



CBES

Center for BioEnergy
Sustainability

Indicators to Support Sustainability of Bioenergy Systems

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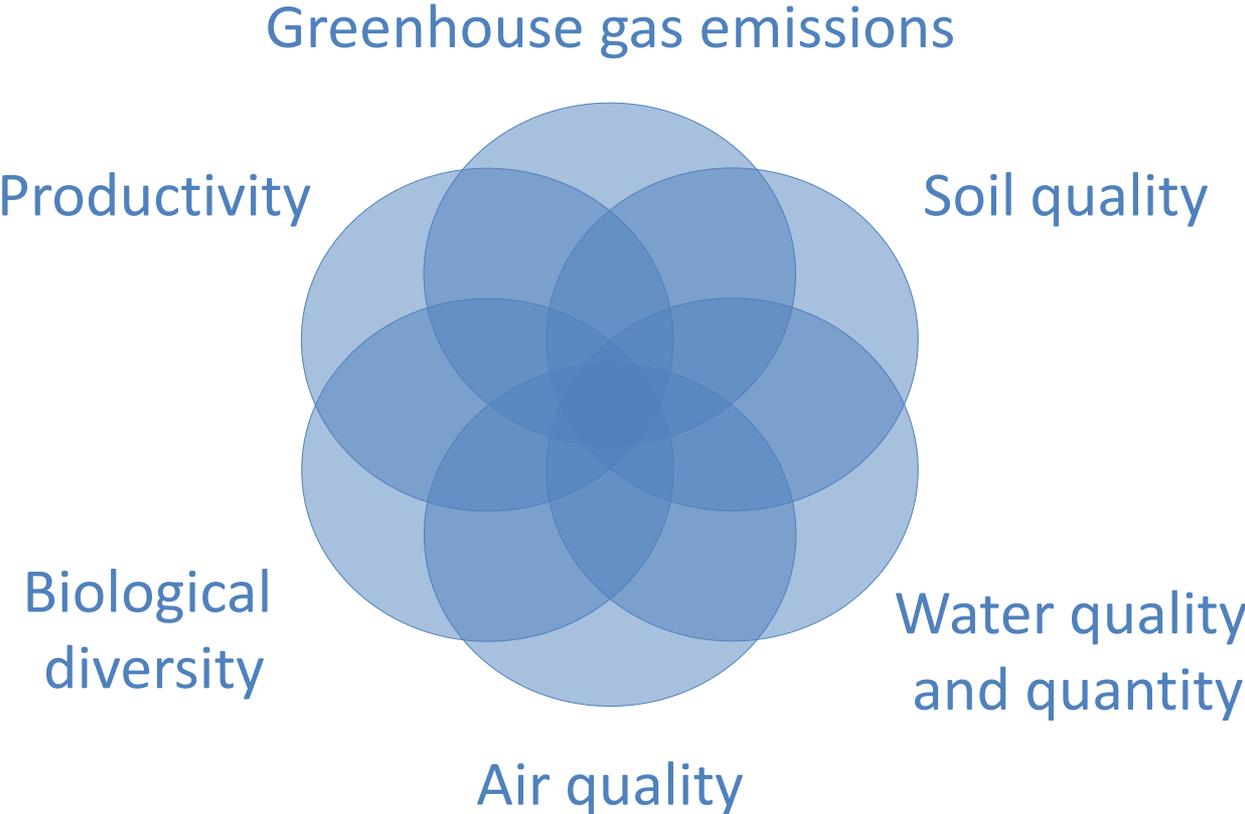
Center for BioEnergy Sustainability
Oak Ridge National Laboratory

Based on:

Virginia H. Dale, Mark E. Downing, Laurence M. Eaton, Rebecca A. Efroymson, Michael R. Hilliard, Keith L. Kline, Matthew H. Langholtz, Paul N. Leiby, Gbadebo A. Oladosu, Maggie R. Stevens (order TBD). In preparation. Indicators to support socioeconomic sustainability of bioenergy systems.

Allen C. McBride, Virginia H. Dale, Latha M. Baskaran, Mark E. Downing, Laurence M. Eaton, Rebecca A. Efroymson, Charles T. Garten Jr., Keith L. Kline, Henriette I. Jager, Patrick J. Mulholland, Esther S. Parish, Peter E. Schweizer, and John M. Storey. 2011. Indicators to Support Environmental Sustainability of Bioenergy Systems. *Ecological Indicators* 11(5):1277-1289.

Categories of Indicators of Environmental Sustainability



Sustainability

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



Sustainability Indicators

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

Should be:

- Useful to various stakeholders
- Technically effective
- Practical



Many Groups Working to Develop Indicators for Bioenergy Sustainability

- Examples
 - GBEP (Global Bioenergy Partnership)
 - BRDi (Biomass Research & Development)
 - RSB (Roundtable on Sustainable Biofuels)
 - CSBP (Council on Sustainable Biomass Production)
- Differences
 - Number of indicators
 - Broadness of indicators
 - Management practices vs. effects



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

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 (m³/ha/day for production, m³/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 ($\text{kgC}_{\text{eq}}/\text{GJ}$)
 - 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



Air Quality

Indicators

- Tropospheric ozone (ppb)
- Carbon monoxide (ppm)
- Particulate matter less than 2.5 μm diameter ($\text{PM}_{2.5}$; $\mu\text{g}/\text{m}^3$)
- Particulate matter less than 10 μm diameter (PM_{10} ; $\mu\text{g}/\text{m}^3$)



Related environmental concerns

- Health
- Visibility
- Plant productivity

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

Productivity

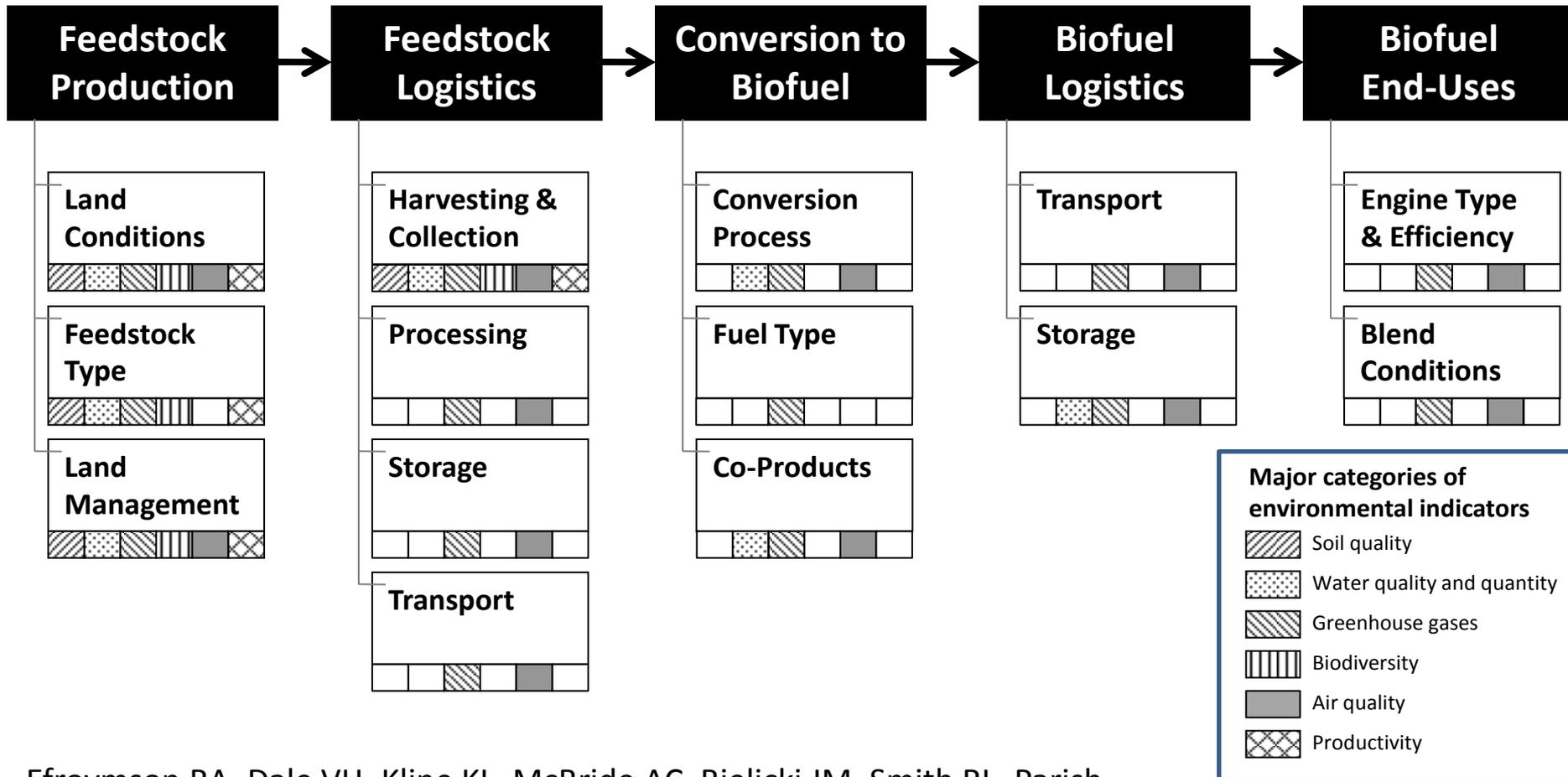
Indicator

- Aboveground net primary productivity (gC/m²/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

Indicators Across the Biofuel Supply Chain



Efroymson RA, Dale VH, Kline KL, McBride AC, Bielicki JM, Smith RL, Parish ES, Schweizer PE, Shaw DM. In review. Environmental indicators of biofuel sustainability: What about context?

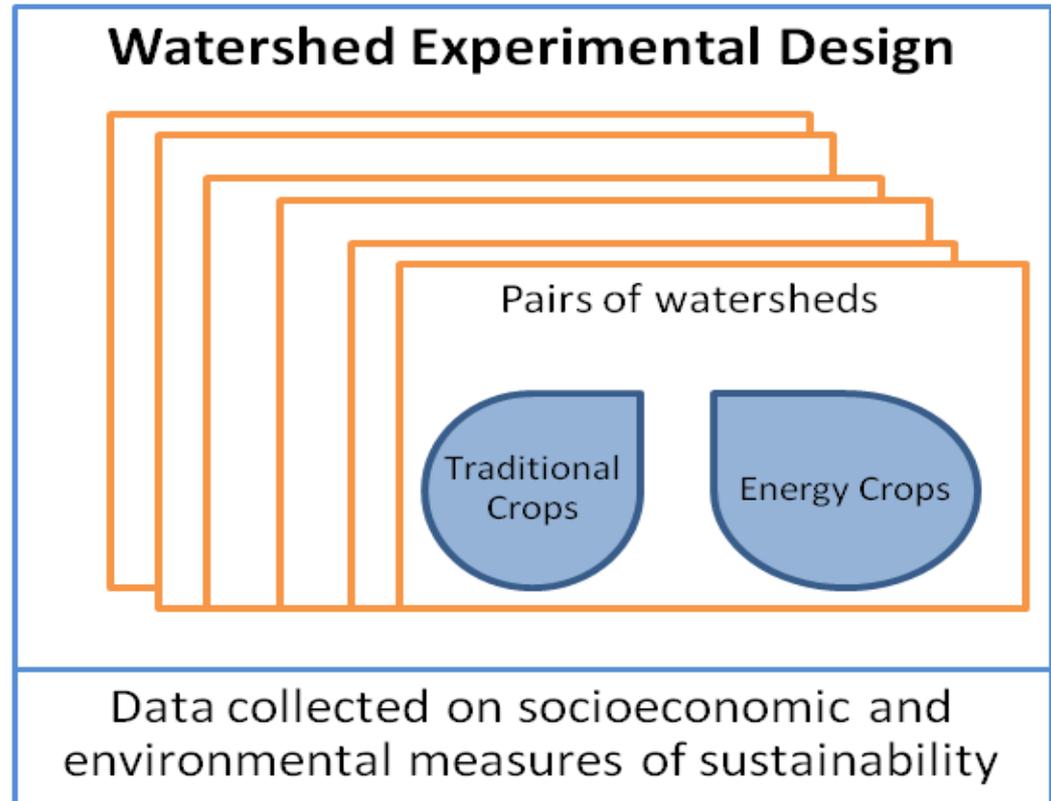
Adapting Suite to Particular Contexts

- 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



Testing the Indicator Suite

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

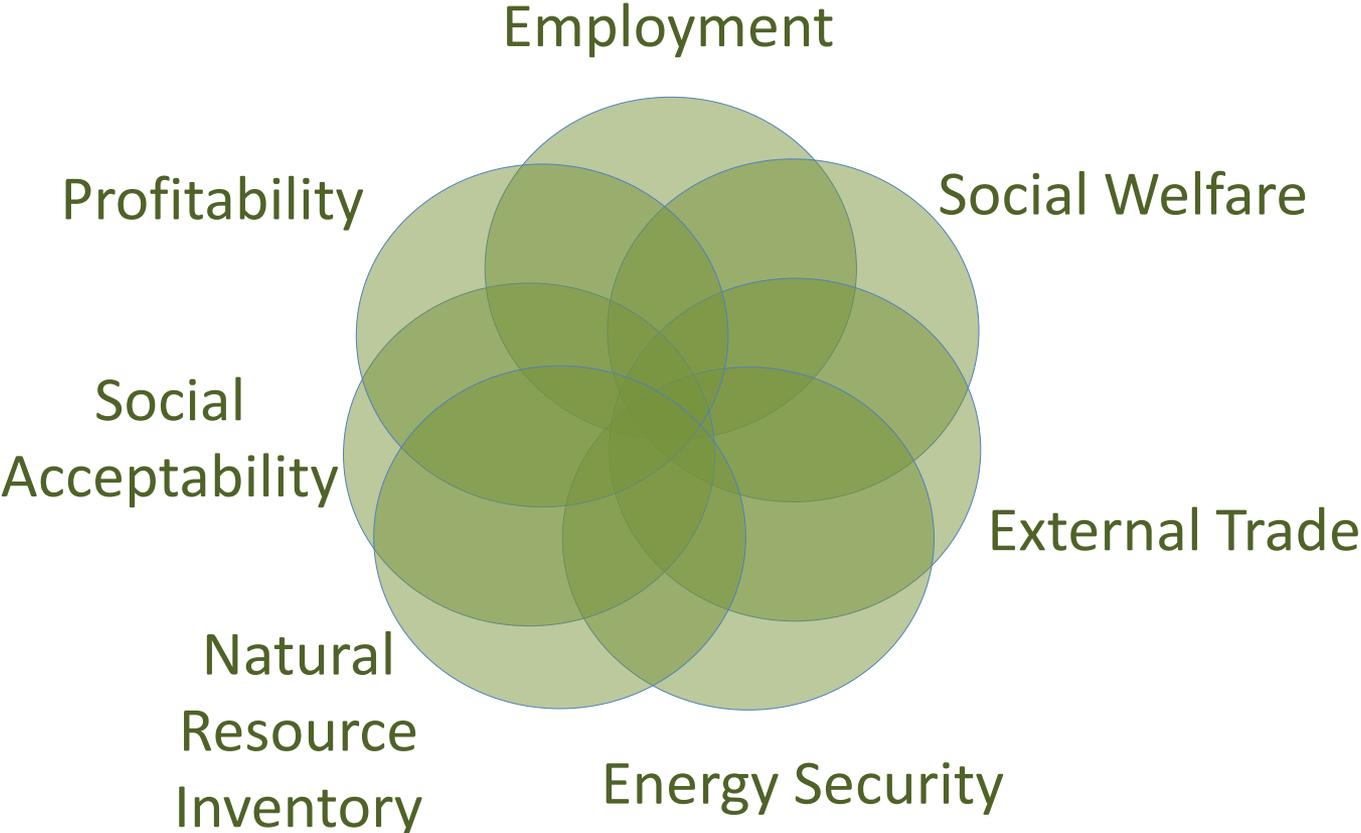


Landscape Perspective

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



Categories of Indicators of Socio-Economic Sustainability



Profitability and Employment

Indicators

- Return on investment (%)
- Industry/segment earnings
 - (\$/year)
- Employment
 - (full-time jobs, by region)
- Investment risk
 - (fixed costs, payback period, B/C)

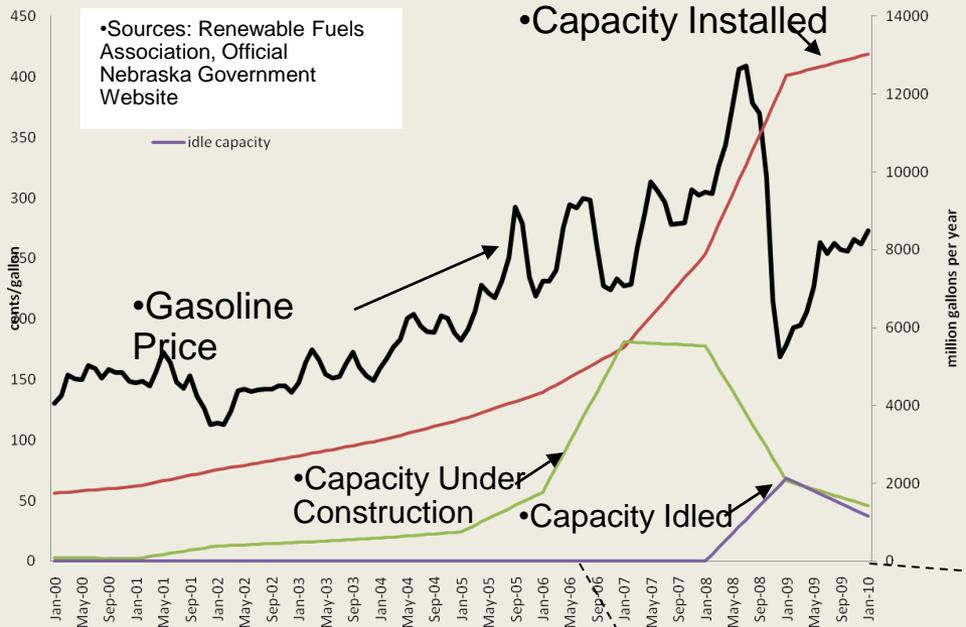


Related concerns

- Economic competitiveness
- Economic sustainability:
 - Business growth vs. failures
- Jobs for Rural workers and communities



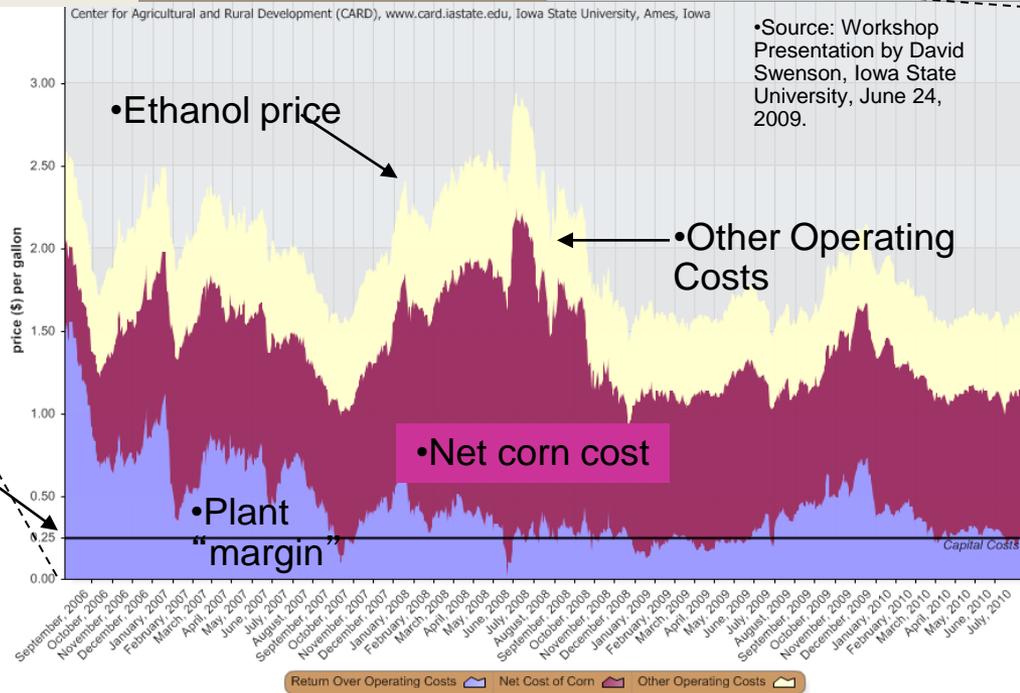
U.S. Grain Ethanol Capacity vs. Gasoline Price



Example: Market Volatility Has Been Very Challenging to the Developing Biofuels Industry

•Ethanol Plant Operating Margins Volatile, and Have Collapsed to Near Minimum Sustainable

•Line indicates minimum sustainable returns (“margin”) to Ethanol Production Plant. Actual returns highly variable.



Social Welfare; External Trade; Natural Resource Inventories

Indicators (examples)

Social Welfare

- Household income
- Days lost to injury, health
- Food security
 - (% income for food)

External Trade

- Terms of Trade
 - (Export price/Import price)
- Trade volume, balance
 - (net exports)
- Trade patterns
 - (diversification index)

Natural Resource Inventories

- Stock of resources, e.g.
 - Water (by type)
 - Land (by type)
 - Non-renewable energy
- Measures of resource intensity
 - (productivity per acre, per gallon)

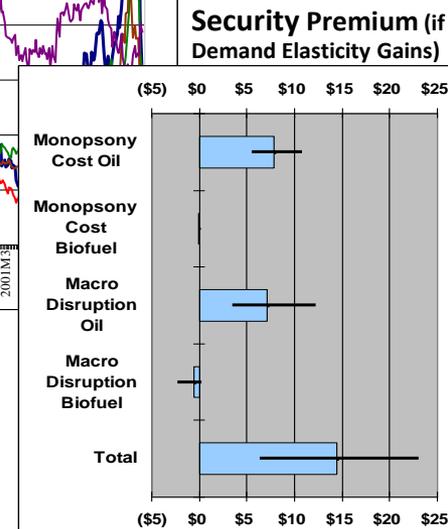
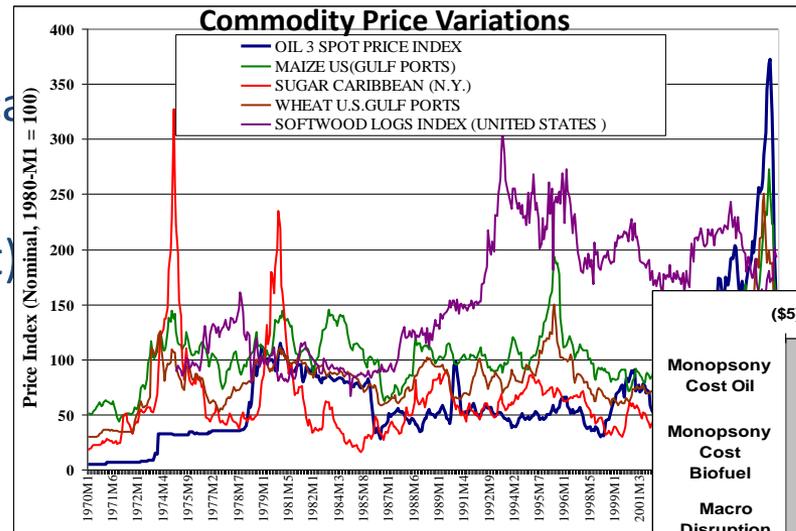
Energy Independence and Security (The E, I and S in EISA)

Indicators

- Fuel import and demand
 - (bill g/yr)
- Fuel supply stability, resilience
 - (price volatility)
- Biomass supply stability
 - (% yield volatility, at various scales)
- Inventory levels
 - (tons feedstock & gals product)
- Energy security premium
 - (\$/gal biofuel)

Related concerns

- Crop failures, oil or bioenergy price shocks
- Macroeconomic losses
- Exposure to import costs



Social Acceptability

Indicators

- Risk of catastrophe (est. annual probability*)
- Public opinion (indexes)
- Open records/info (ISO 26000 etc.)

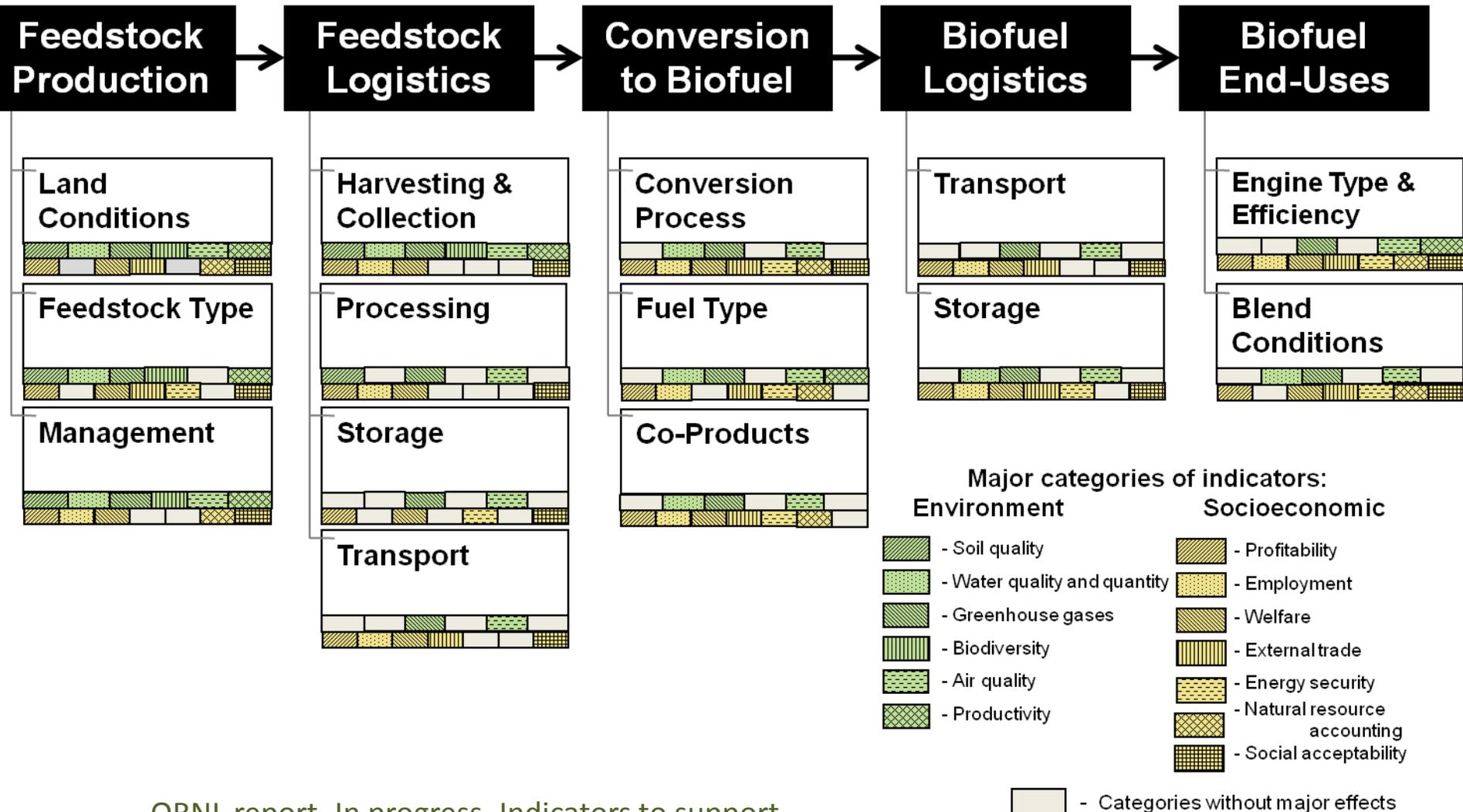
Related concerns

- Accidental deaths
- Environmental disasters
- Perceived risk or problems



*Note: Some indicators are expected to be much lower for biofuels than other fuels. They are relevant for a comparison across fuels, or for an estimate of the incremental reduction when substituting biofuels for other fuels.

Where Categories of Sustainability Indicators Are Affected within the Supply Chain



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



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Visit the CBES website at <http://www.ornl.gov/sci/ees/cbes/>
for more information.

Extra Slides

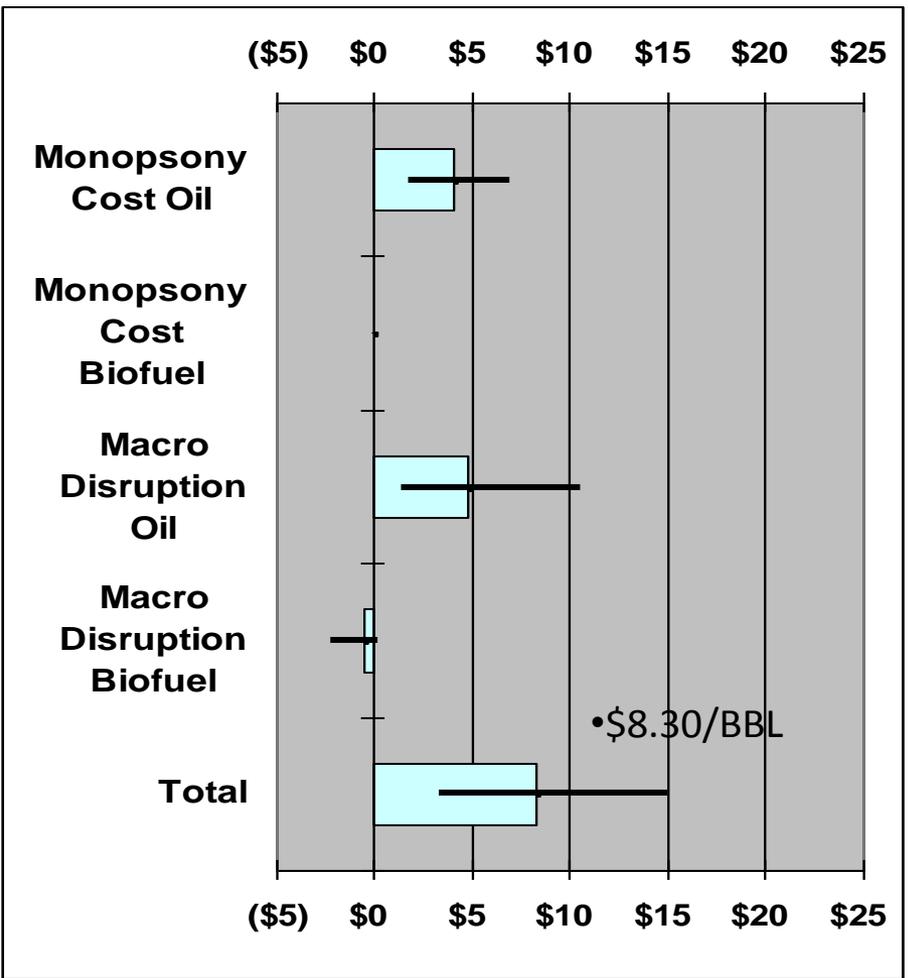
Suite of Sustainability Indicators

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

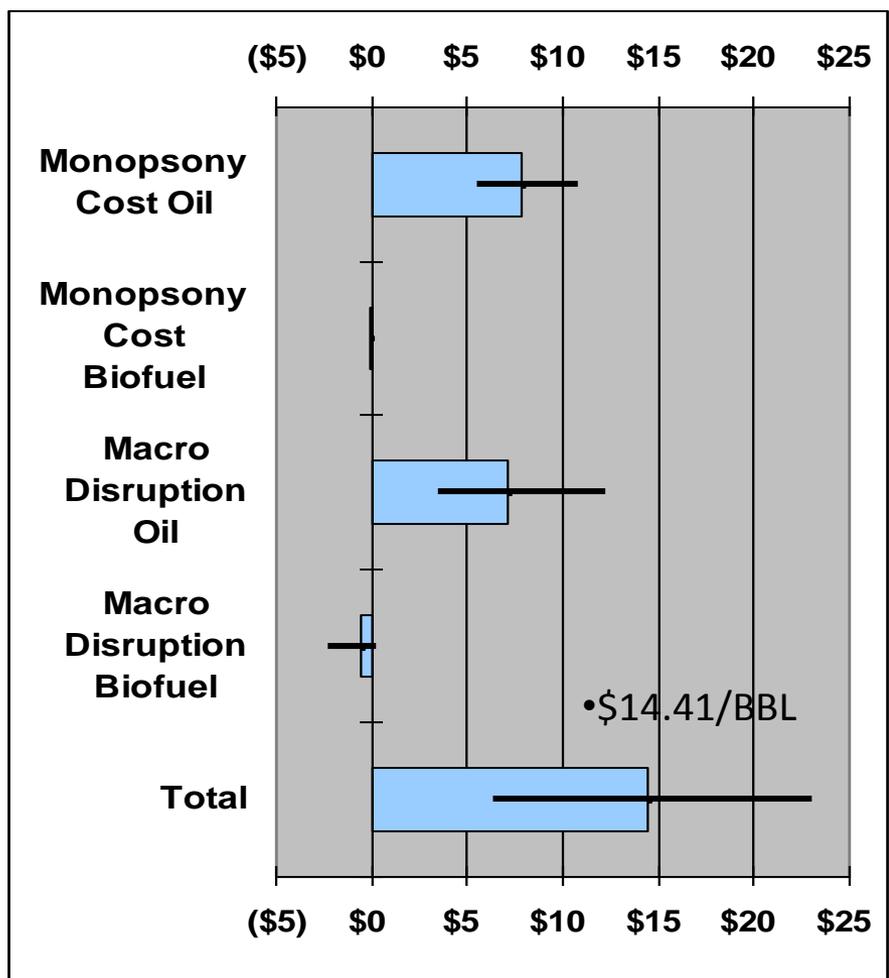
Environment	Indicator	Units
Greenhouse gases	12. CO ₂ equivalent emissions (CO ₂ and N ₂ O)	kgC _{eq} /GJ
Biodiversity	13. Presence of taxa of special concern	Presence
	14. Habitat area of taxa of special concern	ha
Air quality	15. Tropospheric ozone	ppb
	16. Carbon monoxide	ppm
	17. Total particulate matter less than 2.5µm diameter (PM _{2.5})	µg/m ³
	18. Total particulate matter less than 10µm diameter (PM ₁₀)	µg/m ³
Productivity	19. Aboveground net primary productivity (ANPP) / Yield	gC/m ² /year

Our initial findings motivate this work: Estimated Security Benefits of biofuels substantially greater if can increase fuel supply and demand flexibility

•Case if No Elasticity Gains

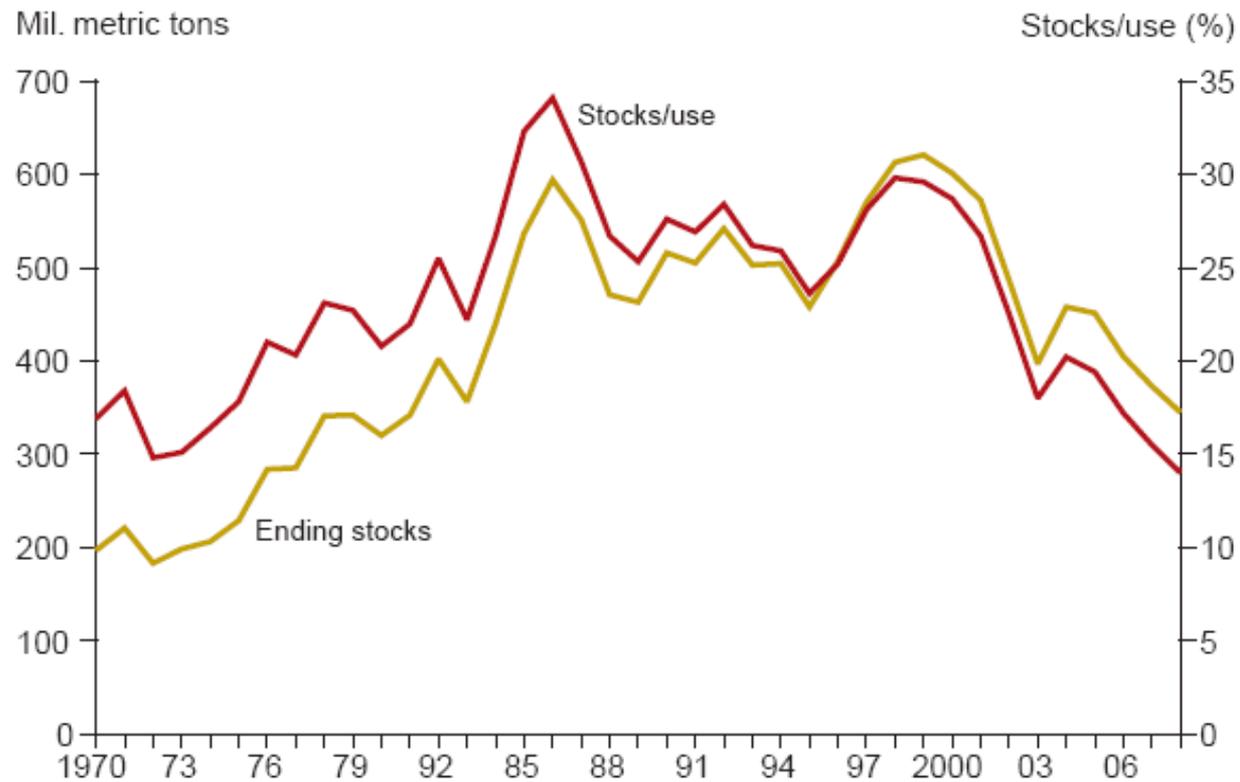


•Premium with Demand Elasticity Gains



A Point of Concern: Declining Trends for World Agricultural Stocks

World grain and oilseed stocks decline, setting the stage for price spikes



Source: USDA, Economic Research Service using USDA, Foreign Agricultural Service, Production Supply, and Distribution Database.

- Source: Trostle, 2008 “Fluctuating Food Commodity Prices - A Complex Issue With No Easy Answers,” *Amber Waves* 6(5).



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Sustainability

Billions-Ton Study:
What can be learned about
Bioenergy Sustainability?

Lunch
12:00 – 1:00 pm



Visit our website at <http://www.ornl.gov/cbes> for more information.