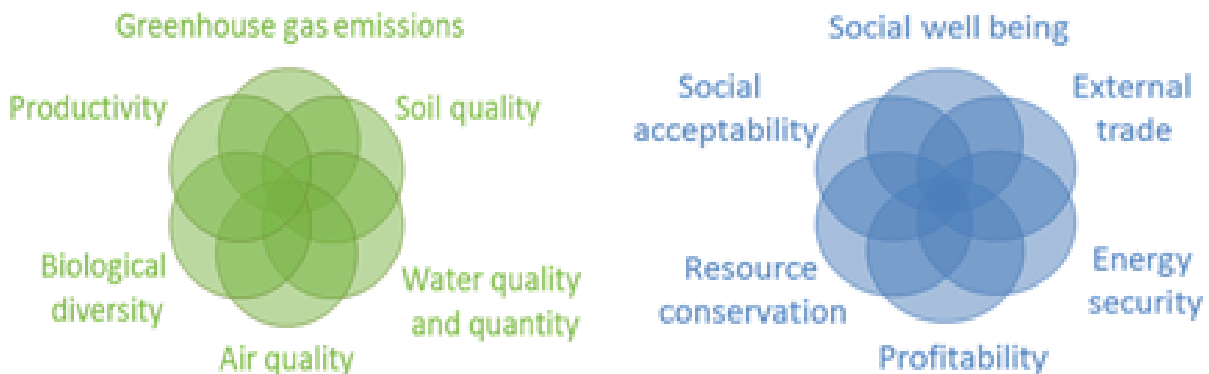


Indicators of Sustainable Bioenergy

(Contact: Virginia Dale, dalevh@ornl.gov, <http://web.ornl.gov/sci/ees/cbes/>)

Indicators

Indicators are needed to assess both socioeconomic and environmental sustainability of bioenergy systems. Effective indicators can help to identify and quantify the sustainability attributes of bioenergy options. A team at Oak Ridge National Laboratory (ORNL) has selected key indicators of bioenergy sustainability and proposed how they are best used in particular contexts. The analysis addressed three goals: (1) choosing from the plethora of indicators proposed by many groups those that appear to be most useful to decision makers; (2) selecting measures of sustainability that are applicable across the entire bioenergy supply chain; and (3) identifying a minimum set of indicators that are practical, doable and incorporate key areas of interest to science. There are six environmental and six socioeconomic categories for indicators of environmental and socioeconomic sustainability.



Proposed Indicators for Sustainable Bioenergy

The proposed environmental and socioeconomic indicators represent a suite designed to reflect major sustainability considerations for bioenergy. McBride et al. (2011) identify major environmental categories of sustainability to be soil quality, water quality and quantity, greenhouse gases, biodiversity, air quality, and productivity and discussed 19 indicators that fit into those categories.

Environmental sustainability indicators

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 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

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



We have identified 16 socioeconomic indicators that fall into the categories of social well-being, energy security, trade, profitability, resource conservation, and social acceptability (Dale et al. 2013). Ten of those 16 socioeconomic indicators are proposed as a minimum list of practical measures of socioeconomic aspects of bioenergy sustainability.

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 output)
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. (2013B) *Ecological Indicators* 26:87-102.

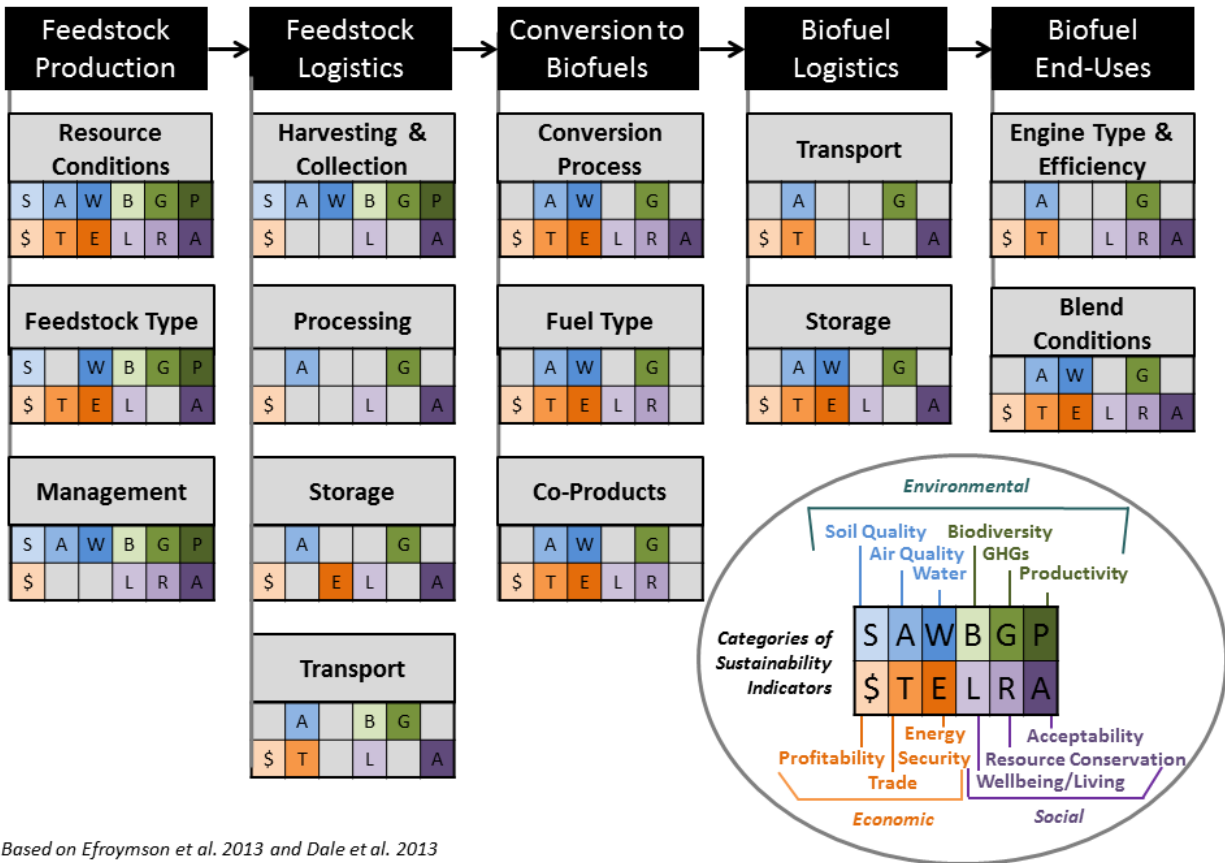
¹⁰ Managed by UT-Battelle for the U.S. Department of Energy



Indicators across the Supply Chain

This suite of indicators reflects major environmental and socioeconomic effects of the full supply chain for bioenergy. These indicators provide a basis to quantify and evaluate sustainability of bioenergy systems across region and systems.

Relevance of 12 Sustainability Indicator Categories Across the Biofuel Supply Chain



Based on Efroymsen et al. 2013 and Dale et al. 2013

References

Dale, VH, RA Efroymsen, KL Kline, MH Langholtz, PN Leiby, GA Oladosu, MR Davis, ME Downing, MR Hilliard. 2013a. Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. *Ecological Indicators* 26: 87-102.

Efroymsen RA, VH Dale, KL Kline, AC McBride, JM Bielicki, RL Smith, ES Parish, PE Schweizer, DM Shaw. 2013. Environmental indicators of biofuel sustainability: What about context? *Environmental Management* 51(2):291-306.

McBride A, VH Dale, L Baskaran, M Downing, L Eaton, RA Efroymsen, C Garten, KL Kline, H Jager, P Mulholland, E Parish, P Schweizer, J Storey. 2011. Indicators to support environmental sustainability of bioenergy systems. *Ecological Indicators* 11:1277-1289.