Interactions between Biofuel Choices and Landscape Dynamics and Land Use

Virginia H. Dale
Oak Ridge National Laboratory

and colleagues:
Lynn Wright, Keith Kline,
Bob Perlack, Robin Graham,
Charles Garten, Mark Downing,
and Virginia Tolbert

See http://bioenergy.ornl.gov

March 2008
ESA conference on the
Ecological Dimensions of Biofuels

Key points

• Landscape implications of biofuel choices are large

• Multiple implications of biofuel choices require multiple indicators

• Land-use change and associated carbon emission are complicated

• There is an opportunity to design biofuel choices to optimize socioeconomic and ecologic benefits
Hypoxia in the Gulf of Mexico

- **Hypoxia** = Very low dissolved oxygen concentrations, generally ≤ 2 mg/L
- It is due to
  - Nutrients
  - Stratification of shallow Gulf waters
- Excessive nutrients promote excessive growth of opportunistic bacteria, cyanobacteria, and algae.
  - Available nutrients are sequestered in plant biomass
  - Blooms die, decompose, and deplete dissolved oxygen in the water column and at the sediment water interface.
  - This oxygen depletion, known as *hypoxia*, occurs.
- Marine species either die or flee the hypoxic zone.

Map showing the extent of the Mississippi-Atchafalaya River Basin

Zones in Northern Gulf of Mexico differ with regard to
- Stratification
- Light limitation
- Nutrient limitation
- Hypoxia
#1 recommendation: opportunities exist for N and P reduction that influences hypoxia

- Conversion to alternative cropping systems
  - Perennials
  - Alternative rotation systems

- Promotion of environmentally sustainable approaches to biofuel production in targeted areas of the basin.

“Not all approaches will be cost-effective in all locations.”

Scale effects of bioenergy feedstock choices

- Choices made at field scale
- Environmental effects
  - At field (or edge of field)
  - Small watershed
  - Entire basin
    - Hypoxia example
- Need indicators of diverse ecosystem services at relevant scales
Multiple implications of increase in bioenergy usage & production

Environmental effects
- Water quality
- Soil quality
- Habitat & biodiversity
- Runoff
- Air quality

Societal effects
- Energy, food & fiber
- Farm profits
- Rural life style
- Recreation

Candidate metrics at multiple scales

<table>
<thead>
<tr>
<th>Categories of metrics</th>
<th>Large watershed</th>
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<tr>
<td>Landscape</td>
<td>Land cover</td>
<td>Production</td>
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<td>Carbon storage</td>
<td>Energy &amp; food</td>
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<td>Habitat conditions</td>
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<td>Stream Ecosystems</td>
<td>Runoff/hydrology</td>
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<td>Nutrients</td>
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<td>Soil Conditions</td>
<td>Nitrogen, phosphorus, &amp; carbon</td>
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Spatial Scale

Temporal scale

Ethanol Production

Production doubles between 2001 and 2005

Production doubles again between 2005 and 2009
Cellulosic Feedstocks Maximum Fossil Energy Replacement Ratio

Fossil Energy Ratio (FER) = \[
\frac{\text{Energy Delivered to Customer}}{\text{Fossil Energy Used}}
\]

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Geographic distribution of potential biomass crops (selected from >140 trial species)

Wright et al. DOE-ORNL-EERE
What about Lignocellulosic Biomass from Corn Stover or Cotton Stalks?

- Availability Depends on:
  - Crop management approach
  - Initial soil carbon levels and soil types
  - Temperature ranges (and futures changes)

Temperature increases N to S, SOM decreases

Effective moisture increases W to E, SOM increases


Analysis Shows Great Variability in Collectable Corn Stover in US

Gross stover production (217 M tons/yr)

Collectable stover (64 M tons/yr)

Collectable stover if tillage practices changed (111 M tons/yr)

Analysis used average corn acreage and harvested grain yields between 1995 and 2000. Collectable stover based on erosion constraints

Conditions Needed for Perennial Crop Availability:
higher perennial yields, lower land costs, and time

- 2012
  - Yields regional ~ 3-6 dt/ac/yr
  - Farmgate price <$30/dt
  - First plantings in 2009

- 2030
  - Yields regional ~ 5-8 dt/ac/yr
  - Farmgate price <$40/dt

Land costs were based on 2005 USDA projections.

Source:
ORNL analysis using Agriculture Policy Simulation Model (POLYSYS) developed jointly by
UT’s Ag Policy Center, USDA/ERS, ORNL, and OSU Great Plains Ag Policy Center

Soil Carbon and Root Distribution
Results of Perennial Crops Studies

- Improved with land conversion
  - from traditional crops to perennial energy crops
  - tillage to no-till.
- Greatest increases in soil carbon on poorer quality sites
- Soil carbon increased mainly in upper 10 cm
- Switchgrass plantings changed carbon below 60 cm with root penetration > 120 cm
- Root penetration increased soil porosity, infiltration and reduced compaction

Sources:
Tolbert, VR et al. (2002) Environmental Pollution 116, S97-S106.
Landscape Benefits of Perennial Energy Crops are most positive when:

- Replacing annual crops or pasture, not forests
- Minimum tillage and cover crop management used
- Nutrient and chemical applications < annual crops
- Native or non-invasive species used
- Harvesting considers bird nesting timing.
- Used as buffers between annual crops and water ways

Sources: McLaughlin and Walsh. (1998). Biomass and Bioenergy. and Wright and Tolbert (several reports)
Latest questions: Implications of making fuel from plant biomass

Recent controversy

- Feb 2 2008 *Science* reports\(^1\) claim that biofuels cause high greenhouse gas emissions due to land-use change.

- Their conclusions depend on the misleading premise:
  - Biofuel production in the US causes forests and grasslands elsewhere to be converted to agriculture.

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\(^1\) "Land Clearing and the Biofuel Carbon Debt" (J. Fargione *et al.*)
"Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through emissions from Land Use Change" (T. Searchinger *et al.*)
Land-use change and associated carbon emissions are complex

- Driven by
  - Interactions among cultural, technological, biophysical, political, economic, and demographic forces
  - Within a spatial and temporal context
- Making it essential to understand the forces behind land-clearing to reduce emissions.

But net emissions associated with biofuels may be lower than estimated.

- Searchinger and Fargione assert that soybean prices accelerate clearing of rainforest
- Based on studies not designed to identify the causal factors of land clearing.
  - satellite imagery (cannot assess why changes occurred)
  - focused on land classification after deforestation
Soil carbon sequestration influence on emissions was not adequately considered

Deep-rooted perennial biofuel feedstocks in the tropics could enhance soil carbon storage by 0.5 to 1 metric ton/ha/year*


Influence of fire on emissions was not adequately considered

- Repeated fire allows people to maintain land claims at low perceived cost.
- Fires cover large areas:
  - 250-400 million hectares burned each year between 2000 and 2005.
  - Searchinger postulates that 10.8 million hectares to be needed for future biofuel
- Biofuels offer enhanced employment and incomes:
  - Can help establish economic stability
  - And thus reduce
    - Recurring use of fire on previously cleared land
    - Pressures to clear more land
Critical to understand that land-use change

- is a dynamic process
- continues regardless of biofuel production
- provides an alternate conclusion about the potential impacts of biofuels on greenhouse gas emissions.

Can biofuel system be sustainable?
The challenge of sustainability
What do we need to consider?

I. Feedstock type

Future feedstocks

- Agricultural feedstocks for cellulosic fuels
  - Crop residues (e.g. stover)
  - Perennial grasses (e.g. switchgrass)
  - Short rotation tree crops (e.g. poplar)

- Forest feedstocks
  - Fuel reduction treatments
  - Industrial wastes

The challenge of sustainability

Is addressing all 6 dimensions throughout world
Spatial juxtaposition influences sustainable bioenergy systems

Forman* suggest that under ideal land management that decisions be based on:

1st - water and biodiversity concerns
2nd - cultivation, grazing, and wood products
3rd - sewage and other wastes
4th - homes and industry

In reality

- Planning under pristine conditions is typically not possible
- Extant development of the region constrains opportunities for land management.

Innovations of Landscape Design

- Integrated — environmental & socioeconomic dynamics, consequences
- Alternative bioenergy regimes & policies
- Potential for spatial optimization
- Scale-sensitive
  - Economic, social, & environmental constraints & metrics at multiple scales

Conclusions

- Landscape implications of biofuel choices are large
  - Illustrated by hypoxia in Gulf
  - Mandates need for systems approach
- Multiple implications of biofuel choices require multiple indicators
- Land-use change and associated carbon emission are complicated
  - Driven by interactions among cultural, technological, biophysical, political, economic and demographic forces
  - Within a spatial and temporal context
- There is an opportunity to design biofuel choices to optimize socioeconomic and ecologic benefits
Overall Conclusion

Different places and different goals have unique solutions.