Assessing Additionality of Carbon Savings with Corn Ethanol

Madhu Khanna and Weiwei Wang
University of Illinois, Urbana-Champaign

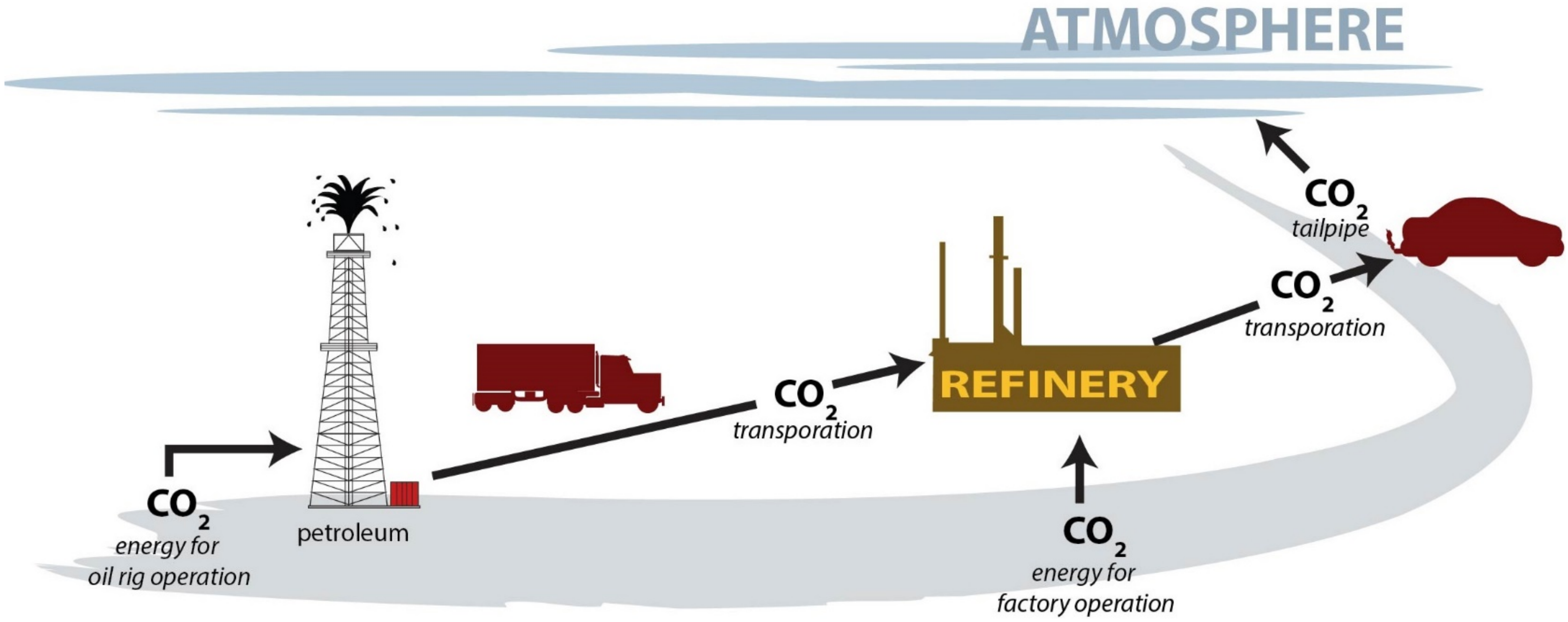
Motivation for this research

- Calculation of carbon intensity of corn ethanol is based on the assumption that corn is a carbon neutral feedstock
  - Includes life-cycle emissions but not biogenic emissions

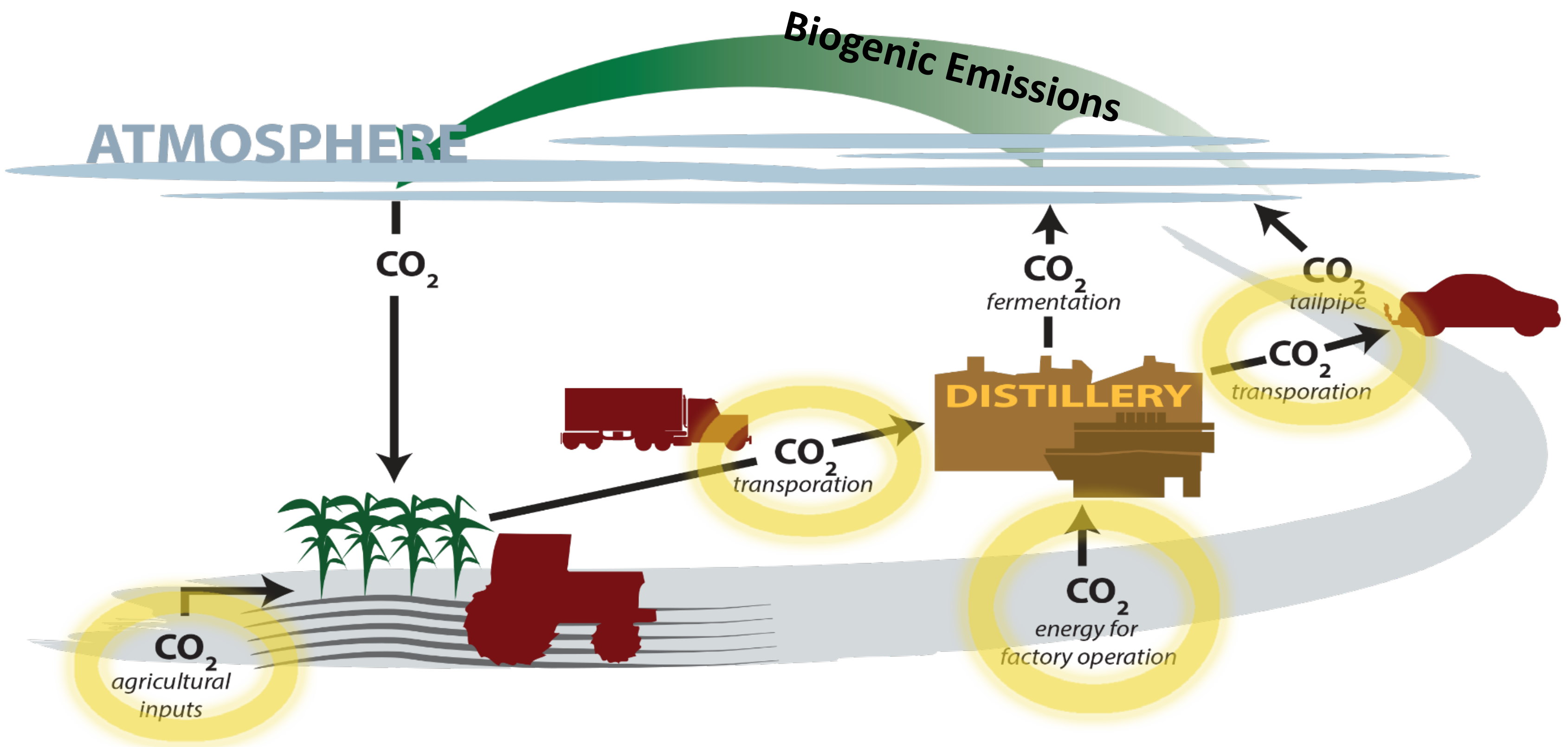
- Requires assuming that all the corn grown for ethanol is additional to corn production otherwise

  - All corn used for ethanol is sequestering additional carbon than would have been sequestered otherwise
  - This additional carbon then balances the carbon released during corn ethanol production at the refinery and corn ethanol combustion in the vehicle (tail pipe emissions)

Carbon emissions from fossil fuel use in vehicle



Carbon Emissions from Biofuel Use in Vehicle



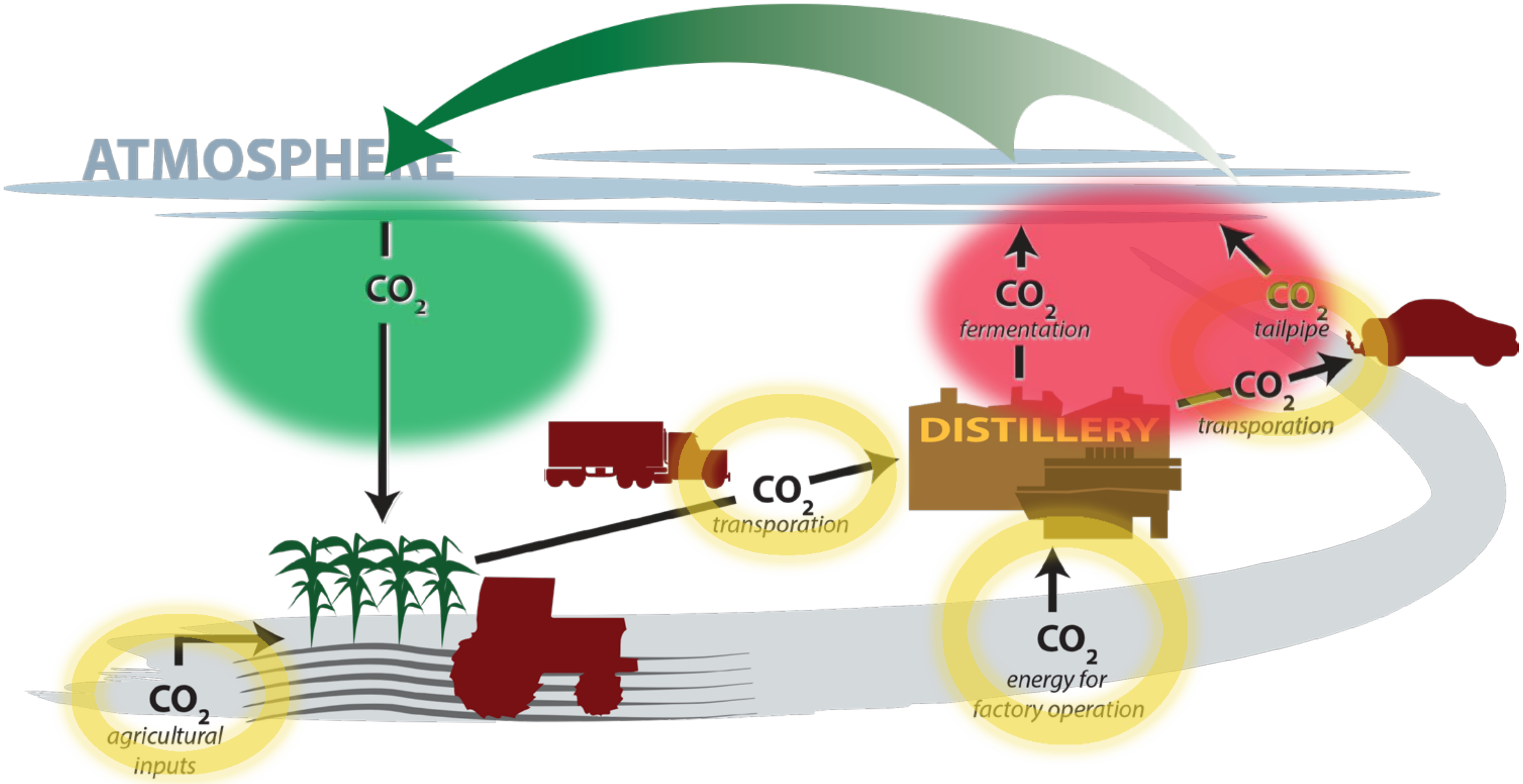
- Ethanol emissions from tailpipe 74
- Emissions from ethanol plant 33
- Total biogenic emissions 107

LCA Accounting Rules (grams CO_2e/MJ)

Corn Ethanol		**Fossil Gasoline**	
• Ag inputs and N_2O	32	• Refinery	11
• Distillery	31	• Crude production	6
• Transport & other	5	• Transport	3
Subtotal	68	Subtotal	20
• DDGS credit	-14	• Tailpipe emissions	74
Total Emissions	52	Total emissions	94

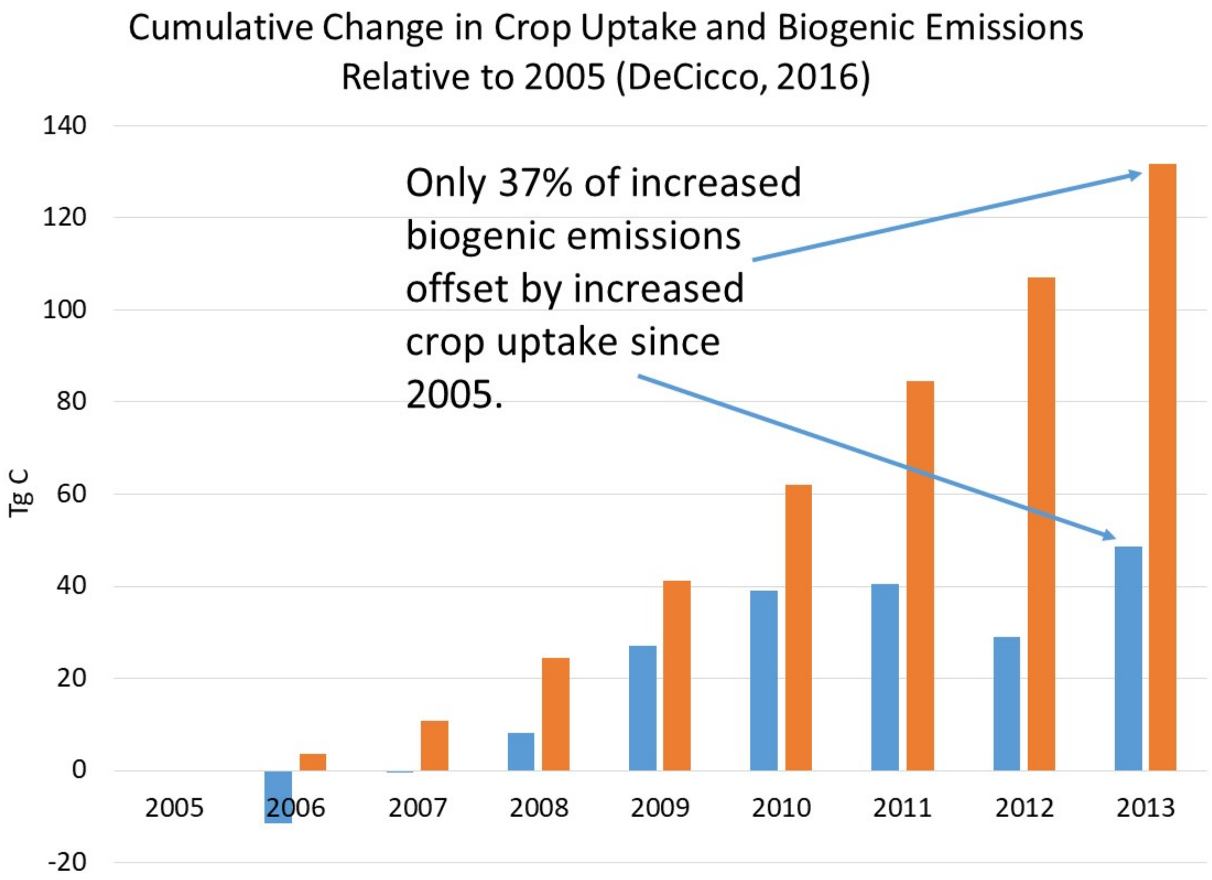
45% emission reduction from corn ethanol

Effect of corn ethanol on carbon cycle



Annual Basis Carbon Accounting Method

- Track physical carbon flows on an annual basis (ABC).
  - Any additional flow of carbon to atmosphere is an emission
  - Any additional flow of carbon from the atmosphere into crops is negative emissions



*Plevin, RJ, MA Delucchi, and F. Creutzig. 2014. “Using attributional life cycle assessment to estimate climate-change mitigation benefits misleads policy makers.” *J. of Industrial Ecology* 18:73-83.

DeCicco, et al. 2016. “Carbon balance effects of U.S. biofuel production and use.” *Climatic Change* 138:667-680.

ABC Accounting Rules (grams CO_2e/MJ)

Corn Ethanol	
• Total LCA Emissions	52
• Tailpipe emissions	74
• Fermentation	33
• Total emissions	159
Net crop uptake offset	40
Total Emissions	119

Fossil Gasoline	
• Refinery	11
• Crude production	6
• Transport	3
Subtotal	20
• Tailpipe emissions	74
Total emissions	94

Concerns with ABC Accounting Approach

- A "before" and "after" approach that attributes all changes over time to biofuel production
- Choice of starting point can overturn results
- Assumes that corn is the only crop that is affected by increased demand for corn ethanol
    - Ignores changes in biogenic carbon uptake due to reallocation of land among all row crops competing for land
    - Changes in carbon uptake due to changes in crop production in the rest of the world

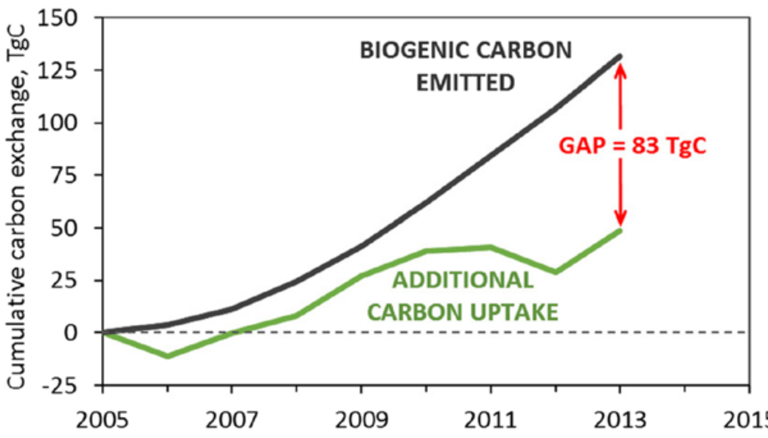


Fig. 2 Cumulative carbon emitted by US biofuel use compared to cumulative additional carbon uptake on cropland from 2005 to 2013 [Reproduced from DeCicco et al. 2016]

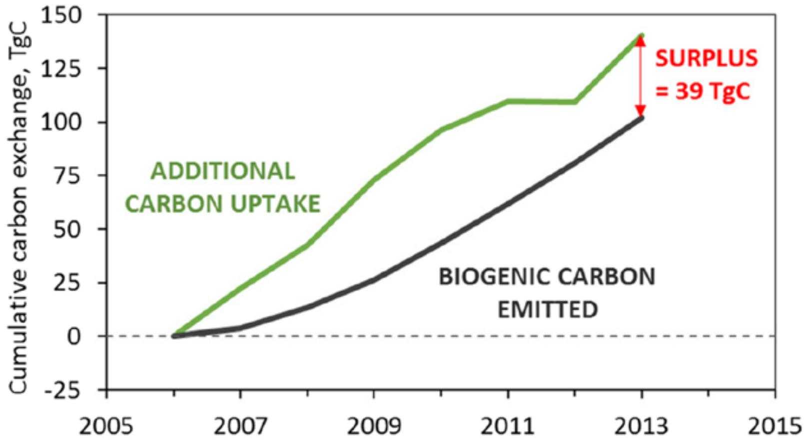


Fig. 3 Cumulative carbon emitted by US biofuel use compared to cumulative additional carbon uptake on cropland from 2006 to 2013

DeKliene et al., 2017

Purpose of this Research

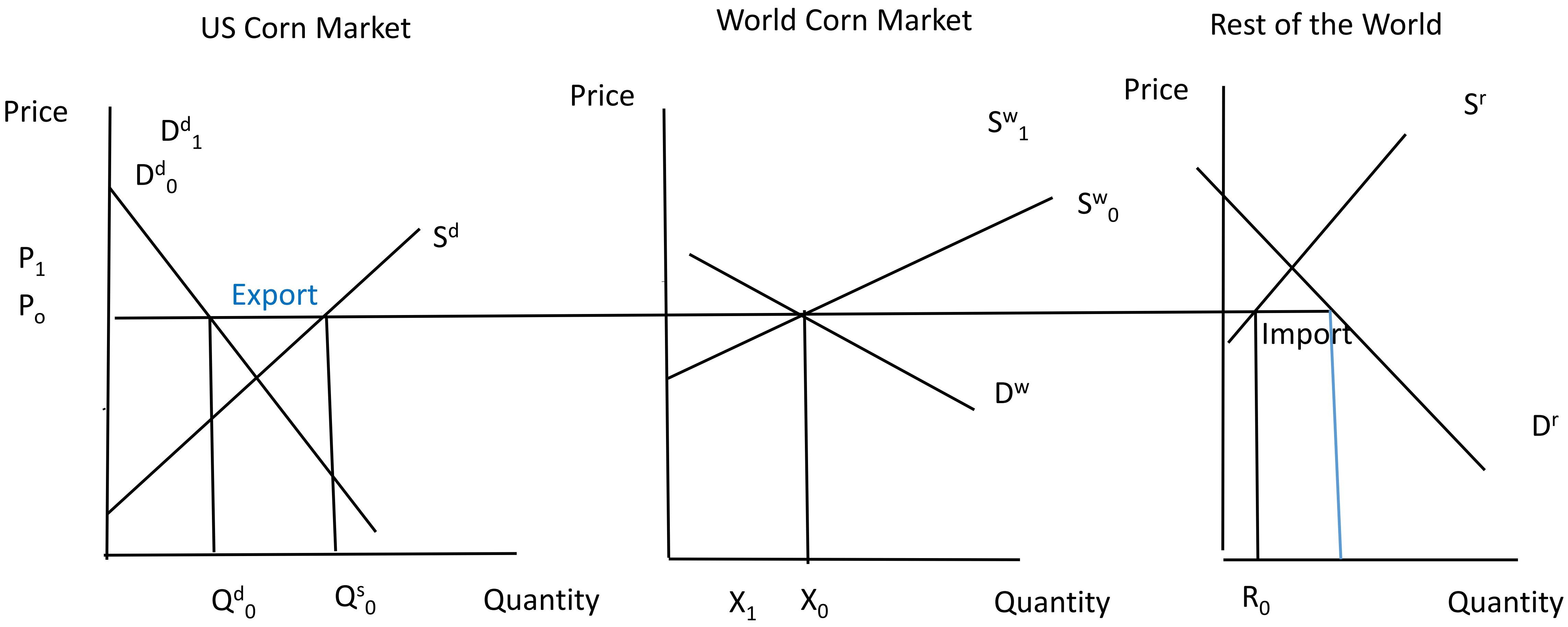
- To examine the extent to which the corn used for ethanol production is carbon neutral using an Anticipated Baseline Approach

- To examine the implications of including
  - any biogenic emissions and direct and indirect lifecycle emissions due to corn ethanol

  on the carbon intensity of corn ethanol and the carbon savings achieved by the Renewable Fuel Standard

- Compare findings using an anticipated baseline approach with those of the Annual Basis Carbon Accounting Approach in DeCicco (2016)

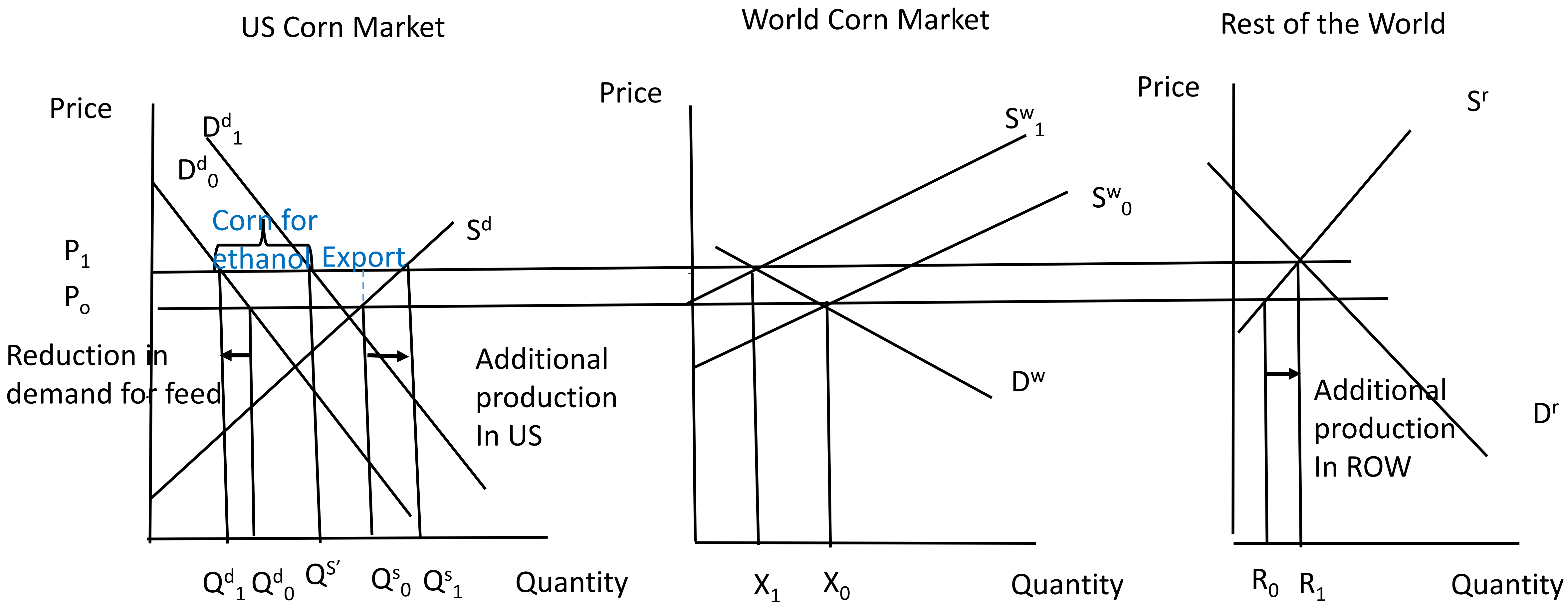
Conceptual Framework for our Analysis



Static Impact of Corn Ethanol on Domestic and World Corn Production

Without Ethanol

D^D_1, D^D_0: Domestic demand curve for corn without ethanol (0) and with ethanol (1)
Q^d_0 , Q^d_1 : Demand for corn without ethanol (0) and with ethanol (1)
Q^S_0 , Q^S_1 : Supply of corn without ethanol (0) and with ethanol (1)
P_1, P_0: Price of corn without ethanol (0) and with ethanol (1)
S^D S^R Supply curve for corn, domestic (D) and rest of the world (R)
S^w Excess supply curve for corn from the US
D^w Excess demand for US corn in the world market
D^R: Demand for corn in the Rest of the world
X_1, X_0 : Exports of US corn without ethanol (0) and with ethanol (0)
R_1,$R_{0:}$ Production of corn in the rest of the world without ethanol (0) and with ethanol (0)



D^D_1, D^D_0: Domestic demand curve for corn without ethanol (0) and with ethanol (1)

Q^d_0 , Q^d_1 : Demand for corn without ethanol (0) and with ethanol (1)

Q^S_0 , Q^S_1 : Supply of corn without ethanol (0) and with ethanol (1)

P_1, P_0: Price of corn without ethanol (0) and with ethanol (1)

S^D S^R Supply curve for corn, domestic (D) and rest of the world (R)

S^w Excess supply curve for corn from the US

D^w Excess demand for US corn in the world market

D^R: Demand for corn in the Rest of the world

X_1, X_0 : Exports of US corn without ethanol (0) and with ethanol (0)

R_1,R_0: Production of corn in the rest of the world without ethanol (0) and with ethanol (0)

Static Impact of Corn Ethanol on Domestic and World Corn Production

With Ethanol

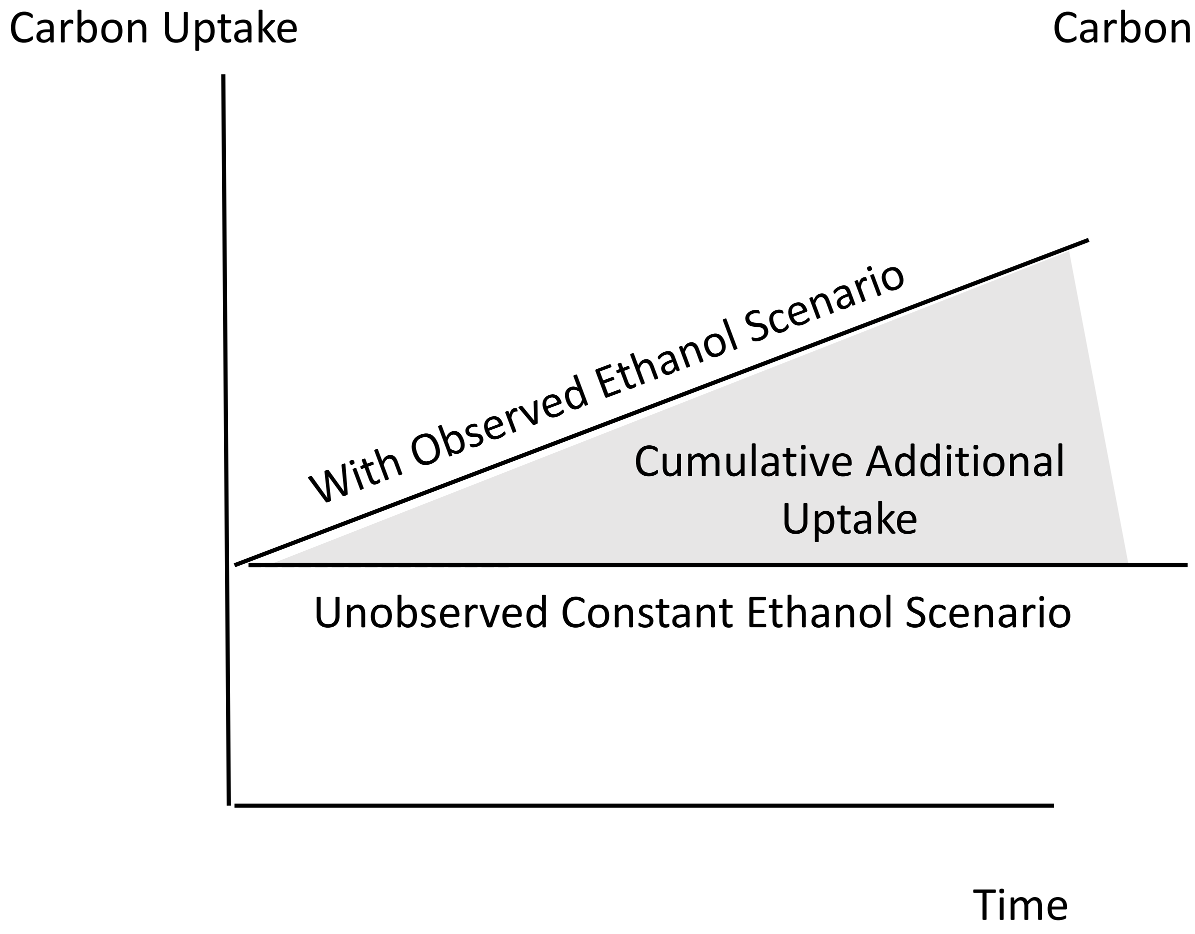
Biogenic impacts in other markets

- Increase in corn acreage in response to increased demand for corn ethanol can lead to changes at the

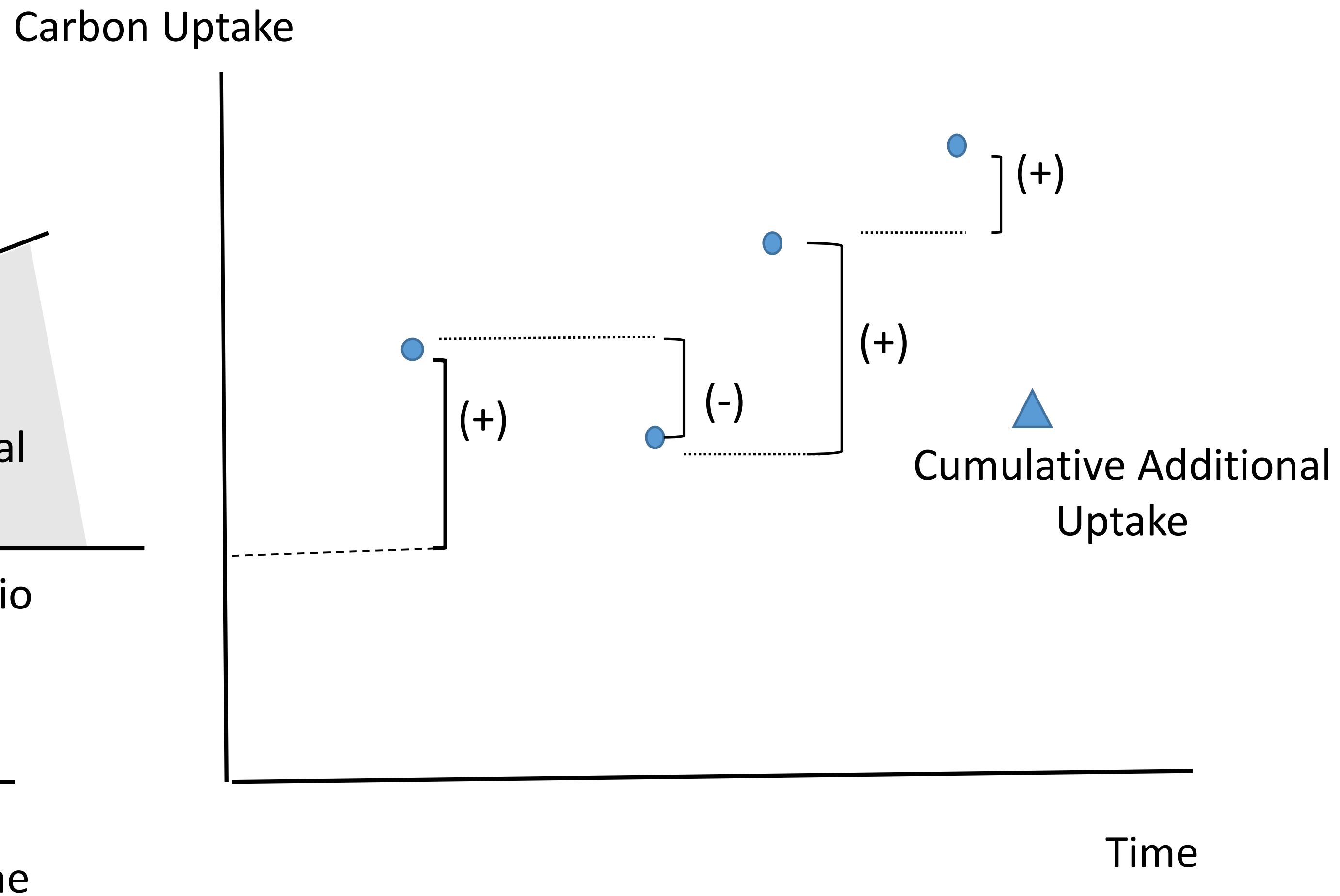
  - Intensive margin- switch land from other crops to corn
    - Could increase or decrease overall carbon uptake depending on relative yields per acre
    - Increase crop yields that are price elastic and increase carbon uptake per unit land

  - Extensive margin – increase total cropland by converting marginal land to cropland
    - Increase carbon uptake on pasture land by crop production

Effect of Corn Ethanol Production Over Time on Biogenic Carbon Uptake



Anticipated Baseline Approach



Annual Basis Carbon Accounting Approach

The Unobserved and Observed Ethanol Scenarios are the same except for the level of ethanol produced

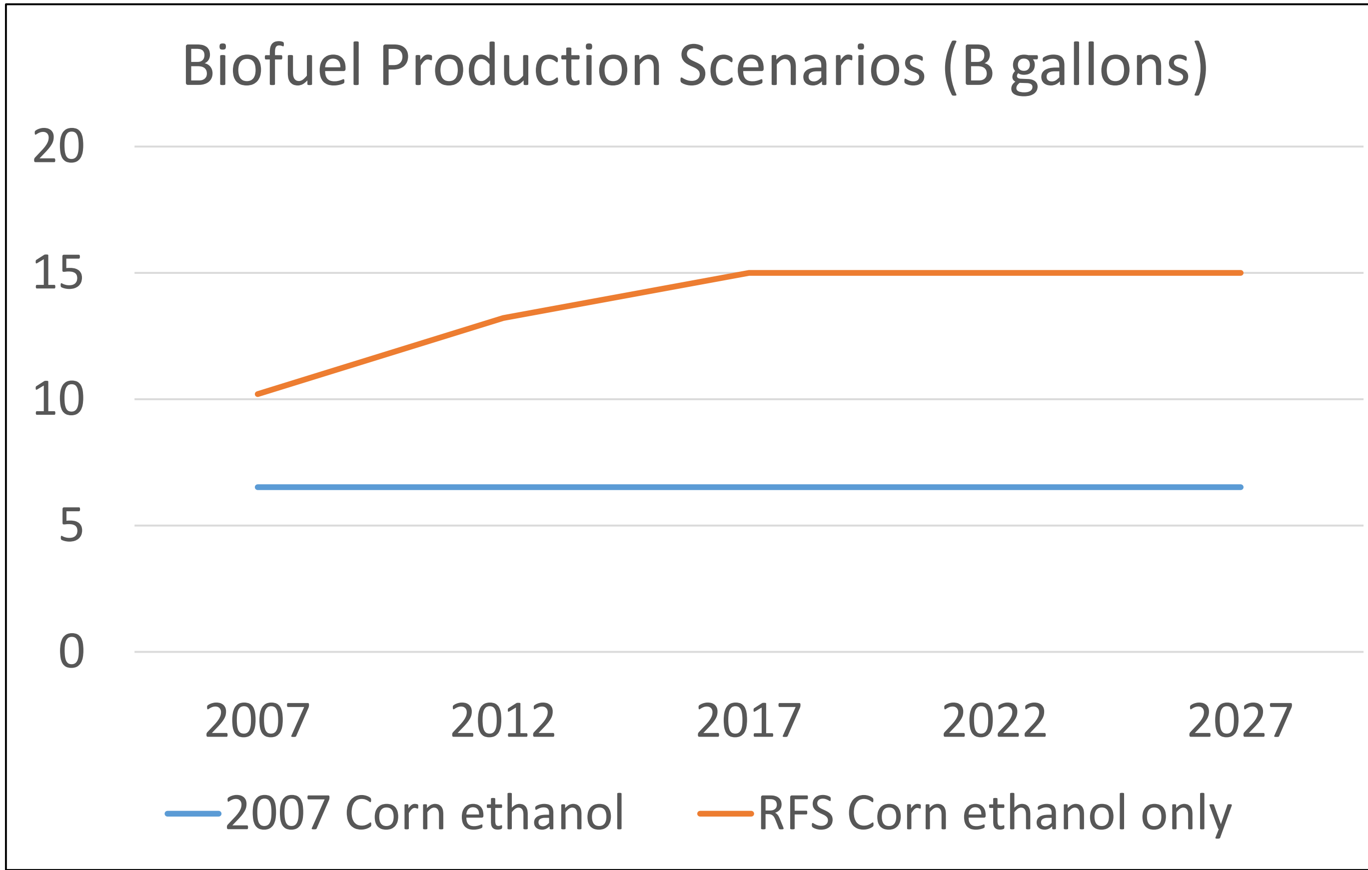
Life-Cycle and Biogenic Carbon Impacts

- Direct life-cycle emissions based on assumed crop yields, input application rates using GREET carbon emission parameters
- Changes in biogenic carbon uptake in the US
- Changes in biogenic carbon uptake in the rest of the world
- Direct and indirect land use change emissions
- Reduction in methane emissions due to reduced livestock production in the US
- Rebound effect in fuel market

Scenarios Simulated

- Baseline Scenario: Corn ethanol level kept constant at 2007 level for the future
- Policy scenarios: Corn ethanol production at the observed levels over 2007-2017
  - (i) results analyzed upto 2017
  - (ii) results analyzed upto 2017

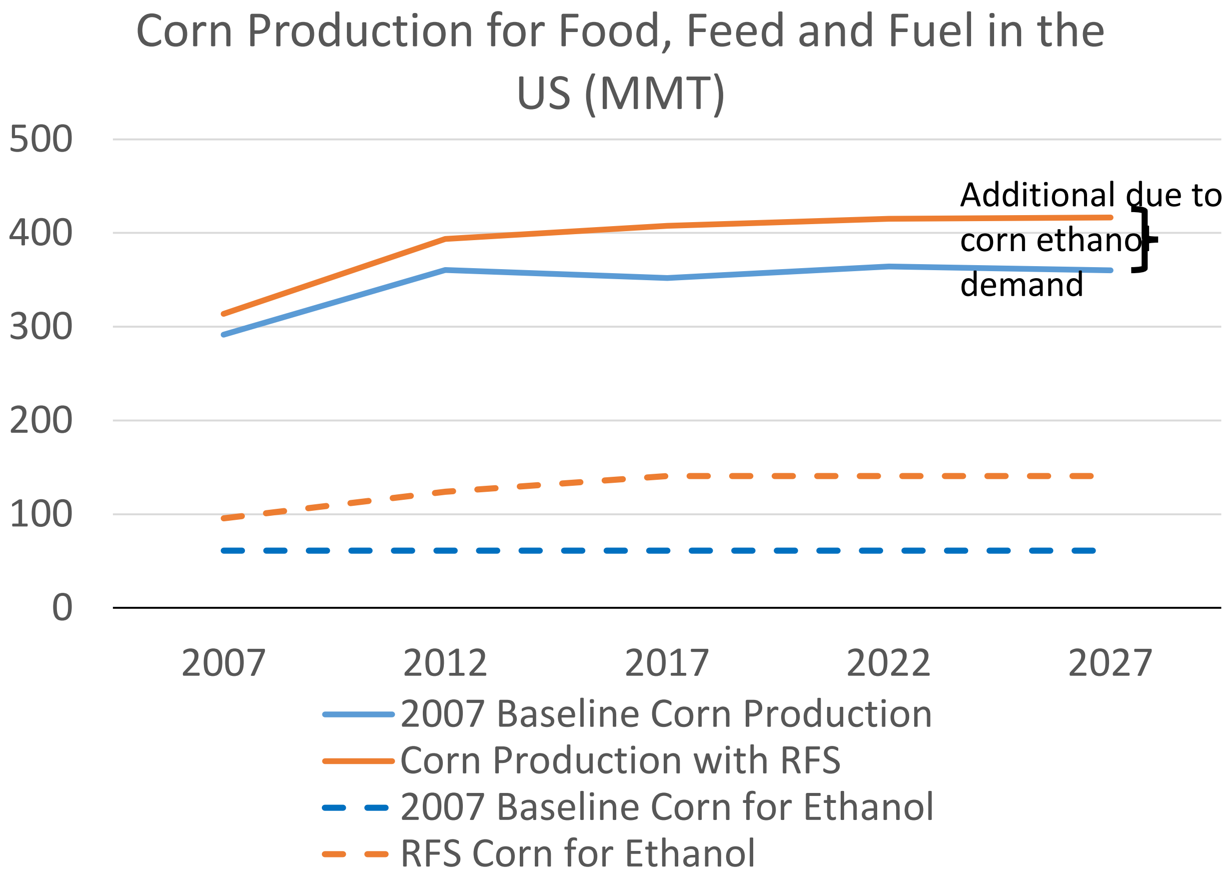
	2007 Corn ethanol	RFS Corn ethanol only
2007	6.5	10.2
2012	6.5	13.2
2017	6.5	15.0
2022	6.5	15.0
2027	6.5	15.0

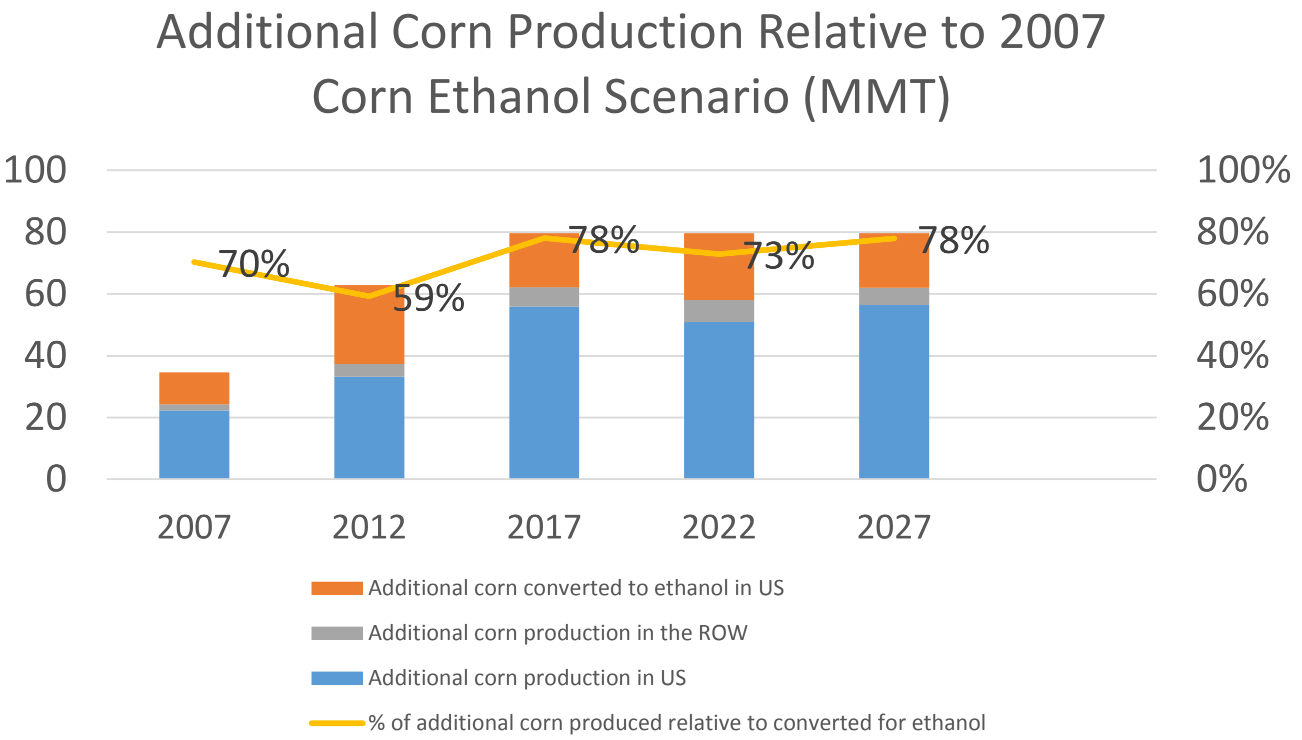


Biofuel and Environmental Policy Analysis Model with Forestry Sector

- Integrated model of the agricultural, forestry and transportation sectors
- Open economy model with 25 regions in the rest of the world
- Dynamic model with a rolling horizon
- 295 heterogeneous crop reporting districts
- 14 major crops in the US
- 5 types of land: cropland, cropland pasture, forestland pasture, forests, permanent pasture

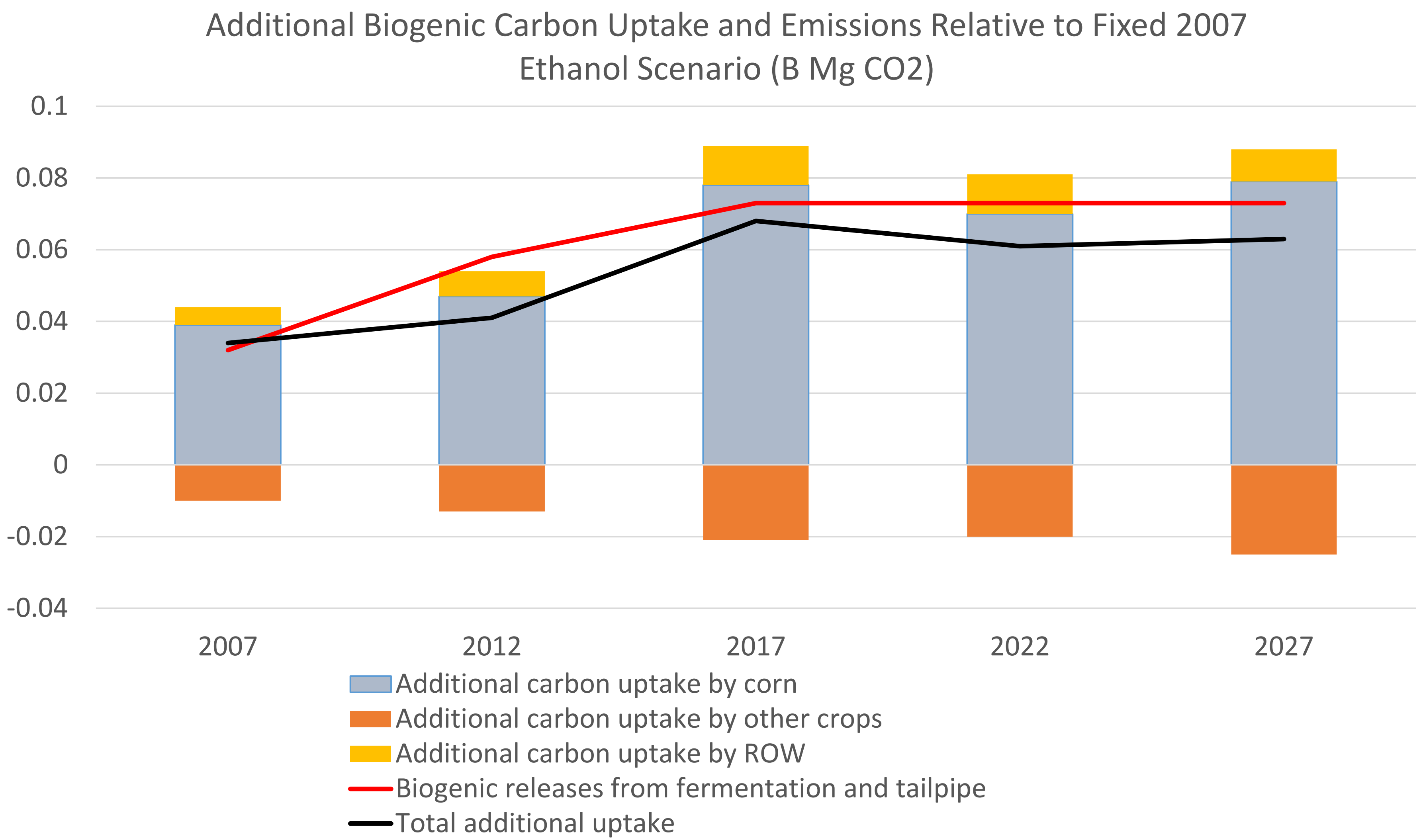
Establishing additional effects of RFS on Corn Production

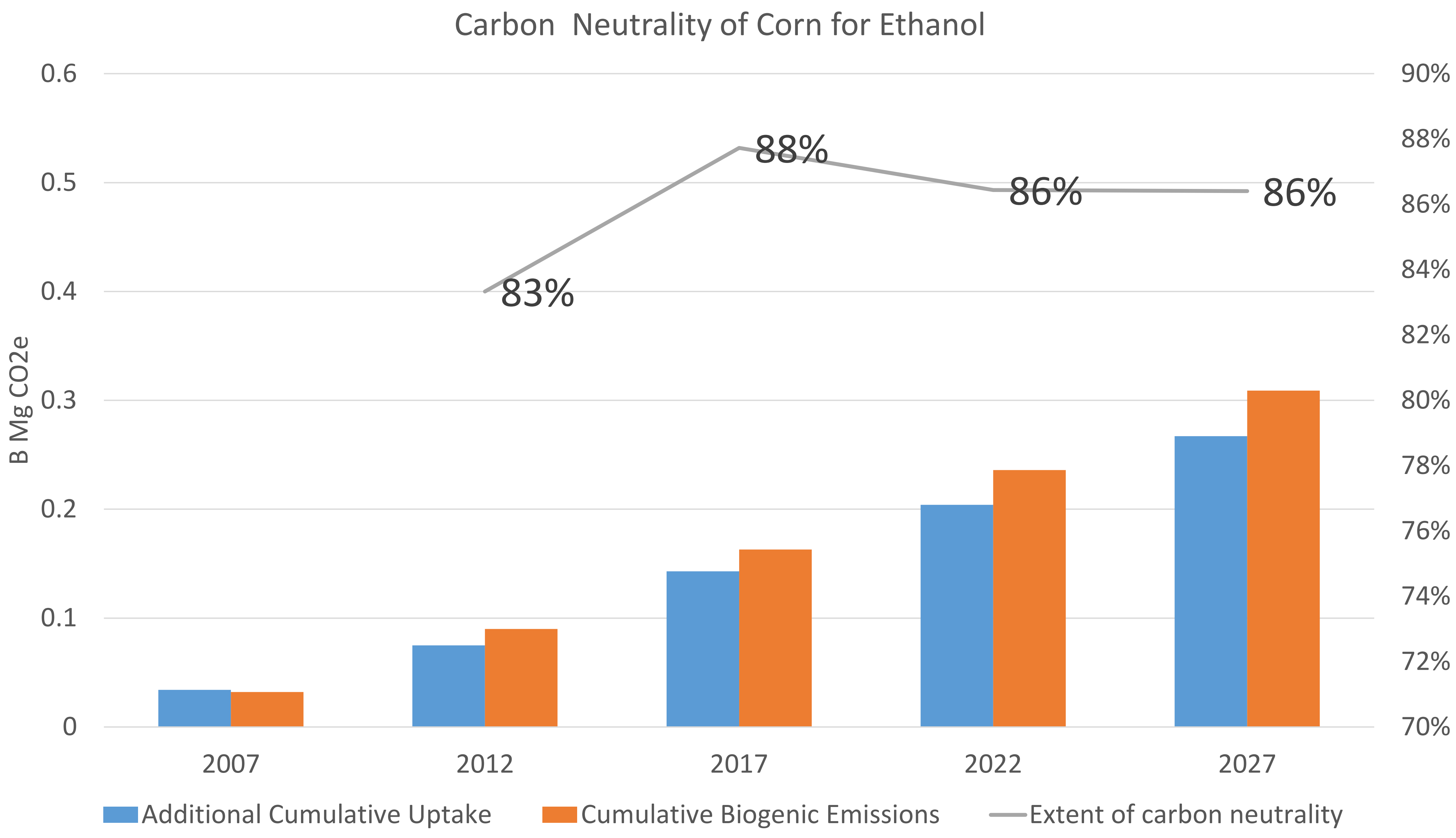




Additional corn produced in US and ROW < Corn needed for ethanol

Additional Biogenic Carbon Uptake Less than Biogenic Emissions from Corn Ethanol Production




Carbon Neutrality of Corn for Ethanol
B Mg CO2e
0.6
0.5
0.4
0.3
0.2
0.1
0
90%
88%
86%
84%
82%
80%
78%
76%
74%
72%
70%
83%
88%
86%
86%
2007
2012
2017
2022
2027
Additional Cumulative Uptake
Cumulative Biogenic Emissions
Extent of carbon neutrality

Carbon Intensity of Corn Ethanol (grams CO_2e/MJ)

ABC Accounting Approach

Corn Ethanol

• Total LCA Emissions	52
• Tailpipe emissions	74
• Fermentation	33
• Total emissions	159
Net crop uptake offset	-40
Total Emissions	119

Anticipated Baseline Approach

Corn Ethanol

• Farm emissions	33.6
• Refinery and T&D	35
• DDGS credit	-14
• Total LCA Emissions	54.6
• Tailpipe emissions	74
• Fermentation	33
• Total emissions	161.6
Net crop uptake offset	- 87.5
Total Emissions	74.1

Corn ethanol is 21% less carbon intensive than gasoline

Multi-Sector Effects of Corn Ethanol Production (Cumulative Changes in Carbon Emissions) (B Mg CO2e)

Cumulative change	2007-2017	2007-2027
Ag. Sector Emissions (incl. domestic land use emissions)	0.1	0.23
Fuel Sector (gasoline and diesel)	-0.45	-1.1
All Renewable Fuels	0.10	0.25
Total savings relative to Baseline	**-0.25 (-1.1%)**	**-0.65(-1.5%)**
Biogenic Emissions		
Carbon uptake by corn	-0.48	-1.25
Carbon uptake by other crops	0.12	0.34
Carbon uptake by ROW	-0.06	-0.16
Total net uptake	-0.43	-1.07
Biogenic emissions from fermentation and tailpipe	0.52	1.25
Net biogenic emissions	**0.095 (82% carbon neutrality)**	**0.176 (86% carbon neutrality)**
Savings net of biogenic emissions	**-0.152 (-0.7%)**	**-0.47 (-1.1%)**
Indirect Emissions		
International ILUC	0.025	0.062
International Fuel Rebound	0.066	0.612
Domestic Livestock Emissions	-0.328	-0.414
Net indirect emissions	**-0.24**	**0.26**
Net Change in Emissions including ROW gasoline	**-0.39 (-1.7%)**	**-0.21 (-0.1%)**
Net change in emissions excluding ROW gasoline	**-0.46 (2%)**	**-0.82 (1.9%)**

Conclusions

- Biogenic carbon neutrality of corn for ethanol cannot simply be assumed
  - Our assessment is 85% carbon neutrality
- Need for combining a dynamic economic model with LCA and carbon cycle modeling to estimate additionality of carbon effects that should be attributed to ethanol
- Direct carbon savings (including life-cycle and biogenic) with corn ethanol are 21% relative to gasoline
  - Will be lower with indirect land use change emissions included
- Ongoing work: Sensitivity analysis of carbon neutrality to alternative parameter assumptions