Environmental Sustainability Indicators

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Presentation to
Biomass Research and Development
Technical Advisory Committee

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http://www.ornl.gov/sci/ees/cbes/
Bioenergy Sustainability Research

• Advance common definitions of environmental & socioeconomic costs and benefits of bioenergy systems

• Quantify opportunities, risks, & tradeoffs associated with sustainable bioenergy production in specific contexts

ORNL’s goals support US Department of Energy objective:

Enable long-term supply of sustainable feedstock and clean, domestic bioenergy
Focusing on bioenergy sustainability brings together disparate perspectives.
Common categories for environmental and socioeconomic sustainability

- Greenhouse gas emissions
- Soil quality
- Water quality and quantity
- Air quality
- Biological diversity
- Productivity

Social well being
- Social acceptability
- External trade
- Resource conservation
- Profitability
- Energy security
- Profitability

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

Recognize that measures and interpretations are context specific
### Categories of environmental sustainability indicators

<table>
<thead>
<tr>
<th>Environment</th>
<th>Indicator</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil quality</td>
<td>1. Total organic carbon (TOC)</td>
<td>Mg/ha</td>
</tr>
<tr>
<td></td>
<td>2. Total nitrogen (N)</td>
<td>Mg/ha</td>
</tr>
<tr>
<td></td>
<td>3. Extractable phosphorus (P)</td>
<td>Mg/ha</td>
</tr>
<tr>
<td></td>
<td>4. Bulk density</td>
<td>g/cm³</td>
</tr>
<tr>
<td>Water quality and quantity</td>
<td>5. Nitrate concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>6. Total phosphorus (P) concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>7. Suspended sediment concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>8. Herbicide concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>9. storm flow</td>
<td>L/s</td>
</tr>
<tr>
<td></td>
<td>10. Minimum base flow</td>
<td>L/s</td>
</tr>
<tr>
<td></td>
<td>11. Consumptive water use (incorporates base flow)</td>
<td>feedstock production: m³/ha/day; biorefinery: m³/day</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse gases</td>
<td>12. CO₂ equivalent emissions (CO₂ and N₂O)</td>
<td>kgC_{eq}/GJ</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>13. Presence of taxa of special concern</td>
<td>Presence</td>
</tr>
<tr>
<td></td>
<td>14. Habitat area of taxa of special concern</td>
<td>ha</td>
</tr>
<tr>
<td>Air quality</td>
<td>15. Tropospheric ozone</td>
<td>ppb</td>
</tr>
<tr>
<td></td>
<td>16. Carbon monoxide</td>
<td>ppm</td>
</tr>
<tr>
<td></td>
<td>17. Total particulate matter less than 2.5μm diameter (PM_{2.5})</td>
<td>μg/m³</td>
</tr>
<tr>
<td></td>
<td>18. Total particulate matter less than 10μm diameter (PM_{10})</td>
<td>μg/m³</td>
</tr>
<tr>
<td>Productivity</td>
<td>19. Aboveground net primary productivity (ANPP) / Yield</td>
<td>gC/m²/year</td>
</tr>
</tbody>
</table>

McBride et al. (2011) *Ecological Indicators* 11:1277-1289
### Environmental indicators for algal based fuel

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Soil quality</th>
<th>Water quality</th>
<th>Water quantity</th>
<th>Greenhouse gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bulk density</td>
<td></td>
<td>2. Nitrate conc in streams (and export)</td>
<td>5. Peak storm flow</td>
<td>8. CO₂ equivalent emissions (CO₂ and N₂O)</td>
</tr>
<tr>
<td>3. Total P conc in streams (and export)</td>
<td></td>
<td>4. Salinity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Minimum base flow</td>
<td></td>
<td>7. Consumptive water use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Total particulate matter less than 10μm diam. (PM₁₀)</td>
<td>16. Primary productivity or yield</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Also have evaluated socioeconomic indicators

Apply across supply chain
Looking at the biofuel supply chain in terms of environmental sustainability indicators

Red boxes highlight those environmental categories for indicators of progress toward sustainability bioenergy that are of particular importance for eucalyptus.

Legend:
- Soil quality
- Water quality and quantity
- Greenhouse gases
- Biodiversity
- Air quality
- Productivity

### Categories of socioeconomic sustainability indicators

<table>
<thead>
<tr>
<th>Category</th>
<th>Indicator</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social well-being</td>
<td>Employment</td>
<td>Number of full time equivalent (FTE) jobs</td>
</tr>
<tr>
<td></td>
<td>Household income</td>
<td>Dollars per day</td>
</tr>
<tr>
<td></td>
<td>Work days lost due to injury</td>
<td>Average number of work days lost per worker per year</td>
</tr>
<tr>
<td></td>
<td>Food security</td>
<td>Percent change in food price volatility</td>
</tr>
<tr>
<td>Energy security</td>
<td>Energy security premium</td>
<td>Dollars /gallon biofuel</td>
</tr>
<tr>
<td></td>
<td>Fuel price volatility</td>
<td>Standard deviation of monthly percentage price changes over one year</td>
</tr>
<tr>
<td>External trade</td>
<td>Terms of trade</td>
<td>Ratio (price of exports/price of imports)</td>
</tr>
<tr>
<td></td>
<td>Trade volume</td>
<td>Dollars (net exports or balance of payments)</td>
</tr>
<tr>
<td>Profitability</td>
<td>Return on investment (ROI)</td>
<td>Percent (net investment/initial investment)</td>
</tr>
<tr>
<td></td>
<td>Net present value (NPV)²</td>
<td>Dollars (present value of benefits minus present value of costs)</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Category</th>
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<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource conservation</td>
<td>Depletion of non-renewable energy resources</td>
<td>MT (amount of petroleum extracted per year )</td>
</tr>
<tr>
<td></td>
<td>Fossil Energy Return on Investment (fossil EROI)</td>
<td>MJ (ratio of amount of fossil energy inputs to amount of useful energy output)</td>
</tr>
<tr>
<td>Social acceptability</td>
<td>Public opinion</td>
<td>Percent favorable opinion</td>
</tr>
<tr>
<td></td>
<td>Transparency</td>
<td>Percent of indicators for which timely and relevant performance data are reported</td>
</tr>
<tr>
<td></td>
<td>Effective stakeholder participation</td>
<td>Number of documented responses to stakeholder concerns and suggestions reported on an annual basis</td>
</tr>
<tr>
<td></td>
<td>Risk of catastrophe</td>
<td>Annual probability of catastrophic event</td>
</tr>
</tbody>
</table>

Looking at the biofuel supply chain in terms of socioeconomic sustainability indicators

Figure 1. A framework for selecting and evaluating indicators of bioenergy sustainability. Steps for the framework are shown in blue; supporting components of the assessment process are in green. Note that steps 1, 2, and 3 interact and occur concurrently.
Sustainability benefits of switchgrass (a “model” perennial crop)

Note: Specific crops are appropriate for different conditions

- **DECREASED WINDFLOW AND EVAPORATION**
- **GREATER INFILTRATION**
- **LOWER FERTILIZER APPLICATION THAN CORN**

Assessing multiple effects of bioenergy choices

An optimization model identifies “ideal” sustainability conditions for using switchgrass for bioenergy in east Tennessee

Spatial optimization model

- Identifies where to locate plantings of bioenergy crops given feedstock needs for Vonore refinery
- Considering
  - Farm profit
  - Water quality constraints

Balancing objectives: Design of cellulosic bioenergy crop plantings may both improve water quality and increase profits while achieving a feedstock-production goal.
Balancing objectives: Design of cellulosic bioenergy crop plantings may both improve water quality and increase profits while achieving a feedstock-production goal.

Land area recommended for switchgrass in this watershed: 1.3% of the total area (3,546 ha of 272,750 ha)
Using Multi-Attribute Decision Support System (MADSS): to compare sustainability of 3 scenarios in east Tennessee
Leverages data from SE Partnership for Integrated Biomass Supply Systems (IBSS)
Case Study of MADSS Applied to East TN: Determines relative contributions of three “pillars” to overall sustainability

Key to chart

Environmental sustainability
Social sustainability
Economic sustainability

[Parish et al. (In press) Assessing multimetric aspects of sustainability. Ecosphere]
By-products of tree harvest for saw timber and pulp in Southeast Region (SE) of US are increasingly used for bioenergy
U.S. Wood Pellet Trade

Figure: U.S. Pellet Export (US EIA, 2014)

Exports grew rapidly after 2007

2010 Wood Pellet Trade flow from US to major EU markets and from Net exporters within EU, in 1000 MT

Data source: Lamers et al., 2013 and Eurostat, 2012
Natural forest area
- Replaced by:
  - Agriculture
  - Development
  - Plantations
- In Savannah fuelshed, area increased since 2007

Plantation area continues to expand in both fuelsheds

Data description: FIA RPA 2012
Observations to date

- Pellets industry is expanding but is not a major driver of forest activity
- Forest harvest is primarily driven by demand for lumber
- Ecological objectives can be achieved with wood-derived bioenergy (Dale et al. 2015. Frontiers in Ecol and Evol)
- Sustainability concerns
  - Biodiversity
  - Changes in land use or management
  - GHG and climate forcing effect estimates
    - Reference conditions
    - Time and space (scales)
  - Opportunities
    - Jobs
    - Water quality improvement
    - Preserving land as forests
    - Continual improvement in practices = increasing sustainability
  - Need stakeholder engagements
    - Communications
    - Science-based reviews
Consider indicators within system as an opportunity to **design landscapes** that add value

Dale et al. (In review) Incorporating Bioenergy into Sustainable Landscape Designs. Renewable & Sustainable Energy Reviews
Recommended practices

• Avoid negative effects
  – Identify & conserve priority biodiversity areas
  – Apply location-specific management of biofuel feedstock production systems.

• Attend to site selection and environmental effects in the
  – Selection and location of the feedstock
  – Transport of feedstock to the refinery
  – Refinery processing
  – Final transport and dissemination of bioenergy.

• Monitor, assess & report on key measures of sustainability

• Attend to what is “doable”

• Communicate opportunities and concerns to the stakeholders and get their feedback

• Employ adaptive management
Next steps for ORNL research

- Continue to develop and test tools for assessment of progress toward bioenergy sustainability
  - Using diverse approaches
    - Mathematical aggregation
    - Multi-Attribute Decision Support Systems (MADSS)
    - Landscape design approach
    - Social effects (field survey instrument/application)
  - Focus on particularly challenging indicators
    - Biodiversity
    - Water quality
- Case studies of evaluating progress toward sustainability
  - Pellet production in SE US
  - Cellulosic feedstocks in midwestern US – new BETO project led by Antares Group, Inc.
Thank you!

This research is supported by the U.S. Department of Energy (DOE) Bio-Energy Technologies Office and performed at Oak Ridge National Laboratory (ORNL). Oak Ridge National Laboratory is managed by the UT-Battelle, LLC, for DOE under contract DE-AC05-00OR22725.
Landscape Design Approach

1. Establish goals specific to context
2. Ascertaining constraints & opportunities
3. Identify optimal options for feedstock types, locations, & logistics
4. Evaluate & select design options
5. Monitor outcomes
6. Adjust decisions as needed

Dale et al. (In review) Incorporating Bioenergy into Sustainable Landscape Designs.
Renewable & Sustainable Energy Reviews
Opportunities for Management of Biofuel Systems to Support Sustainability Goals

THE STATUS QUO
INHERENTLY UNSUSTAINABLE
Production of Non-Conventional Petroleum with Loss of and Harm to Natural Ecosystems
- Increasing greenhouse gas emissions
- Shale oil
- Oil sands mining
- Loss of biodiversity and wildlife habitat
- Altered natural hydrology
- Decreased soil organic carbon
- Increased transportation hazards
- Offshore drilling
- Damaged water quality
- Increasing costs to find and access

POORLY MANAGED
Use of Unsustainable Land Management Practices and/or Conversion of Perennial Ecosystems to Intensive Agriculture
- Increased greenhouse gas emissions
- Increased soil organic carbon
- Increased soil erosion
- Increased fertilizer use and leaching/ emissions
- Damaged water quality

SUSTAINABLY MANAGED
Development of Biofuels Based on Sustainable Land Management Practices and Perennial Feedstocks
- Reduced greenhouse gas emissions
- Reduced soil erosion
- Reduced fertilizer use and leaching/emissions
- Increased sustainable rural development
- Increased soil organic carbon
- Increased food security
- Improved water quality

Ecological objectives can be achieved with wood-derived bioenergy


- EPA’s Clean Power Plan proposal recognizes the complexity and importance of system boundaries in time and space.
- With increasing demand for forest products, forest area in the US typically expands
- Managed forests benefit neighboring landscapes by
  - limiting intrusion of disturbances
  - enhancing ecosystem services
- Net benefits from bioenergy can accrue immediately or within a few years with sustainable forest management practices
Obstacles to developing and deploying more sustainable landscape designs

- Landowner rights
- Traditional practices
- Up front planning required
- Coordination and outreach, stakeholder engagement
- Complexity/level of effort
- Higher initial costs
- Lack of consensus on objectives, priorities

Case Study of MADSS Applied to East TN: Rates environmental & socioeconomic sustainability

Key to chart

- **Biodiversity**
- **Productivity**
- **Air quality**
- **Hydrology**
- **Soil quality**
- **Energy security**
- **Social acceptability**
- **Resource conservation**
- **Social well-being**
- **External trade**
- **Profitability**
- **Greenhouse gases**
- **Greenhouse gases**
- **External trade**
- **Profitability**
- **Energy security**
- **Social acceptability**
- **Resource conservation**
- **Social well-being**

[Parish et al. (In review) Assessing multimetric aspects of sustainability. *Ecosphere*]
Most US timberland is in SE, under private, non-corporate ownership.

Source: FIA RPA 2012; Timberland: forestland capable of >20cft/acre-year of industrial wood
Application of landscape design approach

Two major export ports for energy pellets in SE USA:
- Savannah: mostly intensively managed pine plantations
- Chesapeake: both pine and mixed hardwoods

Advisory team:
- NCASI
- Weyerhaeuser
- Plum Creek

Collaborators:
- NCSU: Bob Abt
- USDA: Karen Abt
- Utrecht University: Floor Van der Hilst, Anna Duden, Steef Hanssen

Fuelsheds: counties near pellet mills that use Chesapeake, VA, and Savannah, GA ports
Net carbon in fuelsheds is increasing

Data description: FIA RPA 2012
Factors to consider: woody biomass for pellets is at end of value chain

**Market options**

- Saw timber → Sawmill
- Pulpwood → Paper mill
- Round wood export
- None of above, chips

**Landowner decisions**
- if/when
  - Planting
  - Site prep/Fertilize
  - Thinning
  - Sales

**External/logger decisions**
- What/how to cut (may be certified)
- Markets (determined by price)

**Landscape, land-use history, ownership**

**Uncertainty about future markets inhibits investment in more efficient production systems**

**Other uses:**
- Energy for plant
- Particle board
- Fiberboard

**Feedstock for pellet mill**

**Pre-commercial thinning**

**Commerical thinning**
Project Title: Enabling Sustainable Landscape Design for Continual Improvement of Operating Bioenergy Supply Systems

Principle Investigator: Antares Group, Inc.

Key Participants: FDC Enterprises • Poet-DSM • DuPont Industrial Biosciences • Iowa Ag Biofibers • Idaho National Lab • Oak Ridge National Lab • Argonne National Lab • AgSolver • USDA Agricultural Research Service • U.S. Geological Survey • Biomass Market Access Standards (BMAS) Group • Pennsylvania State University • Iowa State University • Purdue University • PacificAg • Scientific Certification Systems (SCS) • Iowa Department of Agriculture and Land Stewardship (IDALS) • Agricultural Technology Innovation Partnership (ATIP) • Monsanto

Proposed Project Goals:

• Identify and monitor key environmental sustainability indicators over time along with the impacts from conservation practices being implemented.
• To provide outreach to biomass end-users and growers and to increase the implementation herbaceous perennial energy crops over time.
• Chart a course for continuous improvement and provide an adaptive backdrop for environmental, social and economic activities in biomass fuel sheds.
• To collect detailed feedstock production and logistics data and perform associated techno-economic, lifecycle analyses.
• To create new or improved subfield analysis business and conservation tools for farm-level landscape planning which are applicable to target cellulosic feedstocks.

| Total Project Budget | $13,247,189 |
| EERE Funds Requested | $9,979,990 |
| Applicant Cost Share | $3,267,199 |
Overall Approach

- Code for checks
  - Completed
  - Tested in East TN
  - Reviewed

From the Multi-Year Program Plan DOE’s Bioenergy Technologies Program