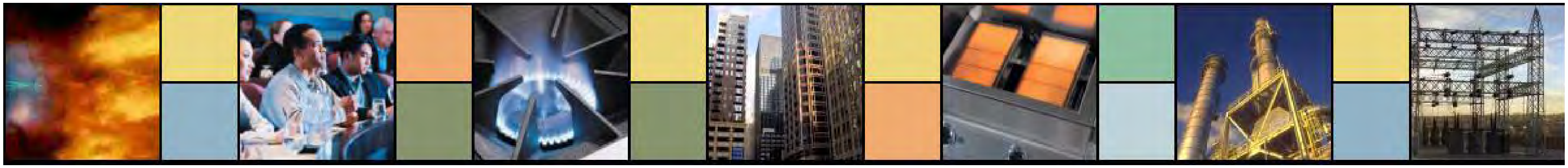

The Global Warming and Land Use Impact of Corn Ethanol - A Detailed Assessment at the Plant Level of the Illinois River Ethanol Facility

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Background

Scope

- Develop Understanding of the Global Warming Impact (GWI) of Corn Ethanol Produced at the Illinois River Energy (IRE) Ethanol Plant
  - Take current agricultural practices into account with Survey of Corn Growers delivering to IRE
  - Take current ethanol plant production methods into account with actual Energy Balance of the IRE Plant
  - Look at land use changes with Satellite Data

Goal

- Coordinate with EPA, DOE, CA and other Policy Stakeholders
- Inform Policy Making Process

Use of Life Cycle Analysis (LCA) to Determine the Global Warming Impact (GWI) of Corn Ethanol - Introduction

- The GWI of Corn Ethanol for the purpose of this study is defined as the sum of the emissions of

  Carbon Dioxide (CO_2),
  Nitrous Oxide (N_2O), and
  Methane (CH_4)

  emitted on a **<u>life cycle basis</u>** weighted by the global warming potential of each gas as defined by the Intergovernmental Panel on Climate Change (IPCC).

- Common Units are:

  gCO_2eq/MJ

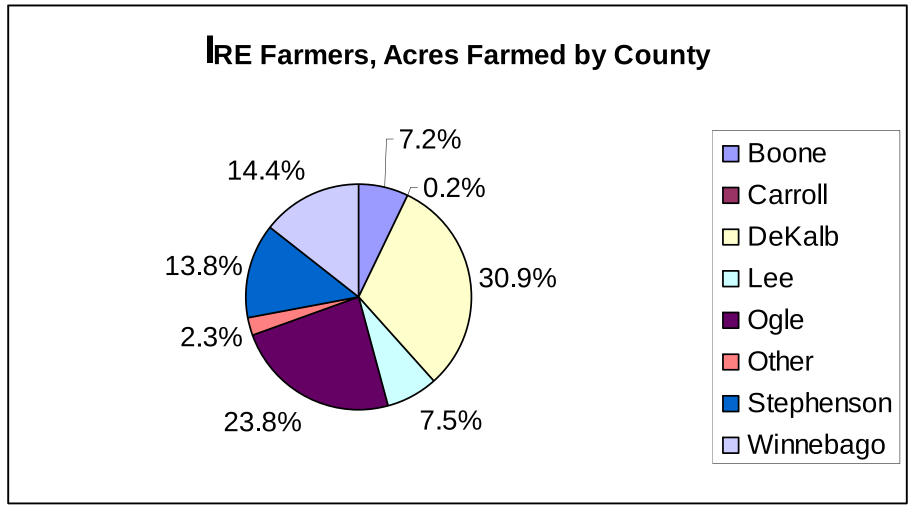
  $gCO_2eq/MMBtu$

Use of Life Cycle Analysis (LCA) to Determine the Global Warming Impact (GWI) of Corn Ethanol - Introduction

Life Cycle Analysis (LCA) of Corn Ethanol	Life Cycle Analysis of Petroleum-Based Fuels
GWI contributions from:	**GWI contributions from:**
Feedstock production including agricultural inputs and on-farm energy use: fertilizer inputs, tractor fuel, custom work, etc.	Oil Exploration and Extraction
Transportation from the field/farm to the Ethanol Plant	Transportation to the Refinery
Conversion at the Ethanol Plant including combustion of thermal fuel and use of purchased electricity	Conversion at the Refinery
Distribution to the Blending Terminal/Gas Station	Distribution to the Enduser/Gas Station
Combustion in the Vehicle	Combustion in the Vehicle

Survey of Corn Growers Delivering to IRE

- Conducted Growers Survey of IRE growers
- Mailed out to 100 growers
- Stratified random sampling
- 31% response rate
- 29 valid responses
- Respondents delivered 2.5 million bushels to IRE over 12 month period
  - 12% of all bushels processed
  - Equivalent of 6.9 million gallons of ethanol produced at IRE



Agricultural Practices Survey, Selected Results

Yield

	2005 Bu/acre	2006 Bu/acre	2007 Bu/acre
Yield	167.4	183.1	196.1
STD	23.3	23.3	19.5
N=28			

N-Fertilizer

	lb/acre	g/bu
Mean	159	368
STD	40	90
N=27		

Tractor Fuel

	gal/acre	gal/bu
Mean	5.5	0.028
STD	2.2	0.011
N=18		

Custom Machine Hire

	Fertilizer Application (gal/bu)	Pesticide Application (gal/bu)	Combining of Crop (gal/bu)	Crop Hauling (gal/bu)	Total Custom Machine Hire (gal/bu)	Total Custom Machine Hire (Btu/bu)
Mean	0.0026	0.0024	0.0012	0.0011	0.0073	933
STD	0.003381	0.005616	0.002957	0.002878		
N=14						

Approach

- Life Cycle Modeling for the present study is based on Argonne National Laboratory's "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation" (GREET) Model.
- Agriculture on-farm energy assumptions (tractor fuel, custom hauling, etc.) in GREET 1.8b version are based on USDA average data for the Midwest.
- Following the GREET methodology, we substituted IRE Survey Data into the GREET underlying data templates.

IRE Survey Substitutes GREET Default Values

Corn Farming Energy Inputs		IL Avg	IRE Avg	US Avg	US Avg	IRE Avg	GREET 2010
Data Source:		**1996 USDA**	**1996 USDA**	**1996 USDA**	**2001 USDA**	**2001 USDA**	**1996 USDA Mod**
Yield	bu/acre	126.0	**196.1**	125.0	139.3	**196.1**	158
Seed	kernels/acre	25384.0	*25384.0*	25495.0	28739.0	28739.0	
Fertilizer:							
Nitrogen	lb/acre	160.0	**159.0**	129.4	133.5	**159.0**	146
Potash	lb/acre	102.0	**118.0**	59.3	88.2	**118.0**	51
Phosphate	lb/acre	71.0	**64.0**	48.2	56.8	**64.0**	62
Energy:							
Diesel	gal/acre	7.0	**5.2**	8.6	6.9	**5.2**	
Gasoline	gal/acre	3.0	**0.3**	3.1	3.4	**0.3**	
LPG	gal/acre	5.0	*5.0*	6.4	3.4	3.4	
Electricity	kWh/acre	15.0	15.0	77.1	33.6	33.6	
Natural gas	cu ft/acre	150.0	150.0	200.0	246.0	246.0	
Custom work	Btu/bu	3146.0	**933.0**	3366.0	1581.0	**933.0**	
Input hauling	Btu/bu	920.0	**384.0**	663.0	202.0	**384.0**	
Conversions to Btu/bu (LHV)							
Diesel	Btu/bu	7,136	3,422	8,837			
Gasoline	Btu/bu	2,764	163	2,870			
LPG	Btu/bu	3,371	2,166	4,322			
Electricity	Btu/bu	406	261	2,105			
Natural Gas	Btu/bu	1,170	752	1,573			
Custom work	Btu/bu	2,662	789	2,848			
Input hauling	Btu/bu	721	301	520			
Total Ag Energy (LHV)	Btu/bu	18,230	7,855	23,075	16,176	7,192	22,500

GREET 1.8b – July 2008 Revised to: **12,635 Btu/bu**

*Values in Blue are Substituted Survey Values

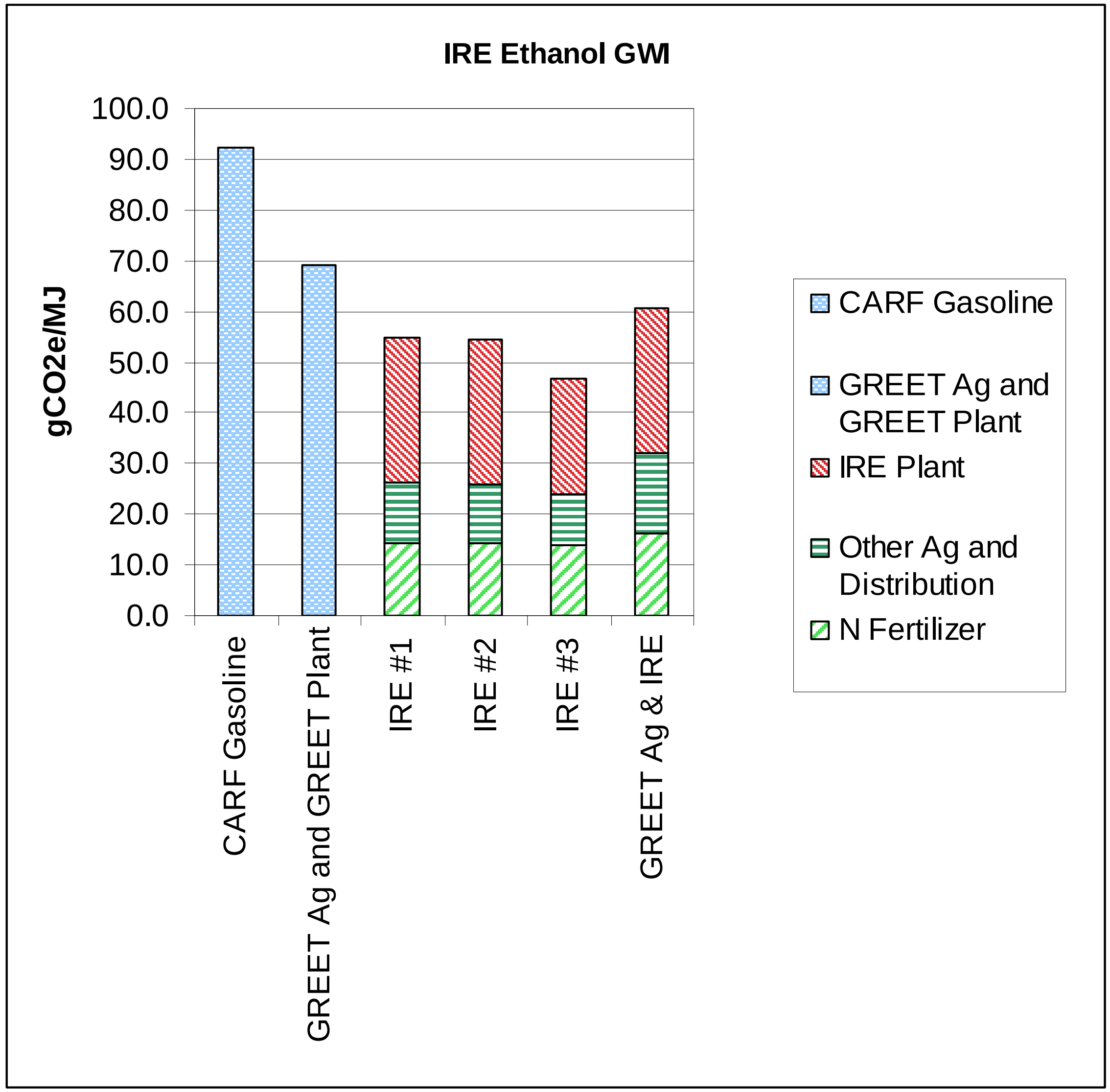
IRE Plant Energy Consumption

	IRE (LHV)	GREET
Thermal Energy (Btu/gal)	26,981	33,330
Electricity (kWh/gal)	0.71	0.75
Yield (gal/bu)	2.73	2.72

IRE GWI: Results

Cases

- Gasoline
- GREET Agriculture Default with GREET Default Plant Energy Consumption
- GREET Agriculture Default with IRE Plant Energy Consumption
- IRE Case #1: Substituting GREET derived ag. inputs (USDA-1996 template) with IRE Survey
- IRE Case #2: Substituting USDA-2001 template with IRE Survey
- IRE Case #3: Sensitivity to Case 1. Substituting Illinois SERC grid for ComEd grid



IRE GWI Results

	CARF Gasoline	GREET Ag and GREET Plant	IRE #1	IRE #2	IRE #3	GREET Ag & IRE
			GWI (g/MJ)			
N Fertilizer			14.2	14.2	13.9	16.3
Other Ag and Distribution			11.9	11.6	9.9	15.8
IRE Plant			28.7	28.7	22.9	28.7
GREET Ag and GREET Plant		69.1				
CARF Gasoline	92.1					
Total GWI:	92.1	69.1	54.8	54.5	46.7	60.8
Red. GREET Default:			-20.7%	-21.2%	-32.4%	-12.0%

IRE GWI Results

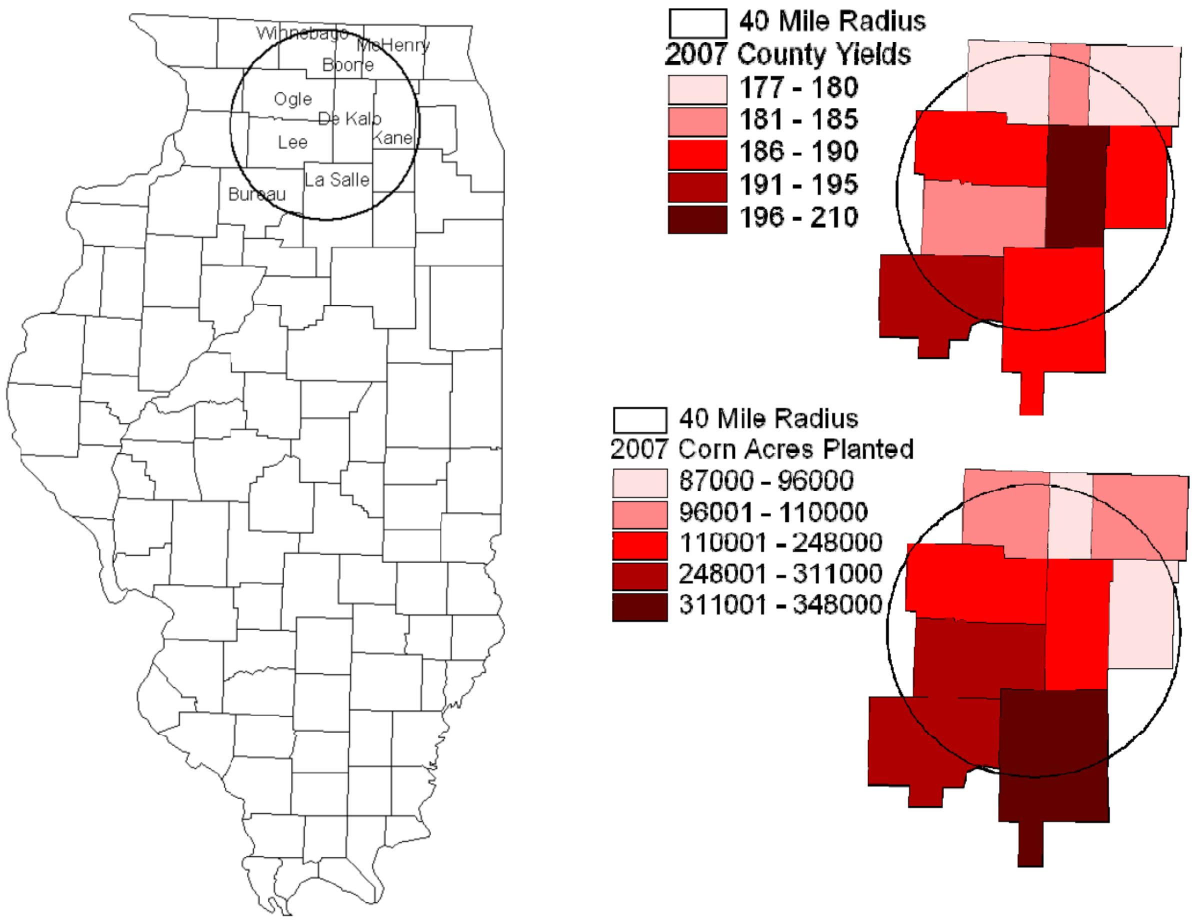
- IRE ethanol offers significantly reduced life cycle global warming emissions compared to the current GREET default values for current US average corn ethanol and for gasoline.
- Depending on the assumptions GWI reductions from GREET Default's National Average corn ethanol range between 21% to 32%.
- The key components contributing to the GWI reduction are:
  - High prevailing yields and lower nitrogen application (196.1 bu/acre vs 158 bu/acre yield and 368 gN/bu vs 420 gN/bu)
  - Reduced agricultural energy consumption in IRE's corn draw area (5.5 gal/acre vs. 11.7 gal/acre)
  - Lower custom work and input hauling energy consumption
  - Lower ethanol plant energy consumption (29,404 Btu/gal vs. 35,889 btu/gal, LHV inclusive of electricity)

Impact of Land Use Change

- Recent discussions in literature assert that land use change from corn agriculture results in large GWI increases from direct and indirect effects
  - Direct Effects: Change in crop rotations of corn draw area around ethanol plant
  - Indirect Effects (example): Increased corn production results in decreased soy production locally which results in increased soy production elsewhere
- Searching et al cites 104 g/MJ for LUC (30 year amortization)
- Current study takes detailed look at direct LUC
- Current study establishes carbon balance between N2O Emissions and C-Sequestration for the IRE Corn Draw Area

Determine Corn Draw Area (from Survey)

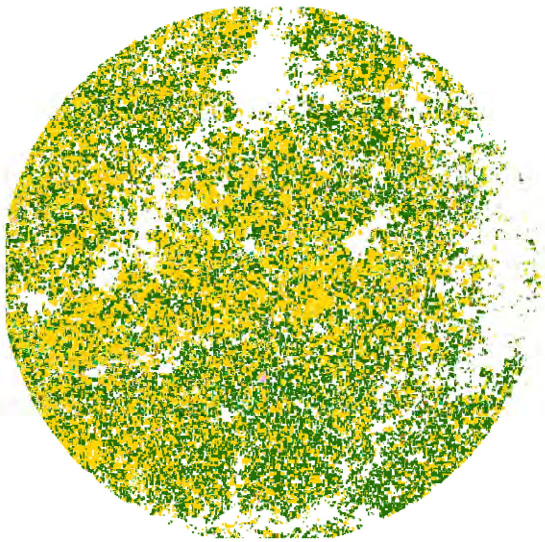
Counties in the 40-mile Radius and USDA NASS Data



Determine Crop Rotations for IRE Corn Draw Area

What Were 2007 Corn Acres in 2006
(Land Use Change to Corn)

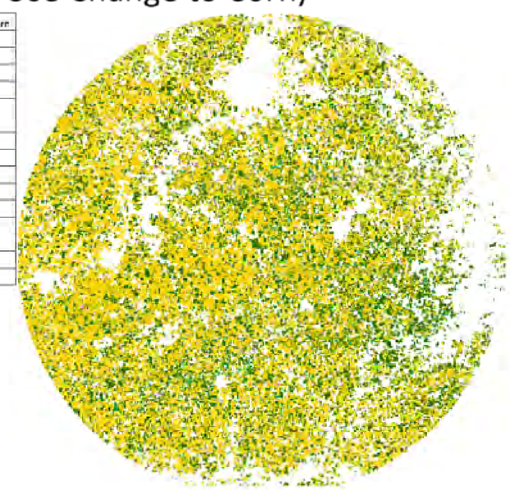
Legend	Acres Converted to Corn
Corn	682924
Soybeans	665744
Winter Wheat	14451
Other Small Grains	739
Win. Wht./Soyb. Dbl. Cropped	279
Alfalfa	6941
Other Crops	11212
Fallow/Idle Cropland	6821
Grass/Pasture/Non Ag	93009
Woodland	3463
Urban/Developed	1846
Water	120
Wetlands	11
Total	1494959



- USDA-NASS Cropland Data Layer
- Derived from satellite imagery
- 40 mile radius surrounding IRE

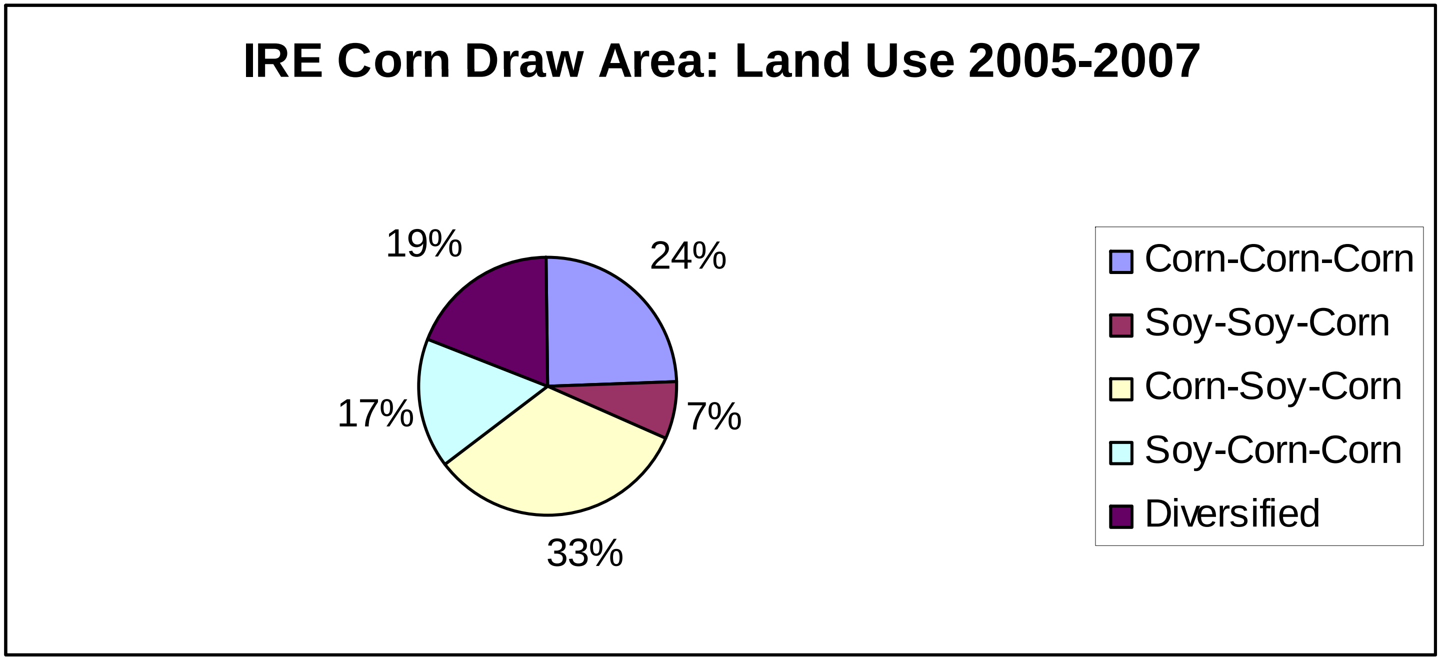
What Were 2007 Corn Acres in 2005
(Land Use Change to Corn)

Legend	Acres converted to corn
Previously Corn	873,451
Soybeans	460,778
Winter Wheat	196
Other Small Grains	8783
Win. Wht./Soyb. Dbl. Cropped	599
Oats	784
Alfalfa	14,570
Other Crops	13,032
Fallow/Idle Cropland	965
Grass/Pasture/Non Ag	143347
Woodland	10961
Urban/Developed	3502
Water	149
Wetlands	5017
Total	1,494,717

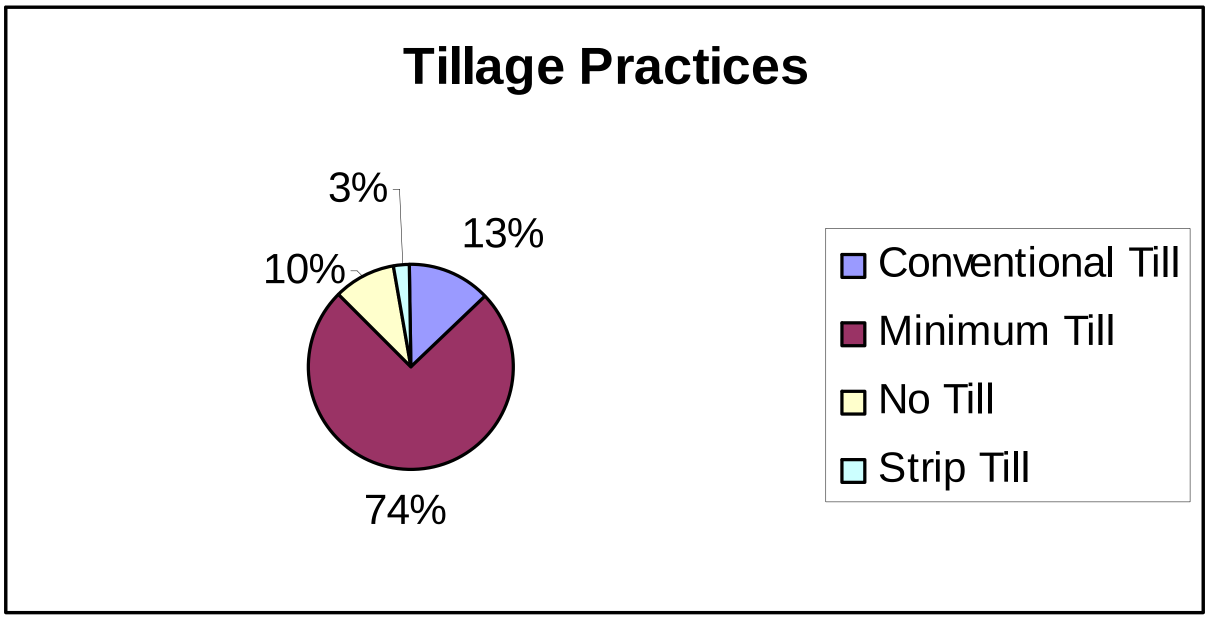


- Interpret non-cropland areas with caution
  - Uses 2001 NLCD

Determine Crop Rotations from Satellite Imagery



Determine Tillage Practices from IRE Growers Survey



Apply Emissions and Sequestration Factors

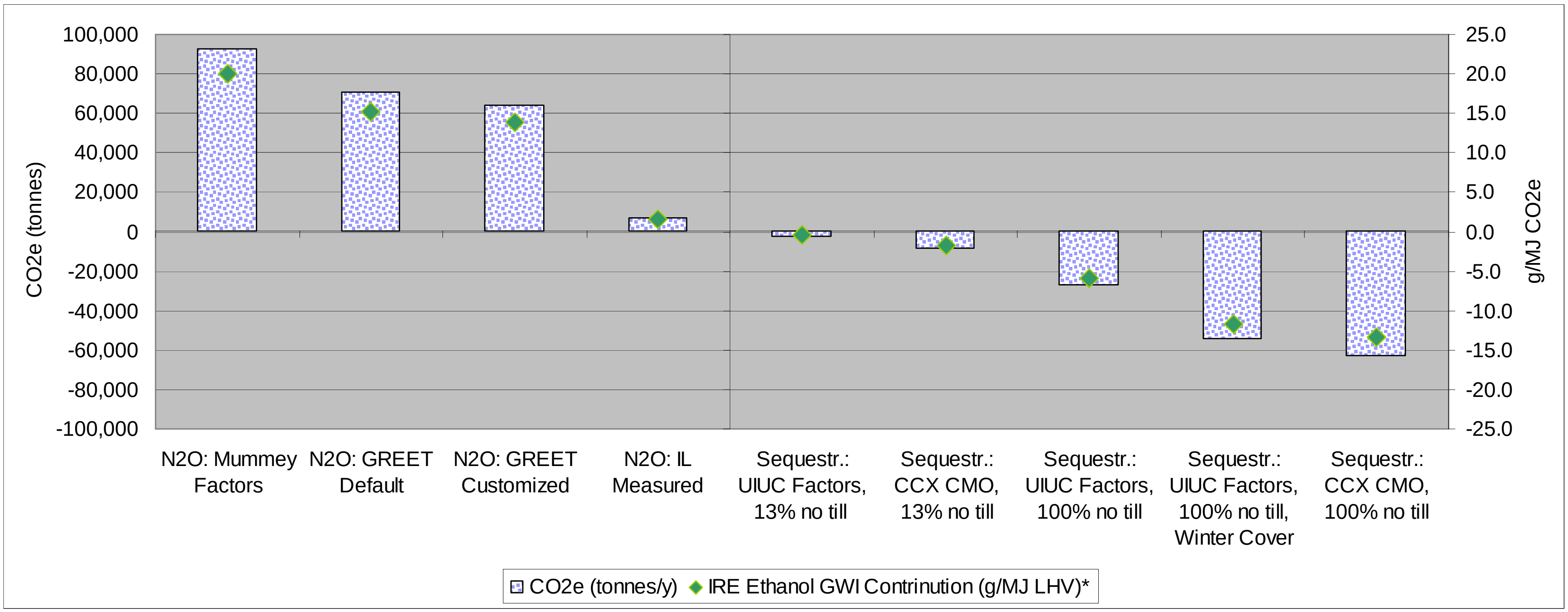
Table 17: N_2O Emission Factors by Mummey et al

	CSC and SSC kg N_2O-N/ha per y	SCC and CCC kg N_2O-N/ha per y	Diversified kg N_2O-N/ha per y
Conv.Till	3.7	2.9	4.8
No Till	4.2	3.6	4.6

Table 20: CO_2 Sequestration Factors by Eve et al

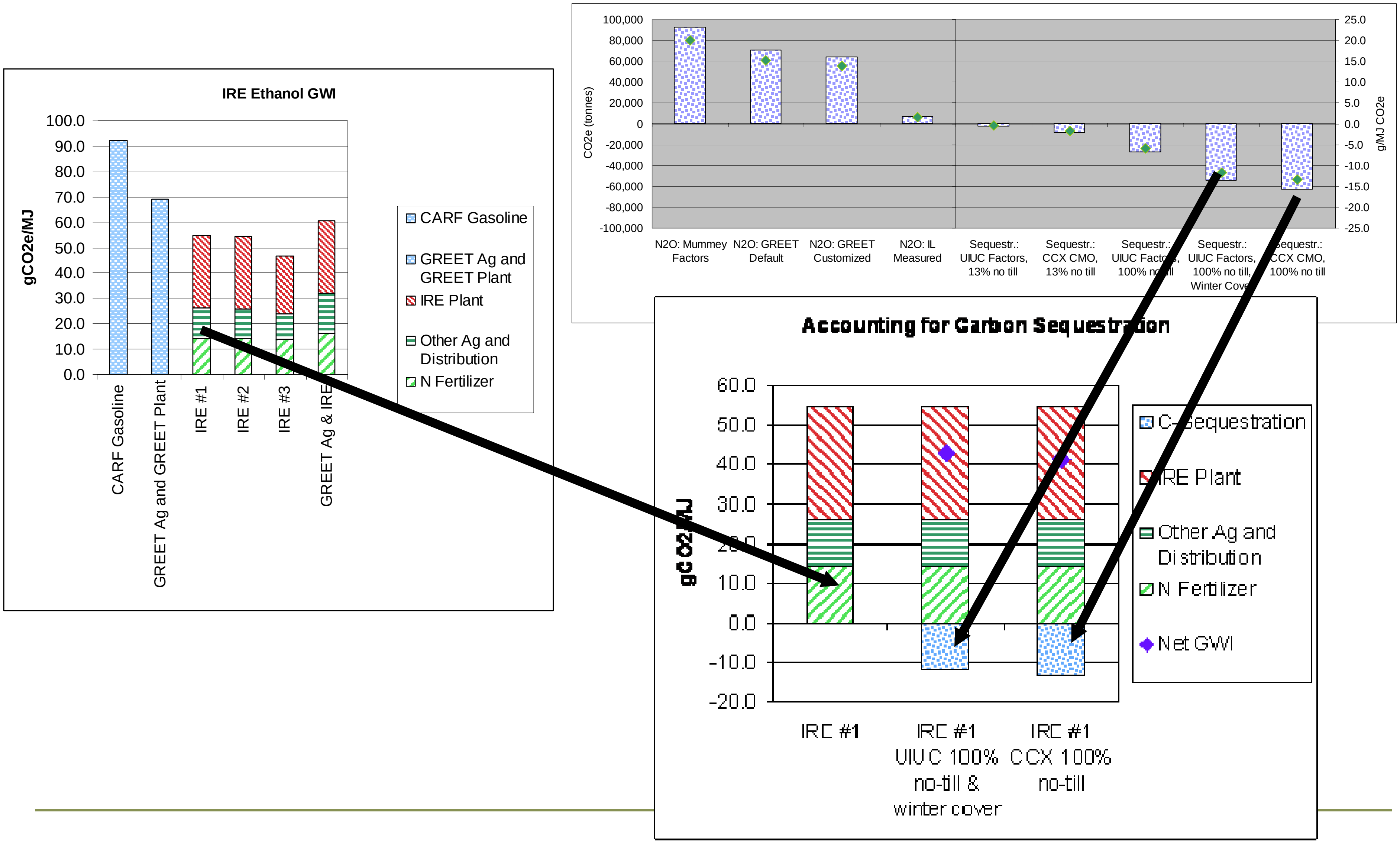
	CSC and SSC MT C/acre per year	SCC and CCC MT C/acre per year	Diversified MT C/acre per year
Conventional Till	0.01	0.05	-0.15
No Till	0.02	0.2	-0.1

Carbon Sequestration vs. N2O Emissions

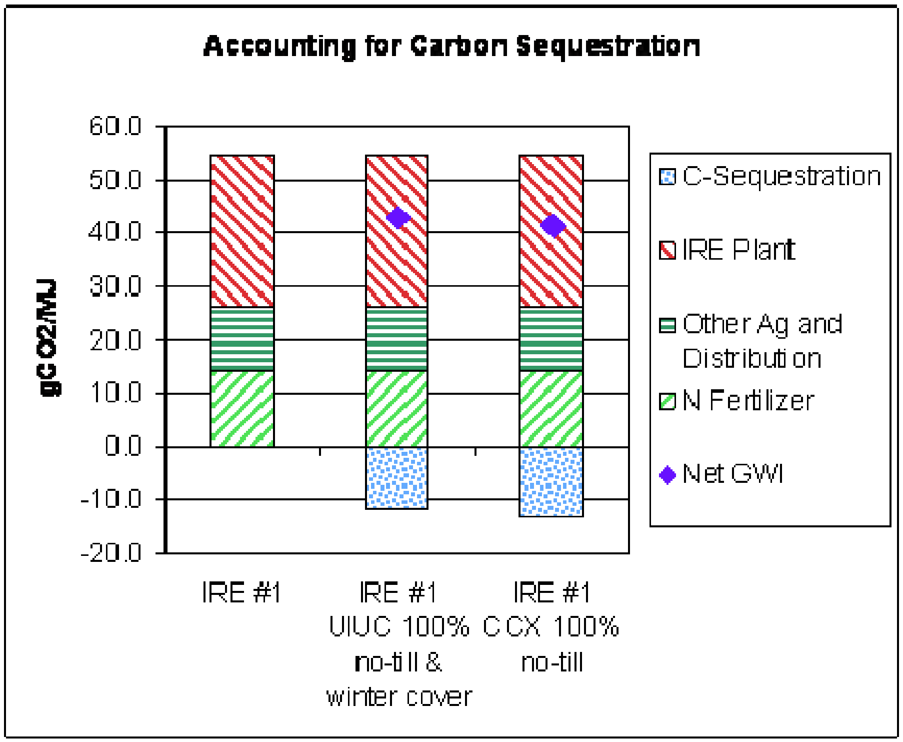


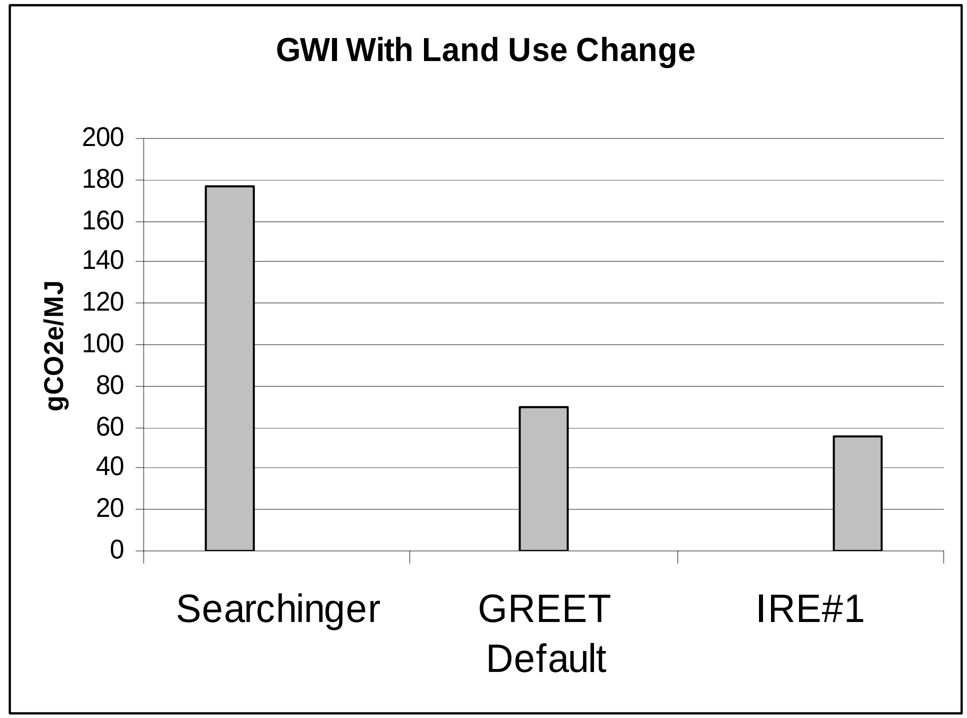
- Depending on the Methodology, no-till and planting of winter cover crops can result in large projected carbon sequestration values (50,000 tonnes or 12 g/MJ of CO_2e)

Take Carbon Sequestration Into Account



Take Carbon Sequestration into Account





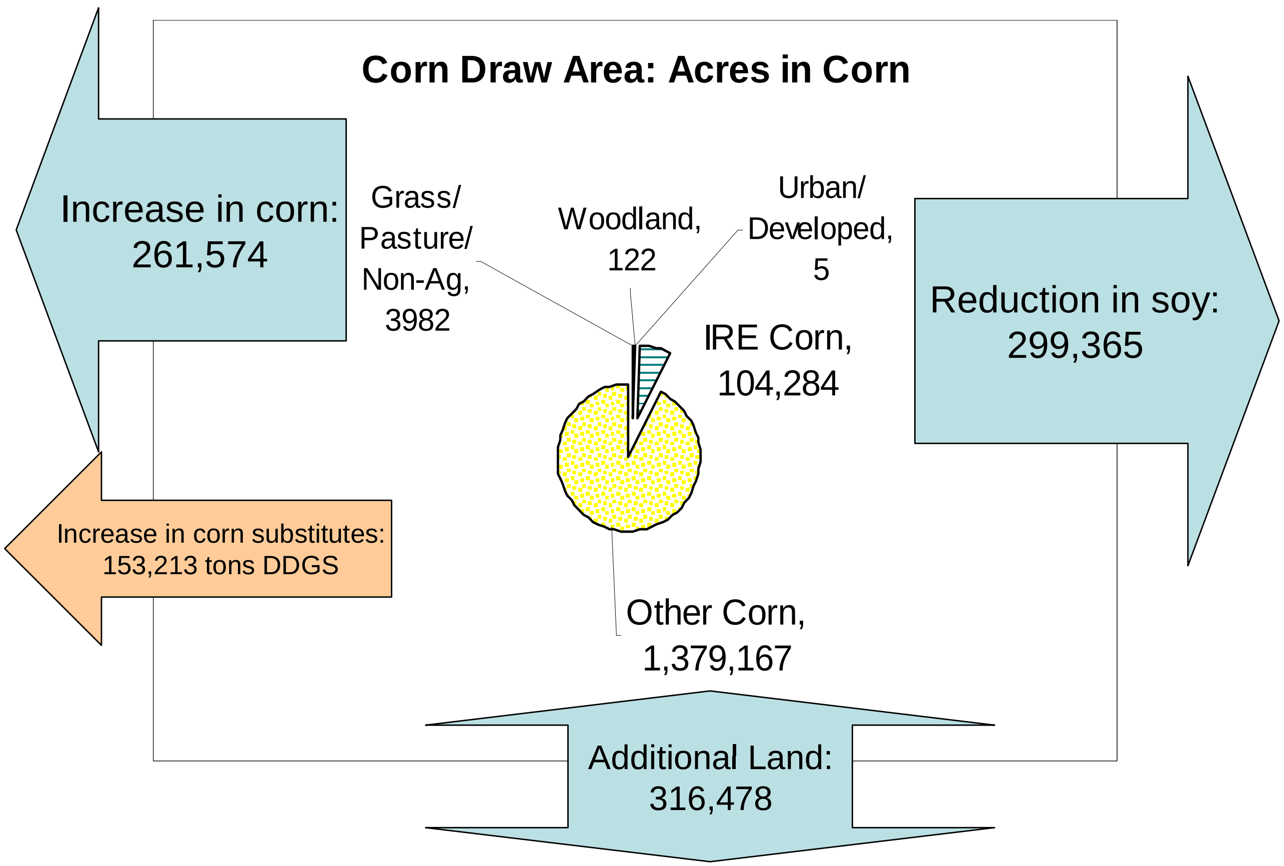
- IRE Case #1
  Ethanol GWI with SERC Electric Grid with winter cover and no till: 43.1 gCO2e/MJ
- Searchinger GWI for Corn Ethanol: 177 gCO2e/MJ (incl. 104 gCO2e/MJ from Land Use Change). GREET Default and IRE include 0.7 gCO2e/MJ for Land Use Change).

Results

- The current statistical approach may result in over-estimating pasture to agricultural land conversions and therefore over-estimate net emissions additions
- Carbon sequestration effects could be of the same magnitude as N2O emissions
- Variable rate nitrogen fertilizer application, winter crops, and no-till can significantly improve the overall GWI from land use change
- Ethanol produced from
  - low carbon agricultural practices combined with
  - modern, low carbon ethanol plant energy systems

  could constitute an "Advanced Biofuel" if only direct land use change impacts are considered.

New Study:
Did the Ethanol Plant Cause Extensification or Intensification in Agriculture



Questions?

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