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

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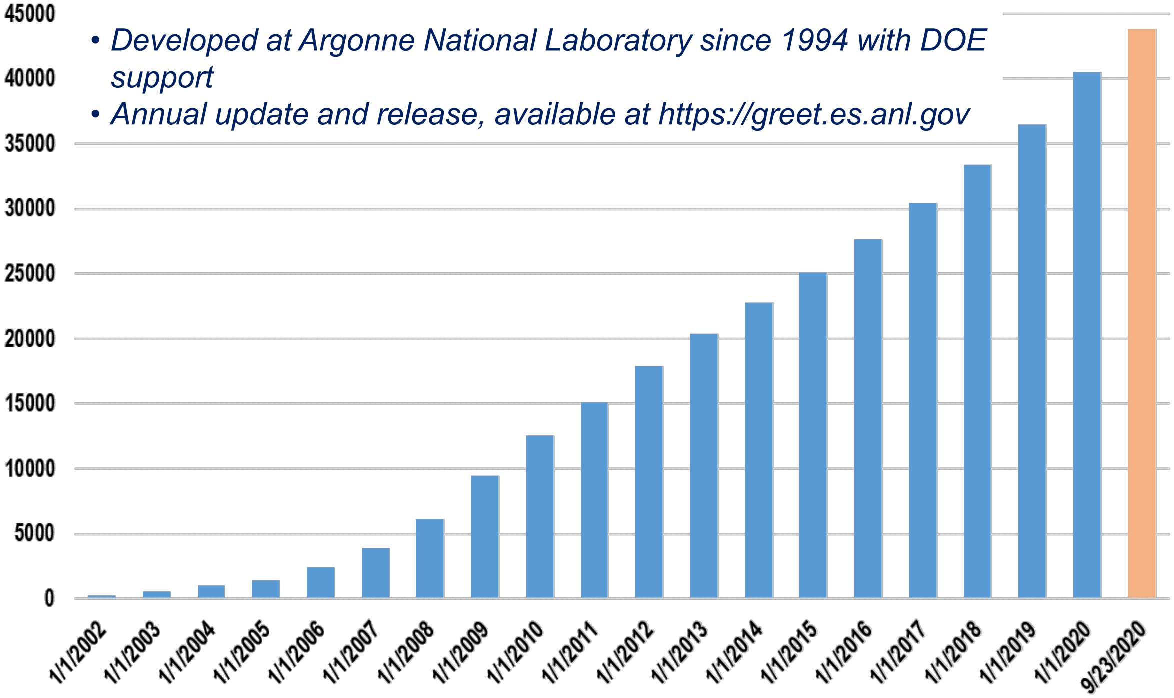
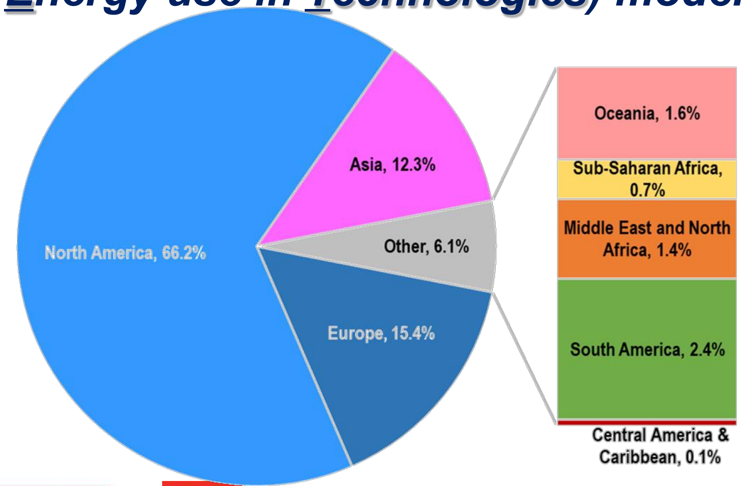
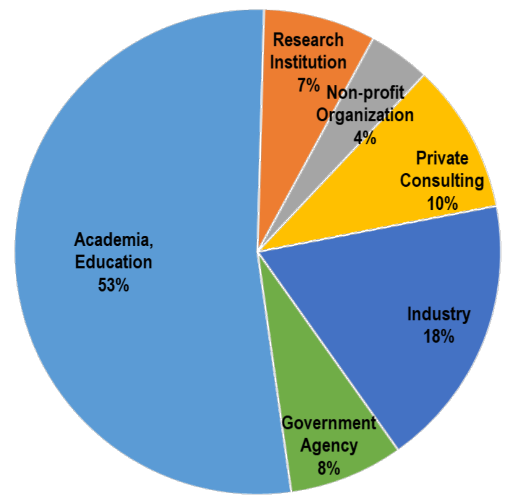
The GREET® (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) model: ~ 43,800 registered GREET users globally

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





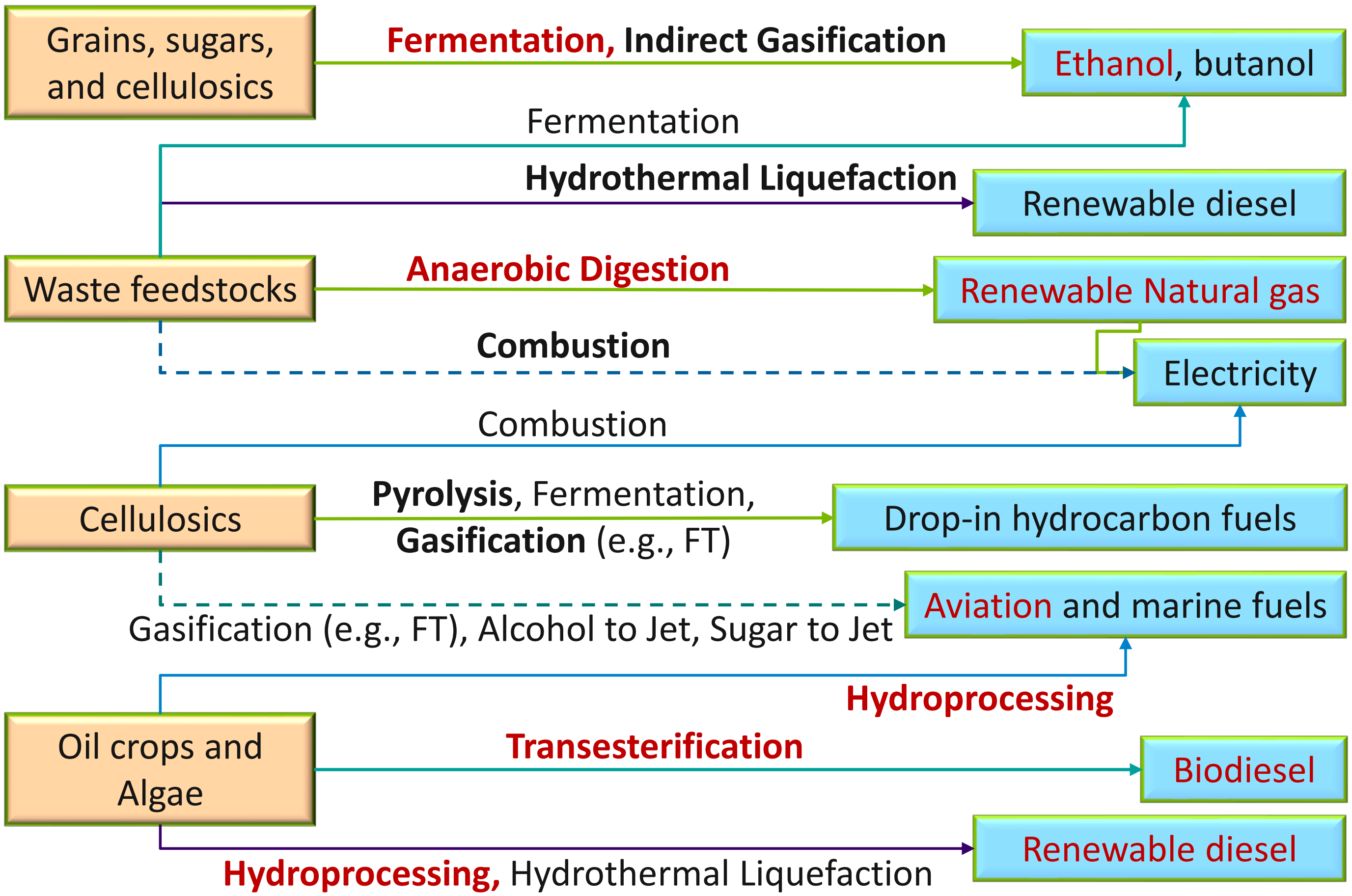


GREET applications by federal, state, and international agencies

California Environmental Protection Agency Air Resources Board

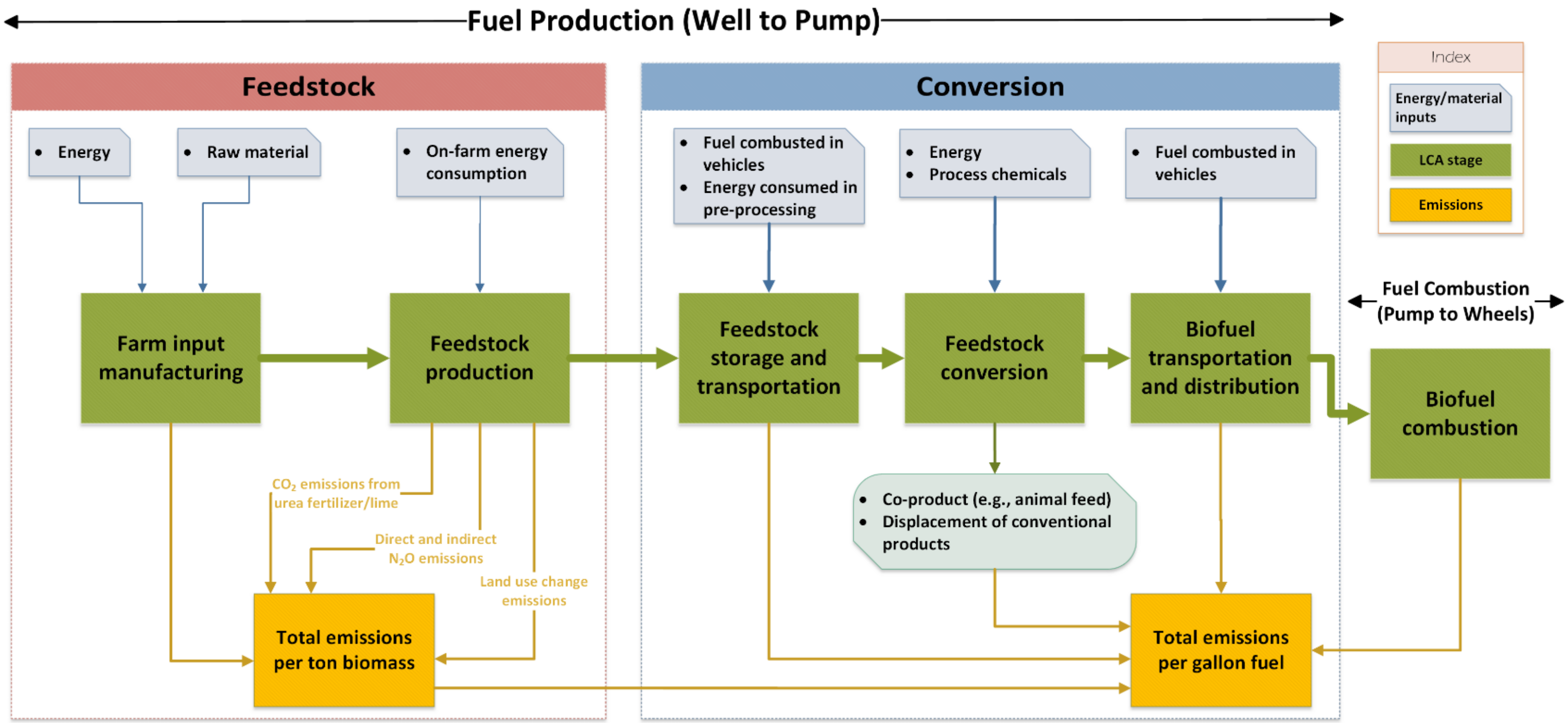
- CA-GREET3.0 built based on and uses data from ANL GREET
- Oregon Dept of Environmental Quality Clean Fuel Program
- EPA RFS2 used GREET and other sources for LCA of fuel pathways
- National Highway Traffic Safety Administration (NHTSA) fuel economy regulation
- FAA and ICAO Fuels Working Group using 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

GREET 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

GREET 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

Illinois Department of Commerce and Community Affairs

Norm Sims, Director

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

TECHNICAL PAPER

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

Michael Wang, Christopher Saricks, and May Wu
Center for Transportation Research, Argonne National Laboratory, Argonne, Illinois

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

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Energy and greenhouse gas emission effe[cts of corn] and cellulosic ethanol with technology im[provements] and land use changes

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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 D[unn] ... Amgad Elgowainy

Wang et al. Biotechnol Biofuels (2015) 8:178
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Influence of corn oil recovery on life-cycle greenhouse gas emissions of corn ethanol and corn oil biodiesel

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Modeling and Analysis — Biofpr

Life-cycle greenhouse gas emissions of corn kernel fiber ethanol

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LETTER

Shifting agricultural practices to produce sustainable, low carbon intensity feedstocks for biofuel production

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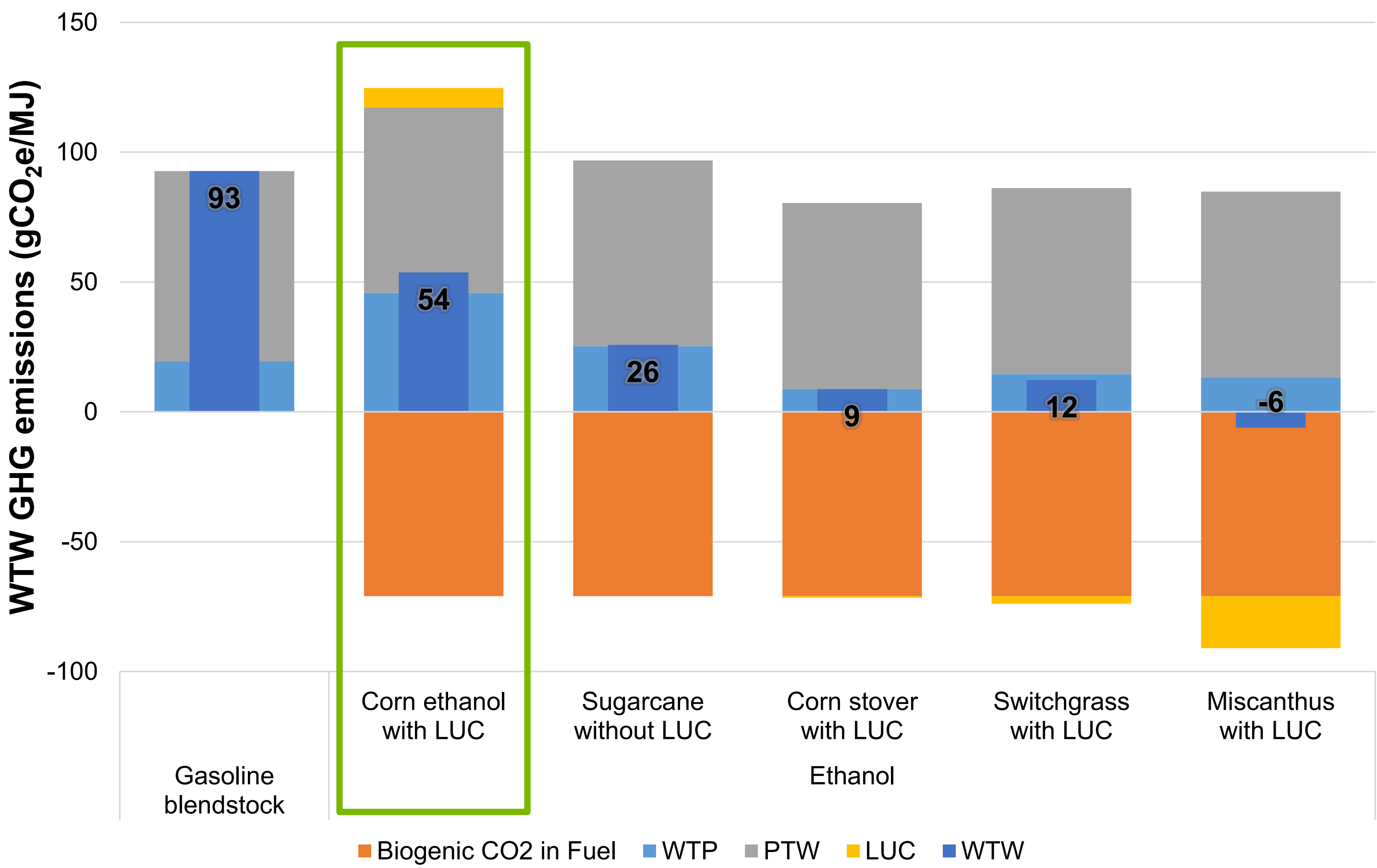
Keywords: corn production, soil organic carbon, biofuel, regionalized life cycle analysis, cradle-to-farm-gate GHG emissions

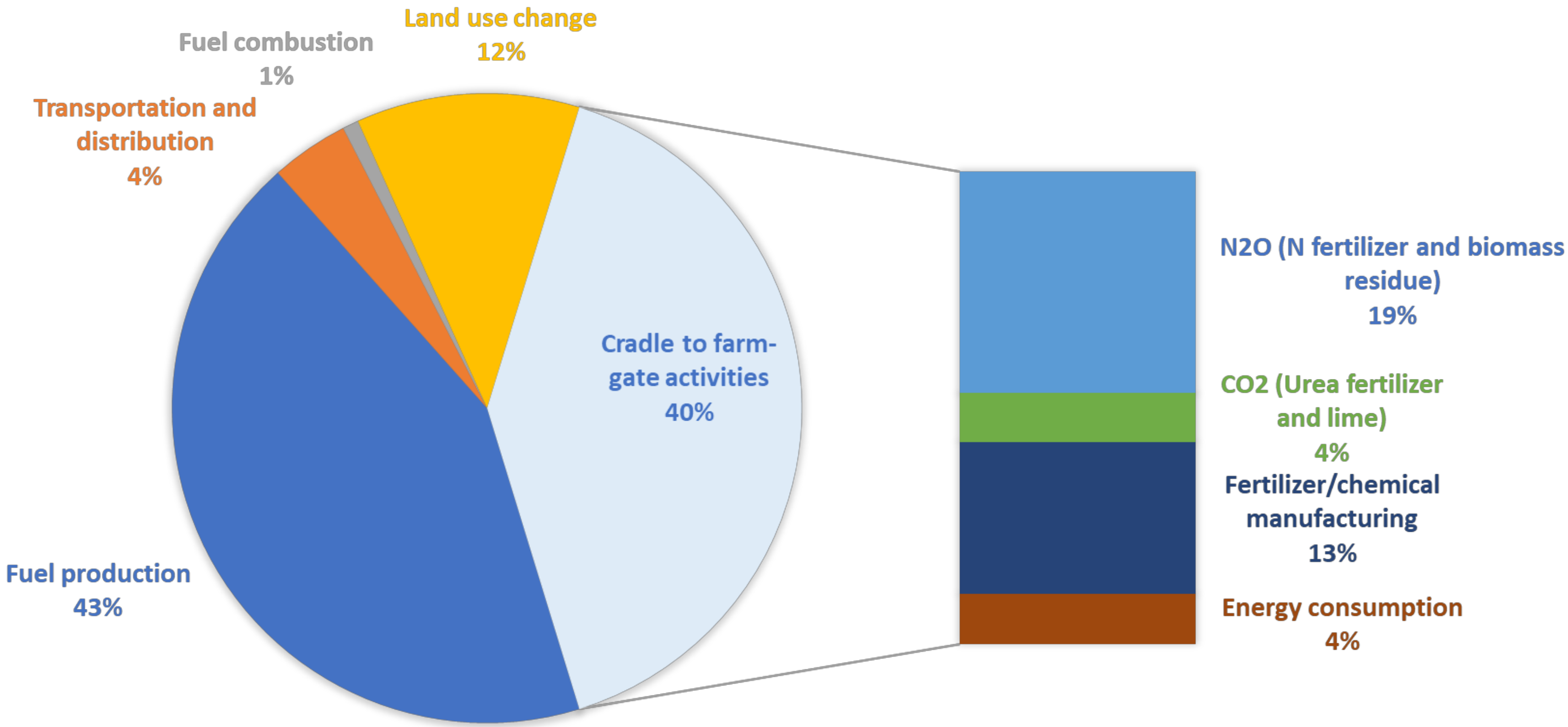
Abstract
The carbon intensity (CI) of biofuel's well-to-pump life cycle is calculated by life cycle analysis (LCA) to account for the energy/material inputs of the feedstock production and fuel conversion stages and the associated greenhouse gas (GHG) emissions during these stages. The LCA is used by the California Air Resources Board's Low Carbon Fuel Standard (LCFS) program to calculate CI and monetary credits are issued based on the difference between a given fuel's CI and a reference fuel's CI. Through the Tier 2 certification program under which individual fuel production facilities can submit their own CIs with their facility input data, the LCFS has driven innovative technologies to biofuel conversion facilities, resulting in substantial reductions in GHG emissions as compared to the baseline gasoline or diesel. A similar approach can be taken to allow feedstock petition in the LCFS so that lower-CI feedstock can be rewarded. Here we examined the potential for various agronomic practices to improve the GHG profiles of corn ethanol by performing feedstock-level CI analysis for the Midwestern United States. Our system boundary covers GHG emissions from the cradle-to-farm-gate activities (i.e. farm input manufacturing and feedstock production), along with the potential impacts of soil organic carbon change during feedstock production. We conducted scenario-based CI analysis of ethanol, coupled with regionalized inventory data, for various farming practices to manage corn fields, and identified key parameters affecting cradle-to-farm-gate GHG emissions. The results demonstrate large spatial variations in CI of ethanol due to farm input use and land management practices. In particular, adopting conservation tillage, reducing nitrogen fertilizer use, and implementing cover crops has the potential to reduce GHG emissions per unit corn produced when compared to a baseline scenario of corn–soybean rotation. This work shows a large potential emission offset opportunity by allowing feedstock producers a path to Tier 2 petitions that reward low-CI

Corn ethanol achieves >40% reduction in GHG emissions



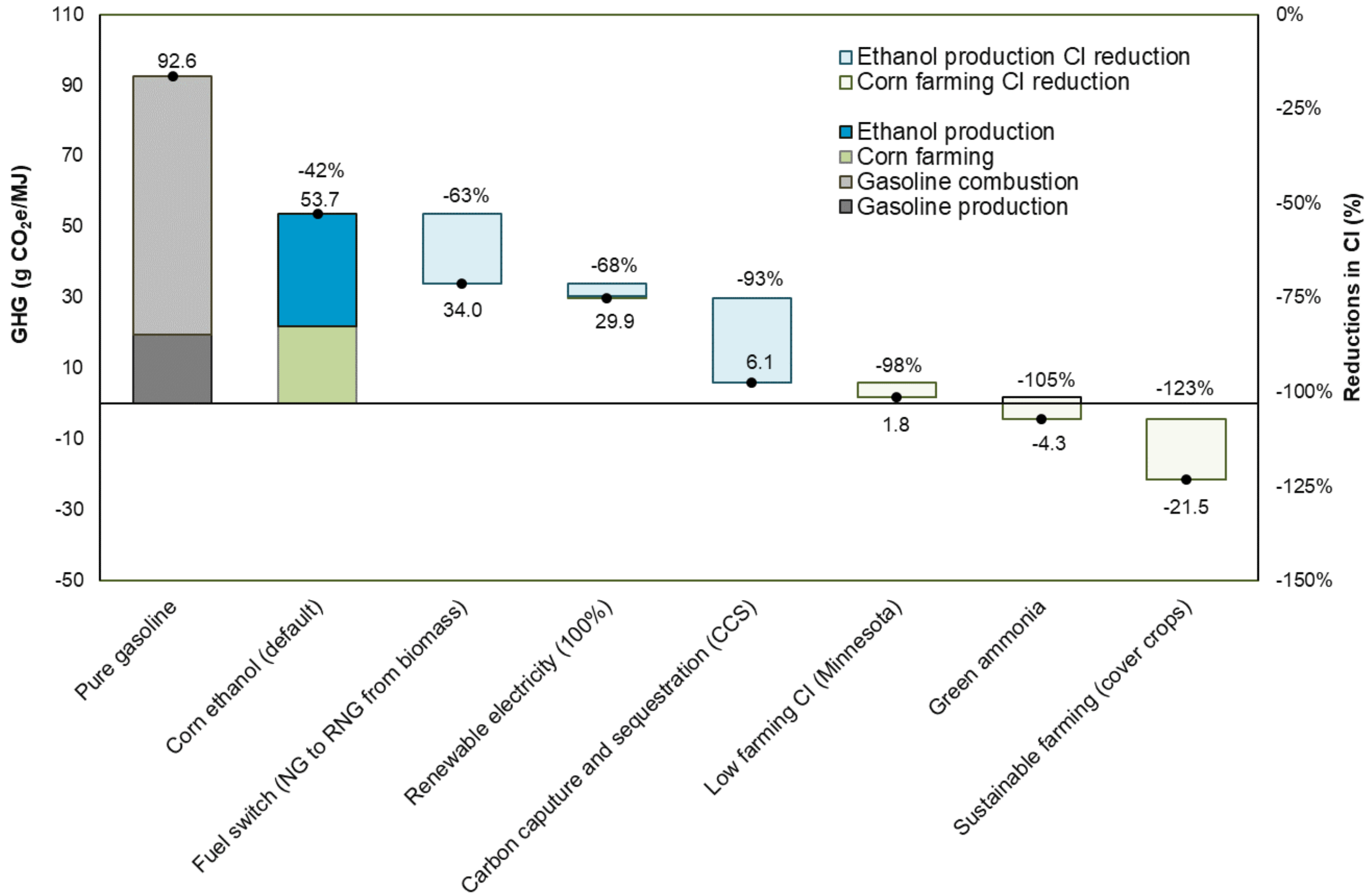
- Corn ethanol results are based on GREET 2020
- The U.S. average corn farming data are used
- Land use change (LUC) emissions are included
- Soil organic carbon (SOC) changes from farming practices (e.g., tillage, cover crops, etc.) are NOT considered here

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



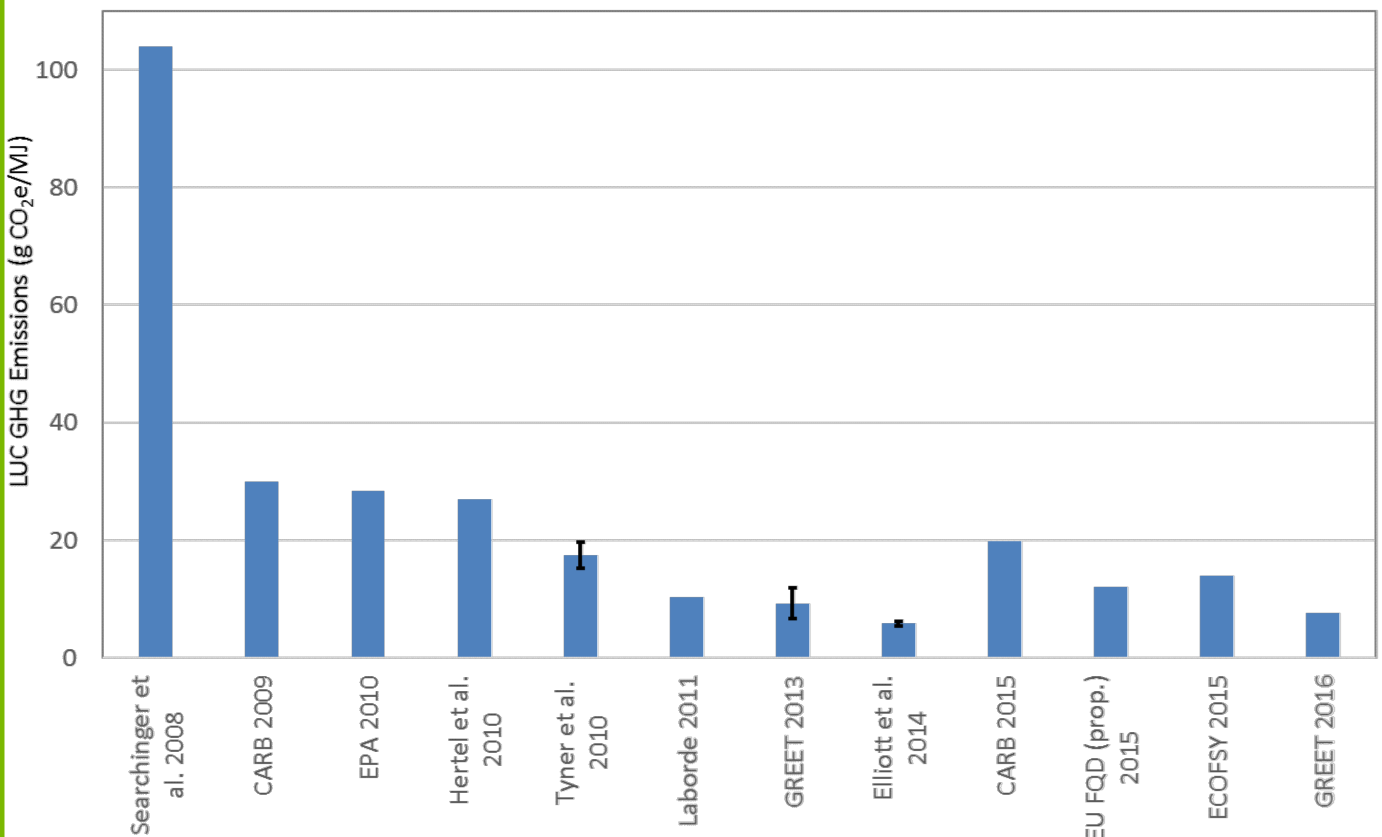
Dry Milling Corn Ethanol w/ Corn Oil Extraction.
DSG credit, -11 g CO_2e/MJ, is not included

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_2e/MJ
- With RNG, renewable electricity, and CCS, CI of corn ethanol might be lowered to 6.1 g CO2e/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

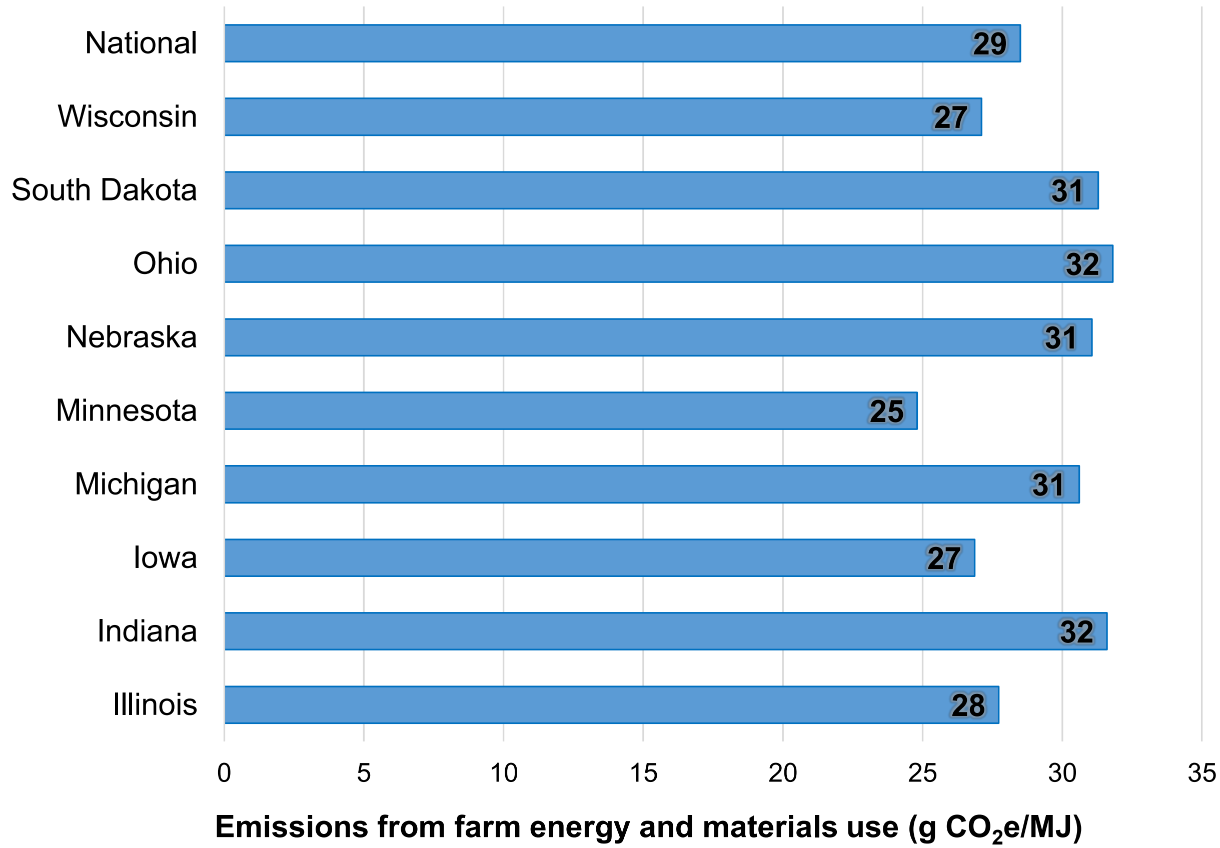
Estimated LUC GHG emissions for corn ethanol have gone down significantly in the past 10 years



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**

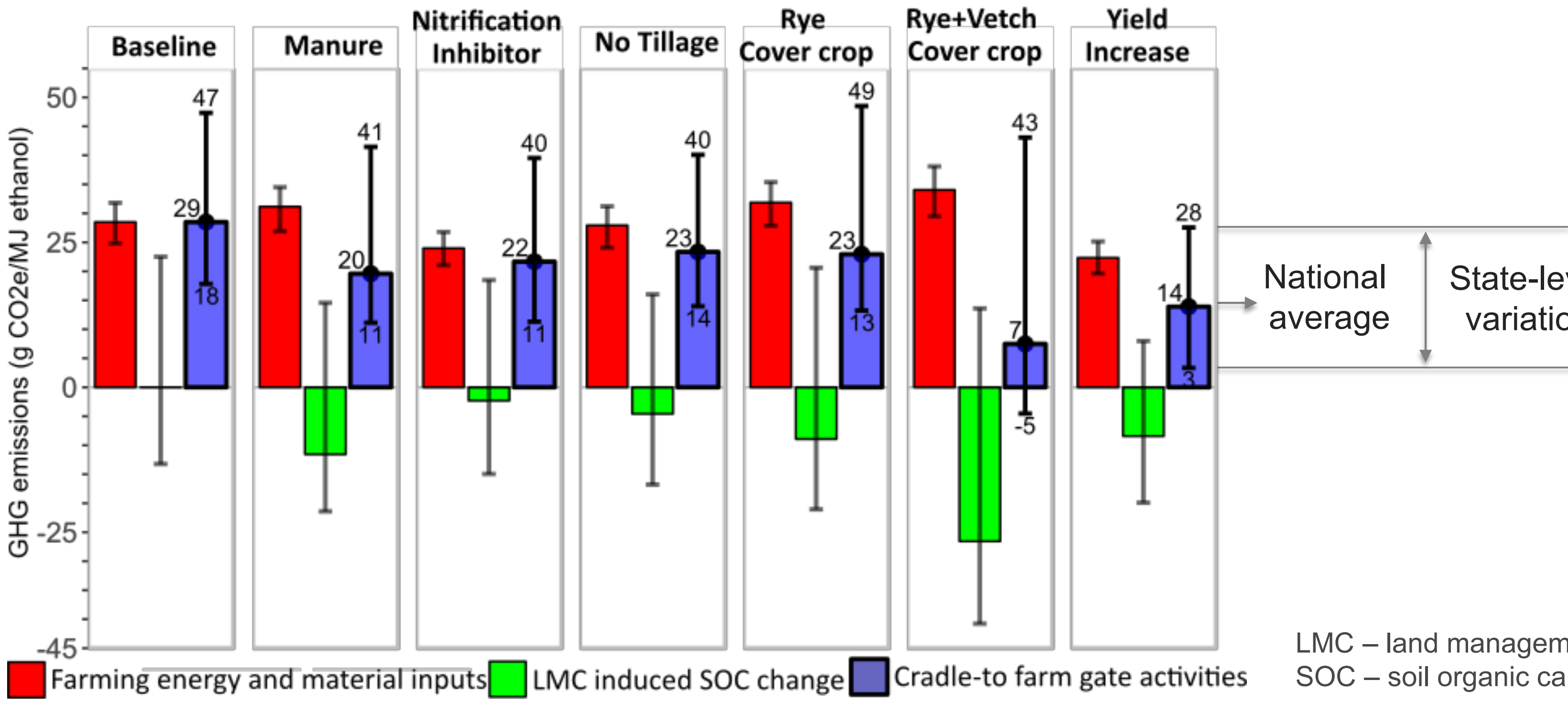
Even with current farming practices, significant variation exists among states in feedstock-related CI for corn ethanol



The CI variation reflects:

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

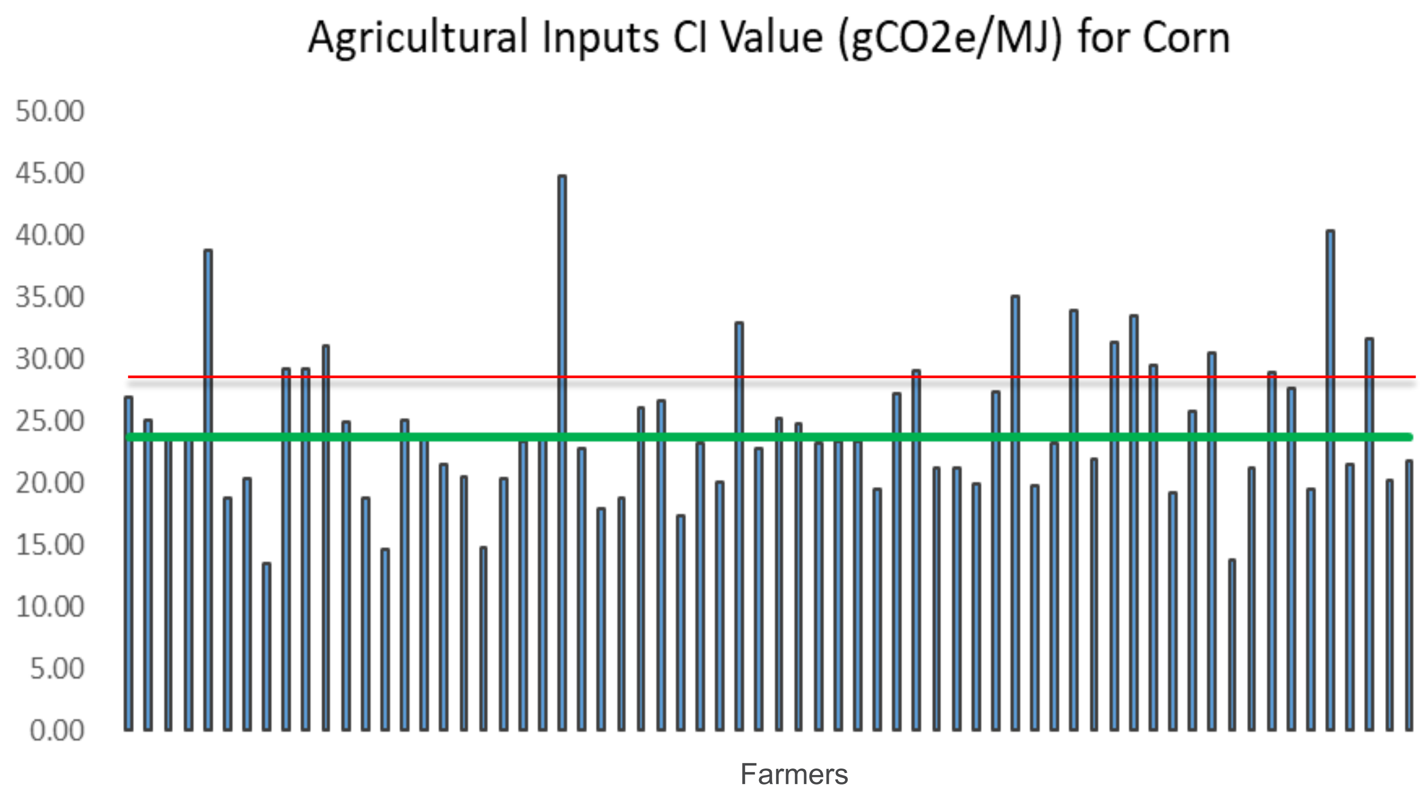
Farming practices significantly influence corn ethanol CI by state



LMC – land management change
SOC – soil organic carbon

- 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, N2O 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



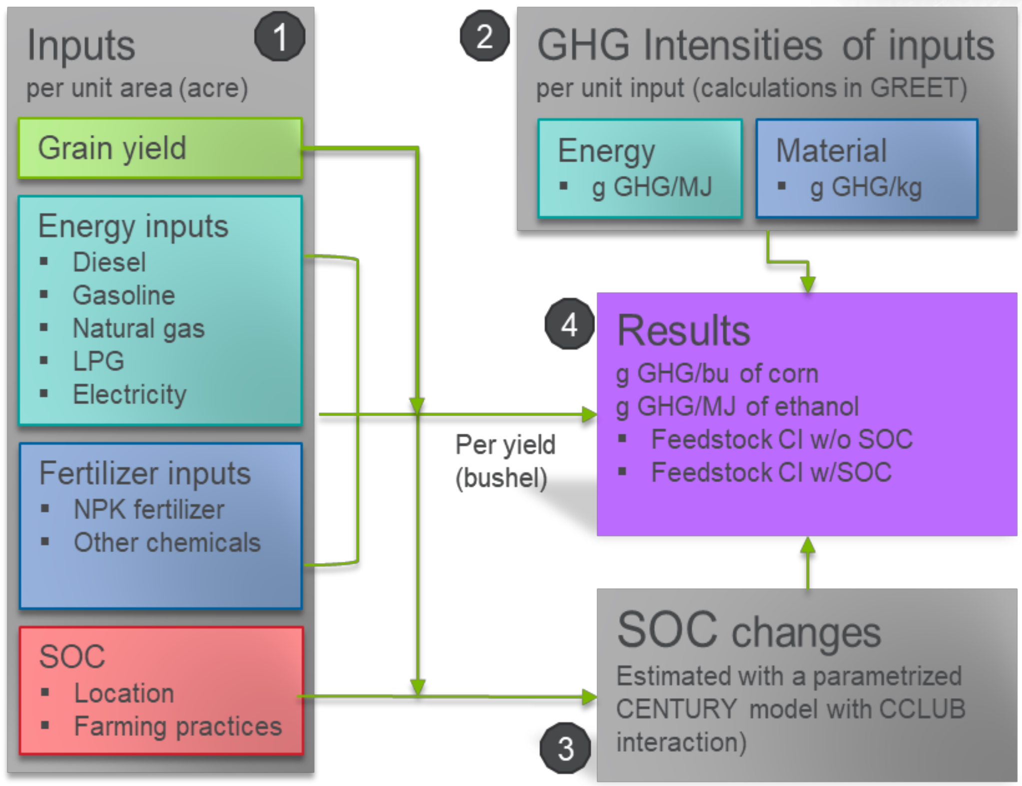
National average CI: 29.5 g/MJ

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)

- 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