues:
Land-use change,
Ecosystem services,
GMOs

Soil Quality

Indicators

- **Total organic carbon (Mg/ha)**
- **Total nitrogen (Mg/ha)**
- **Extractable phosphorus (Mg/ha)**
- **Bulk density (g/cm^3)**

Related environmental concerns

- Carbon balance
- Nutrient availability and mineralization
- Cation exchange capacity
- Humification
- Eutrophication potential
- Infiltration
- Water holding capacity

Key contextual variables

- Soil type and past disturbance/use

Water Quality and Quantity

Indicators

- **Nitrate concentration (mg/L)**
- **Total P (mg/L)**
- **Suspended sediment (mg/L)**
- **Herbicides (mg/L)**
- **Base flow (L/s)**
- **Peak storm flow (L/s)**
- **Consumptive water use (m^3/ha/day for production, m^3/day for processing)**

Related environmental concerns

- Eutrophication
- Potability
- Habitat degradation
- Erosion
- Water availability

Key contextual variable

- Precipitation

Greenhouse Gas Emissions

Indicator

- **Net carbon equivalent emissions or sequestration (kgC_{eq})**
  - **CO_2: calculated using life-cycle analysis**
  - **N_2O: estimated using process or statistical models**

Sources and sinks

- C: Net change (stocks)
- CO_2: Fossil fuel use
  - Manufacture & transport of agricultural inputs
  - On-site agricultural operations
  - Processing and conversion
  - Transportation
- N_2O: Nitrification and denitrification in soil
- N_2O: Fertilizer production
- Methane is context-specific but typically less important than N_2O or CO_2

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Biological Diversity

Indicators

- **Presence of taxa of special concern**
- **Habitat area of taxa of special concern (ha)**

Examples of taxa of special concern

- Rare species
- Keystone species
- Taxa likely to be affected by bioenergy systems
  - Arthropods
  - Birds
  - Small mammals
  - Ground flora
  - Aquatic organisms

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Air Quality

Indicators

- **Tropospheric ozone (ppb)**
- **Carbon monoxide (ppm)**
- **Particulate matter less than 2.5µm diameter ($PM_{2.5}$; µg/m^3)**
- **Particulate matter less than 10µm diameter (PM_{10} ; µg/m3)**

Related environmental concerns

- Health
- Visibility
- Plant productivity

Ozone and secondary $PM_{2.5}$, formed from precursors, must be modeled (e.g., CMAQ calibrated to local conditions).

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Productivity

Indicator

- **Aboveground net primary productivity (gC/m^2/yr)**

- Allows comparison between natural and production land
- Can be measured using conventional ecological techniques, or using yield as proxy
- Management-related contextual variables particularly important

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

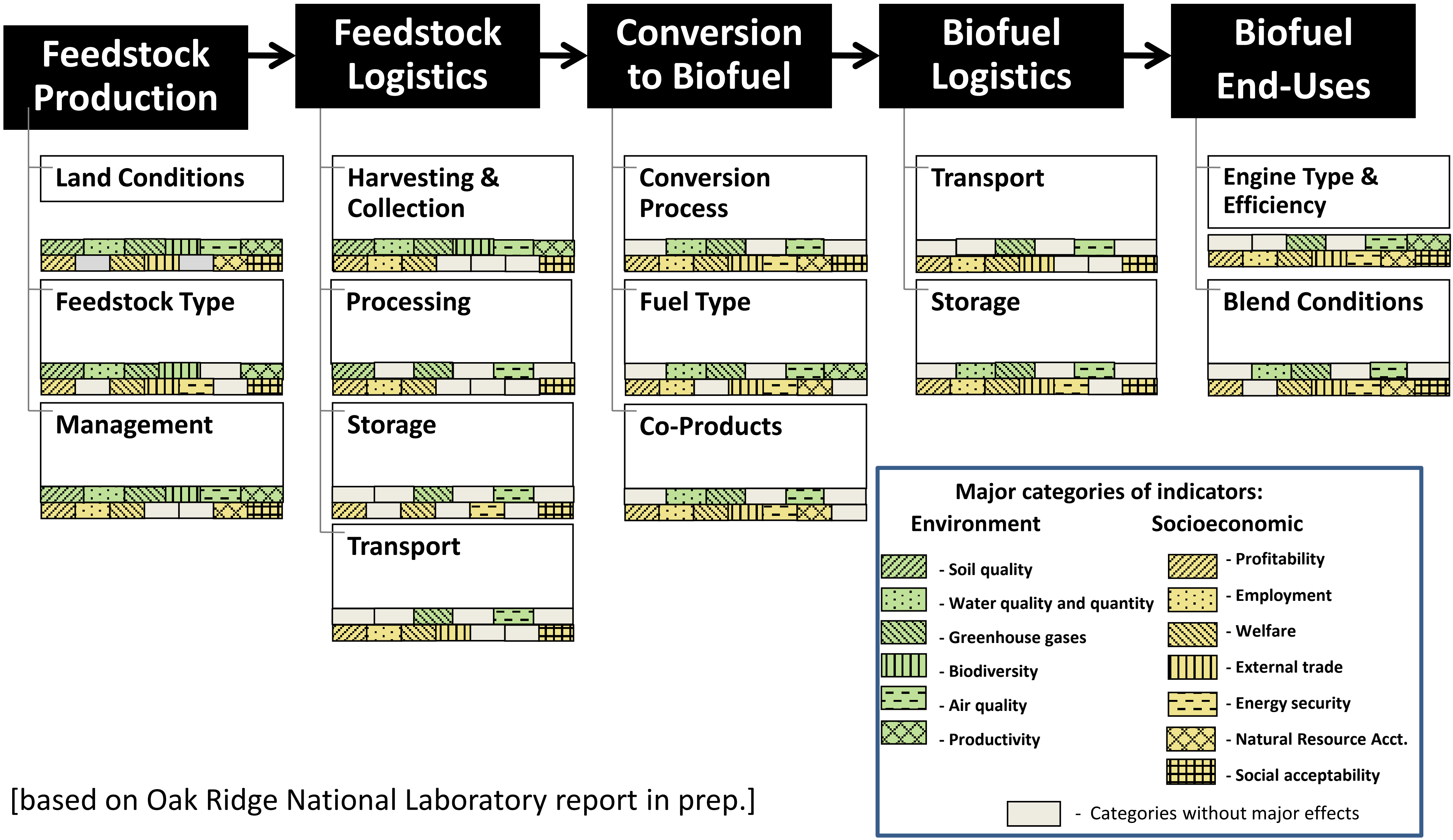
Environment	Indicator	Units
Greenhouse gases	12. CO_2 equivalent emissions (CO_2 and N_2O)	kgC_{eq}/GJ
Biodiversity	13. Presence of taxa of special concern	Presence
	14. Habitat area of taxa of special concern	ha
Air quality	15. Tropospheric ozone	ppb
	16. Carbon monoxide	ppm
	17. Total particulate matter 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, 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. Indicators to support environmental sustainability of bioenergy systems. *Ecological Indicators* 11(5) 1277-1289.

Social and Economic Indicators

- Holistic approach: a basic suite of indicators is proposed to provide focus and comparable data collection and analysis
- Next Step: Identify socioeconomic indicators of sustainability

Depiction of Where Categories of Sustainability Indicators Experience Major Effects within the Biofuel Supply Chain



[based on Oak Ridge National Laboratory report in prep.]

U.S. Biomass Potential Updates July 2011:

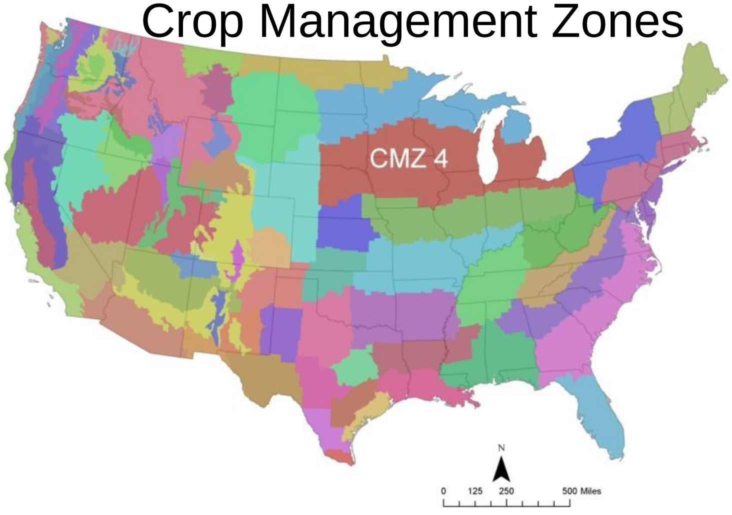
ORNL-led draft report externally reviewed by:

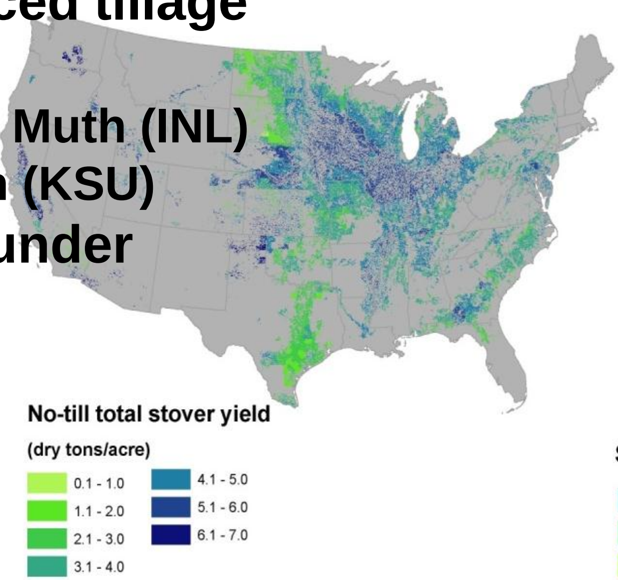
- 3 USDA
- 4 university
- 2 national institute/council
- 2 international

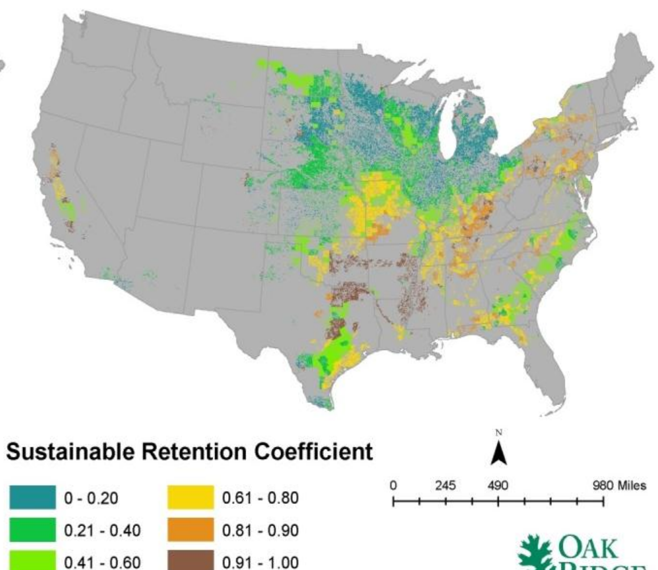
2005 BTS	2011 Update
National estimates – no spatial information	County-level with aggregation to state, regional and national levels
No cost analyses – just quantities	Supply curves by feedstock by county – farmgate/forest landing
Crop residue removal sustainability addressed from national perspective; erosion only	Crop residue removal sustainability modeled at soil – scale; erosion & soil C
No explicit land use change modeling	Land use change modeled for energy crops
Long-term, inexact time horizon (2005; ~2025 & 2040)	2010 – 2030 timeline (annual)
2005 USDA agricultural baseline and 2000 forestry RPA/TPO	2010 USDA agricultural baseline 2010 FIA inventory and 2007 forestry RPA/TPO
Erosion constraints to forest residue collection	Greater erosion plus wetness constraints to forest residue collection

BT Update Ag-Crop Residue Collection Assumptions

- **Yields and acres planted and harvested (baseline forecast)**
- **Stover to grain ratio**
- **Tillage (conventional, reduced, no-till) and rotations**
- **<u>Sustainability</u> - residue retention coefficients estimated for erosion and soil carbon with separate coefficients for reduced tillage and no-till**
  - **Developed by Dave Muth (INL) and Richard Nelson (KSU)**
- **No residue removal under conventional till**
- **Collection efficiency**

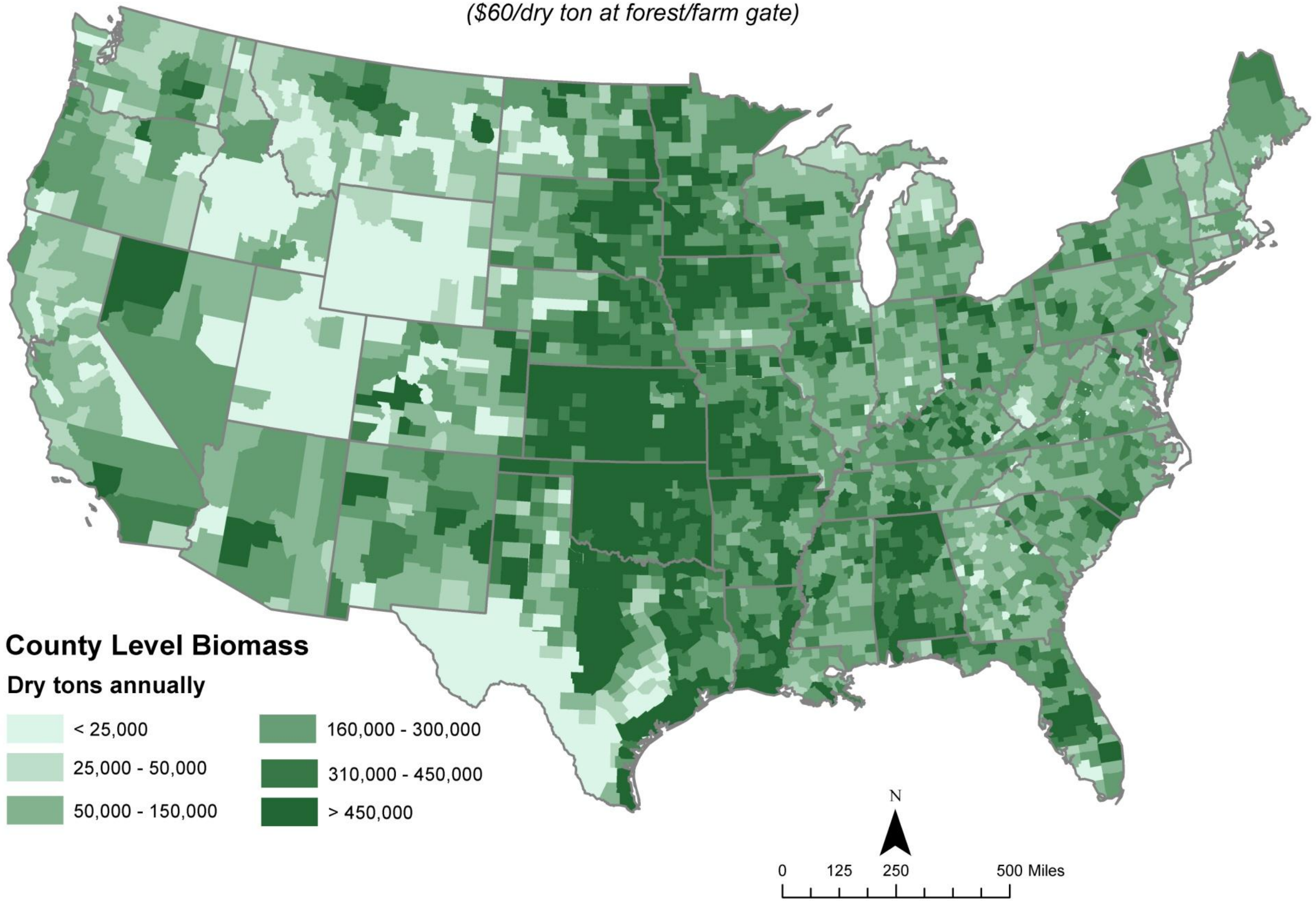






Total Potential Resources, 2030

($60/dry ton at forest/farm gate)



Consider integrated systems and indicators that help identify opportunities to add value

Thank you!

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Additional information:

- "Billion-Ton Update" http://www.bioenergykdf.net
- ORNL Center for Bioenergy Sustainability: http://www.ornl.gov/sci/besd/cbes/
- DOE Biomass and Biofuels Program: www.eere.energy.gov/biomass/
- DOE Office of Science, Bioenergy Research Centers: http://genomicsgtl.energy.gov/centers/
- Alternative Fuels Data Center - http://www.eere.energy.gov/afdc/fuels/ethanol.html
- Bioenergy Feedstock Information Network: http://bioenergy.ornl.gov/
- Biomass R&D Initiative: www.biomass.govtools.us

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Supplemental slides

Biomass Location for Optimal Sustainability Model (BLOSM) http://blosm.ornl.gov

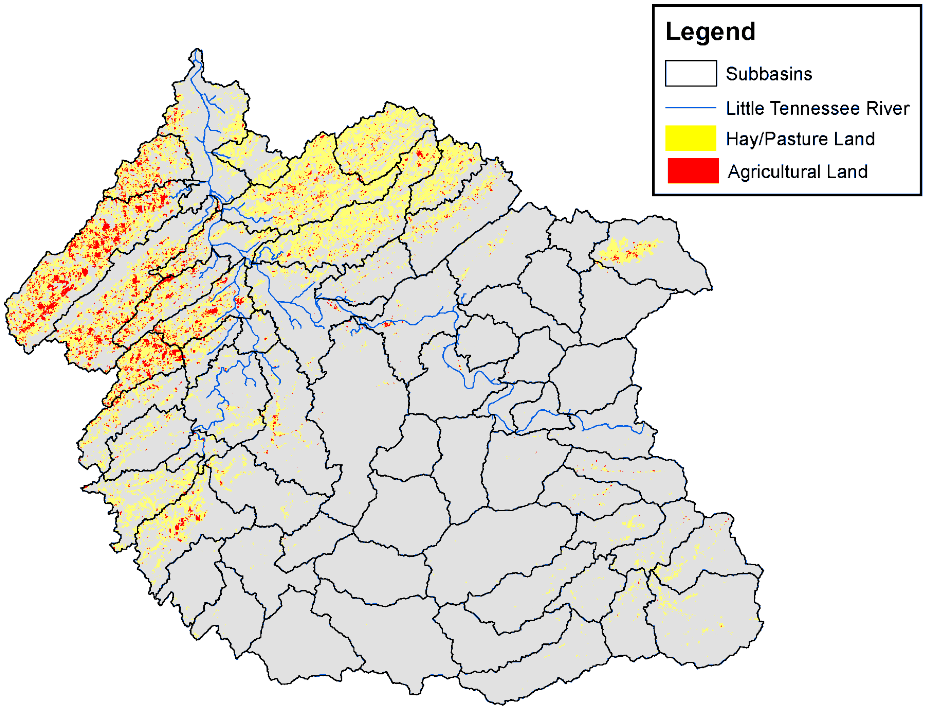
- A spatial optimization model that identifies where to locate plantings of bioenergy crops in a particular region given feedstock goals

- Considers farmer's profit and environmental constraints
  - Profit estimates by county and subbasin are derived from Policy Analysis System (POLYSYS)
  - Crop yields are from a national grid of switchgrass yield potential based on yield observations from 39 field trials conducted across the US (Jager et al. 2010)
  - Estimates of effects on water quality and quantity are developed by Soil and Water Assessment Tool (SWAT) as parameterized for switchgrass

- The long-term goal is to have BLOSM be a tool for simultaneous environmental and economic analysis and policy research that helps users understand the interaction between multiple aspects of sustainability

Current use and projected conversion under the "Balanced" scenario

Existing Agricultural and Hay/Pasture lands in the Lower Little Tennessee watershed



Locations of switchgrass plantings recommended by BLOSM's 'Balanced' Scenario

Currently there are 13,683 acres of agricultural land and 84,265 acres of hay/pasture land in this watershed.

The total land area recommended for switchgrass is 1.3% of the total watershed area (8,527acres out of 674,000 acres).

Key Definitions

- **Indicator** is a measure of performance
  - Purpose influences the choice of indicators (from Cairns *et al.* 1993).
    - To assess the condition of the environment
    - To monitor trends in condition over time.
    - To provide an early warning signal of changes in the environment
    - To diagnose the cause of an environmental problem.
  - Tradeoffs between desirable features, costs, and feasibility often determine the choice of indicators.

Testing the Indicator Suite

- Indicators should be tested in a variety of systems
- Testing is essential for next steps
  - Evaluate utility
  - Measure variability
  - Establish protocols
  - Establish targets
  - Revise suite of indicators
  - Assign relative weights…
- Context-specific knowledge