Opportunities for Lowering GHG Emissions of Corn Ethanol

Michael Wang

Systems Assessment Center
Energy Systems Division
Argonne National Laboratory

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Gen-1 Ethanol Opportunities: Improving Lifecycle GHG Benefits of Existing Biofuel Production
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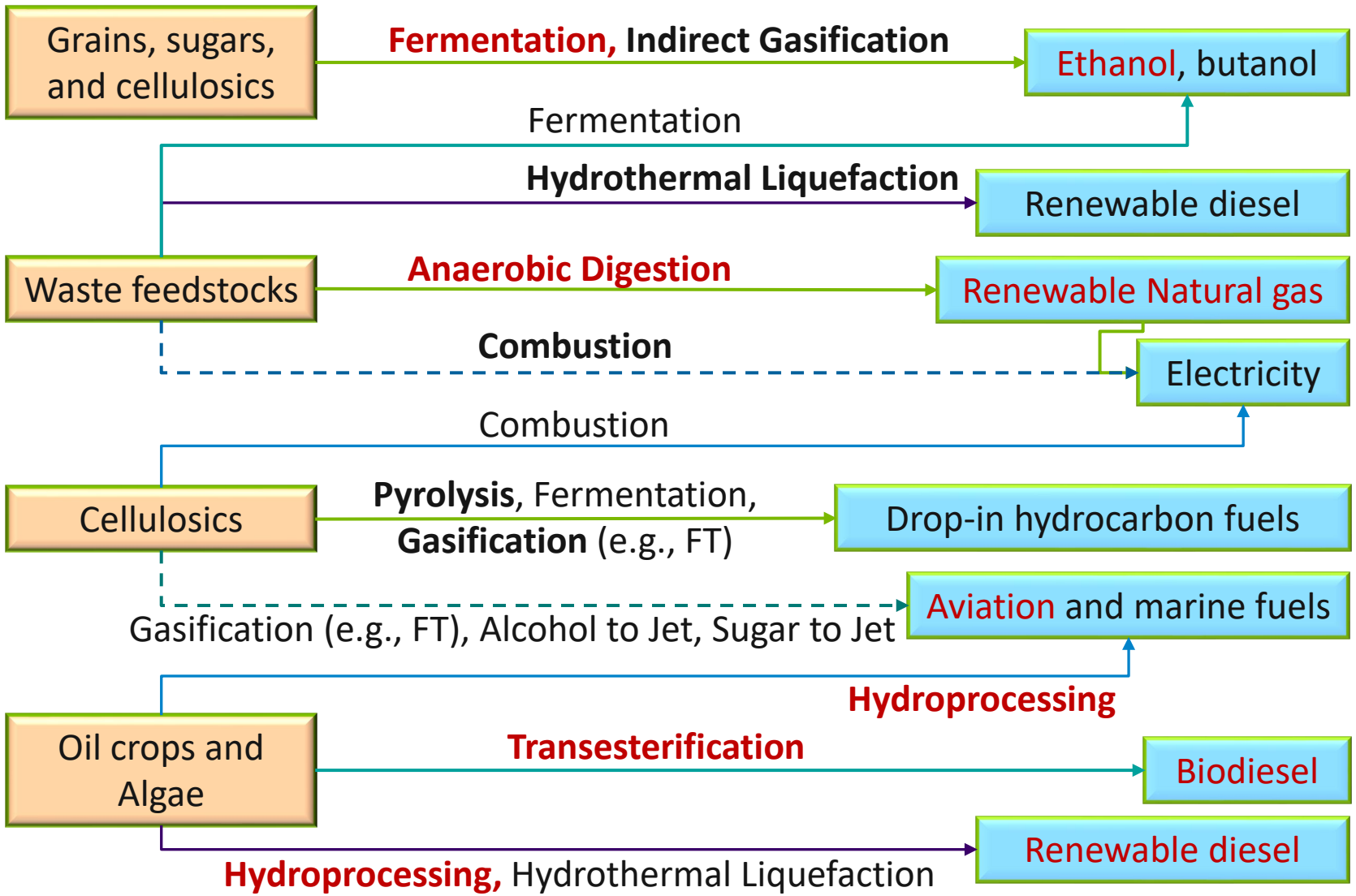
National, state, and international fuel regulations/programs promote production of low-carbon biofuels

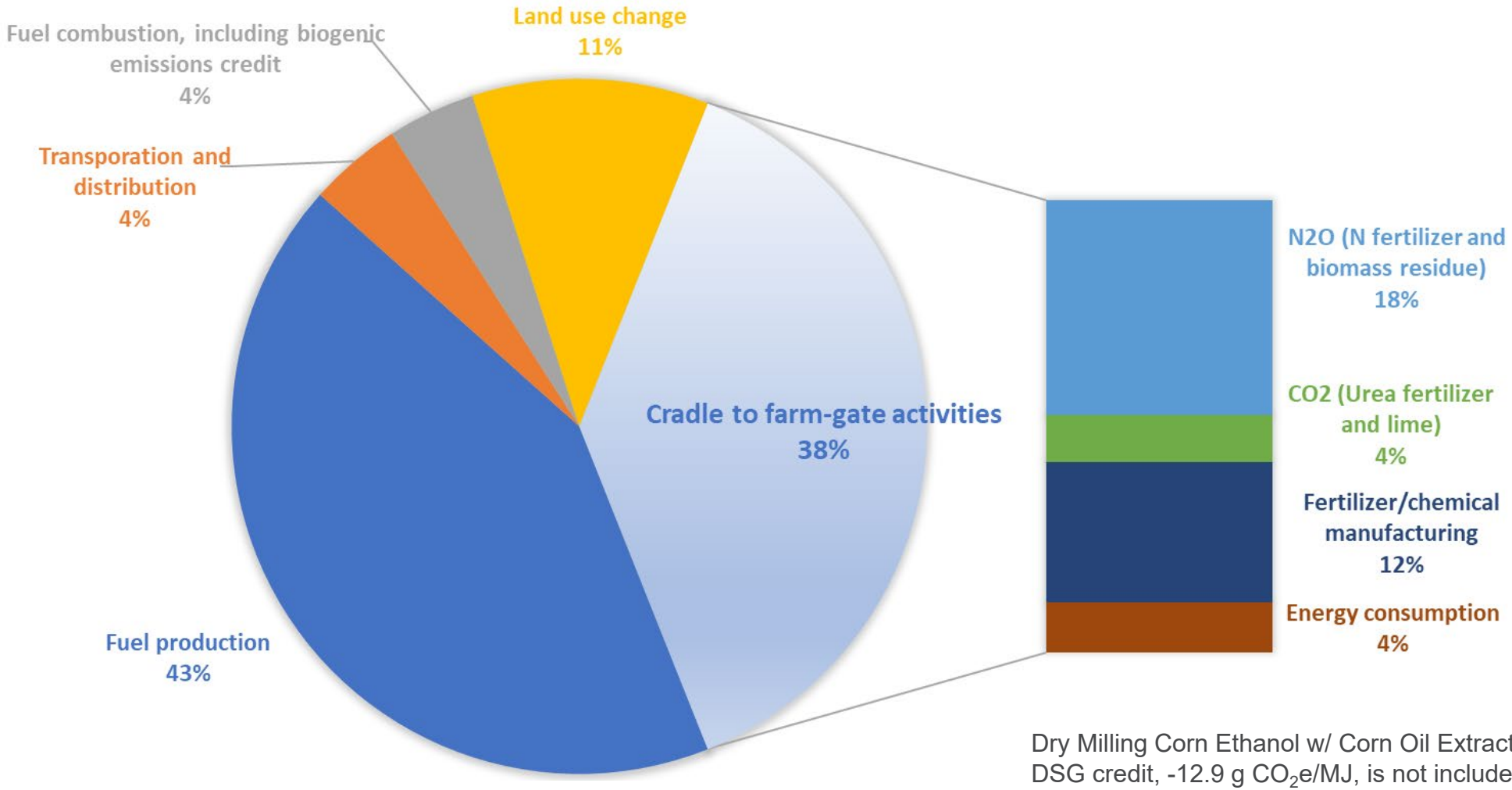
- California Low Carbon Fuel Standard
- Oregon State Clean Fuel Program
- Washington State Clean Fuel Standard (under development)
- EPA Renewable Fuel Standard
- ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)
- Environment and Climate Change Canada Canadian Clean Fuel Standard (under development)
- European Commission Renewable Energy Directive II
- Brazil RenovaBio Program
- **They all are based life cycle analysis to determine carbon intensity of fuel pathways**

GREET includes a variety of biofuel technology pathways



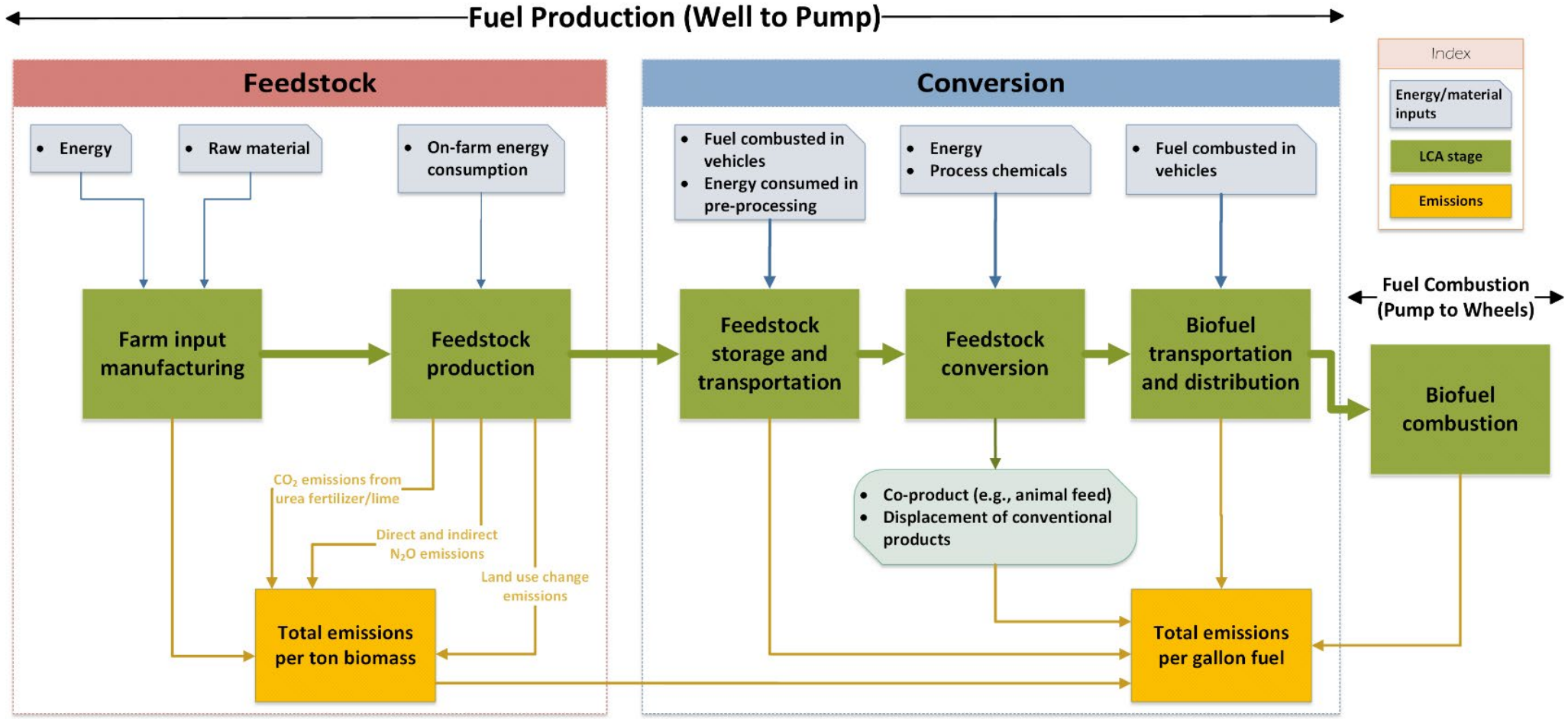
- The highlighted options have significant volumes in LCFS and RFS
- Ethanol accounts for >15 billion gallons nationwide, and >1.1 billion gallons in CA

Feedstock and ethanol production are two significant contributors to corn ethanol LCA GHGs



Dry Milling Corn Ethanol w/ Corn Oil Extraction.
DSG credit, -12.9 g CO_2e/MJ, is not included

GREET includes details of both biofuel feedstock and conversion

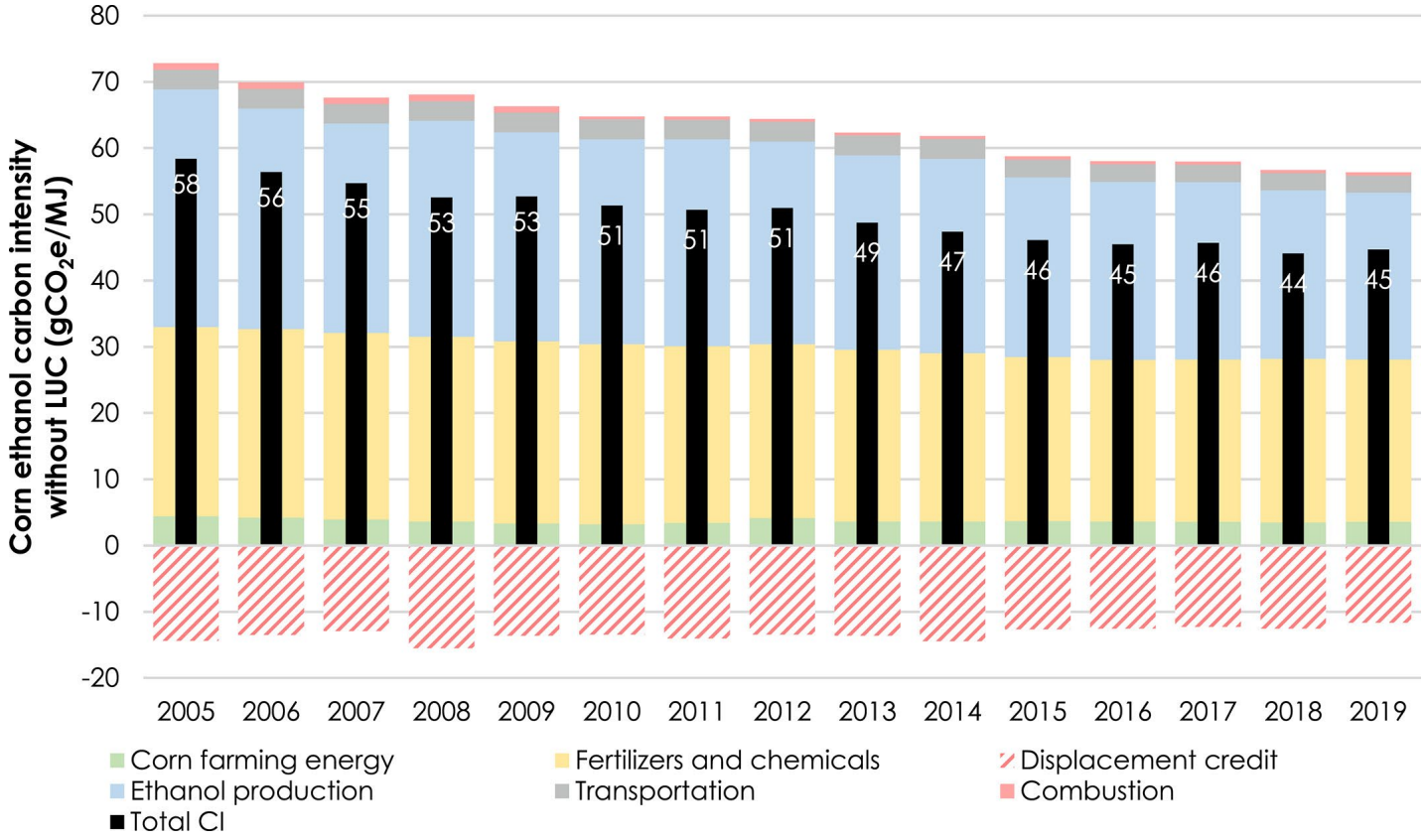


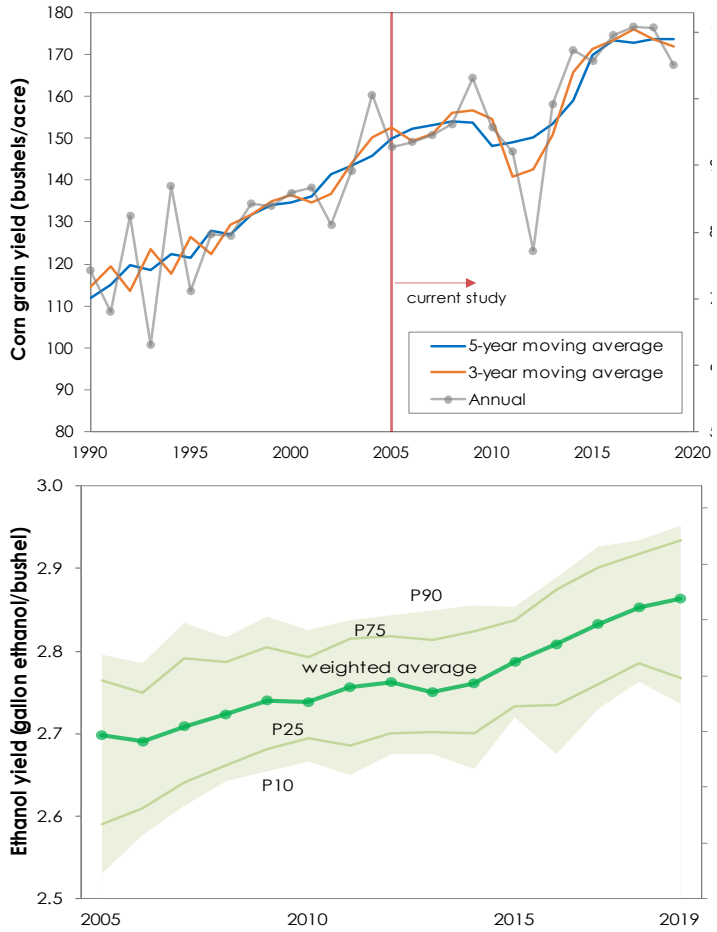
- EU REDII, ICAO CORSIA, RenovaBio (partial), and forthcoming Canadian Clean Fuel Standard allow feedstock certification

- All biofuel regulations/programs allow biofuel facility certification

Recent retrospective analysis shows continuing GHG reductions of U.S. corn ethanol over 15 years

- Between 2005 and 2019, corn yield increased from 148 to 168 bushels/acre, a 13.5% increase
- Corn ethanol yield increased from 2.7 in 2005 to 2.86 gal/bushel in 2009, a 6.5% increase
- CI of ethanol decreased by 23% from 58 to 45 g CO_2e/MJ (w/o LUC emissions), vs. gasoline CI of 93 g/MJ

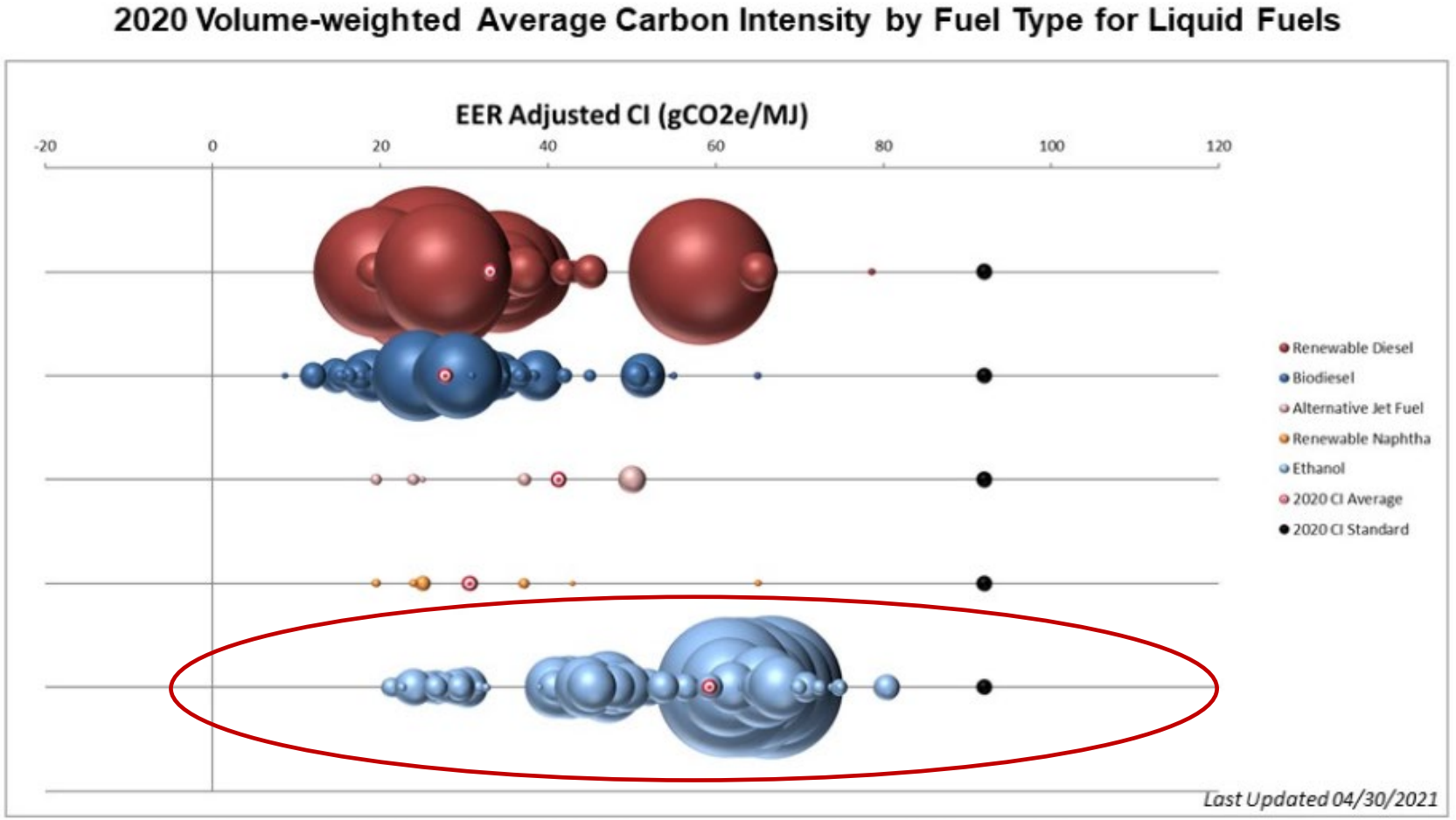




Source: Lee et al. (2021) Biofuels, Bioproducts & Biorefining

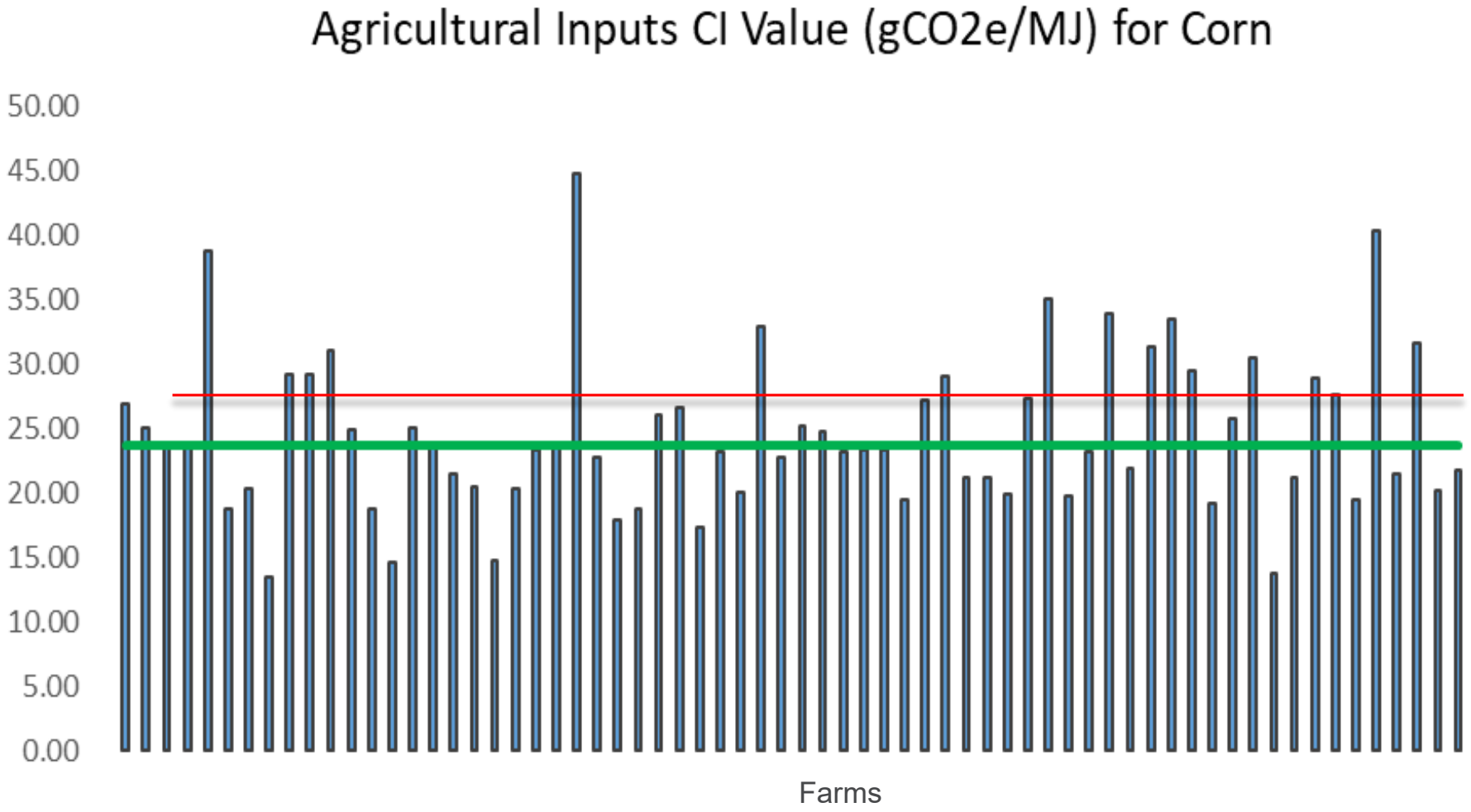
California LCFS has stimulated technology innovation and deployment to lower biofuel CIs

- Tier 1 CI lookup tables for different biofuel pathways by CARB establish transparent pathway CIs
- Tier 2 pathway CI certification encourages further lowered CI of biofuels
- Ethanol Tier 2 CI certified under LCFS is as low as 20 g/MJ



Source: CARB (2022) (https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard)

Farm-level corn CI shows significant variation and opportunity to reduce feedstock CI – CIs of corn for 71 individual farms in South Dakota



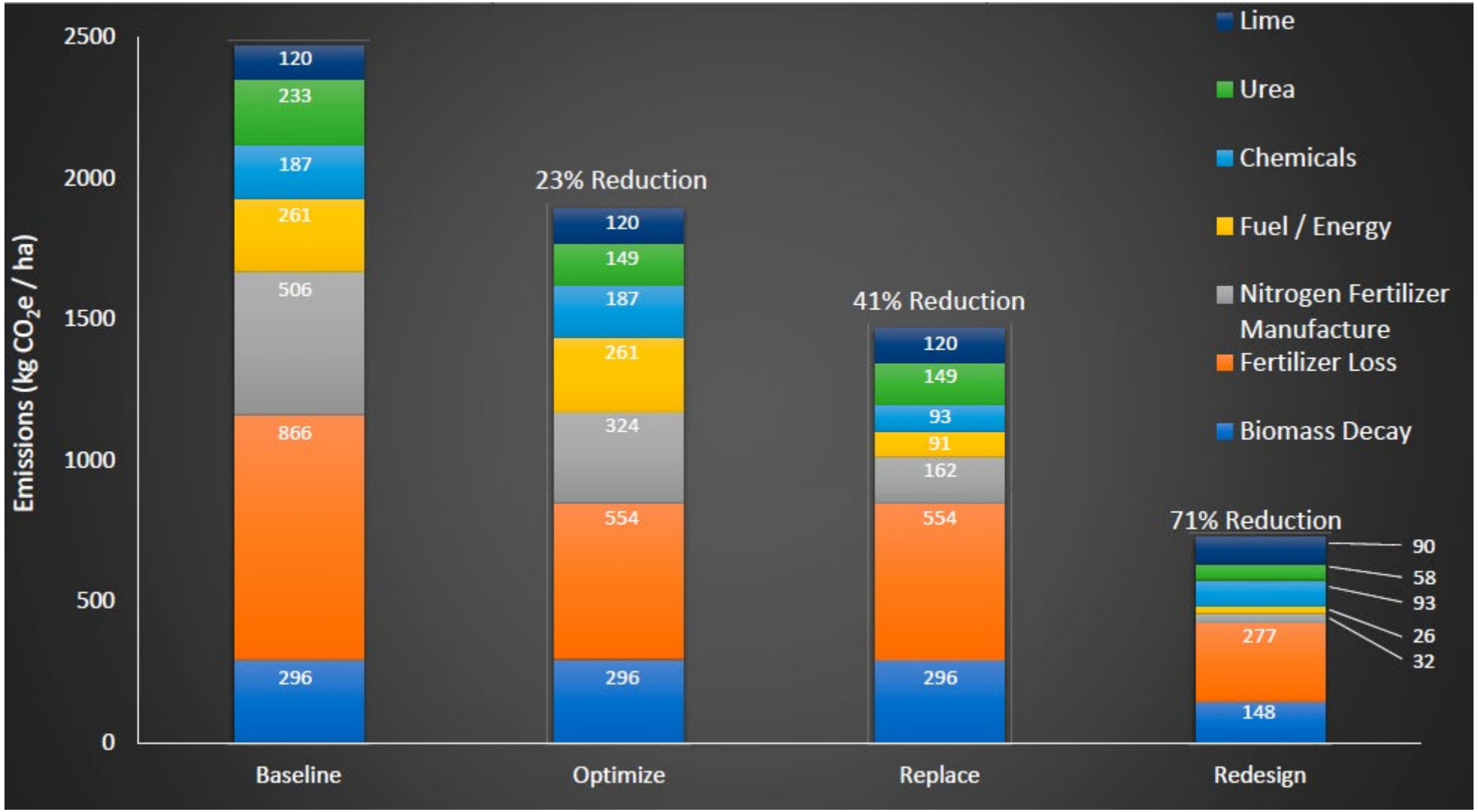
- Range of the 71 farms: 13–45 g/MJ, representing an opportunity of 34% reduction in corn ethanol CI vs. gasoline CI

National average CI: 29.5 g/MJ

Average of 71 farms: 23.6 g/MJ

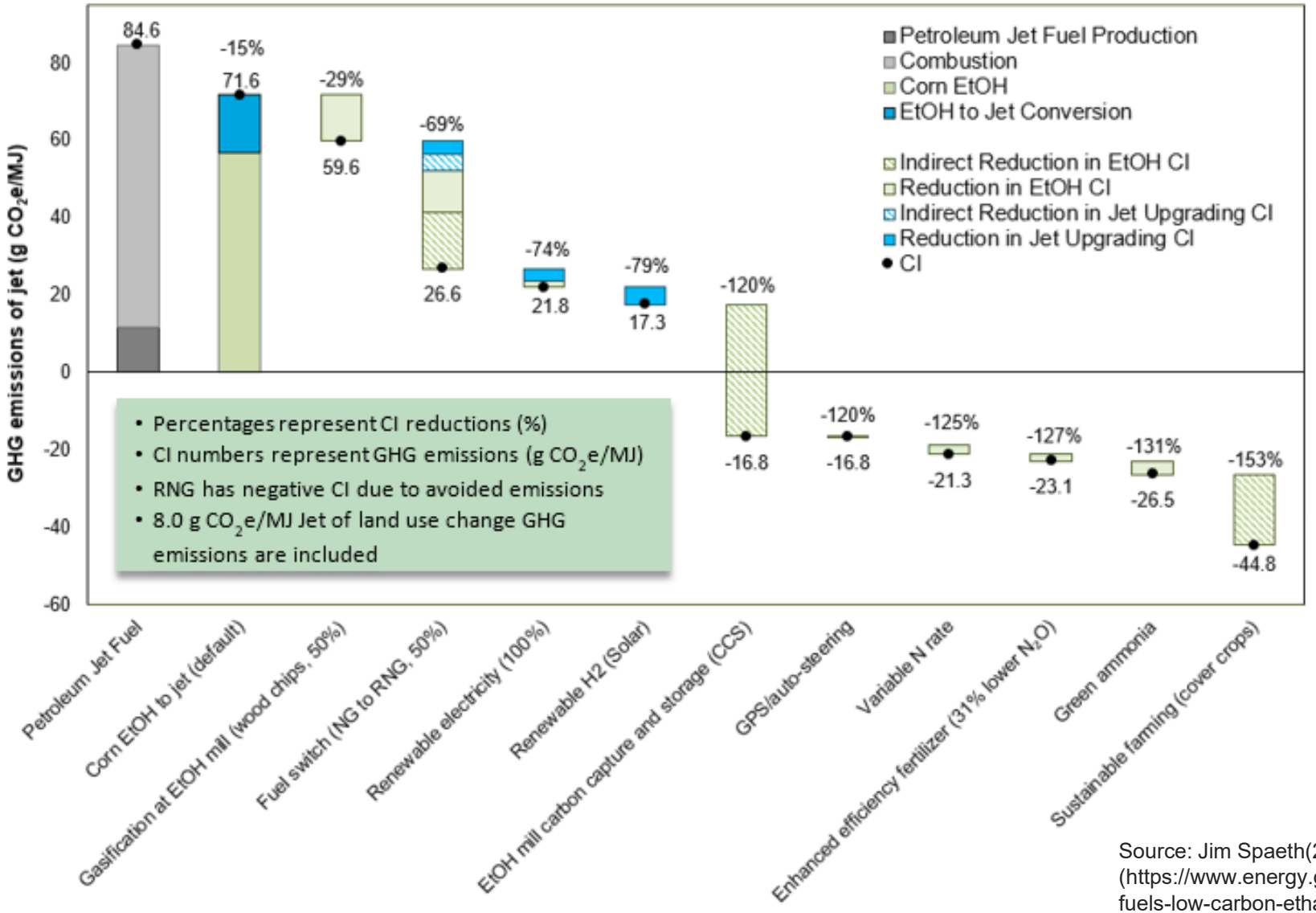
Source: Liu et al. (2021) Environmental Research Letters

GHG reduction potentials for 3 technical phases in farming shows significant improvement with each transition



Source: Northrup et al. (2021) PNAS

Conversion and feedstock potentials for carbon neutrality and negativity of corn ethanol and ETJ



Source: Jim Spaeth(2021) (https://www.energy.gov/eere/bioenergy/articles/sustainable-aviation-fuels-low-carbon-ethanol-production)

Contact information

Michael Wang mwang@anl.gov

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Contact information

Hui Xu hui.xu@anl.gov

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