

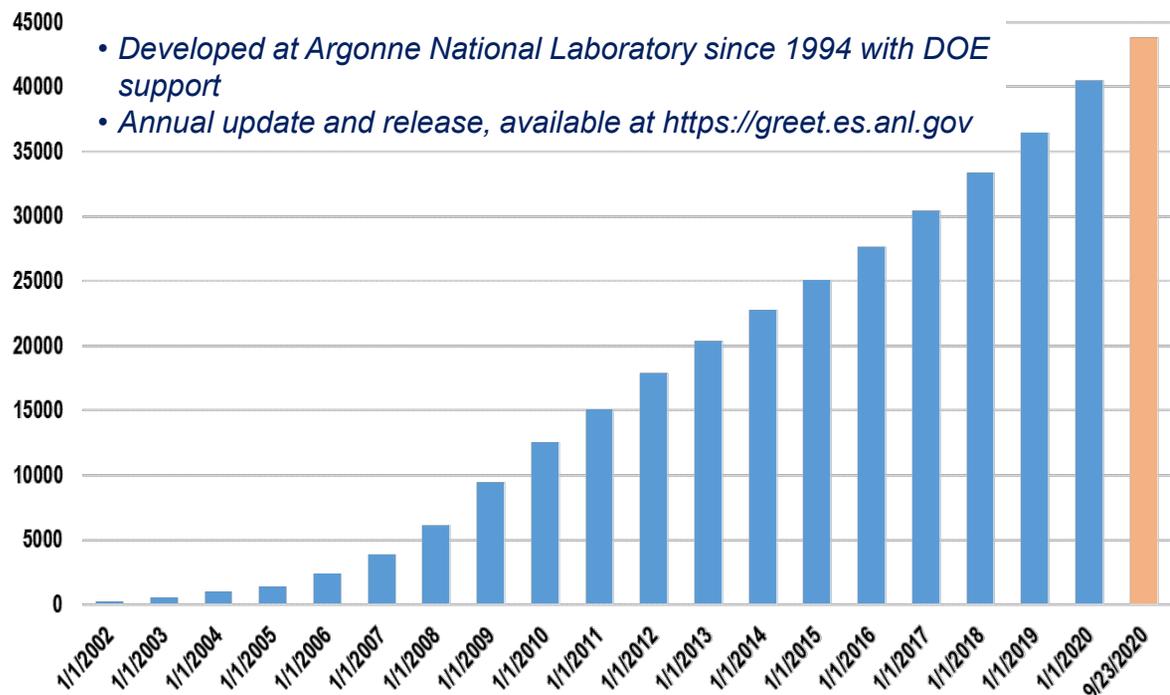
# Life-Cycle Greenhouse Gas Emission Reductions of Ethanol with the GREET Model



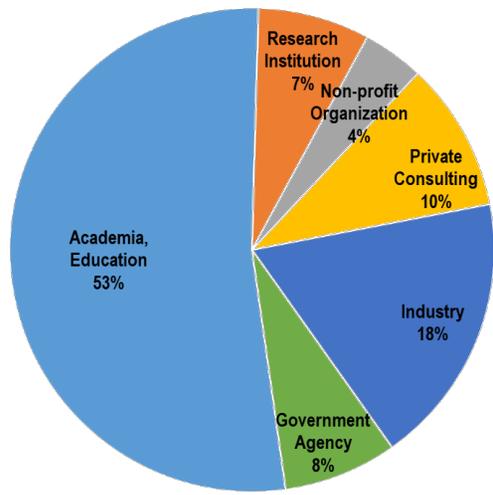
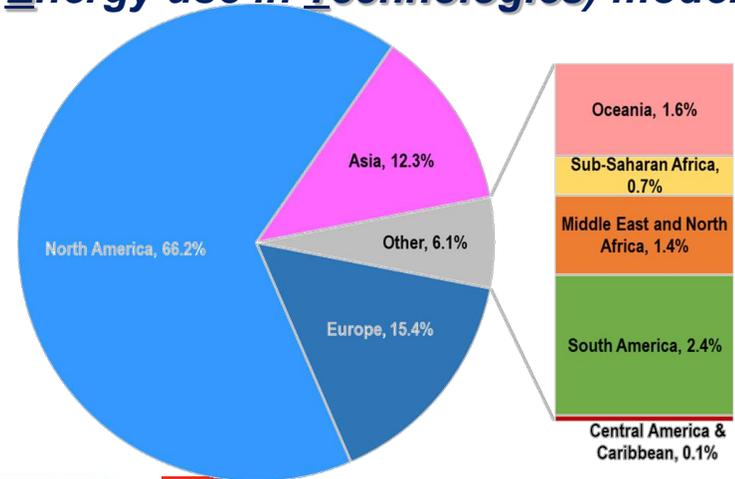
Michael Wang, Uisung Lee, Hoyoung Kwon, and Hui Xu  
Systems Assessment Center  
Energy Systems Division  
Argonne National Laboratory

Presentation at the 2021 National Ethanol Conference  
February 17, 2021

# The GREET® (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model: ~ 43,800 registered GREET users globally



- Developed at Argonne National Laboratory since 1994 with DOE support
- Annual update and release, available at <https://greet.es.anl.gov>



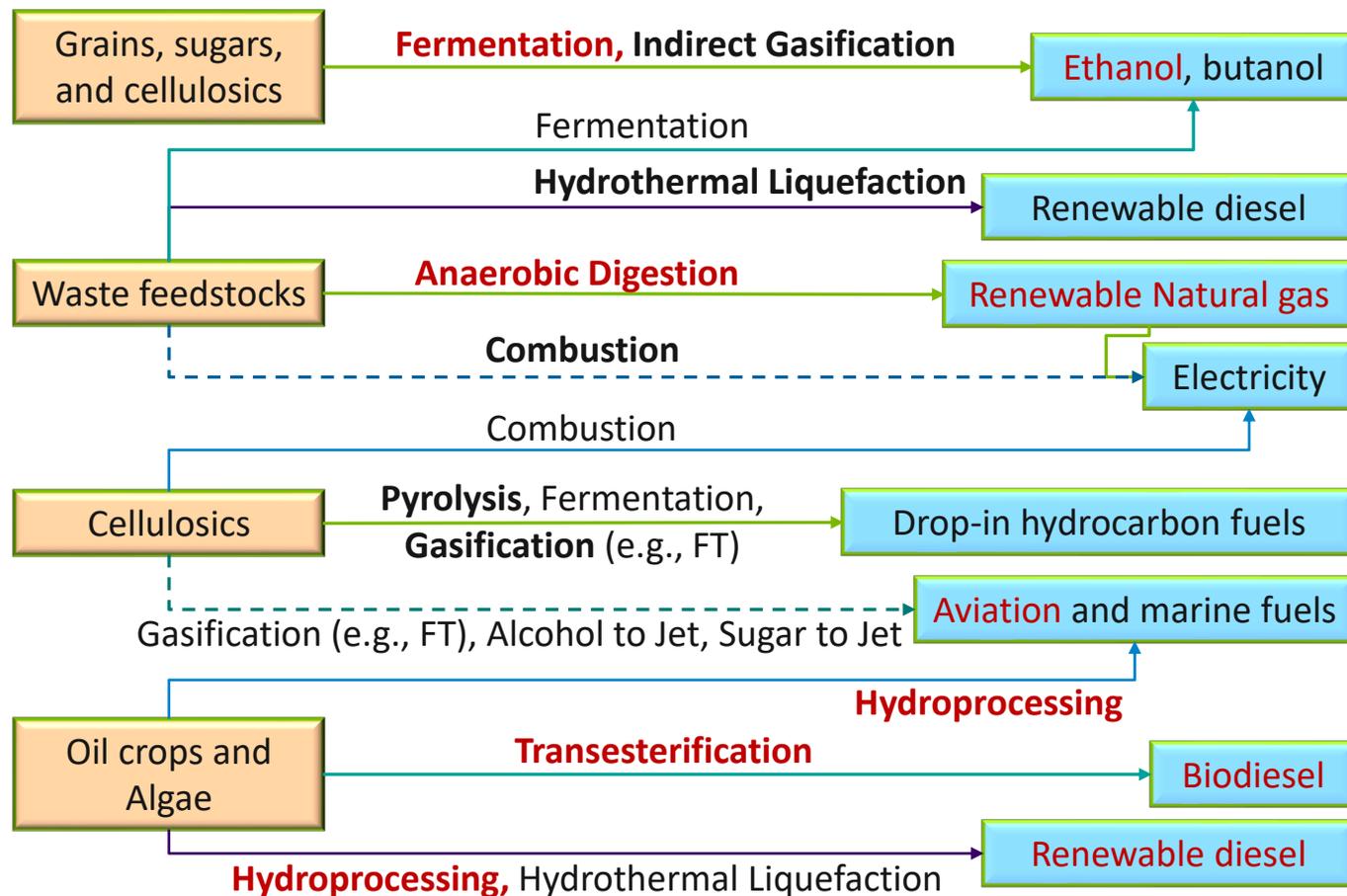
# ***GREET applications by federal, state, and international agencies***

California Environmental Protection Agency  
 Air Resources Board



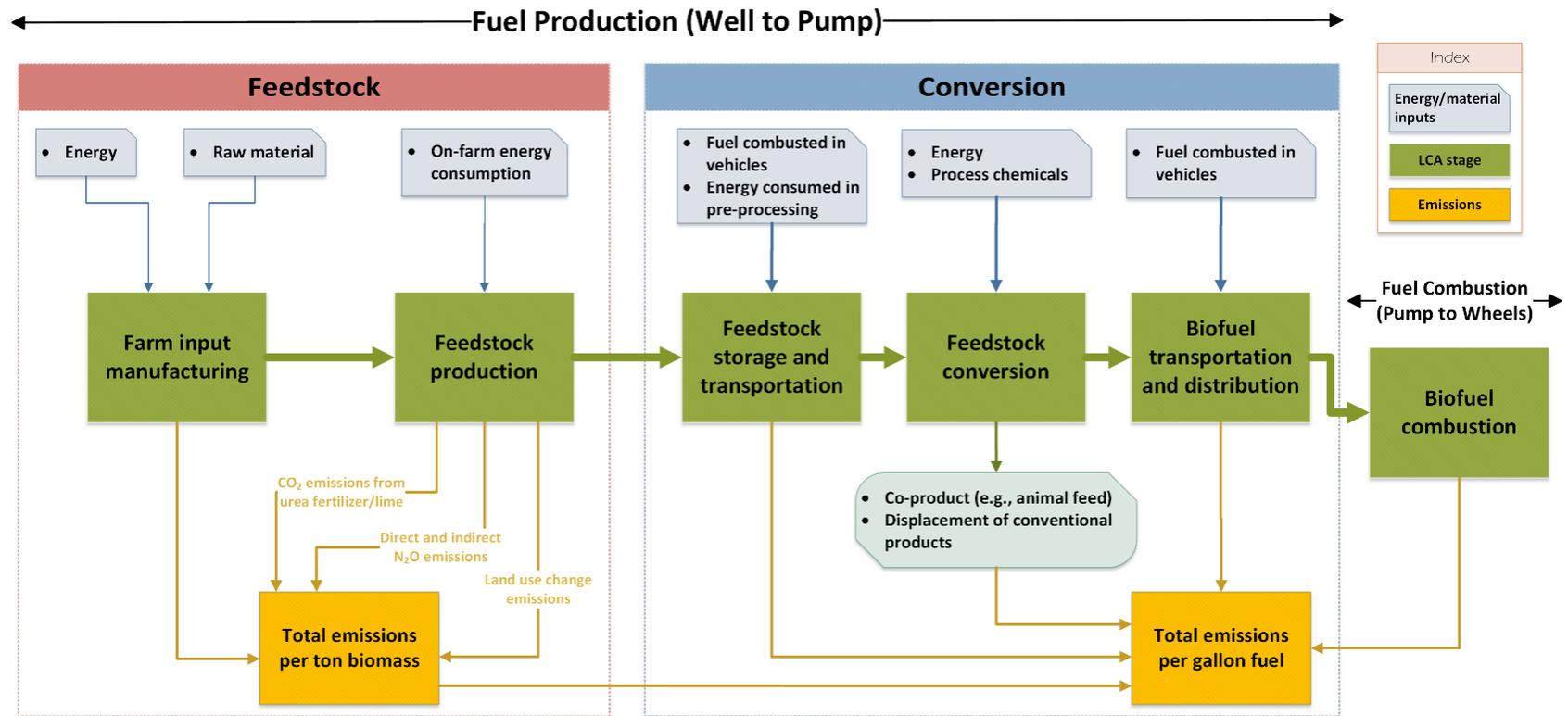
- CA-GREET3.0 built based on and uses data from ANL GREET
- Oregon Dept of Environmental Quality Clean Fuel Program
- EPA RFS2 used GREET and other sources for LCA of fuel pathways
- National Highway Traffic Safety Administration (NHTSA) fuel economy regulation
- FAA and ICAO Fuels Working Group using GREET to evaluate aviation fuel pathways
- GREET was used for the US DRIVE Fuels Working Group Well-to-Wheels Report
- LCA of renewable marine fuel options to meet IMO 2020 sulfur regulations for the DOT MARAD
- US Dept of Agriculture: ARS for carbon intensity of farming practices and management; ERS for food environmental footprints; Office of Chief Economist for bioenergy LCA
- Environment and Climate Change Canada: develop Canadian Clean Fuel Standard

## REET includes a variety of biofuel technology pathways



- Consistent comparison across all relevant technologies key to providing actionable insights.
- The highlighted options have significant volumes in LCFS and RFS
- Ethanol accounts for >15 billion gallons nationwide, and >1.1 billion gallons in CA

# REET includes details of both biofuel feedstock and conversion



- EU REDII and forthcoming Canadian Clean Fuel Standard allow feedstock certification
- But CA LCFS does not allow

- All biofuel regulations in place or under development allow biofuel facility certification
- Biofuel facility certification is allowed under LCFS Tier1/2

# Argonne has been examining corn ethanol GHG emissions with the GREET model since 1996

OPEN ACCESS

Environ. Res. Lett. 7 (2012) 045005 (13pp)  
doi:10.1088/1748-9326/7/4/045005

ENVIRONMENTAL RESEARCH LETTERS  
doi:10.1088/1748-9326/7/4/045005

## Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use

Michael Wang, Jeongwoo Han, Jennifer B I Amad Elgowainy

Wang et al. *Bioethanol Biofuels* (2015) 8:178  
DOI 10.1186/s13068-015-0350-8



Modeling and Analysis



## Life-cycle greenhouse gas emissions of corn kernel fiber ethanol

Zhangcai Qin, Qianfeng Li, Michael Wang, Jeongwoo Han, Jennifer B. Dunn, Energy Systems Division, Argonne National Laboratory, Argonne, IL, USA

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Environmental Research Letters

RESEARCH

Open Access

## Influence of corn oil recovery on life-cycle greenhouse gas emissions of corn ethanol and corn oil biodiesel

Zhichao Wang<sup>1</sup>, Jennifer B. Dunn<sup>2\*</sup>, Jeongwoo Han<sup>2</sup> and Michael Q. Wang<sup>2</sup>

ABSTRACT

**Background:** Corn oil recovery and conversion to biodiesel has been widely adopted in the US. EPA has projected 2.6 billion liters of biodiesel will be produced from corn oil by 2022. This study develops four co-product treatment methods: (1) displacement, and (4) process-level energy allocation. Life-cycle GHG emissions for corn oil choice of co-product allocation method because significantly less corn oil bioproducts a dry mill. Corn ethanol life-cycle GHG emissions with the displacement, margins are similar (61, 62, and 59 g CO<sub>2</sub>e/MJ, respectively). Although corn ethanol and D conversion burdens in both the hybrid and process-level energy allocation method the latter because it has lower energy content per selling price as compared to process-level allocation approach, ethanol's life-cycle GHG emissions are lower at life-cycle GHG emissions from the marginal, hybrid allocation, and process-level 59, and 45 g CO<sub>2</sub>e/MJ, respectively. Sensitivity analyses were conducted to invest soy biodiesel, and deflated DGS displacement credits, and energy consumption biodiesel production.

**Conclusions:** This study's results demonstrate that co-product treatment method biodiesel life-cycle GHG emissions and can affect how this fuel is treated under Fuel Standards.

**Keywords:** Corn ethanol, Corn oil recovery, Biodiesel, Life cycle analysis, GHG

BACKGROUND

In the past several years, corn oil recovery has been widely adopted in U.S. dry-mill corn ethanol plants, which produce around 80% of U.S. corn ethanol [1]. Over 80% of today's dry-mill ethanol plants have adopted

corn oil recovery corn oil in for biod kg of corn oil, 10 stock, were used if States, while during bean oil were used use of biodiesel p increase in the fut tion Agency (EE

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TOP PUBLISHING  
Environ. Res. Lett. 2 (2007) 024001 (13pp)

ENVIRONMENTAL RESEARCH LETTERS  
doi:10.1088/1748-9326/2/2/024001

## Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types

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Online at stacks.iop.org/ERL/2/024001

ABSTRACT

Since the United States has increased from 175 in the ethanol used for farm ethanol growth, corn farm plants has been reduced natural gas. However, as have been made to further to other fuels, such as corn types—categorized according power, and production of types can have distinctly fuel-cycle basis. In particular, 3% increase in fuel is the show that, in order to act closely examine and difficult corn ethanol production.

Keywords: corn ethanol,

### 1. Introduction

During the second oil decided to promote the national transportation programme began in 1 ethanol were used that production, the federal incentive of 54 cents per incentive was later reduced. Besides the federal government provided incentives to ethanol plants.

The 1990 Clean Air oxygenated fuel program 1748-9326/07/024001+13\$

Life-cycle analysis  
Energy balance  
Greenhouse gas emissions  
Land use change



## Energy and greenhouse gas emission effect and land use changes

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Land use change

### 1. Introduction

Since the beginning of the U.S. fuel ethanol program in 1980, production of corn ethanol in the United States has grown from 76 dam<sup>3</sup> in 2000 to 40.1 hm<sup>3</sup> in 2009 [1]. The U.S. Congress in the 2007 Energy Independence and Security Act (EISA) established a corn ethanol production target of 56.8 hm<sup>3</sup> a year by 2015 plus 79.5 hm<sup>3</sup> of advanced biofuel production by 2022

[2]. The production capacity of corn ethanol in the United States has already exceeded 49.2 hm<sup>3</sup> a year, and the construction of new facilities is expected to result in additional production capacity of 5.3 hm<sup>3</sup> of corn ethanol [1]. Meanwhile, investments in research, development, deployment, and commercialization of advanced biofuel technologies have been accelerated in the past several years [3–6]. Parallel to these efforts, regulatory efforts such as the

## Fuel-Cycle Fossil Energy Use and Greenhouse Gas Emissions of Fuel Ethanol Produced from U.S. Midwest Corn

Illinois Department of Commerce and Community Affairs  
Norm Sims, Director

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## Fuel Ethanol Produced from Midwest U.S. Corn: Help or Hindrance to the Vision of Kyoto?

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ABSTRACT

In this study, we examined the role of corn-feedstock ethanol in reducing greenhouse gas (GHG) emissions, given present and near-future technology and practice for corn farming and ethanol production. We analyzed the full-fuel-cycle GHG effects of corn-based ethanol using updated information on corn operations in the upper Midwest and existing ethanol production technologies. Information was obtained from representatives of the U.S. Department of Agriculture, faculty of midwestern universities with expertise in corn production and animal feed, and acknowledged authorities in the field of ethanol plant engineering, design, and operations. Cases examined included use of E85 (85% ethanol and 15% gasoline by volume) and E10 (10% ethanol and 90% gasoline). Among key findings is that Midwest-produced ethanol outperforms conventional (current) and reformulated (future) gasoline with respect to energy use and GHG emissions (on a mass emission per travel mile basis). The superiority of the energy and GHG results is well outside the range of model "noise." An important facet of this work has been conducting sensitivity analyses. These analyses let us rank the factors in the corn-to-ethanol cycle that are most important for limiting GHG generation. These rankings could help ensure that efforts to reduce that generation are targeted more effectively.

IMPLICATIONS

Policy-makers have shown considerable interest in the potential to achieve net greenhouse gas reductions by using ethanol (C<sub>2</sub>H<sub>5</sub>OH) as a transportation fuel. At the 1997 Kyoto Conference, U.S. negotiators committed to reducing greenhouse gas emissions between 2008 and 2012 to 7% below the level of 1990. Although yet to be ratified by Congress, the commitment was signed by the U.S. in a recent conference in Buenos Aires, Argentina. This paper examines whether substituting ethanol for

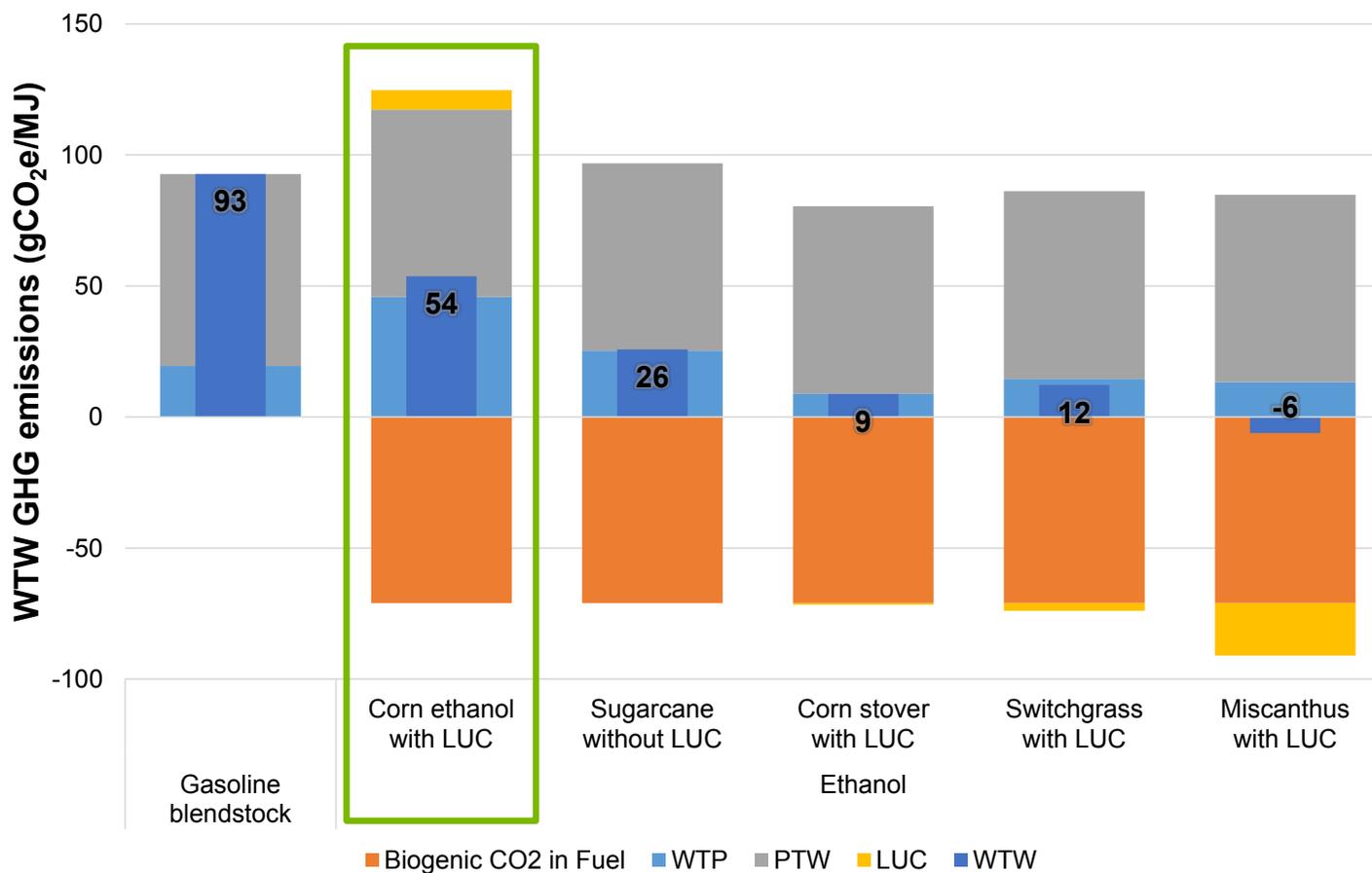
### INTRODUCTION

Concern about global "greenhouse" warming has led to recognition that reducing the rate of atmospheric carbon loading due to fossil fuel combustion may help slow warming. This realization, in turn, has kindled an interest in transportation fuels that contain lower carbon unit of energy delivered or are produced from renewable sources, so that less or no net carbon is added to the atmosphere from fuel combustion. One such fuel is ethanol (C<sub>2</sub>H<sub>5</sub>OH), an alcohol currently produced in the U.S. States by fermentation and distillation of corn or wet- or dry-mill processing. A crop-based fuel such as ethanol has advantages over petroleum because it is renewable and produces zero net carbon emissions during combustion. That is, carbon dioxide produced in combustion is absorbed from the atmosphere by corn or feedstock plants during photosynthesis. However, cultivation and milling of corn consume energy that is provided chiefly by fossil fuels.

Meanwhile, research continues on developing commercial technologies to produce fuel ethanol from cellulose in biomass. Studies have shown that cellulosic ethanol industrially reduces or almost eliminates GHG emissions, relative to use of gasoline.<sup>1,2</sup> However, at present, virtually all large-scale production of fuel ethanol used in the United States is from corn. Corn production is vital to the economies of many states, especially in the upper Midwest. The market for corn and corn products could be significantly enhanced in the near and medium term by a major upturn in the use of ethanol as a transportation fuel, at least until the emergence of commercially viable enzymatic processes yielding large quantities of ethanol from low-value cellulosic biomass. Thus, there is considerable interest in substituting corn-based ethanol for gasoline to reduce GHG emissions, especially in light of the 1997 Kyoto Conference. At that conference, U.S. negotiators committed to controlling

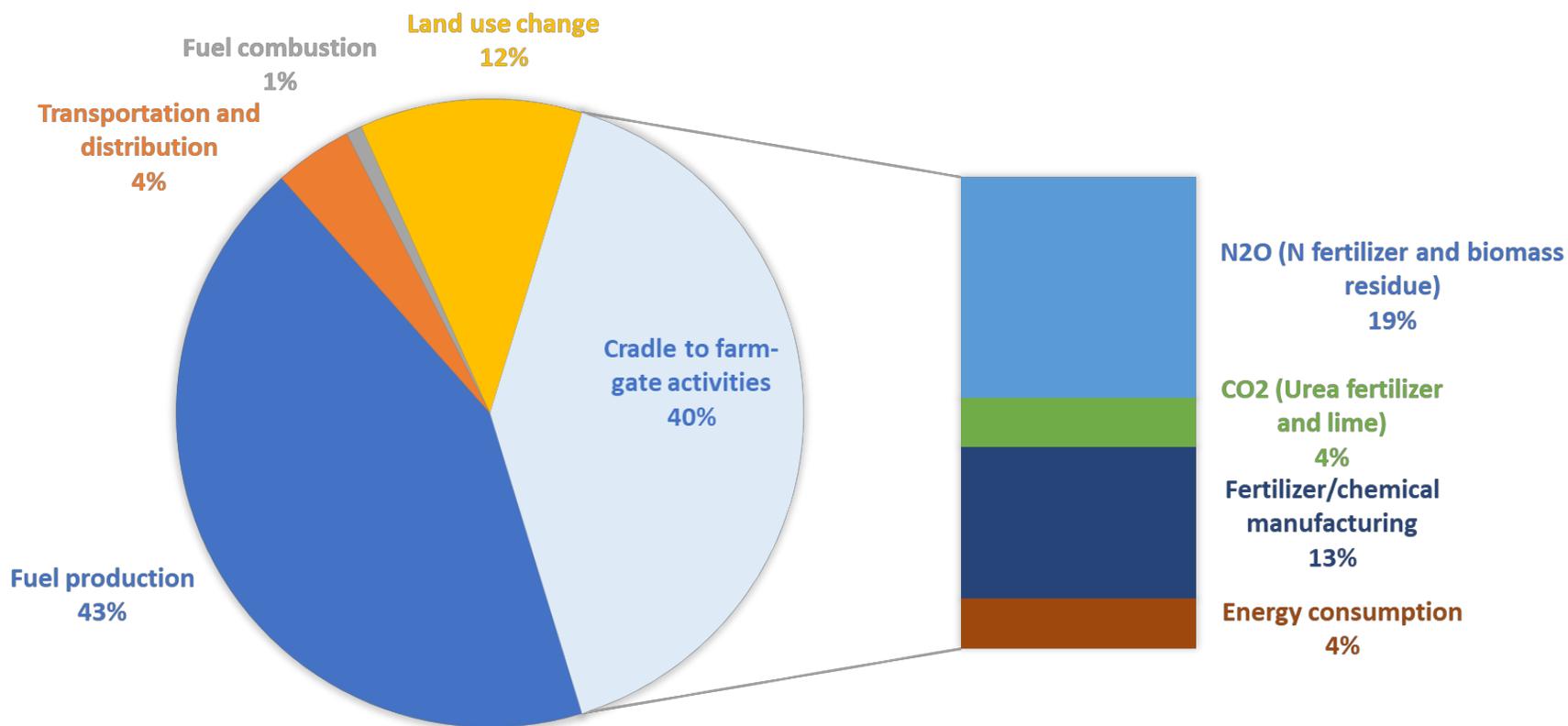
CI

## Corn ethanol achieves >40% reduction in GHG emissions



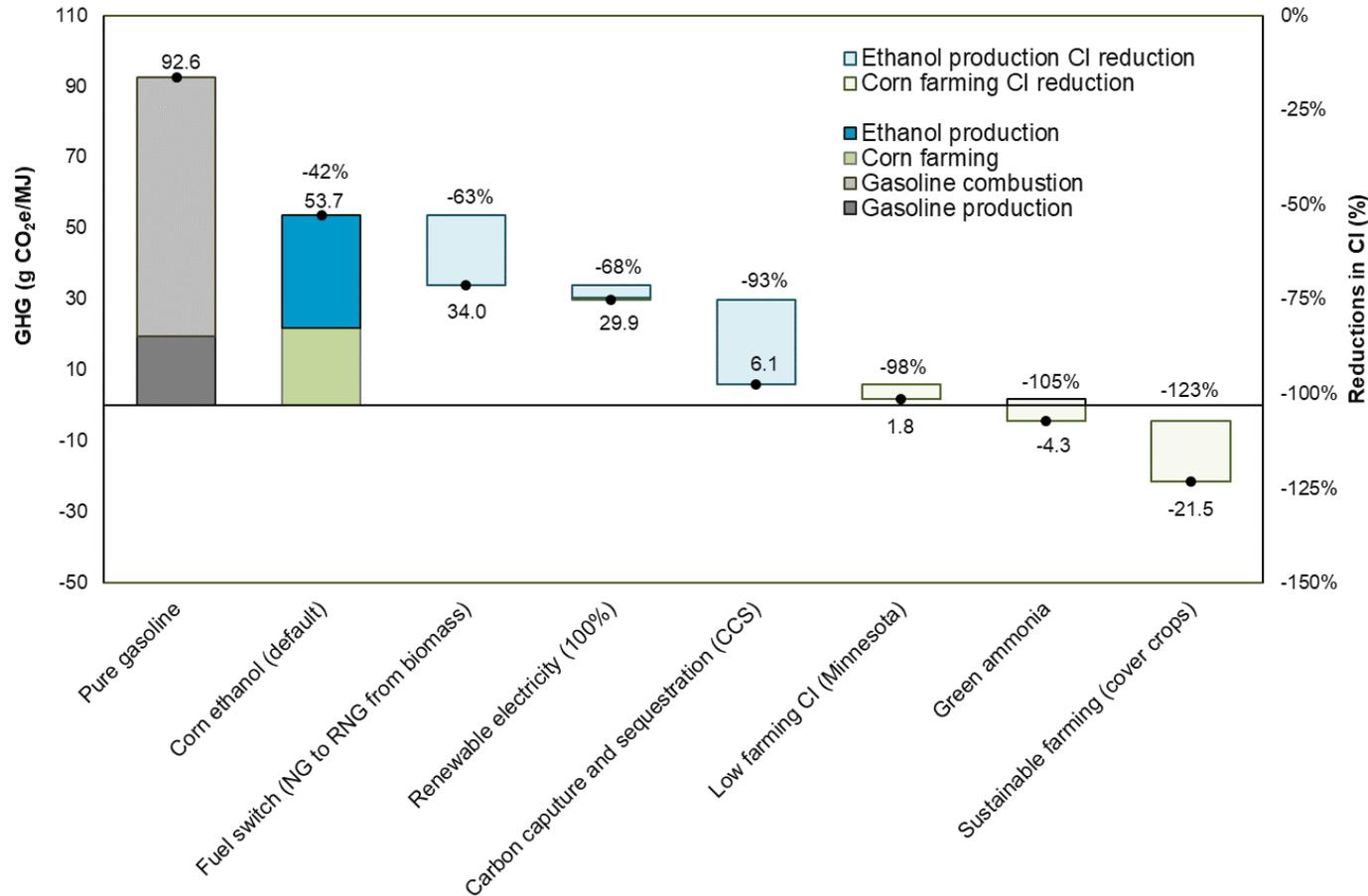
- Corn ethanol results are based on GREET 2020
- The U.S. average corn farming data are used
- Land use change (LUC) emissions are included
- Soil organic carbon (SOC) changes from farming practices (e.g., tillage, cover crops, etc.) are NOT considered here

# Feedstock is a significant contributor to corn ethanol LCA GHGs: 40% of corn ethanol carbon intensity (CI)



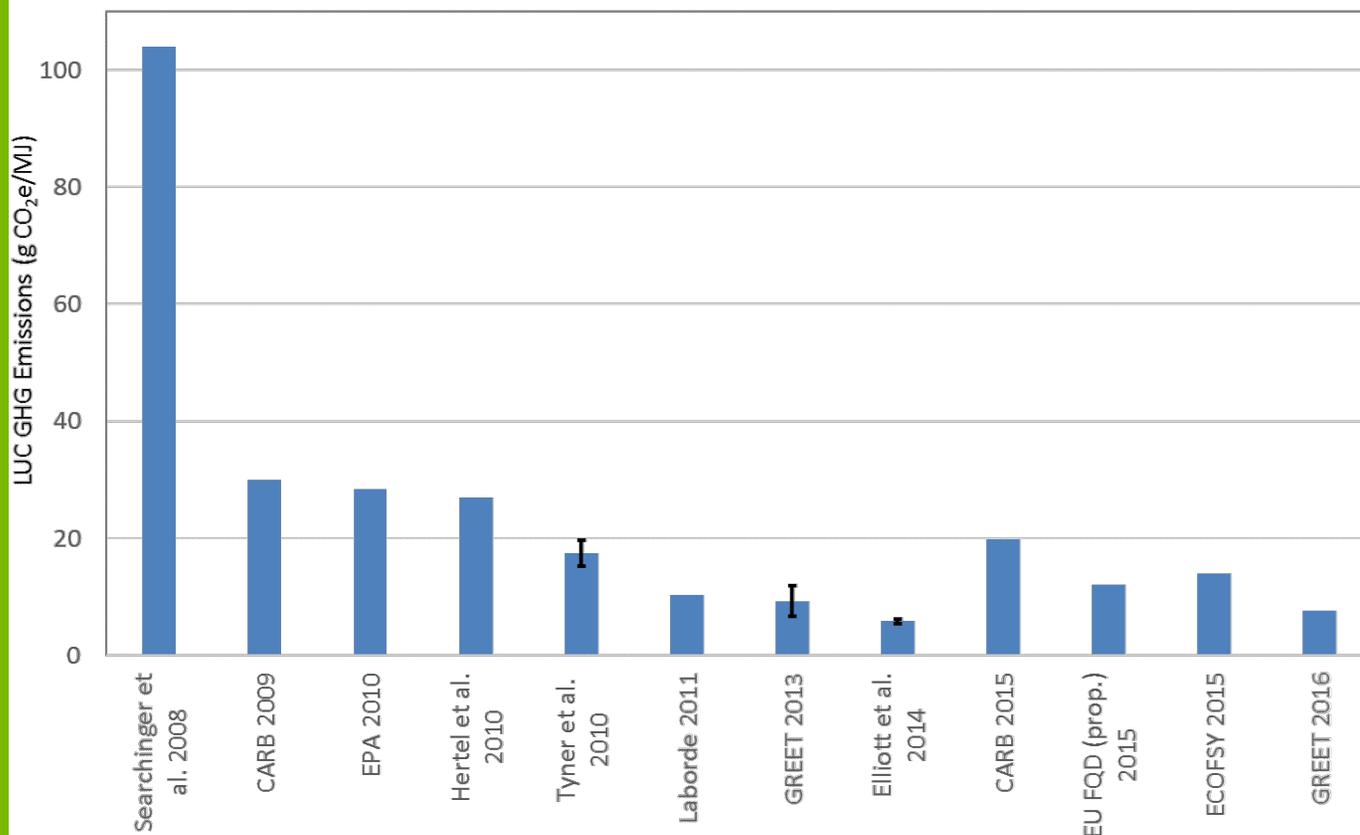
Dry Milling Corn Ethanol w/ Corn Oil Extraction.  
DSG credit, -11 g CO<sub>2</sub>e/MJ, is not included

# Additional measures for corn ethanol can help reduce GHGs below zero



- Results show accumulative reductions with additional options added to the baseline
- Replacing NG with RNG sourced from biomass could reduce CI by 20 g CO<sub>2</sub>e/MJ
- With RNG, renewable electricity, and CCS, CI of corn ethanol might be lowered to 6.1 g CO<sub>2</sub>e/MJ
- Adding low farming input and green ammonia options could push CI to near zero
- Sustainable farming (e.g., cover crops) could achieve negative CI, given SOC accumulation credits

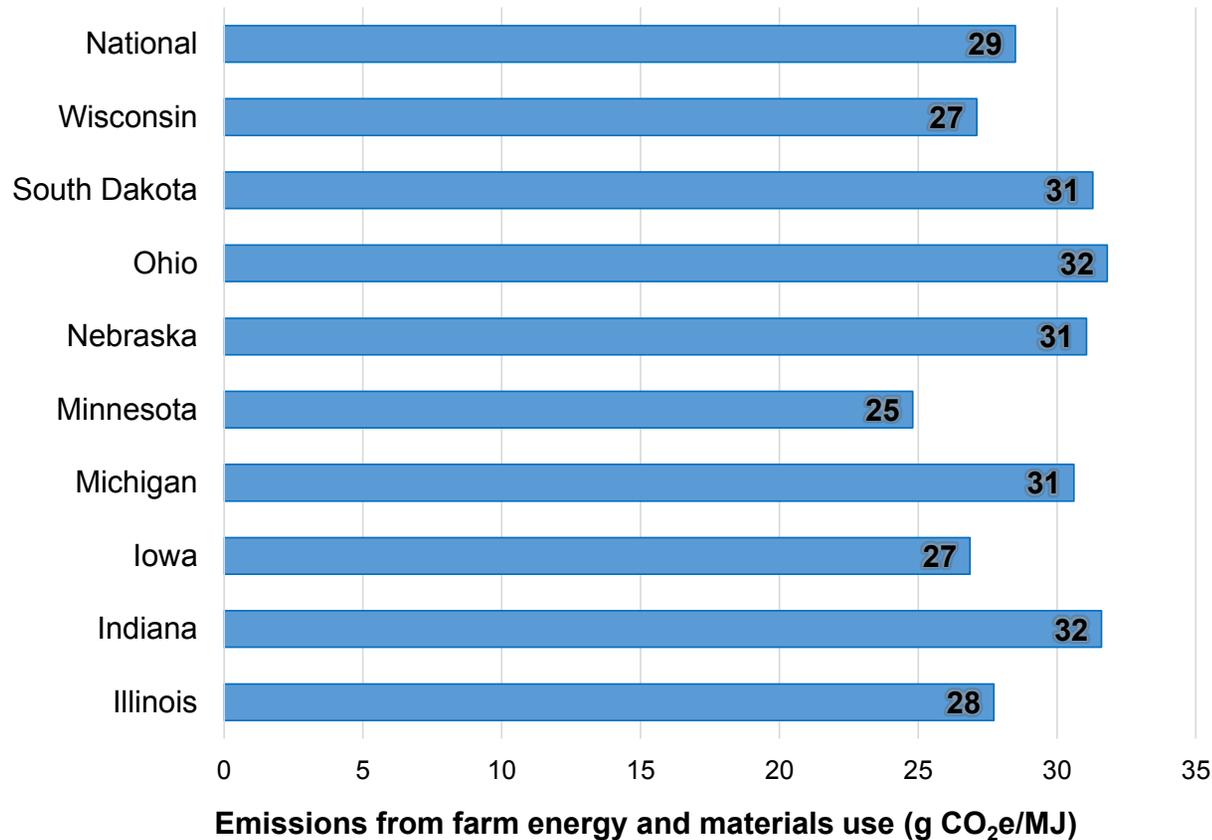
## Estimated LUC GHG emissions for corn ethanol have gone down significantly in the past 10 years



### Critical factors for LUC GHG emissions:

- Land intensification vs. extensification
  - Crop yields: existing cropland vs. new cropland; global yield differences and potentials
  - Double cropping on existing land
  - Extension to new land types: cropland, grassland, forestland, wetland, etc.
- Price elasticities
  - Crop yield response to price
  - Food demand response to price
- **SOC changes from land conversions and land management**

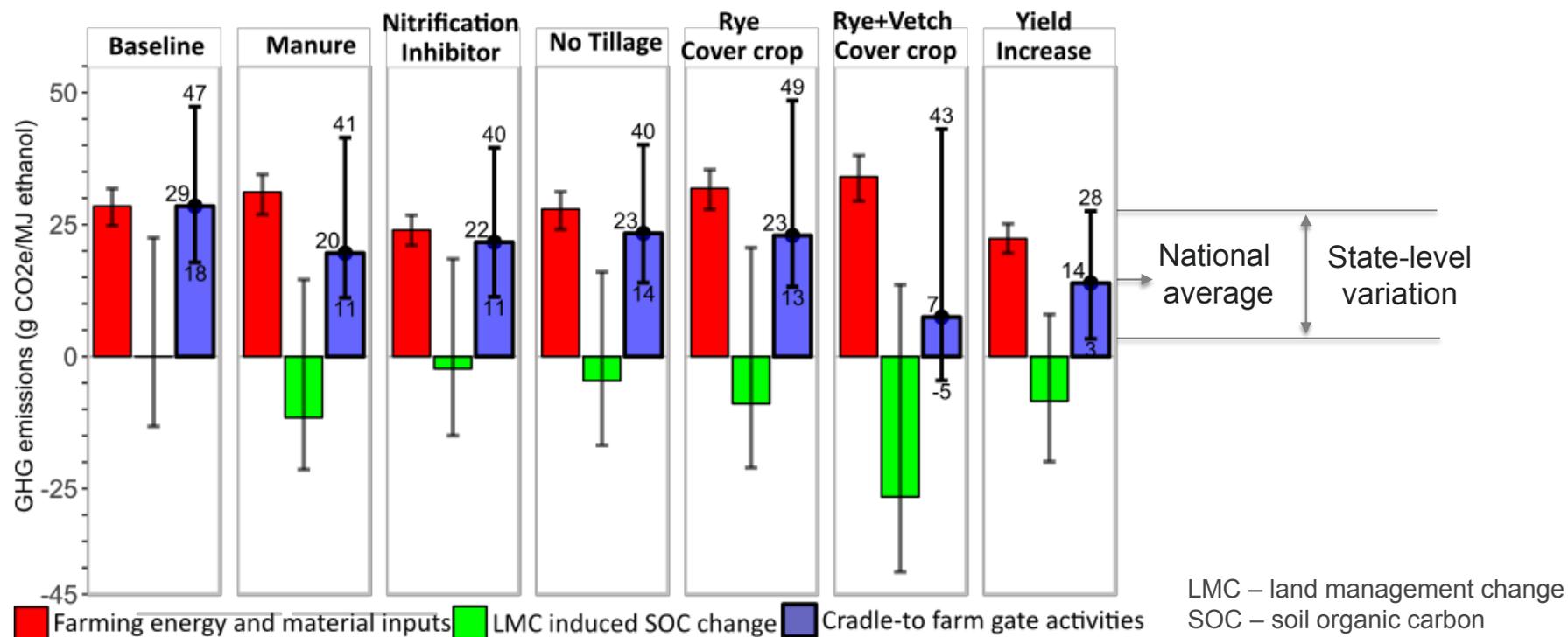
## ***Even with current farming practices, significant variation exists among states in feedstock-related CI for corn ethanol***



### **The CI variation reflects:**

- Soil fertility
- Climate
- Farming practices
  - Till, minimum till, non-till
  - Manure application
  - Irrigation
  - Etc.

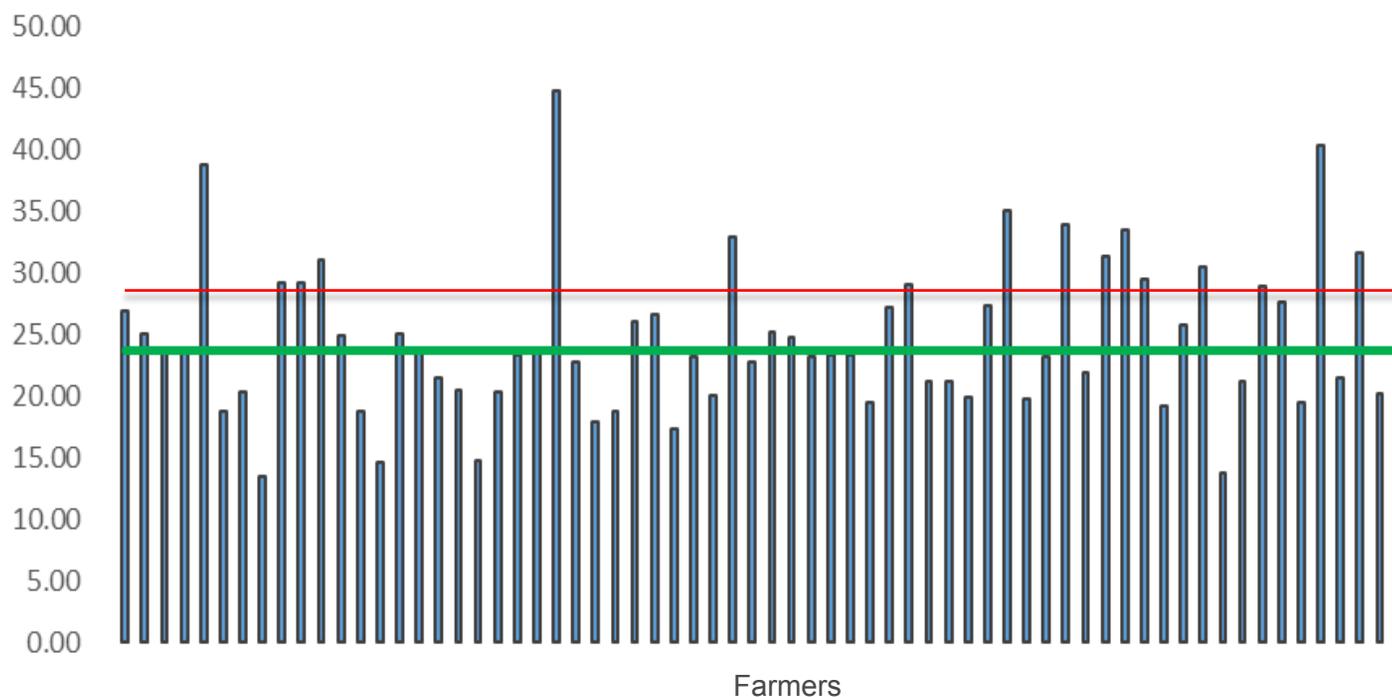
## Farming practices significantly influence corn ethanol CI by state



- These additional land management changes can result in significant GHG reductions for corn ethanol from both SOC changes and direct farming activity GHG changes.
- Along with LMC-induced SOC change, N<sub>2</sub>O emissions contribute the most to the cradle-to-farm gate GHG emissions

## Worked with POET and Farmers Business Network, Argonne developed CIs of corn for 71 individual farms in South Dakota

Agricultural Inputs CI Value (gCO<sub>2</sub>e/MJ) for Corn



National average CI: 29.5 g/MJ

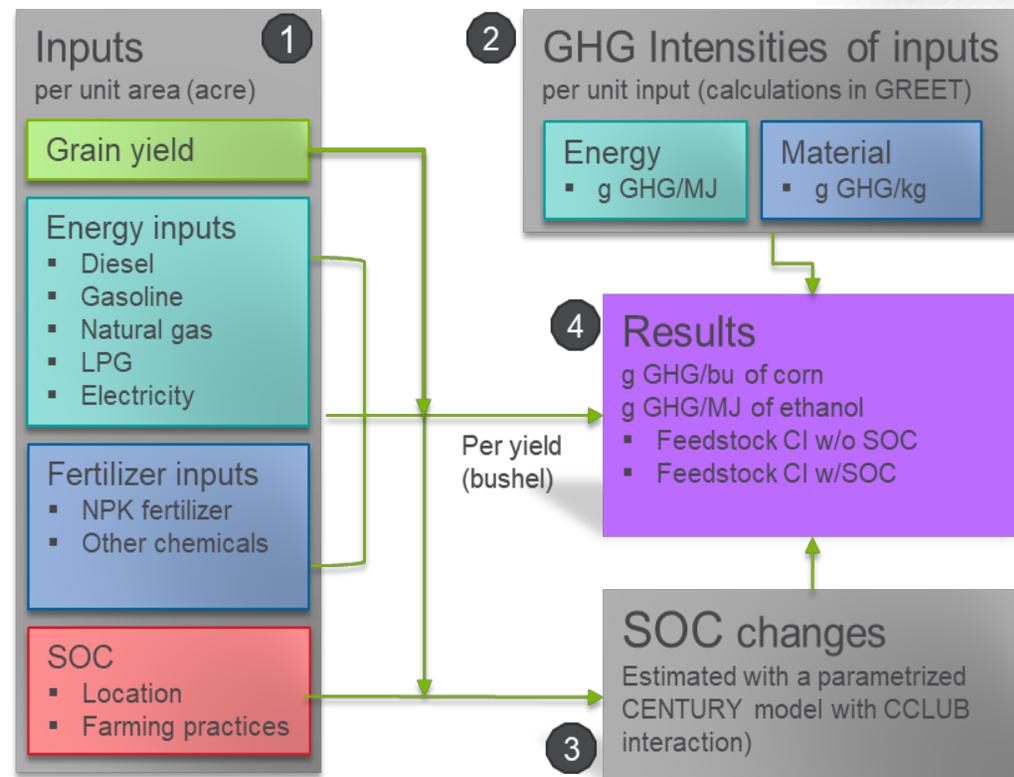
Average of 71 farms: 23.6 g/MJ

- Range of the 71 farms: 13–45 g/MJ, representing an opportunity of 34% reduction in corn ethanol CI vs. gasoline CI

# With DOE support, Argonne developed a feedstock CI calculator ([https://greet.es.anl.gov/tool\\_fd\\_cic](https://greet.es.anl.gov/tool_fd_cic))



- Farm-level data can be used for feedstock CI estimates
- Feedstock CI is linked to the rest of GREET biofuel LCA for biofuel CI
- At present, the calculator includes corn for ethanol
- Effort is under way to include soybeans, sorghum, and rice



*The Feedstock Carbon Intensity Calculator (FD-CIC)*

## ***On-going Argonne efforts to examine deep GHG reductions of ethanol and other biofuels***

- Retrospective analysis of GHG reduction trend of corn ethanol 2005 – 2019
  - Both corn farming and ethanol plants have improved CIs over the 15-year period
  - Results are in a draft journal article currently under review
- Opportunities for corn ethanol and ethanol-to-jet for near zero GHG emissions
  - US DRIVE Net Zero Carbon Fuel Tech Team: Argonne works with three other national labs, OEMs, and energy companies to examine opportunities
  - DOE Bioenergy Technology Office: starch-based biofuel GHG reduction opportunities
- DOE ARPA-E: feedstock certification under biofuel regulations to incentivize sustainable farming practices for agriculture to play a crucial role for a deep decarbonized economy
  - SOC from sustainable farming practices poses great GHG reductions
  - Regulatory agencies and NGOs are concerned with additionality and permanence issues for SOC
- Opportunity to convert ethanol to jet to meet national and international regulations and requirements
  - Argonne is a member of the ICAO's Fuels Working Group to develop carbon intensities of sustainable jet fuels for ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

## Summary

- ❑ Corn ethanol GHG emissions have continued to go down
  - >40% reductions in GHG emissions, with estimated LUC emissions included
  - Improvements in corn farming and ethanol plants have contributed to the down trend
- ❑ Additional opportunities exist to reduce corn ethanol CIs further
  - Sustainable farming practices and land management changes
  - Use of renewable energy and CCS in ethanol plants
- ❑ Biofuel feedstock certification allows agriculture to participate in deep decarbonization
  - EU and Canada give credits for SOC changes from improved land management practices
  - Sustainable production of biofuel feedstocks provide significant opportunities to further reduce biofuel CI