Indicators to Support Environmental Sustainability of Bioenergy

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

"Nem tudo o que pode ser contado conta, e nem tudo que pode ser contado deve ser contado."

William Bruce Cameron

US Department of Energy

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Sustainability

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

15 regional & local studies in the Brazilian Amazon suggest deforestation results from :

- Regional economic opportunities
- Transportation infrastructure
- Political & social forces
- Environmental & social conditions

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Sustainability

Farmer in Rondônia, Brazil

Modeling (validated by farmer interviews) suggest that sustainability exists when farmers use

- A diversity of perennial crops
- No burning

and lead to

- Greater carbon storage
- Less deforestation
- Greater habitat diversity
- Farmers remaining on land > 10yrs

Dale et al. 1994. Modeling effects of land management in the Brazilian settlement of Rondônia. *Conservation Biology* 8:196-206.

Sustainability Indicators

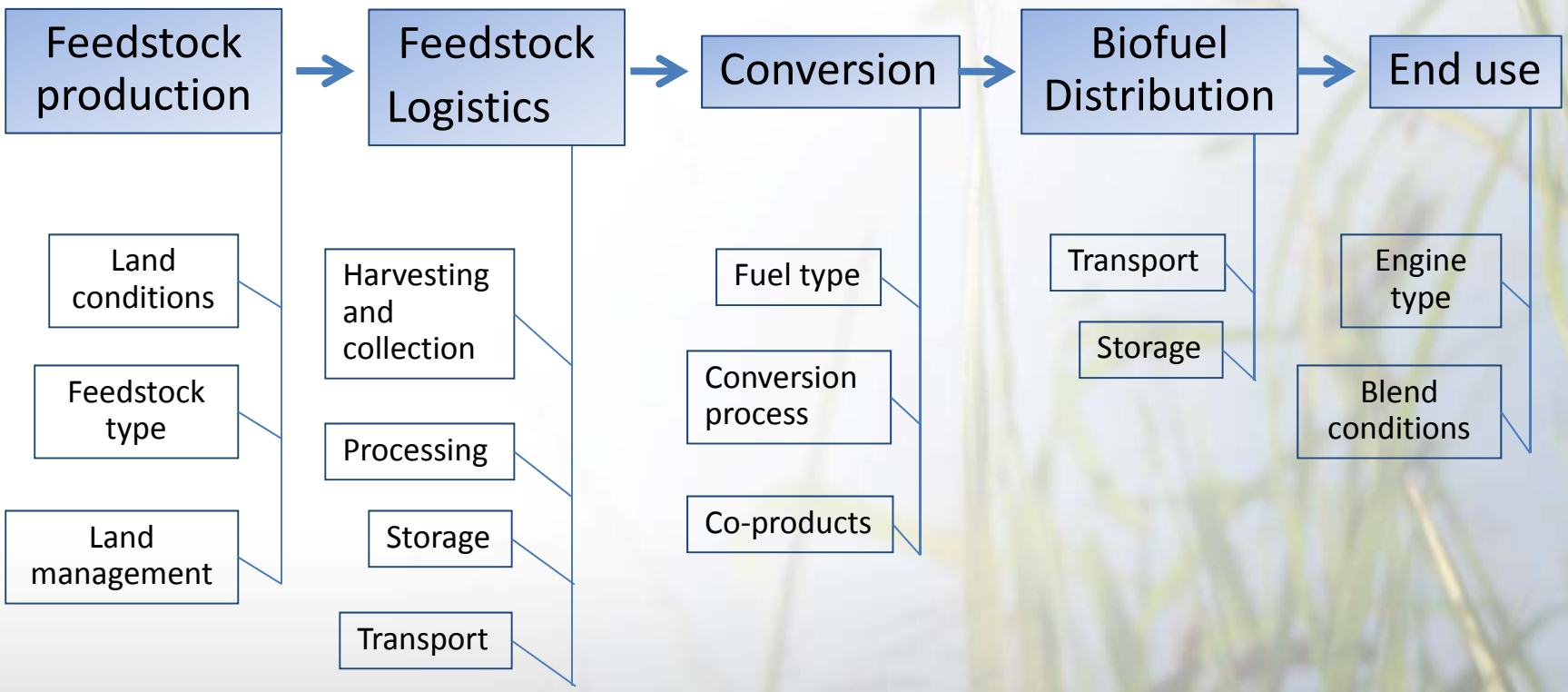
Any measurable quantity that provides information about long-term impacts of human activities on the environment, society, or economy.

They should be

- Useful
  - Policymakers
  - Agronomists
  - 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.

Set of Indicators Should Apply to Entire Supply Chain



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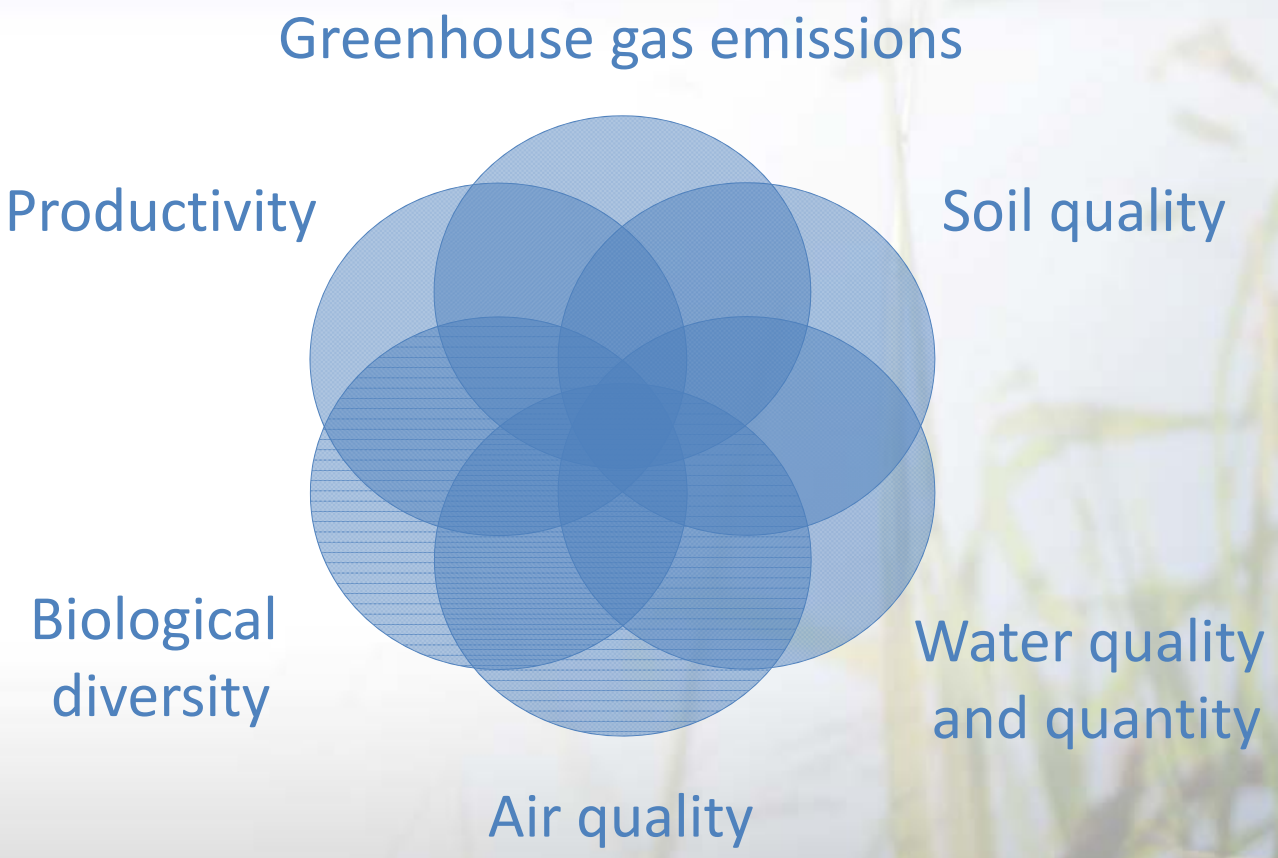
Many Groups Working to Develop Indicators for Bioenergy Sustainability

- Some examples
  - GBEP (Global Bioenergy Partnership)
  - RSB (Roundtable on Sustainable Biofuels)
  - CSBP (Council on Sustainable Biomass Production)

- Concerns
  - Too many indicators
  - Measures that are too broad for practical implementation

Environmental Indicators of Bioenergy Feedstock Sustainability



McBride et al. 2011. Indicators to support environmental sustainability of bioenergy systems. *Ecological Indicators* 11(5) 1277-1289.

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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 variable

- Soil type

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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}/GJ)
  - CO_2: calculated using life cycle analysis (e.g., GREET)
  - N_2O: estimated using process or statistical models (e.g., DAYCENT)

Sources and sinks

- CO_2: Changes in 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 typically less important than N_2O or CO_2.

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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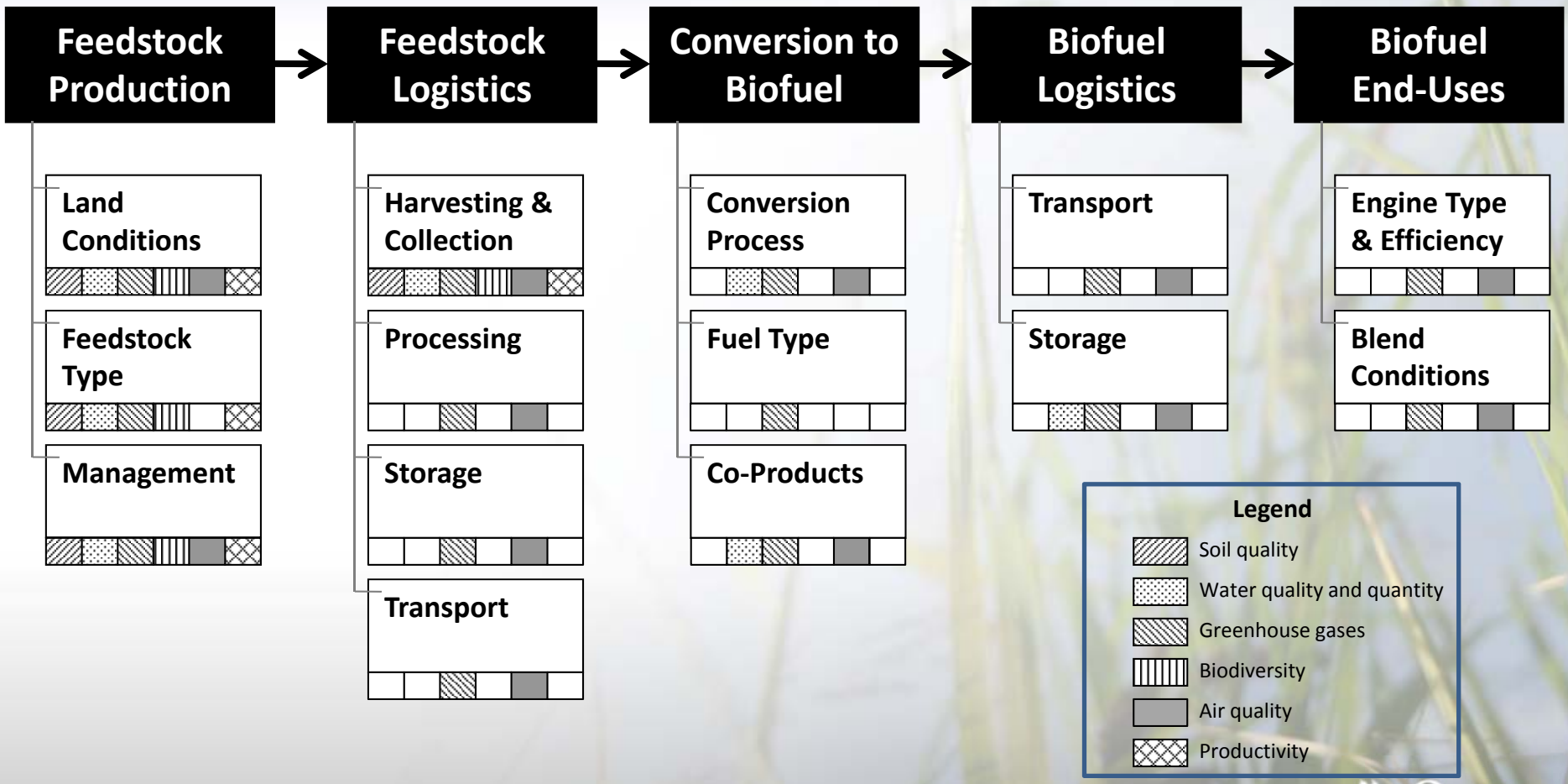
Productivity

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

Contexts for Environmental Indicators of Sustainability in the Biofuel Supply chain



Efroymson et al. In review. Environmental indicators of biofuel sustainability: What about context?

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Considering socioeconomic sustainability requires assuming several conditions exist

- Effective governance
- Legal and regulatory protection
- Acceptable levels of welfare (food, health, safety)

Socioeconomic Indicators

- Profitability
- Employment
- Welfare
- External trade
- Energy security
- Natural resource accounting
- Social acceptability

ORNL report. In progress. Indicators to support socioeconomic sustainability of bioenergy systems.

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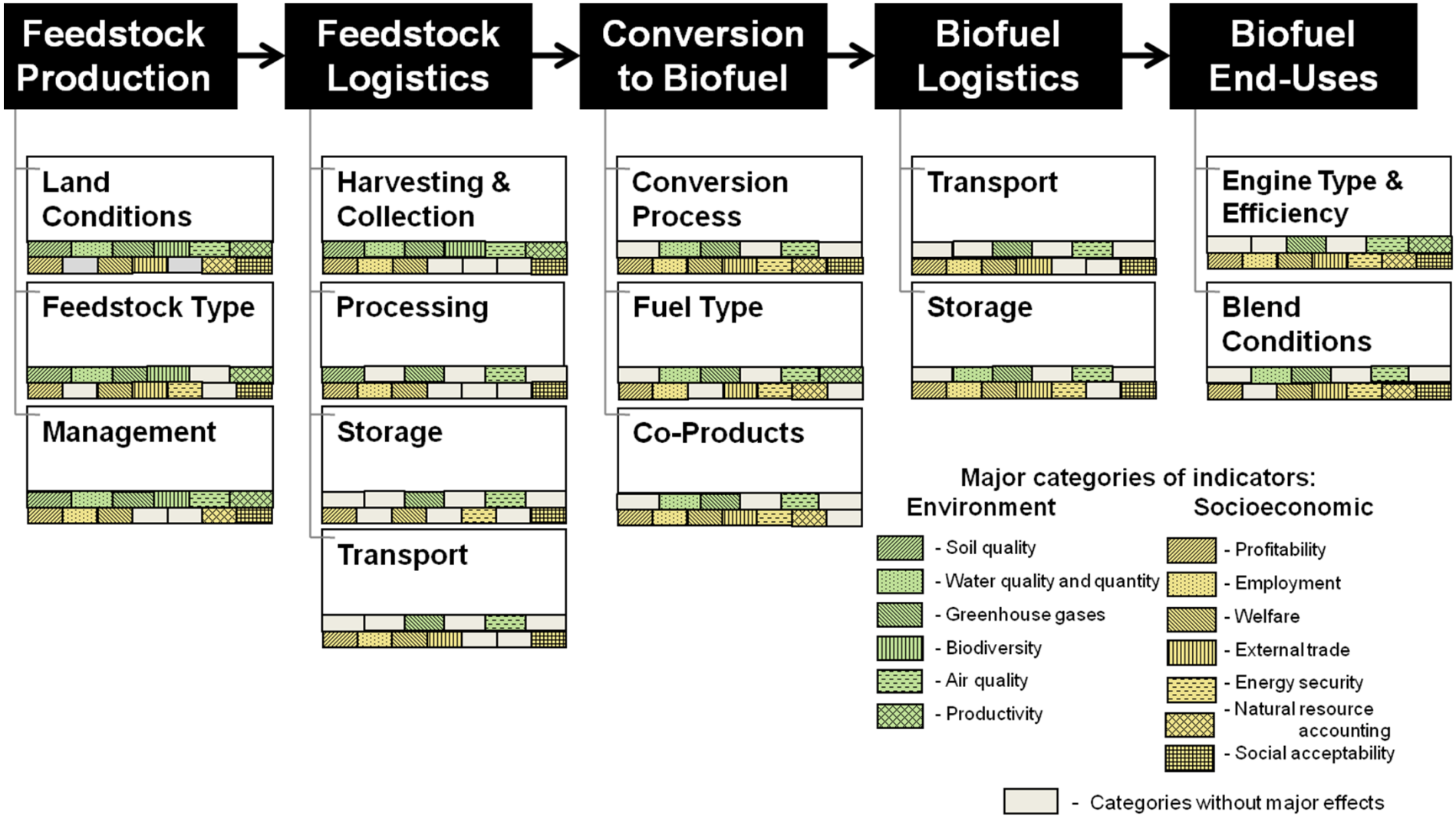
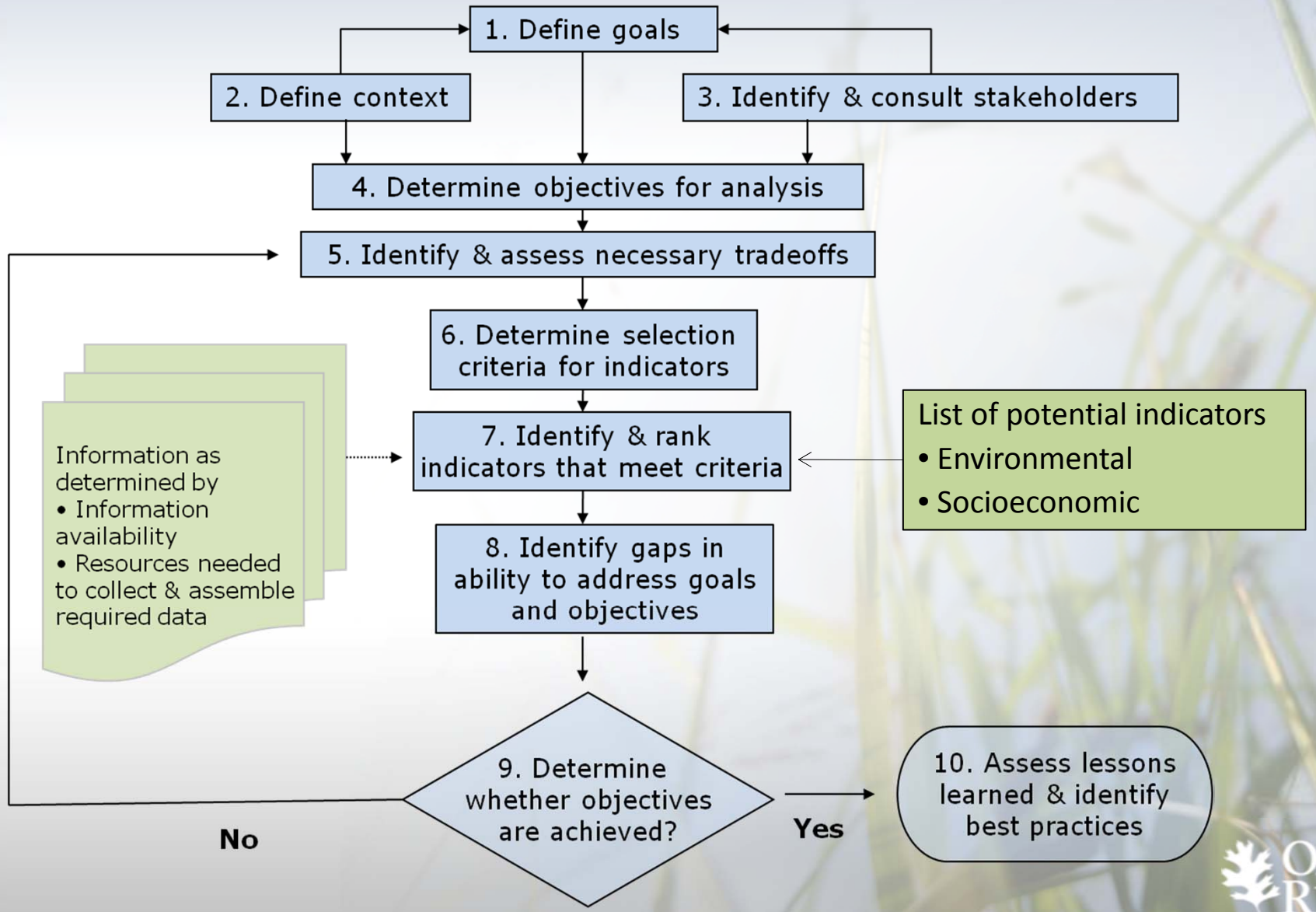
Where Categories of Sustainability Indicators Are Affected within the Supply Chain



Adapting Indicator Set to a Particular Context

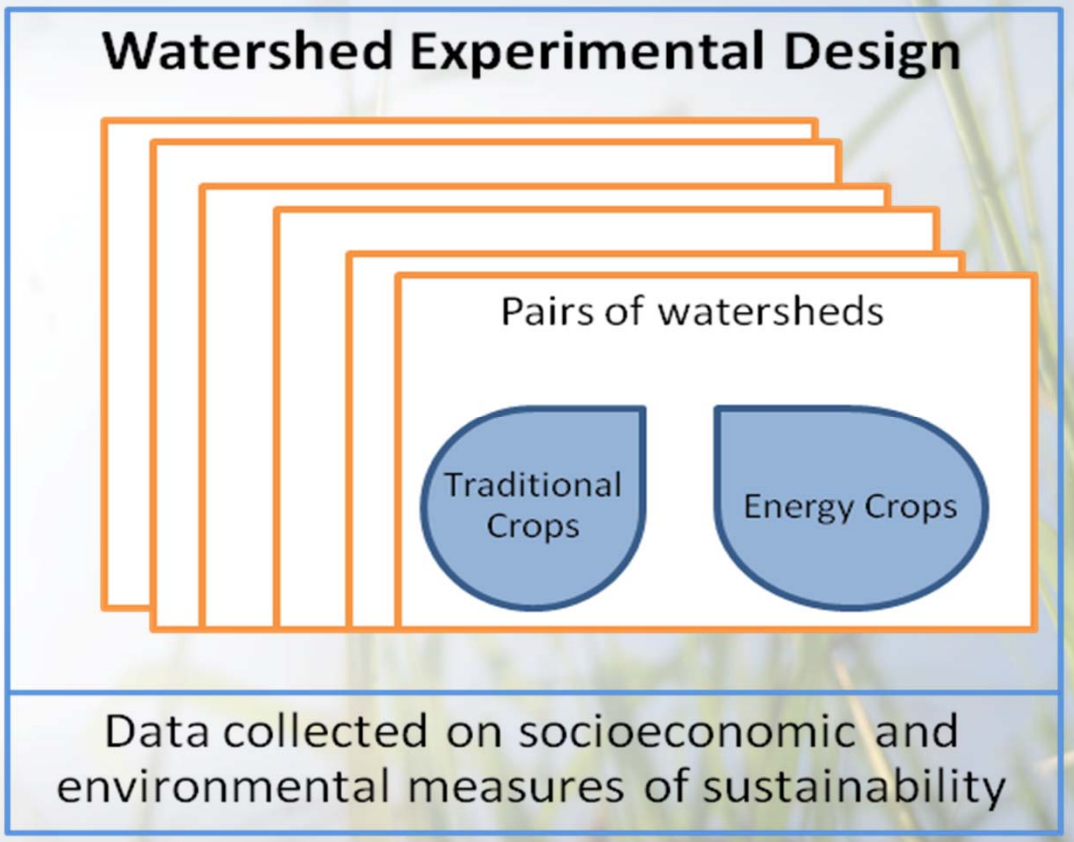
- Indicator set is a starting point for sake of efficiency and standardization
  - Particular systems may require addition of other indicators
  - Budget may require subtraction of some indicators
  - Some indicators more important for different supply chain steps
- Protocols must be context-specific

Framework for Selecting Indicators



Testing the Indicator Suite

- Indicators should be tested in a variety of systems
- Context-specific knowledge
- Paired watershed experiments are ideal



Using an Optimization Model to Identify "Ideal" Sustainability Conditions

Spatial optimization model identifies where to locate plantings of bioenergy crops given feedstock goals

- Considers farmer's profit
- Water quality constraints

Vonore Pilot-Scale Biorefinery

http://blosm.ornl.gov

Parish et al. In review. Multimetric spatial optimization of bioenergy crops across a watershed. *Biofuels, Bioprod. Bioref*.

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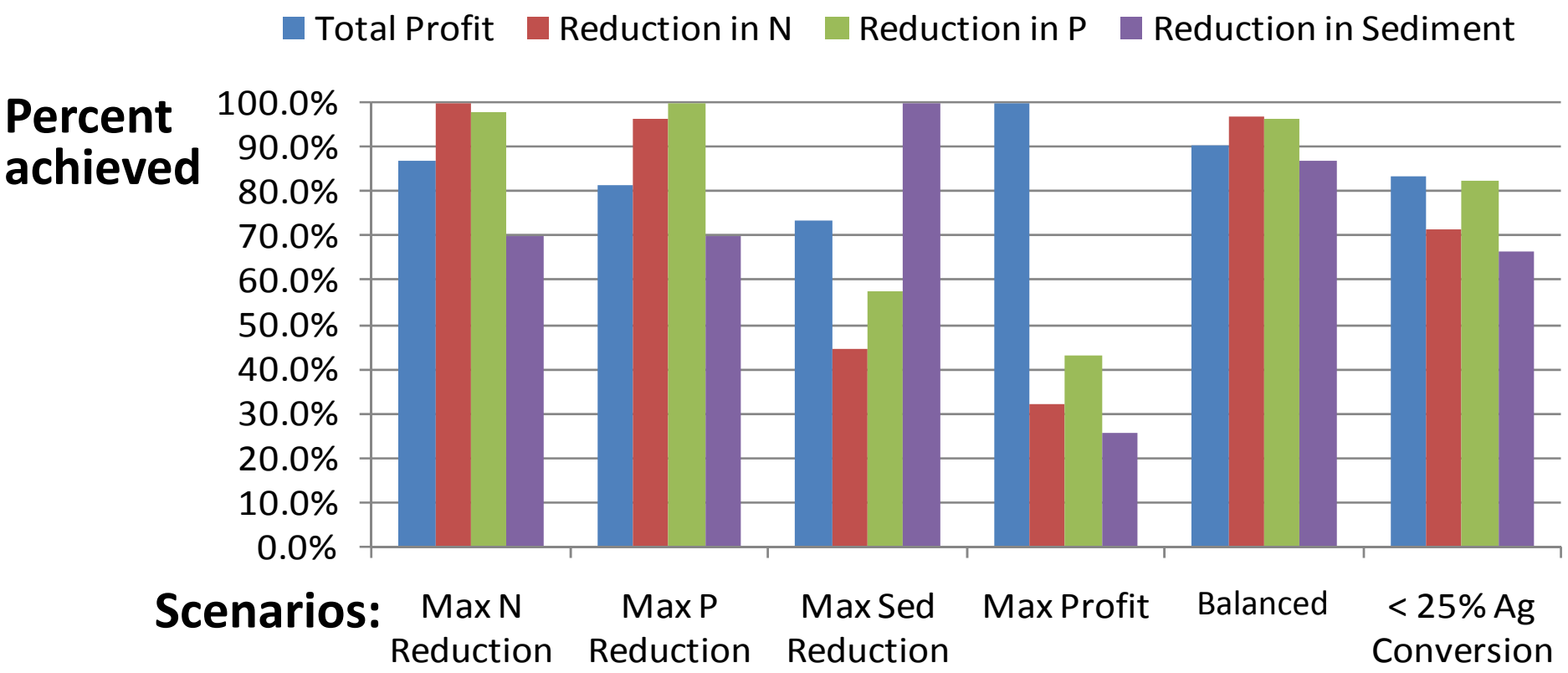
Projections of Potential Achievable

Water quality objectives:



	Max N Reduction	Max P Reduction	Max Sed Reduction	Max Profit	Balanced	< 25% Ag Conversion
% Ag land converted:	58	51	44	27	60	25

The total land area recommended for switchgrass is 1.3% of the total watershed area (out of 272,750 ha).

Landscape Perspective

Consider indicators within entire system (interactions and feedbacks) as an opportunity to design landscapes that add value.

CBES

Center for BioEnergy Sustainability

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