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

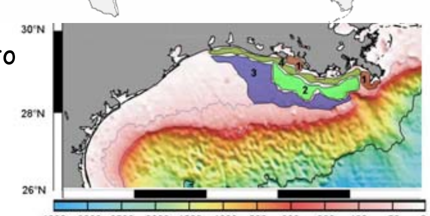
Hypoxia in the Gulf of Mexico

- *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



Hypoxia Advisory Panel of EPA's Science Advisory Board 2007 Report

http://www.epa.gov/sab/panels/hypoxia_adv_panel.htm

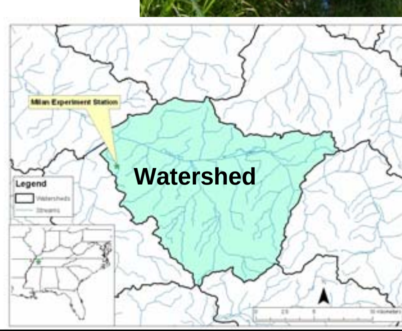
#1 recommendation: opportunities exist for N and P reduction that influences hypoxia

- Conversion to alternative cropping systems
  - Perennials
  - Alternative rotation systems
- Promotion of environmentally sustainable approaches to biofuel production in targeted areas of the basin.

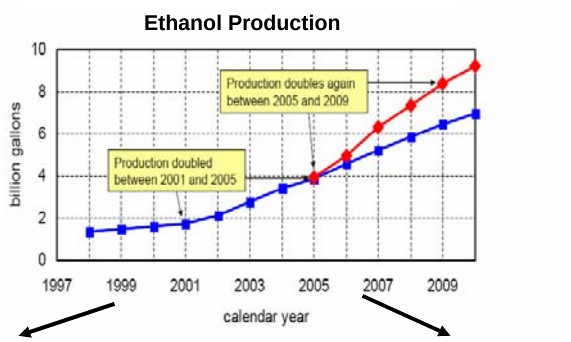
"Not all approaches will be cost-effective in all locations."

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



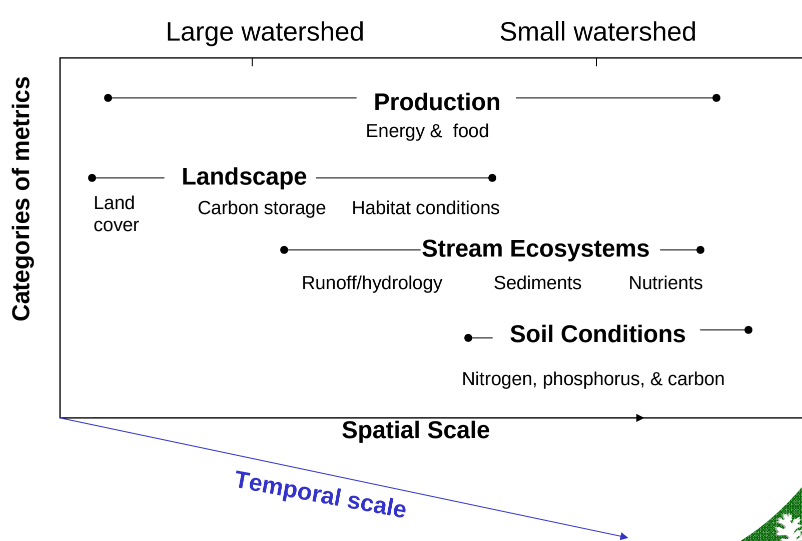
Multiple implications of increase in bioenergy usage & production



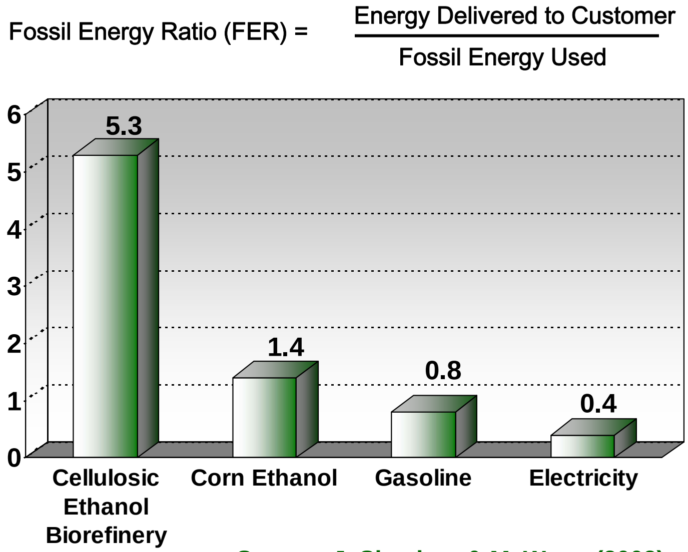
Environmental effects
- Water quality
- Soil quality
- Habitat & biodiversity
- Runoff
- Air quality

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

Candidate metrics at multiple scales



Cellulosic Feedstocks Maximum Fossil Energy Replacement Ratio



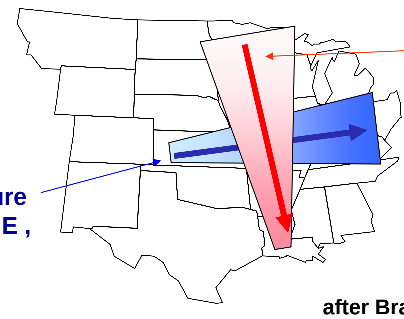
Source: J. Sheehan & M. Wang (2003)

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)



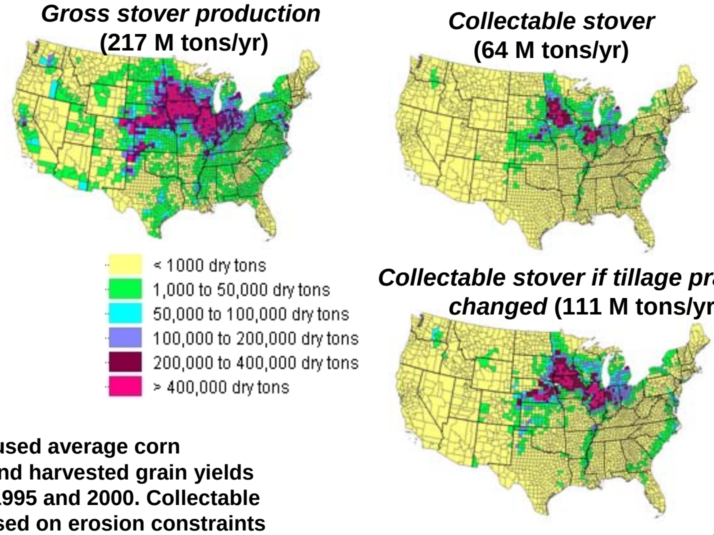
after Brady, N.C. (1974).

Analysis Shows Great Variability in Collectable Corn Stover in US

Gross stover production (217 M tons/yr)

Collectable stover (64 M tons/yr)

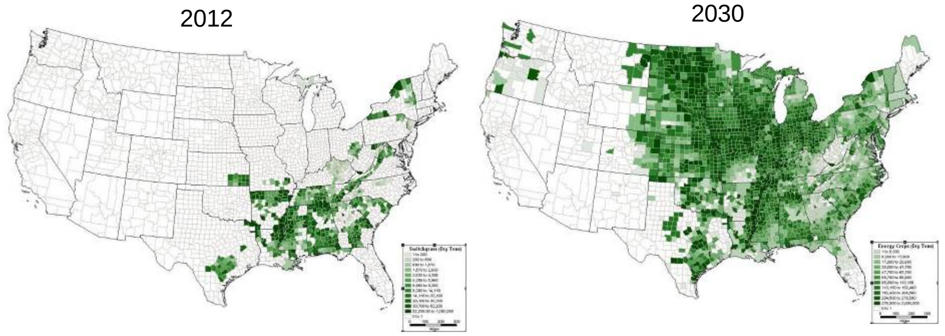
Collectable stover if tillage practices changed (111 M tons/yr)



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

Source: Graham et al. (2007) Agron. J. 99:1-11.

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



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

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

OAK RIDGE National Laboratory

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.
Mann L and Tolbert VR. (2000). Ambio 29: 492-498.

OAK RIDGE National Laboratory

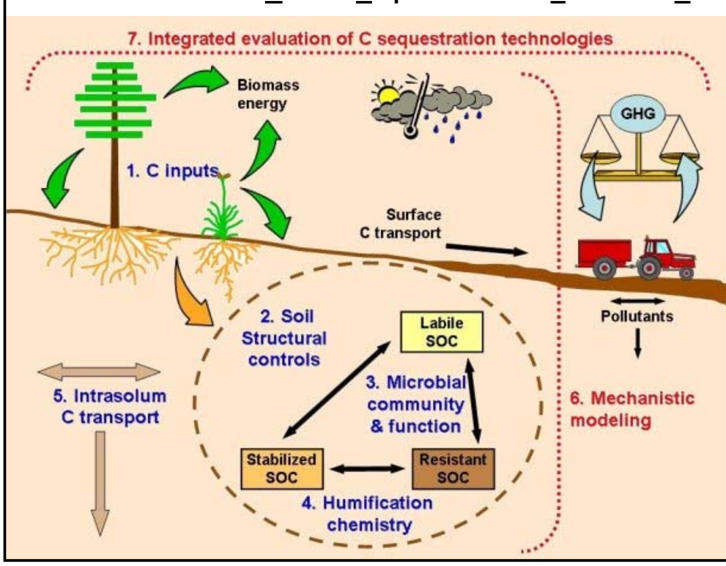
Landscape Benefits of Perennial Energy Crops are most positive when:

- 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

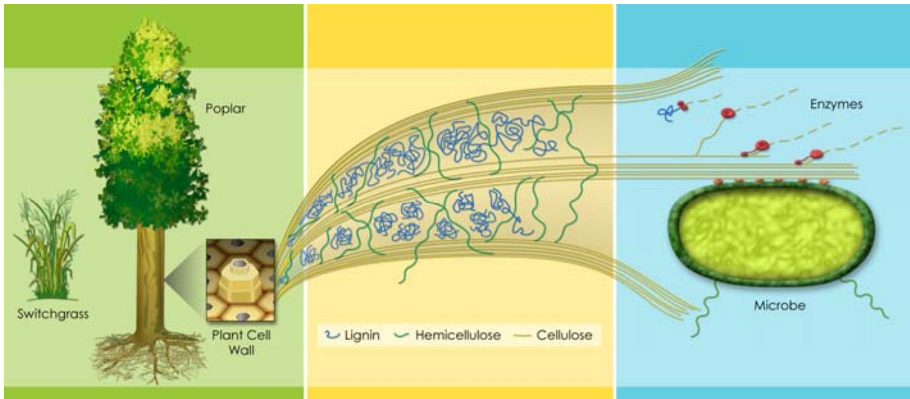
Sources: McLaughlin and Walsh. (1998). Biomass and Bioenergy. and Wright and Tolbert (several reports)

Research Programs Are Addressing Landscape Effects of Perennial Energy Crops

CSiTE Carbon Sequestration in Terrestrial Ecosystems



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.

[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*

* M.J. Fisher et al.(1994) *Nature* **371,** 236.

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

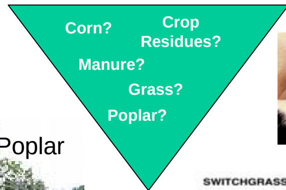
Critical to understand that land-use change

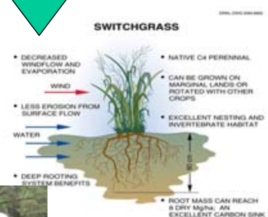
- is a dynamic process
- continues regardless of biofuel production
- provides an alternate conclusion about the potential impacts of biofuels on greenhouse gas emissions.

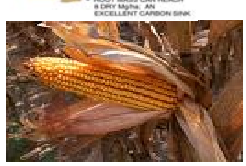
Can biofuel system be sustainable?

The challenge of sustainability
What do we need to consider?

I. Feedstock type



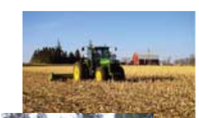


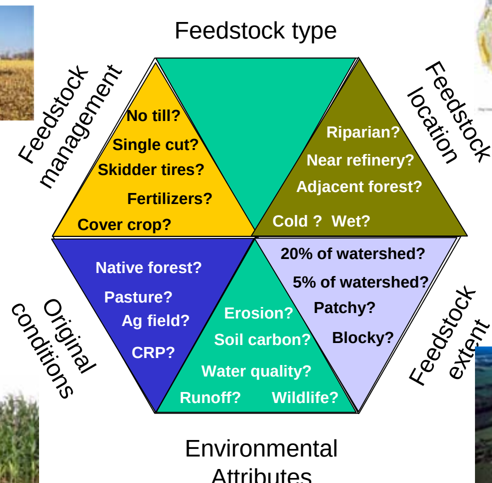


Future feedstocks

- 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

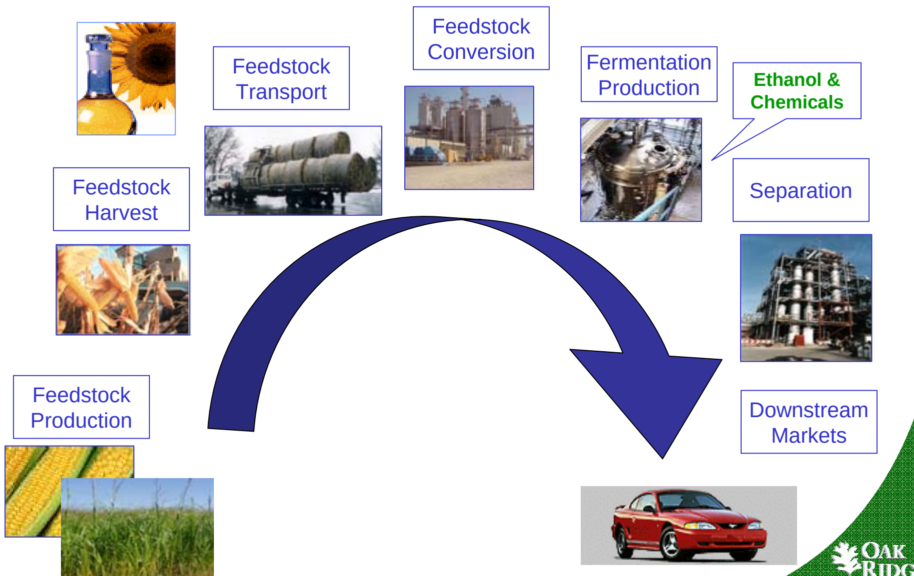
The challenge of sustainability





Is addressing all 6 dimensions throughout world

Spatial juxtaposition influences sustainable of 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.

*Forman, R. T. T. 1995. Land mosaics: the ecology of landscapes and regions. Cambridge University Press. Cambridge, U.K.

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

Oak Ridge National Laboratory

Overall Conclusion

Different places and different goals
have unique solutions.