Economics of a New Generation of Bioenergy Crops: Implications for Land Use and Greenhouse Gases

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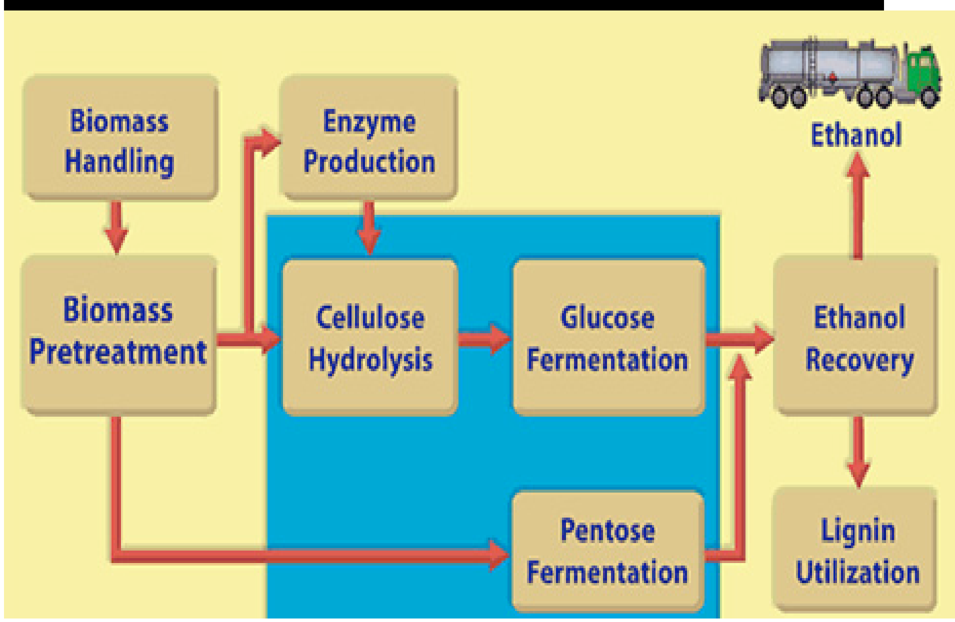
Funding provided by the Illinois CFAR and Dudley Smith Initiative

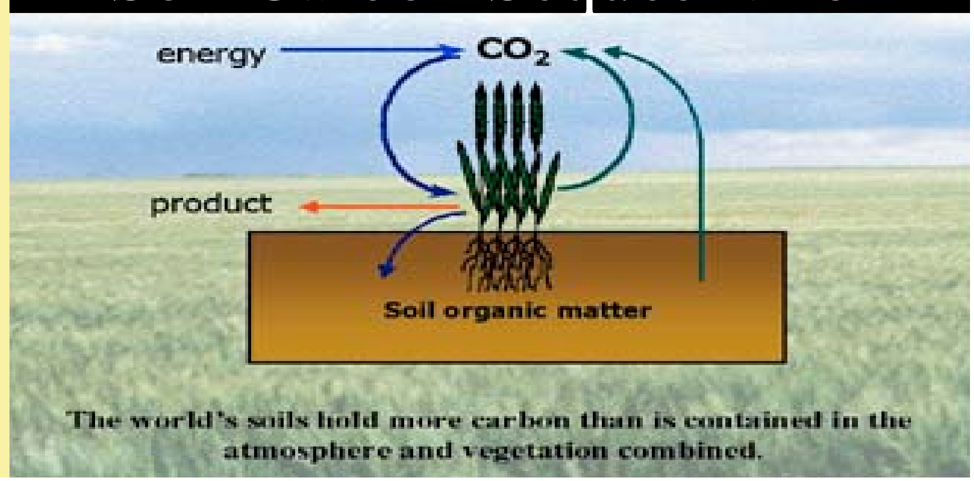
Mitigating Climate Change: Role of Cropland

Renewable Energy

- Providing biomass:
    - Co-fired with coal in power plants
    - Converted to cellulosic ethanol
- Ethanol from corn grain



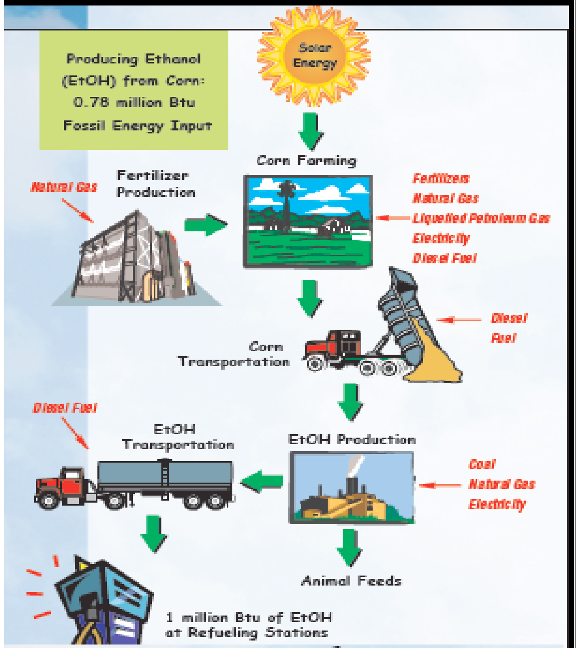
Soil Carbon Sequestration

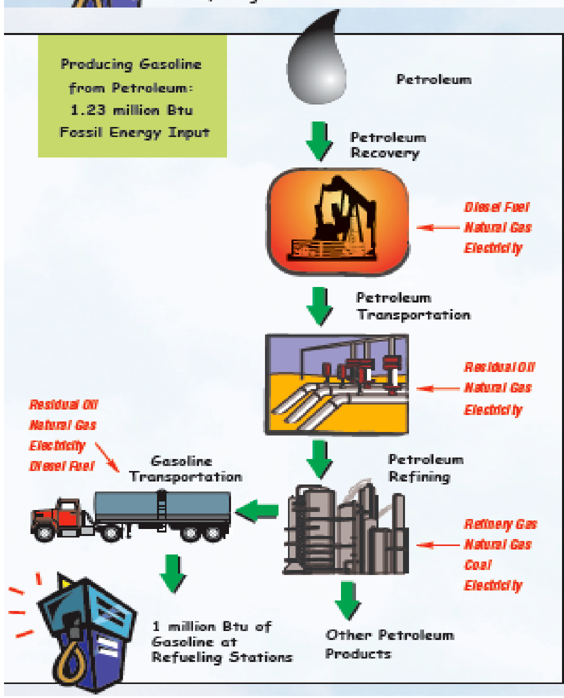


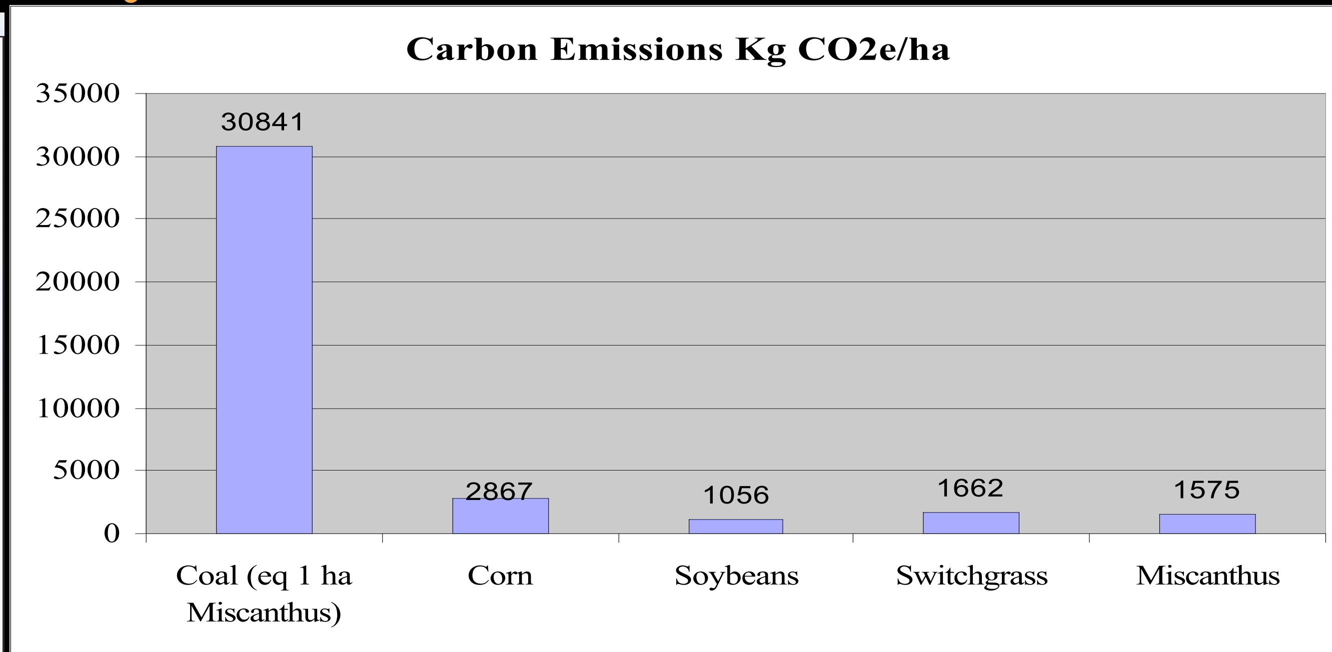
Dedicated Energy Crops : Switchgrass and Miscanthus

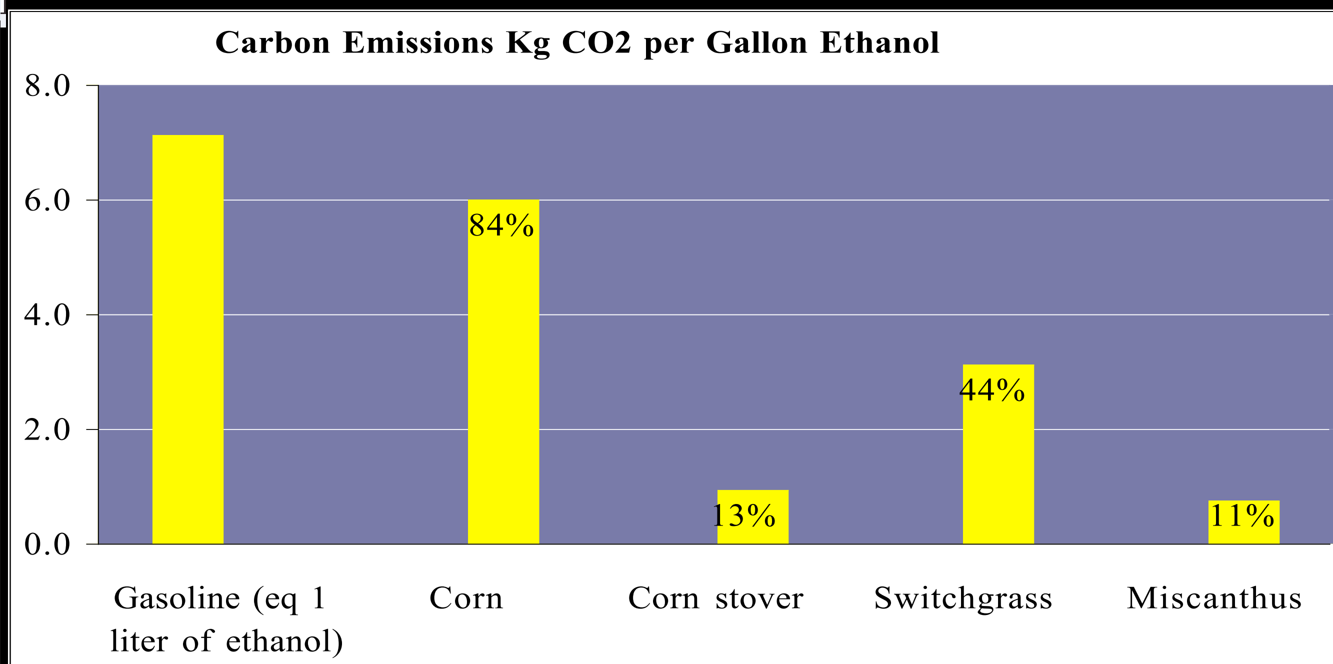
- Adaptable to wide range of growing conditions
- High yielding perennials
- Low initial and annual input requirements
- Compatible with row crop production
    - _ require conventional equipment; winter harvests

Life-Cycle Carbon Emissions



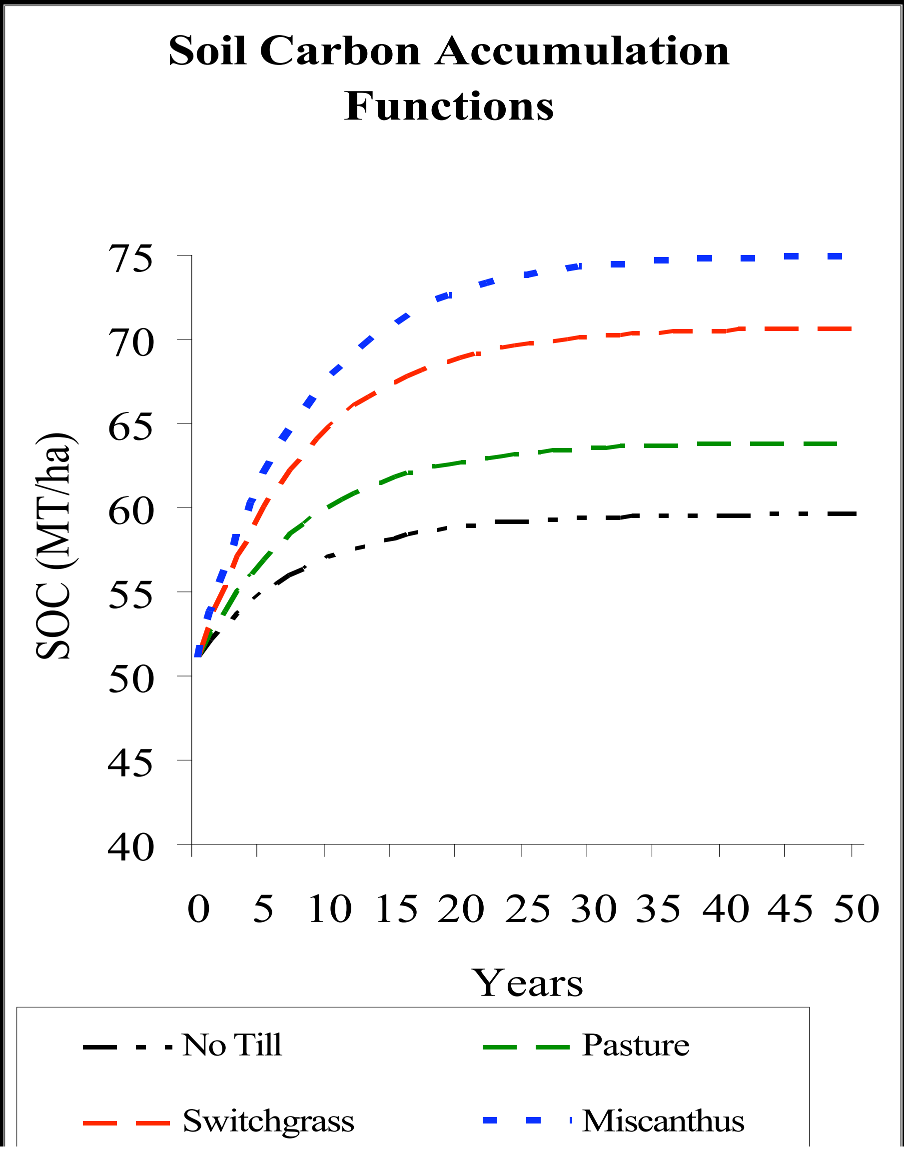


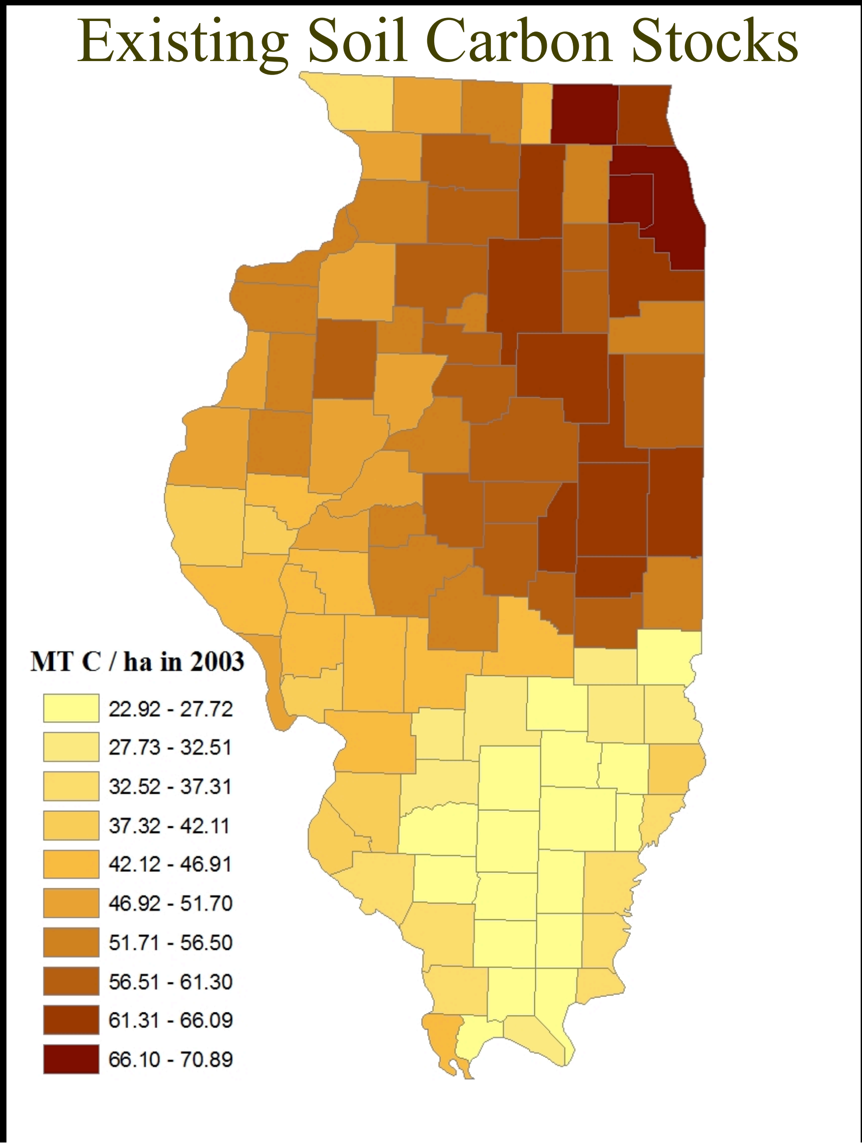




Soil Carbon Sequestration

- Conservation tillage with corn and soybean: 0.3-0.5 MT/ha/yr
- Perennial grasses 3 times higher 0.94-1.4 MT/ha/yr





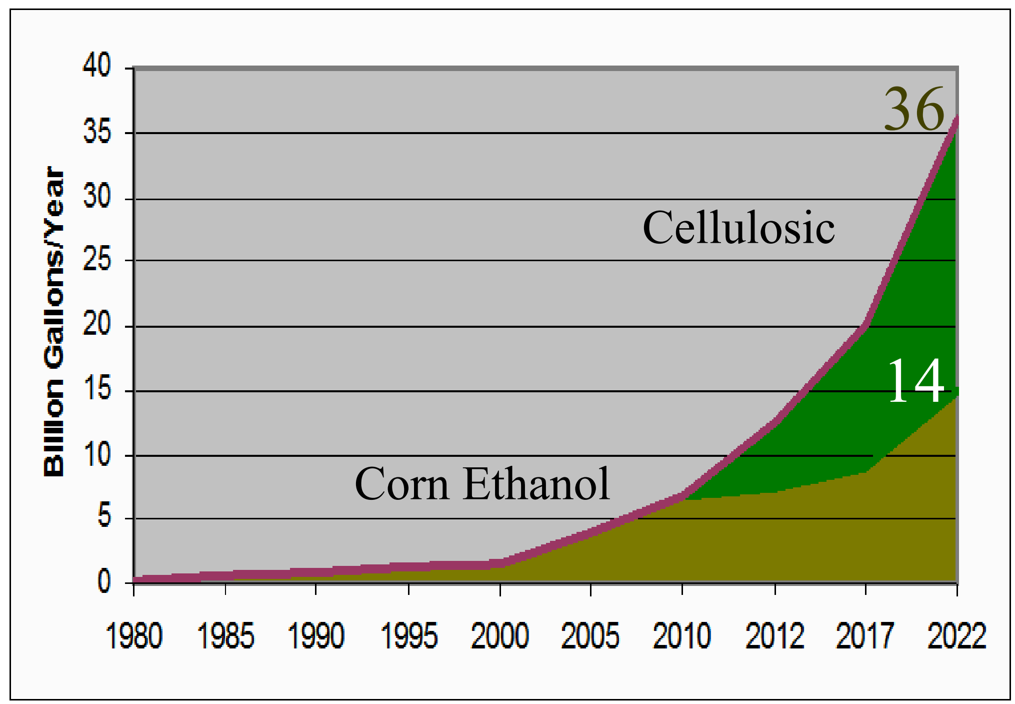
Policy and Market-Based Incentives

Renewable Portfolio Standards

House energy bill: a national standard requiring 15% of electricity to be from renewable sources by 2020

Renewable Fuel Standards

Senate Bill: 36 billion-gallon per year biofuel mandate by 2022, up from 8.5 billion gallons in 2008.



Pilot carbon credit programs

Chicago Climate Exchange

Illinois Conservation Climate Initiative

Regional Greenhouse Gas Initiative

Power plants seeking low cost C offsets

Research Problem

Develop a spatial and dynamic land allocation model to examine (in the context of Illinois 2003-2017):

- Allocation of cropland to bioenergy crops for co-firing in coal-based electricity generating plants based on market incentives

- Implications of co-firing bioenergy for carbon emissions

- Implications of bioenergy crops for costs of carbon mitigation through sequestration and displacement of coal from power plants

- Economic viability of cellulosic ethanol and carbon mitigation potential

Spatial and Temporal Heterogeneity

Profitability of bioenergy crops varies with heterogeneity in

- Productivity, costs and prices of row crops
- Productivity and costs of perennials – age specific
- Location of end uses (power plants) for bio-energy

Carbon mitigation benefits vary spatially and with length of time under a land use

- Soil carbon sequestration rates
  - Vary across space with existing stocks of carbon already in the soil
  - Diminish over time: Non-linear C accumulation function
  - Upper bound to seq. capacity
  - Reversible and asymmetric
- Life-Cycle carbon emissions depend on fertilization rates, machinery use, fuel use: yield dependent

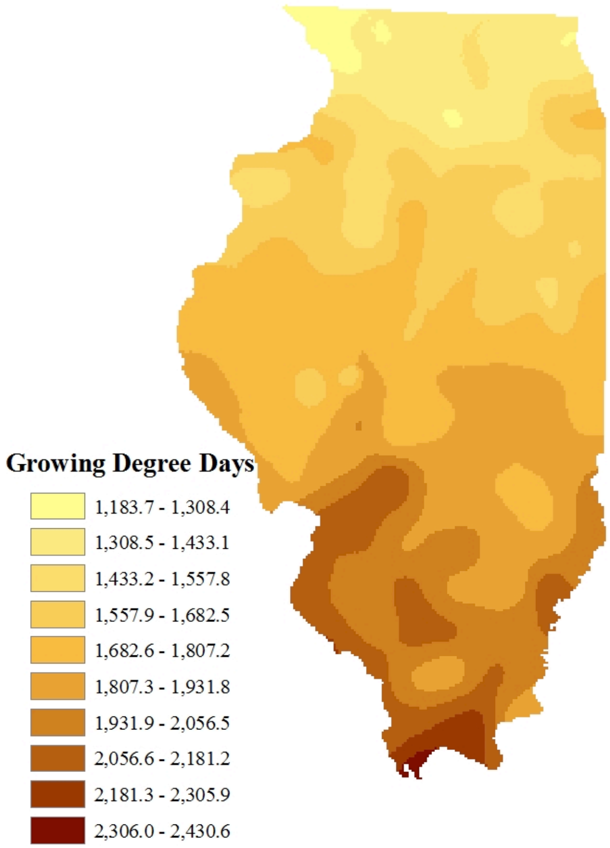
Economic Model

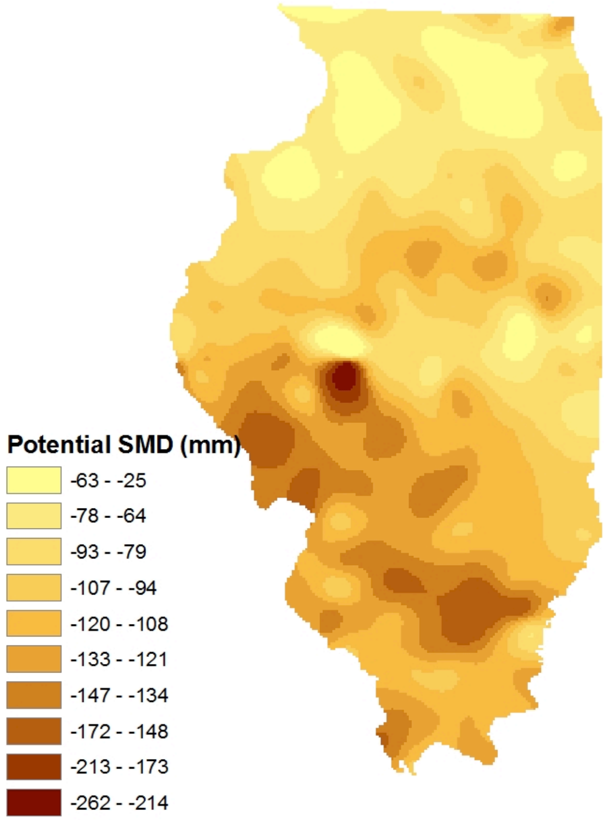
- Objective: Allocate land among 4 row crops, 3 perennials, 2 tillage choices, 18 rotations to maximize discounted value of profits over a 15 year period
- Dynamic: Returns and carbon emissions in the next period depend on decisions in this period and with age of perennials
- Spatial: Returns and carbon emissions/sequestration vary over 102 Illinois counties
- Constraints on
  - Capacity of power plants for co-firing bio-energy (5-25%)
  - Location of existing coal based power plants
  - Crop rotation possibilities
  - Cropland availability
  - Ease of conversion of land from one use to another
  - Sequestration rates with each land use
  - Carbon emission mitigation rate with each land use

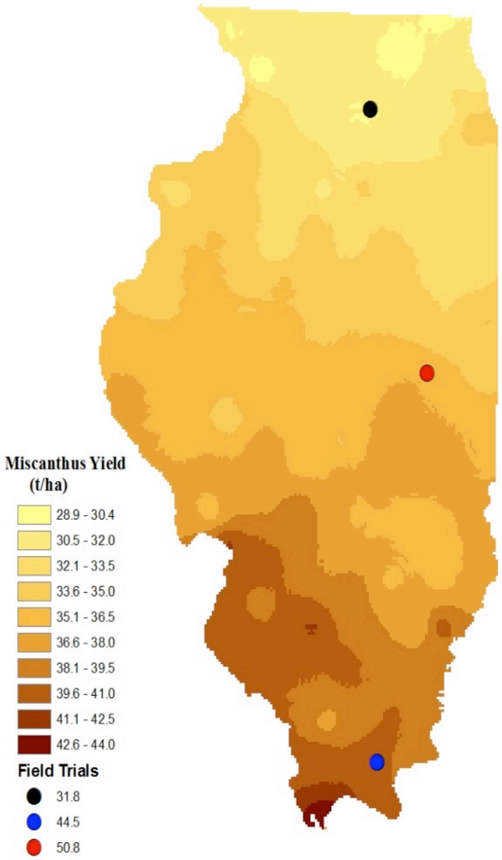
Data for Illinois

- Yields
  - Simulated yield of Miscanthus and Switchgrass
    - Historical climate, soil moisture, solar radiation
  - Historical average yields of conventional crops
- Costs of production by county, tillage and rotation
- Revenues for row crops
- Revenues for energy crops
  - Location of power plants; heat content; cost of coal energy
- Carbon stocks by county
- Carbon accumulation functions by land use and by county
  - Conservation tillage, pasture, switchgrass and miscanthus

Growing Conditions for Miscanthus in Illinois

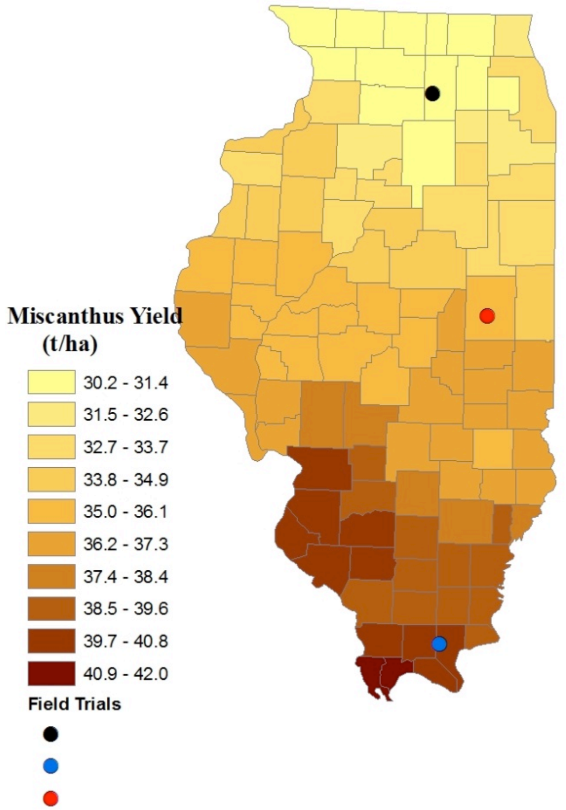


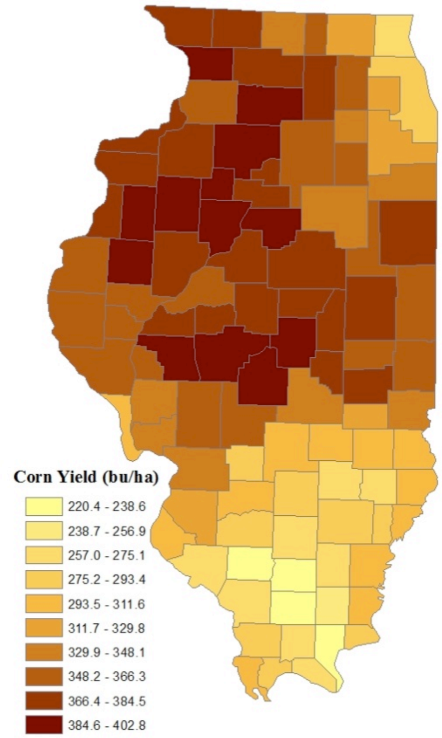


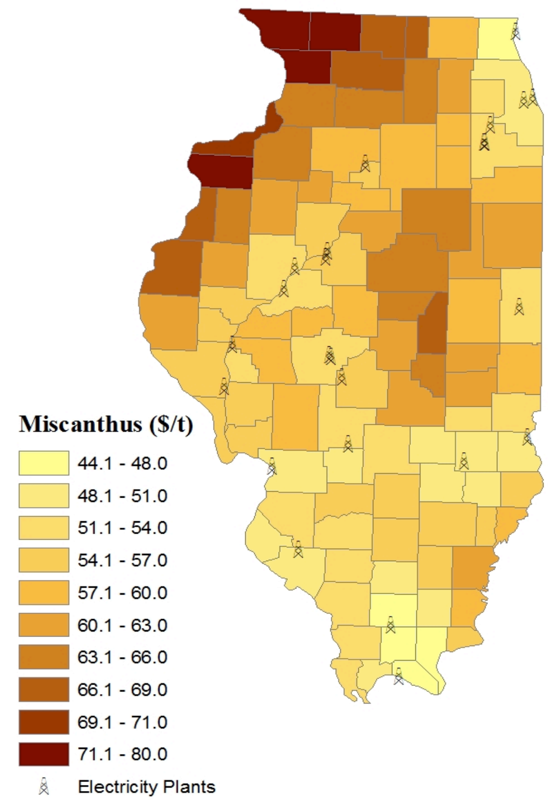


- Yield of Miscanthus simulated using 30 year climate data on solar radiation, temperature, frost dates, precipitation, soil evaporation and water holding capacity at 2 sq km level
- Temperature most important factor in leaf expansion with optimal water and nutrients

Yield/Hectare and Costs of Production







	Actual average yield of Miscanthus(t DM/ha) (2005-06)	Simulated yield of Miscanthus (t DM/ha)	Actual average yield of Switchgrass(t/ha) (2005-06)
North (DeKalb)	28.5	30.6	8.1
Central (Champaign)	42.4	35.4	16.8
South (Dixon Spring)	46.0	39.9	8.6
State Average	**39.0**	**35.3**	**11.2**

Bio-Energy Production with 5% Co-firing Capacity

Bio-Energy Price per MBTU	< $2.5	$3.0	$3.4
Land under conservation till (%)	45.07	44.61	44.29
Land under Miscanthus (%)	0	0.77	1.19
Biomass Supply (MMT with 15% moisture)	0	1.96	2.94
Electricity generated with bio-energy (%)	0	2.5	3.8
Maximum distance for transportation of biomass (miles)	0	32.94	52.32
Carbon Sequestration in 15 years (Million Metric Tons)	15.96	16.86	17.44
By Conservation till (%)	92.95	86.92	82.99
By Miscanthus (%)	0.00	6.37	10.65
Discounted present value of bio-energy subsidy ($M)		496	909

Maximum price a power plant would be willing to pay for biomass based on energy content: $1.185/MBTU

Figure 3.4. Acreage Response to Changes in Bioenergy Price

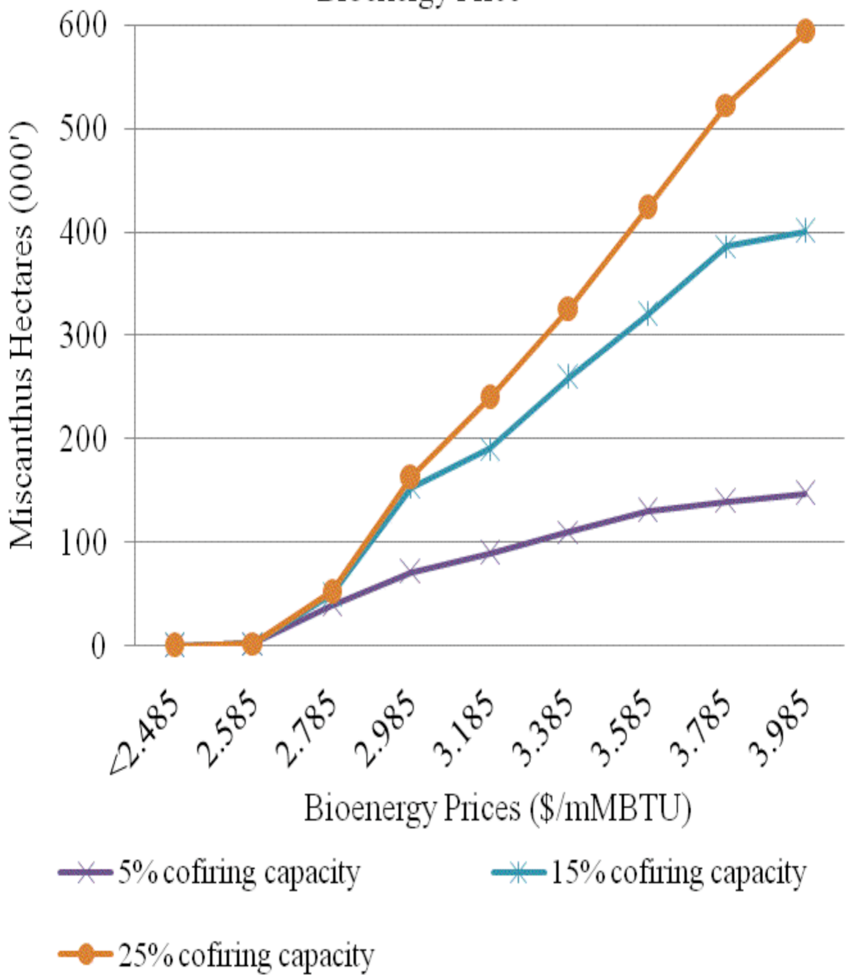
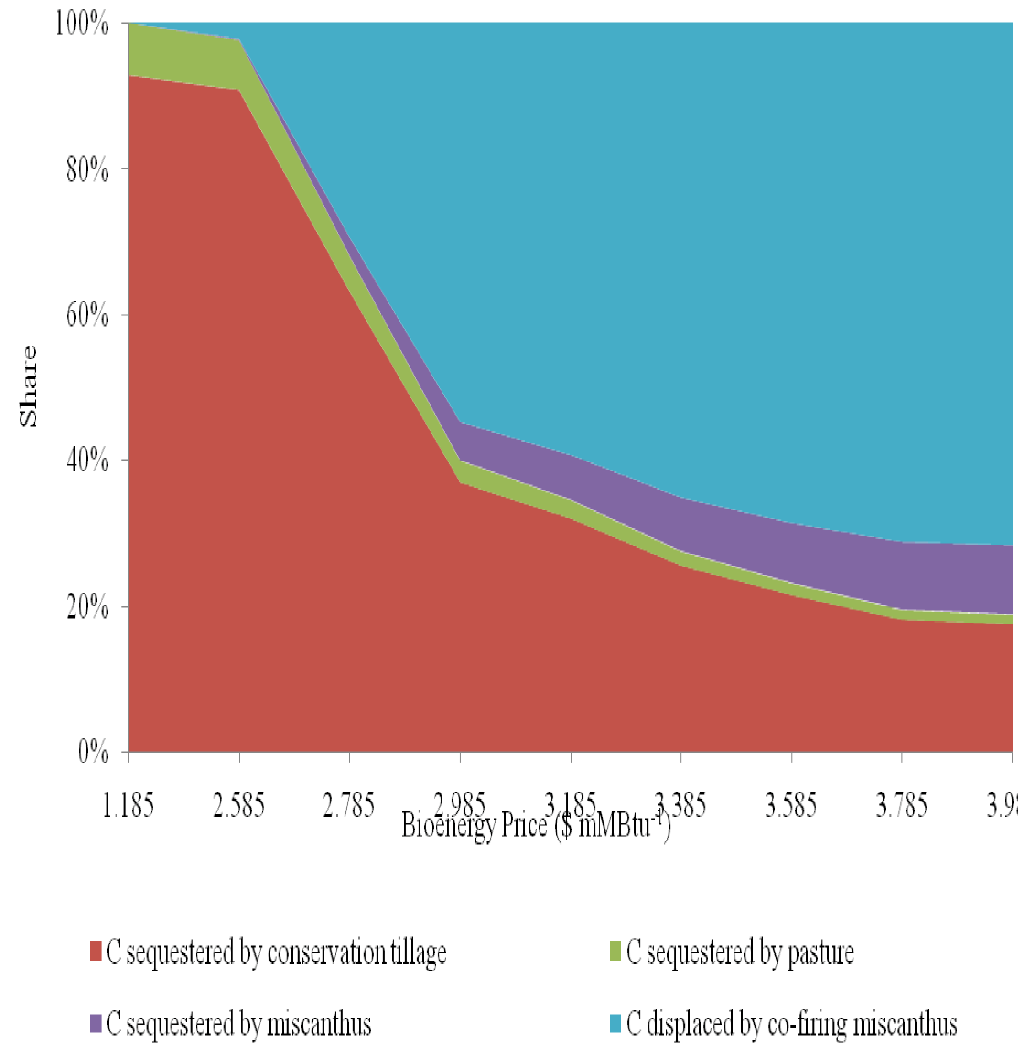
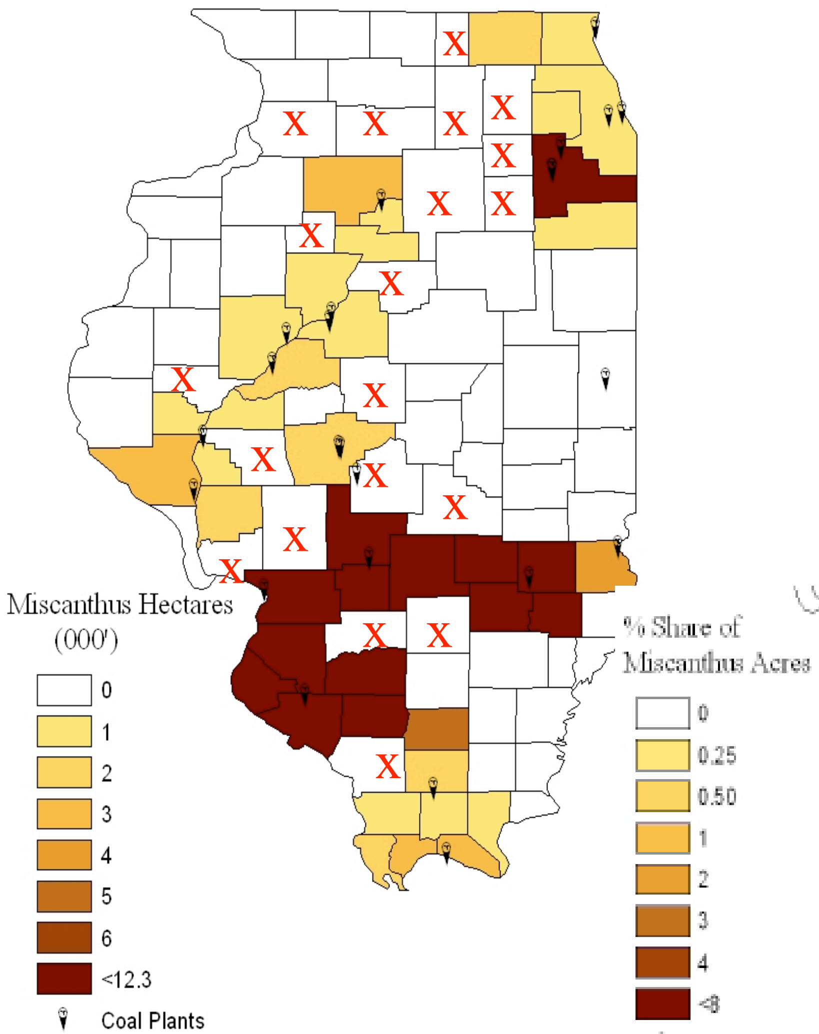


Figure 3.6. Share of Carbon Mitigation by Source with 15% Co-firing

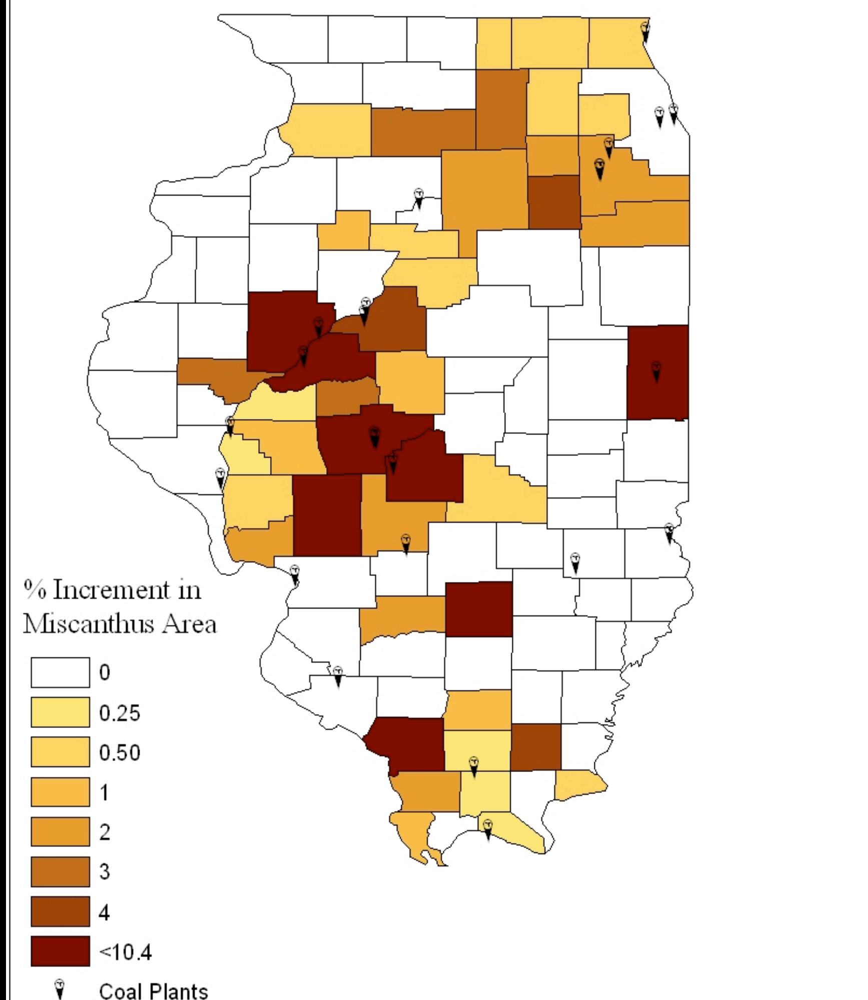


Area under miscanthus at $3 MBtu^{-1} with 15% co-firing limit

At $3.4 MBTU^{-1}



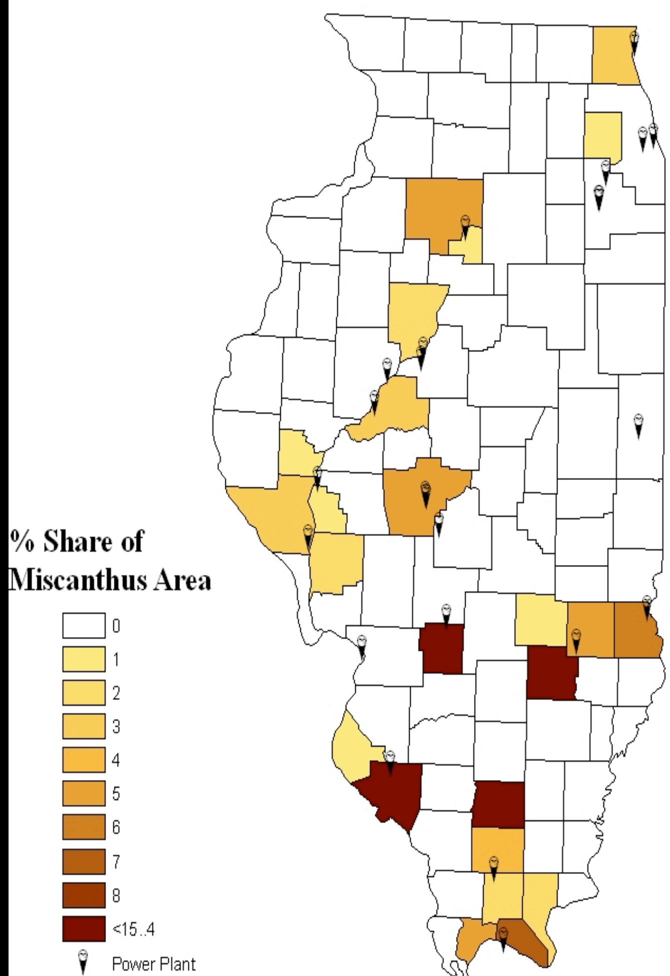
Increase in county share of miscanthus acres with $3.4 MBtu^{-1}



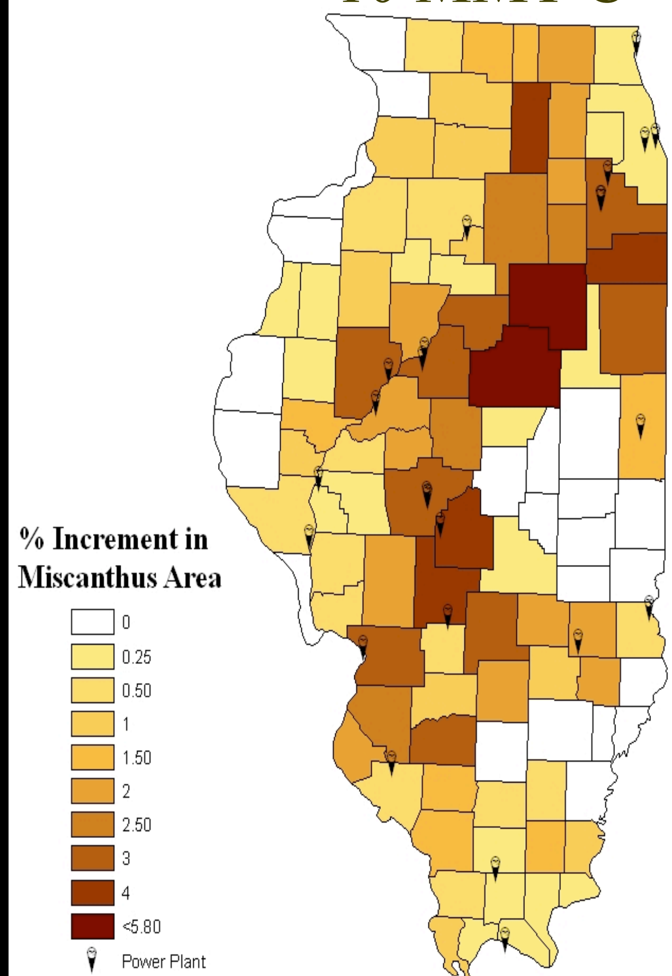
Cost of Carbon Mitigation with Bioenergy

Biomass co-firing capacity (%)	BAU	15% co-firing capacity		
Carbon Mitigation (MMT)	0 MMT	Carbon Subsidy 10MMT 40MMT		Bioenergy Subsidy $2.2/MBTU
Land under conservation till (%)	45	53	53	43
Land under miscanthus (%)	0	0.4	2.8	2.8
Electricity generated with miscanthus (%)	0	1.1	8.1	9.2
Maximum hauling distance (miles)	0	26	70	52.32
Number of counties producing miscanthus	0	24	77	65
Number of power plants co-firing miscanthus	0	14	23	22
Discounted carbon price ($/MT)	0	52	78	-
Annualized carbon price ($/MT per year)	0	2	3	
C mitigated in 15 years (MMT) -Through displacement -Through sequestration: Conservation tillage - Miscanthus	 0 16 0	 5 20 0	 35 19 0	 35 13 4
% of carbon mitigated in 15 years	4	7	15	15
% sulfur displaced in 15 years	0	0.8	6	6
Total Subsidy Payment ($M)	0	246	2706	2173

County Share of Miscanthus Acres with 10MMT C Target

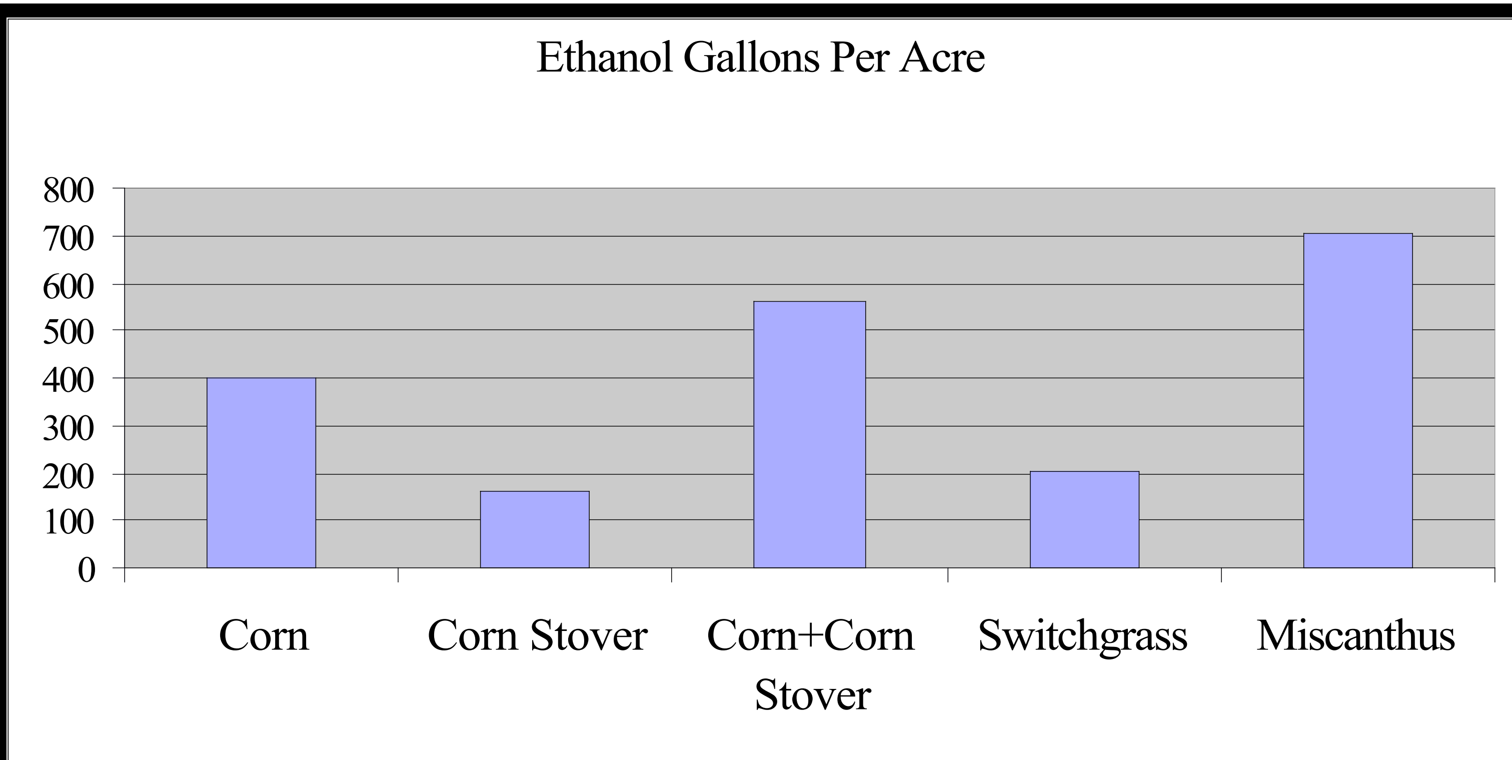


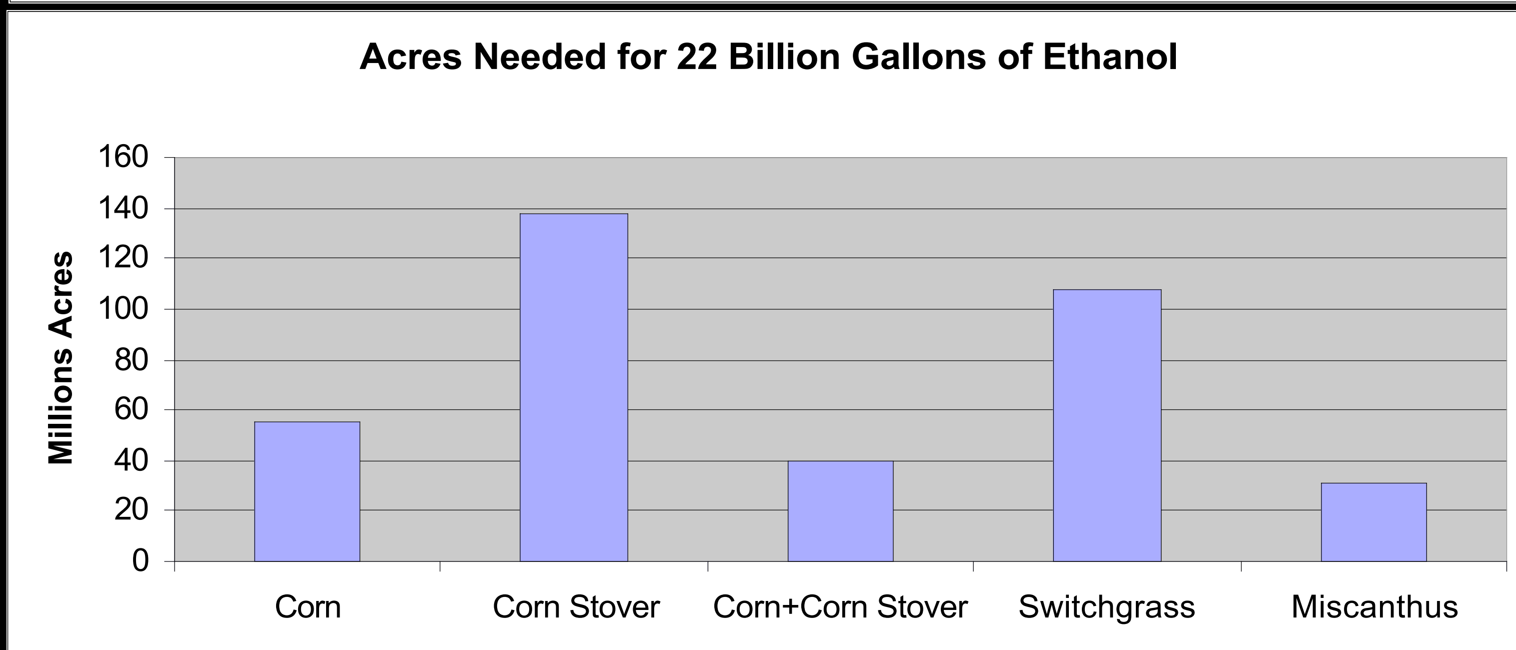
County Share in Increased Miscanthus Acres with 70 MMT C Target Relative to 10 MMT C

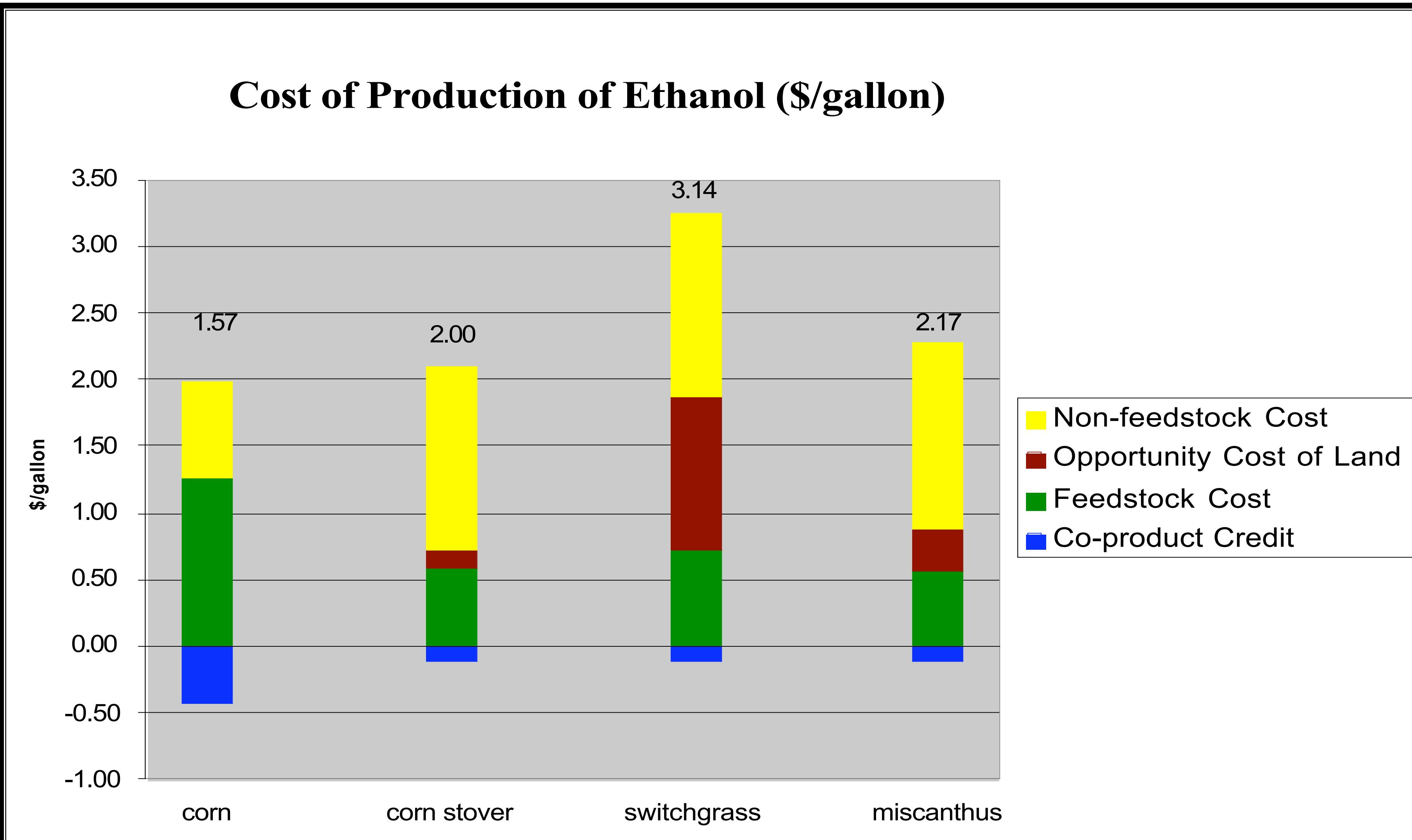


15% Co-firing Constraint

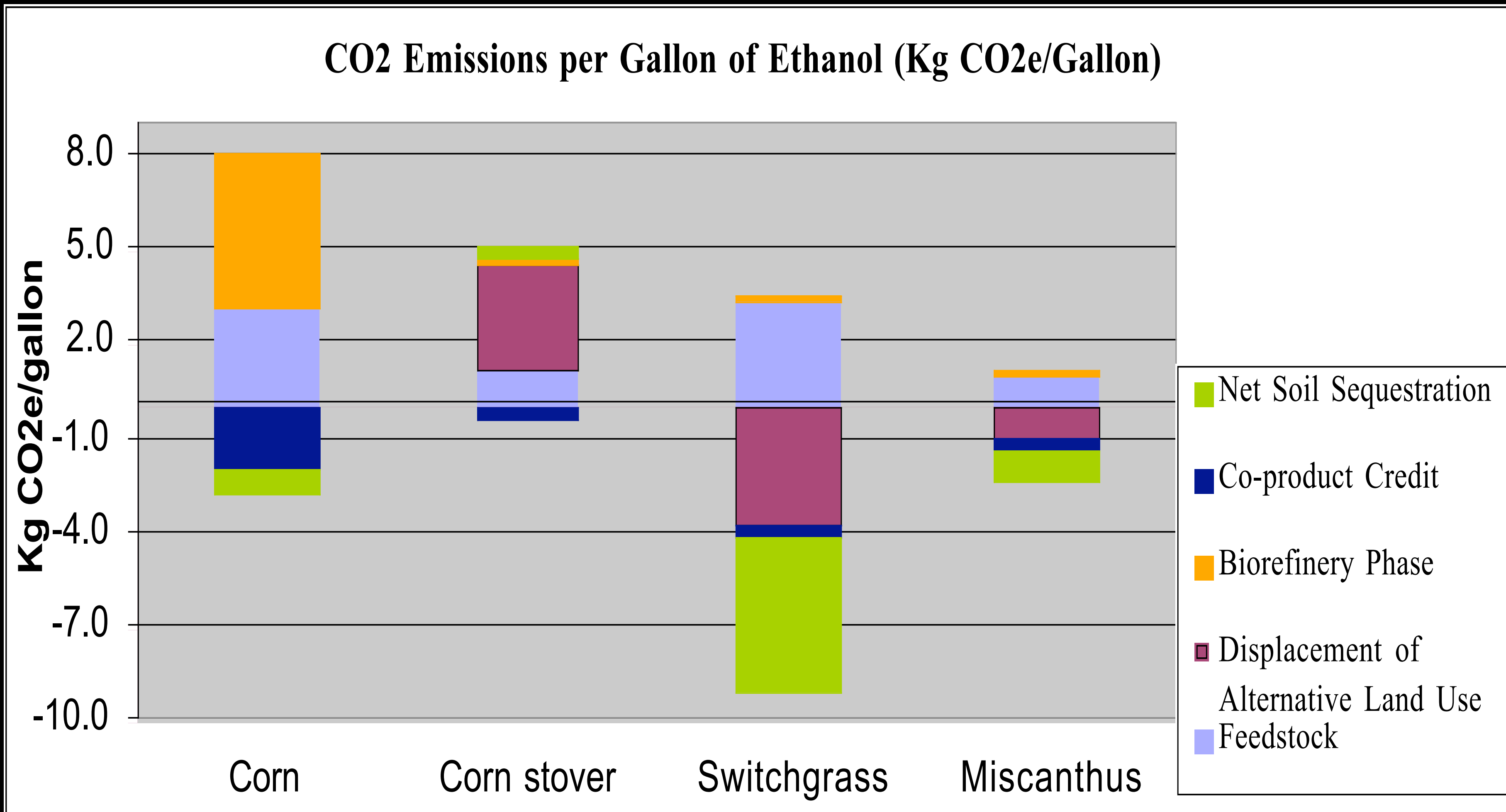
Competitiveness of Cellulosic Ethanol

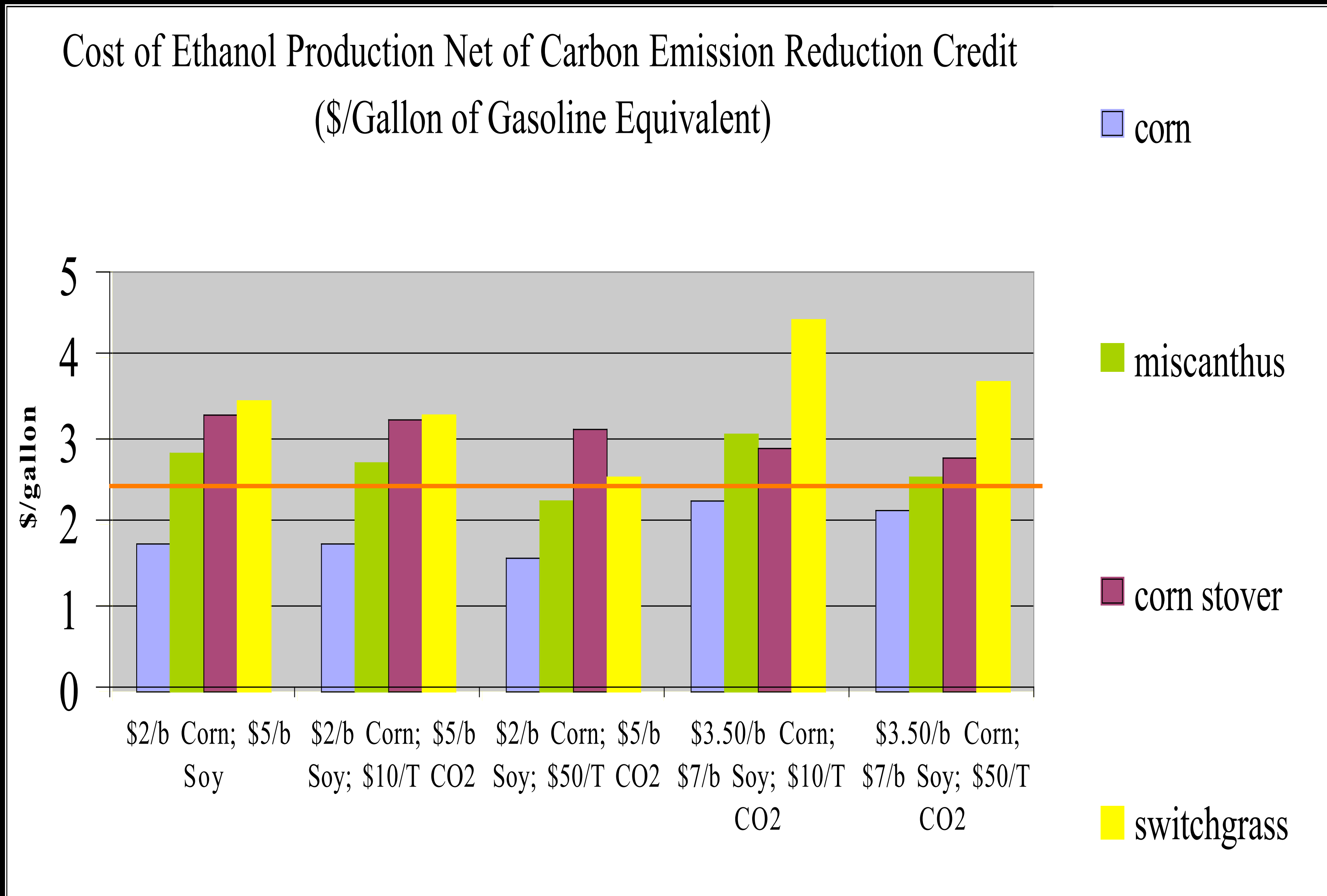

Ethanol Gallons Per Acre
800
700
600
500
400
300
200
100
0
Corn
Corn Stover
Corn+Corn Stover
Switchgrass
Miscanthus


Acres Needed for 22 Billion Gallons of Ethanol
Millions Acres
160
140
120
100
80
60
40
20
0
Corn
Corn Stover
Corn+Corn Stover
Switchgrass
Miscanthus



- Figures above bars represent cost of production net of co-product credit (2003 prices except current energy input costs for corn-ethanol); 40 M gal. corn-ethanol plant and 25 M gal. cellulosic ethanol plant ; Corn price of $3.50/b and Soybean Price $7/b
- Process for cellulosic ethanol production with mature technology: dilute acid prehydrolysis with enzymatic saccharification of remaining cellulose and co-fermentation of glucose to ethanol (USDA/USDOE, 2005)


CO2 Emissions per Gallon of Ethanol (Kg CO2e/Gallon)
Kg CO2e/gallon
8.0
5.0
2.0
-1.0
-4.0
-7.0
-10.0
Corn
Corn stover
Switchgrass
Miscanthus
Net Soil Sequestration
Co-product Credit
Biorefinery Phase
Displacement of Alternative Land Use
Feedstock


Cost of Ethanol Production Net of Carbon Emission Reduction Credit
($/Gallon of Gasoline Equivalent)
corn
miscanthus
corn stover
switchgrass
$/gallon
0
1
2
3
4
5
$2/b Corn; $5/b Soy
$2/b Corn; $5/b Soy; $10/T CO2
$2/b Corn; $5/b Soy; $50/T CO2
$3.50/b Corn; $7/b Soy; $10/T CO2
$3.50/b Corn; $7/b Soy; $50/T CO2

Summary

- Considerable spatial variability in allocation of land to bioenergy crops and to different types of bioenergy crops

- Fairly high bioenergy subsidies needed to induce a switch to miscanthus for electricity generation or ethanol production
  - Unless carbon emissions reduction is valued

- Incentives for bioenergy crops could also come from agro-environmental policy
  - rewarding other soil and water quality benefits from bioenergy crops

- Need for coordination between energy policy, climate policy and conservation policy